Springer Transactions in Civil and Environmental Engineering

Faisal I. Khan
Nihal Anwar Siddiqui
S. M. Tauseef
B. P. Yadav *Editors*

# Advances in Industrial Safety

## Select Proceedings of HSFEA 2018

Springer

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# Foreword

When did the science of risk assessment and process safety take root?

The origin of the concepts and practices that are used to reduce risk and enhance safety can be traced to the origin of life itself. During evolution, those of the organisms who had better sense of perceiving risk of predators or of other factors that could jeopardize their lives were able to survive and perpetuate their breed, while others fell behind or became extinct.

We can identify process safety techniques being used by even small-brained animals! For example, when an ant ventures, every animal tries to take ALARP (as low as reasonably practicable) risk out to forage, and it takes a calculated risk of getting consumed by a predator. It is a risk the ant must take unless it chooses to, instead, starve and so put itself to greater risk of another form.

Likewise, all organisms seem to have instinctively done layers of protection analysis (LOPA) and develop ways to reduce risk. Most animals have individuals looking very similar to each other and move in large groups—like herds of zebras or schools of fishes—to confuse predators who find it difficult to identify the weaker or the slower members of the assemblage to attack. Camouflaging is another LOP technique known since time immemorial. The concept of doing vigil ('system monitoring') by individuals in rotation and raising alarm on sensing danger has also been a part of existence of several species of animals on earth. Even plants exhibit an instinctive ability to perceive risk and either avid it or control the harm by protective measures.

Past accident analysis (PAA) is, arguably, the biggest source of wisdom in the domain of accident forecasting and loss prevention. In day-to-day life, too, PAA is done all the time by all life-forms. Most of all by humans. PAA is nothing but learning from bad experiences. We instinctively do 'past accident analysis' to learn why something unpleasant had occurred—with us or others—and how to prevent its recurrence. We attempt 'inherently safe practices' like keeping away from a boss who is in bad mood—to reduce risk.

Indeed, the instinct to keep off harm's way drives our defense mechanism and we instinctively do all that which forms the basis of the process safety science. Of course, we also tend to take 'calculated risks,' and sometimes mindless risks as well, but that behavior is exception rather than norm.

Yet, despite this in-built circumspection, humankind meets with accidents all the time. By pumping in lots of knowledge and other resources, we are able to reduce risk but never eliminate it. We have also now learnt that with every incremental step toward zero risk, the cost of risk reduction increases exponentially. In other words, attaining zero risk existence is impossible—not because it is not technically feasible but because it is not feasible economically. As a result, balancing technical sophistication with economic viability has become the core of all risk management R&D, including the domain of process safety.

The present volume carries writings which dwell upon very many diverse aspects of safety which have great contemporary relevance. Several of them perform the balancing act between risk reduction and cost escalation which this branch of knowledge is seized with. These contributions take the state of the art forward with a giant leap.

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# Numerical Assessment of Passive Fire Protection in an Oil and Gas Storage Facility

**Vikram Garaniya, Jia Wui Lim, Til Baalisampang, and Rouzbeh Abbassi**

## 1 Introduction

Oil storage and processing facilities, such as refineries, are constantly handling large quantities of hydrocarbons and chemicals in both liquid and gas forms that are inherently flammable. If accidents or errors such as human mistakes, equipment failure or deficiency in management plan were to occur, there is a high risk that property loss, economic disruption and production interruption will occur (Baalisampang et al. 2018a). To tackle such issues, there are a variety of guidelines and standards for refinery construction, building material selection and layout design to prevent accidents from occurring and to reduce the impact of structural, economical and production accidents. However, although guidelines and standards are constantly being updated and implemented, it is observed that chance of fires, detonations and explosions occurring cannot be eliminated in the hydrocarbon processing industry as too much flammable hydrocarbon is being handled (Vervalin 1985), and there are countless modes of failure in this industry (Baalisampang et al. 2018b). According to Chang and Lin (2006), of the type of complex in which fire and explosion have occurred over the past 50 years, 116 of 242 accidents occurred in refineries which contribute to approximately 50% of the accidents. Among the 116 accidents in refineries, 60% of them are related to fire. In addition, Hu et al. (2013) concluded that 27% of major accidents over the past 30 years occurred in petroleum refineries and fire or explosion accounted for 96% of the total number of cases. Based on these researches, it is observed that fire protection systems that are commonly installed in hydrocarbon storage facilities must be considered and selected carefully. This has

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not been extensively studied previously. Fire protection system (FPS) is designed to respond to fire if fire or smoke is detected, and it can be categorised into an active, passive, and inherent fire protection system (Baalisampang et al. 2016). Active fire protection (AFP) is a system or component that requires human action or some mechanisms to activate and is employed to suppress and mitigate the fire. On the other hand, passive fire protection (PFP) system is a defensive mechanism that requires no activation method to prevent the spread of fire and disintegration of structure (Roe 2000). Some examples of PFP are fire rated walls and doors, fire protection spray and self-expanding foam which are designed to limit the temperature rise and excessive heat absorption of equipment and structures. Another type of PFP system is intended to prevent the spread of hydrocarbon particularly liquid hydrocarbon which includes drainage sumps and bunds (Spitzenberger et al. 2016). With such a wide variety of fire protection systems, the choice of an FPS is mainly dependent on the targeted fire type, i.e. pool fire, jet fire or flash fire. A selection of an FPS must be considered carefully to maximise the effectiveness of the PFP applied. In addition, immoderate or excessive use of PFP can lead to problems such as increase in fabrication and building cost, risk of schedule delay (Friebe et al. 2014) and increased difficulty in performing corrosion testing (Tugnoli et al. 2012). Thus, selection of the PFP system and careful consideration of the combination of passive and active fire protection systems are of great importance.

## 2 Literature Review

Since the late nineteenth century, due to the high cost and time required to perform full-scale experiments in the laboratory, numerous mathematical models have been proposed to predict the thermal behaviour of fire. These mathematical models range from simple models such as algebraic correlations that can be solved with a calculator, to complex models such as field modelling which can only be solved with computer software (Carlsson 1999). With the rapid development of technology and computational power, field modelling is progressively becoming the more common model for fire researchers and fire safety engineers to perform fire safety researches and predict the behaviour of fire. Field models, particularly the computational fluid dynamics (CFD) model, is widely recognised as one of the most dominant method to predict the behaviour of hydrocarbon fire and explosion as it allows fire to be simulated even in complex geometries and different surrounding conditions (Baalisampang et al. 2017). To date, there are several CFD software packages designed for fire engineering application, which can precisely predict and estimate the heat and smoke transport during a fire. Fire Dynamics Simulator (FDS) is a CFD software developed by National Instrument of Science and Technology (NIST) which has the capability of modelling fire-driven fluid flow and with emphasis on smoke and heat transport from the fire. With the information on heat transport, thermal load and temperature rise on surrounding structures can be obtained and effect of thermal load can be investigated (McGrattan et al. 2013). Flame Accelerator Simulator (FLACS) is another software for fire modelling that can perform full three-dimensional fire modelling with the input of original 3D drawings, and it has the capability to model jet fire, pool fire and flash fire. This software is suitable for high and low momentum flow fire, passive fire protection optimisation, vessel heat up modelling and heat radiation modelling (Gexcon 2017). In addition, SMARTFIRE is software developed by Fire Safety Engineering Group (FSEG) to perform fire field modelling. The advantage of this software is that it has two modes of operation which are novice mode, which embeds expert knowledge into the software to assist beginners, and expert mode in which users have full control over the configuration and settings (Taylor et al. 1997). Kameleon FireEx (KFX) is another type of CFD software developed by Computational Industry Technologies (ComputIT) which focuses on gas dispersion and fire simulation, mainly for industrial usage.

Although there are extensive applications of numerical simulation in fire impact modelling, as well as predicting performance of fire extinction using AFP system such as water mist or fire hydrants, by reproducing the heat release rate (HRR) decrease of fire in scenario, there is limited research on effectiveness and assessment of PFP system adequacy in specific scenario (Jenft et al. 2013). Currently, there are several research papers (Baalisampang et al. 2017a, b) which performed CFD modelling of fire impact and risk analysis. Rajendram et al. (2015) studied the fire risks and impact associated with jet fire and fireball in offshore facility using FDS. In addition, Ryder et al. (2004) performed consequence modelling using FDS to determine the impact of pool fire in both a small and a large room. Some researchers (Lim et al. 2019; Landucci et al. 2009) have studied the performance of PFP system and determined the adequacy using different methods. This includes Shirvill (1993), Mróz et al. (2016) and Suardin et al. (2009) performed full-scale experiments on various types of PFP material including cementitious material, intumescent coating, ablative building materials and high expansion foam under direct flame impingement or exposure. Dalzell and Melville (1993) presented a method for preliminary design of PFP based on maximum potential fire consequences. Friebe et al. (2014) applied finite element analysis (FEA) to determine the effect of PFP on collapse time of a Floating Production Storage and Offloading (FPSO)'s topside module. In addition, Landucci et al. (2009) adopted finite element analysis to determine the performance of an LPG tank coated with different PFP materials under fire engulfment. Li et al. (2016) used CUrisk, which is a fire risk analysis software to determine the effect of fire barriers on a building. It is worth mentioning that Vianna et al. (2010) performed numerical simulations to determine the adequacy of PFP in an offshore facility using Kameleon Fire Modelling (KFX) and FAHTS. However, only the applied methodology were explained but the detailed information about type of PFP system installed was not stated and only one offshore fire scenario was considered in the paper.

Analysis of effectiveness and performance of PFP system in the oil and gas industry has not been performed extensively. Thus, this study presents the numerical assessment of PFP in an oil and gas storage facility, predominantly in refineries using CFD modelling to determine the effectiveness of various types of commercially available PFP materials. In addition, the study will also assist in determining the accuracy of numerical modelling in PFP system which will allow fire engineers to have higher accuracy when utilising CFD software to determine the application and adequacy of PFP. FDS is used as the main tool in fire scenario modelling as it is a specialised tool for fire modelling which has been well validated and used by professionals.

## 3 Proposed Methodology

The study of PFP system effectiveness in an oil and gas storage facility can be broken down into different stages which form a proposed methodology. The methodology begins with the development of the fire scenario in the oil and gas storage facility, and an accident occurrence credibility score is assigned to each fire scenario to determine the most credible fire scenario. CFD simulation is performed on the most credible fire scenario. In addition, various types of PFP systems will be modelled for the fire scenario. The results of CFD simulation are adopted to determine the effectiveness of various PFP systems in preventing a rise in equipment temperature, fire propagation, structural collapse and impact reduction when exposed to hydrocarbon fire. An overview of the proposed methodology is presented in Fig. 1.

### *3.1 Fire Scenario Development*

In the first step, the development of the fire scenario in oil and gas storage facility is performed. A fire scenario is a description of the major cause of the fire event which generally originates from hazards at the facility that have the potential of threatening the facility or personnel (Ahmad et al. 2013). In an oil and gas storage facility, hazardous products such as crude oil, or any crude oil by-products, are stored and once loss of containment occurs, fire or explosion may occur within a short period of time if they are in contact with an ignition source. The fire can spread at a high rate which leads to a high number of casualties and economic losses (Zhou et al. 2016). In this proposed methodology, fire scenarios are developed based on root causes that lead to the loss of containment from past oil and gas storage facility accidents. Through the generation of fire scenarios, potential fire types such as pool fire, jet fire or flash fire are determined. This is important as each type of fire has unique characteristics and a different mitigation technique (Spitzenberger et al. 2016). The fire scenarios generated are presented in Table 1.

### *3.2 Fire Scenario Credibility Assessment*

In step 2, ranking of each fire scenario is performed based on credibility assessment. Among different types of assessing methods, the Maximum Credible Fire Scenario

**Fig. 1** Proposed methodology

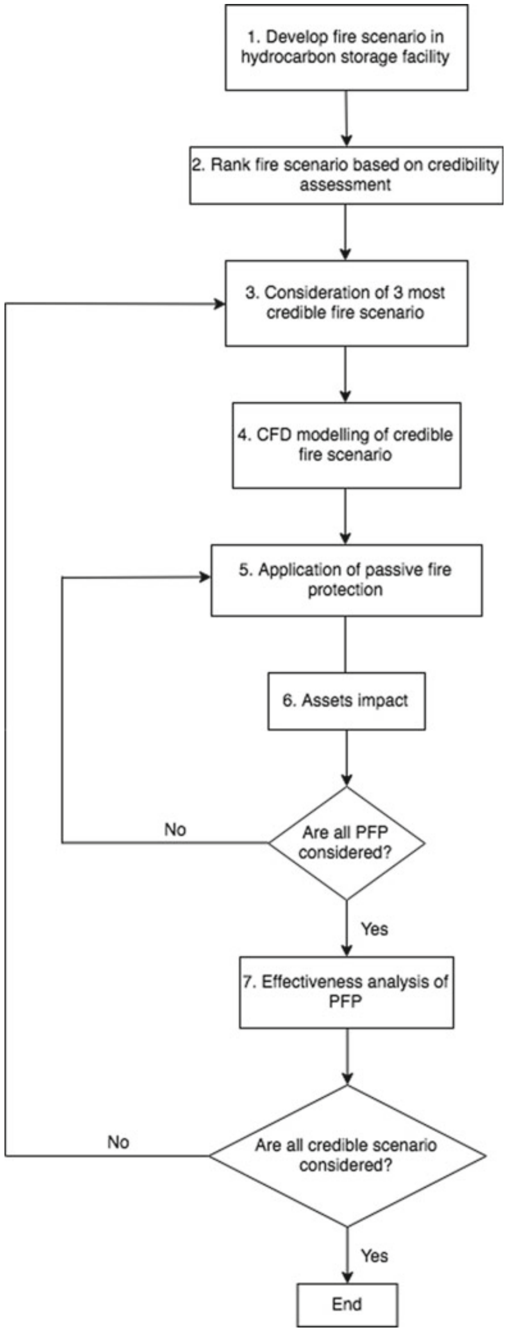

**Table 1** Fire scenarios in oil and gas storage facility

| No. | Fire scenario | Accident location | Year | References |
|---|---|---|---|---|
| *Loading and unloading area* | | | | |
| 1 | Spark from an electric motor ignited leaked jet fuel | Stapleton International Airport | 1990 | Persson and Lönnermark (2004) |
| 2 | Leakage of LPG due to an earthquake caused fire and explosion | Cosmo Oil Chiba Refinery | 2011 | Krausmann and Cruz (2013) |
| 3 | A pool fire was formed during an unloading of crude oil to storage tank | Amuay Refinery | 1982 | Parraga (2013) |
| *Crude oil tank* | | | | |
| 4 | Overfill of crude oil tank caused liquid pool and formed vapour cloud which ignited instantly | Philadelphia Gulf Refinery | 1975 | Persson and Lönnermark (2004) |
| 5 | Leakage of crude oil at rate of 0.006 kg/s due to crack at bottom plate of crude oil storage tank and caused a fire | Fawley Refinery | 1999 | Whitfield (2002) |
| 6 | Pool fire forming at tank roof after an explosion occur at the tank due to contact with ignition source | Tanzania Pipeline Company | 1989 | Persson and Lönnermark (2004) |
| 7 | Lightning strike caused tank roof to fail and ignited after contacting with ignition source resulting in pool fires | Czechowice-Dziedzice Refinery | 1971 | Persson and Lönnermark (2004) |
| 8 | Spark from man lift ignited gas oil vapour causing pool fire | Conoco Refinery | 1999 | Persson and Lönnermark (2004) |
| *Distillation tower* | | | | |
| 9 | Spill of propane from distillation tower due to equipment failure caused liquid pool and vapour cloud ignited | BP America Refinery | 2005 | Holmstrom et al. (2010) |
| 10 | Failure of storm drainage system caused waste oil to wash out of drain and ignited at distillation tower | La Plata Refinery | 2013 | Parks (2013) |

(continued)

**Table 1** (continued)

| No. | Fire scenario | Accident location | Year | References |
|---|---|---|---|---|
| 11 | Crude oil vapour released from main crude column pressure safety valve due to pumps and cooler malfunction | Texaco Refinery | 1994 | Kletz (1998) |
| 12 | Leak of crude oil from a branch in distillation column due to incorrect building material caused a fire | Mazeikiu Refinery | 2006 | Kramer (2006) |
| 13 | Diesel leak in a pipeline in the crude distillation unit caused a flash fire | Chevron Refinery | 2012 | CSB (2015) |
| *Refined oil processing unit* | | | | |
| 14 | Leak of gasoline at rate of 15 kg/s due to failure of block valve to seal pump strainer properly at visbreaker unit | El Paso Refinery | 2001 | Shiva and Fung (2016) |
| 15 | Failure of valve bonnet in hydrocracker unit caused gasoline of 101 kPa pressure to release at a rate of 17 kg/s | Chevron Richmond Refinery | 1999 | Persson and Lönnermark (2004) |
| 16 | Heat exchanger failure caused release of gasoline at a rate of 14.5 kg/s in hydrosulphurisation unit causing explosion and fire | Sodegaura Refinery | 1992 | Persson and Lönnermark (2004) |
| 17 | Release of flammable liquid at a rate of 0.95 kg/s during the removal of malfunctioning pump when shut off valve was open | Ciniza Oil Refinery | 2004 | CSB (2005) |
| *Product storage tank* | | | | |
| 18 | Overfill of 568 $m^3$ gasoline tank caused liquid pool and vapour cloud formation which was then ignited | Texaco Refinery | 1983 | McLennan (2013) |
| 19 | Lightning strike caused naphtha tank to fail and ignited causing a tank fire | Pulau Merlimau Refinery | 1988 | Rodante (2005) |
| 20 | Weld failure caused leakage of refrigerated propane tank and later resulted into a fire. | Umm Said NGL Plant | 1977 | McLennan (2013) |

(continued)

**Table 1** (continued)

| No. | Fire scenario | Accident location | Year | References |
|---|---|---|---|---|
| 21 | LPG leakage at a rate of 2.35 kg/s due to drain valve frozen during drainage operation which was then ignited after contacting the ignition source | Feyzin Refinery | 1966 | McLennan (2013) |
| 22 | Failure of pump house used for blending refined product caused liquid pool to form which later ignited | Pulau Bukom Refinery | 2011 | Lin et al. (2017) |
| *Process pipeline* | | | | |
| 23 | Rupture of expansion joint on transfer line caused release of hydrocarbon | Houston Fuel Oil Refinery | 2002 | Persson and Lönnermark (2004) |
| 24 | Leak of crude oil at rate of 4.35 kg/s from pipe supplying the refinery caused liquid pool to form and formation of vapour cloud which then ignited | ISAD Nord Refinery | 2006 | Garrone (2006) |
| 25 | Leak at bending elbow due to incorrect piping material caused liquid heavy oil pool at distillation unit which ignited causing a fire | Lemont Refinery | 2001 | McLennan (2013) |
| 26 | Weld failure of 2-inch hydrogen line cause hydrogen release at 10.5 kg/s and was ignited resulting into a fire | Chevron Richmond Refinery | 1989 | McLennan (2013) |
| 27 | Erosion failure of 10-in. recycle oil line caused release of liquid at 15.5 kg/s at coking unit and was ignited | Syncrude Oil Refinery | 1984 | Lees (2012) |
| 28 | Corrosion of pipe in catalytic cracker caused hydrocarbon gas with pressure of 1861 kPa release at 30.37 kg/s and ignited | Shell Oil Co. Refinery | 1998 | McLennan (2013) |
| 29 | Leak of propane from piping at propane deasphalting unit at a rate of 34.02 kg/s caused jet fire to occur and flame encroached onto nearby steel structures | McKee Refinery | 2007 | CSB (2008) |

**Table 2** Credibility score calculation for most credible fire scenarios

| Parameters | Values |
|---|---|
| Damage radius (m) | 649 |
| Area inside damage radius ($m^2$) | 1,325,022 |
| Probability of occurrence | 0.000945 |
| Asset density ($/$m^2$) | 10,000 |
| Unacceptable financial loss ($/year) | 10,000 |
| Population density (persons/$m^2$) | 0.0025 |
| Population distribution factor | 0.5 |
| Unacceptable fatality rate (persons/year) | 0.01 |
| Importance factor | 0.2 |
| Unacceptable damage area ($m^2$/year) | 1000 |
| Financial loss factor (Factor A) | 0.614 |
| Fatalities factor (Factor B) | 0.6138 |
| Ecosystem damage (Factor C) | 0.153 |
| Credibility score (L) | 0.67 |

(MCAS) method is adopted to assign a credibility score to each scenario. A credible fire scenario is defined as a fire scenario which has a high degree of occurrence probability and has the potential to cause significant consequence (Khan 2001). The benefits of MCAS method are that it accounts for both the damage it can cause and the probability of occurrence of an accident, which is the optimum method for assessing different fire scenario. With the information on fire scenario credibility, greater concern can be placed on the scenarios with high damage impact and occurrence likelihood. Before MCAS method can be applied, the expected damage of different fire scenarios needs to be quantified in terms of damage radius. The Multivariate Hazard Identification and Ranking System (HIRA) method proposed by Khan and Abbassi (1998) is employed to determine the approximate damage radius for each scenario due to the high sensitivity and accuracy of this method as it accounts for various factors such as leak size, vessel pressure, volume and temperature. An example of the credibility score calculation is shown in Table 2.

### 3.3 *Credible Fire Scenario Selection*

In step 3, the most credible fire scenario is selected for further analysis. According to Khan (2001), fire scenarios with a credibility score greater than 0.5 are credible and they are prone to catastrophic consequences. Based on various fire scenarios developed in Table 1 and MCAS ranking method, the most credible fire scenario is listed in Table 3.

**Table 3** Most credible fire scenario

| No. | Fire scenario | Credibility score |
|---|---|---|
| 1 | Leakage of propane from piping at propane deasphalting unit at a rate of 34.02 kg/s caused a jet fire to occur and flame encroached onto nearby steel structures | 0.67 |

## *3.4 CFD Simulation of the Credible Fire Scenario*

In step 4, a CFD simulation of credible fire scenario is performed. Due to the wide applications of FDS in fire modelling, numerical simulation is performed using FDS. FDS is a CFD model which focuses on smoke and heat transport from the fires (McGrattan et al. 2013). FDS has the capability to model the effect of thermal load and temperature on surrounding environment and can also be used for predicting sprinkler, heat detector and smoke detector activation. A mesh independent analysis is performed prior to the commencement of actual simulation. As the mesh size is decreased, the output result will be more accurate and the main objective of mesh independent analysis is to determine the optimum mesh size for the scenario with least percentage of error in output results. By using results from FDS simulation, thermal load distributions received on equipment are obtained. In addition, wall temperature and total heat radiation are obtained. To generate FDS code with higher accuracy, PyroSim, a software developed by Thunderhead Engineering is utilised. Computer-Assisted Drawings (CAD) geometry is imported into PyroSim as mesh generation; fire setup and simulation setup can be managed efficiently through PyroSim. The parameters used in the simulation setup for the fire scenario are given in Table 4. As the layout for the entire oil and gas storage facility is relatively large, the layout is divided into smaller sections. Figure 2 presents the full layout and the simulation layout for the scenario.

**Table 4** PyroSim simulation setup

| Parameters | Scenario |
|---|---|
| Scenario location | McKee refinery |
| Simulation volume | 129 m × 104 m × 22 m |
| Simulation time (s) | 300 |
| Number of cells | 900,000 |
| Boundary condition | Open |
| Fuel type | Propane |
| Burn radius (m) | 1.5 |
| Burn area ($m^2$) | 7.07 |
| Heat release rate per unit area ($kW/m^2$) | 4600 |
| Output parameters | Net heat flux<br>Wall temperature |

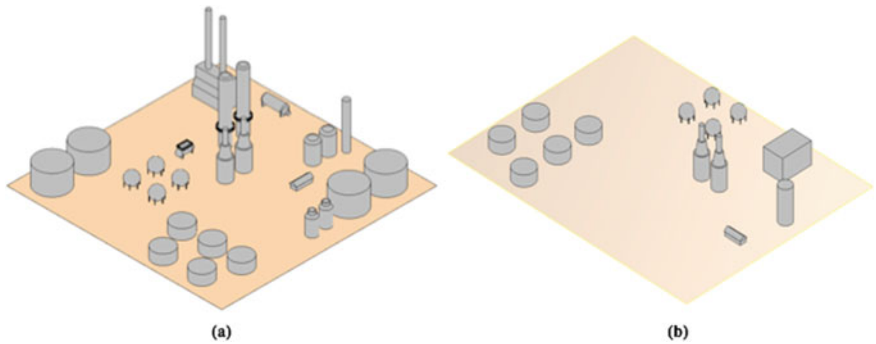


**Fig. 2** **a** Full scenario layout, **b** simulation layout

**Table 5** Structural steel thermal properties (Hurley et al. 2015)

| Material | Structural steel |
|---|---|
| Density (kg/m$^3$) | 7850 |
| Specific heat (kJ/kg K) | 0.46 |
| Conductivity (W/(m K)) | 45.8 |
| Emissivity | 0.95 |
| Absorption coefficient (1/m) | 50,000 |

In the scenario, the simulation time is assumed to be 300 s which is based on the longest time required for a fire rescue team to arrive at the fire scenario and the commencement of fire rescue. In the scenario, the boundary condition is specified as open to indicate the infinite domain which is the representation of real fire scenario as only part of the layout is being modelled. The equipment surface material is assumed to be structural steel with thermal properties stated in Table 5.

## *3.5 Application of Passive Fire Protection*

In step 5, various PFP coatings are applied to the equipment. The main objective of PFP is to avoid structural disintegration by keeping the temperature in the material below critical point, slowing down propagation of the fire and reducing escalation of the fire (Spitzenberger et al. 2016). Thus, by obtaining a credibility score for each fire scenario, the most vulnerable equipment or facility is identified and the higher level of PFP can be applied to that equipment. On the other hand, the least hazardous areas can have low level of PFP as immoderate use of PFP coating can lead to increase in fabrication cost and risk of schedule delay (Friebe et al. 2014). Depending on the type of fire, heat flux received, and duration and size of the fire, a different passive fire protection system can be applied. For jet fire, which is the releasing of gaseous jet or liquid jet through small openings and ignited by ignition source, effective mitigation methods include fire wall, intumescent coating, mineral fibre coating and cementitious material coating. For a pool fire with little momentum, effective passive protection includes self-expanding foam, thermal insulation barrier, intumescent coating or endothermic building material which can withstand long periods of fire exposure. Flash fire, which is defined as the advancing flame front of an ignited vapour cloud, can be protected using thermal insulation barrier and intumescent coating to mitigate thermal impact on structure (Spitzenberger et al. 2016). In the current study, PFP systems in the form of fire proofing coating are applied to the equipment to determine the effectiveness of various PFP coatings in preventing equipment temperature rise and to reduce heat flux received by equipment. The selection of fire proofing coating materials is based on commercially available materials such as intumescent coating, vermiculite spray and gypsum board. The thermal properties of various selected fire proofing coating materials are given in Table 6.

An epoxy intumescent expands instantaneously up to final thickness when exposed to fire in a real-case scenario. However, in this study, the swelling effect of epoxy intumescent is neglected as the chemical and physical changes occurring within the material are too highly complex to be modelled by FDS. This assumption is similar to a statement made by Landucci et al. (2009) where increase in thermal properties due to swelling of the material was neglected. The selected PFP coating materials are specified in PyroSim as a new material. After specifying material properties, a surface of the selected material with specified thickness is applied to equipment thus forming a fire proofing barrier.

**Table 6** Thermal properties of various PFP materials

| | Density (kg/m$^3$) | Specific heat (kJ/kg K) | Conductivity (W/(m K)) | Emissivity | Absorption coefficient (1/m) | References |
|---|---|---|---|---|---|---|
| Epoxy intumescent | 1000 | 1.172 | 0.066 | 0.90 | 50,000 | Landucci et al. (2009) |
| Vermiculite spray | 680 | 0.970 | 0.100 | 0.90 | 50,000 | Landucci et al. (2009) |
| Cementitious material | 1200 | 1.000 | 0.400 | 0.92 | 50,000 | Hurley et al. (2015) |
| Fibre glass | 150 | 0.700 | 0.040 | 0.75 | 50,000 | Hurley et al. (2015) |
| Gypsum board | 930 | 1.090 | 0.170 | 0.90 | 50,000 | Hurley et al. (2015) |
| Mineral wool | 100 | 0.920 | 0.380 | 0.90 | 50,000 | Landucci et al. (2009) |
| Cellular glass | 115 | 0.770 | 0.078 | 0.20 | 50,000 | Hurley et al. (2015) |

### 3.6 Impact Analysis

In step 6, the impact analysis is performed by interpreting thermal load distribution and wall temperature of equipment. Impact analysis only takes thermal load or impact on surrounding facilities into account without considering the chemical or materials being released during the fire process. Impact analysis on assets includes determination of wall temperature measured at different distances away from fire source and assessing the percentage of temperature exceeding structural yield strength threshold (Krueger and Smith 2003). If the threshold is exceeded, there is a high chance of structural material failure. For the application of this study, S355J2H structural steel is assumed to be the equipment material. In general, when the strength factor drops below 60%, the steel structure is assumed to have failed (American Institute of Steel Construction 1978). According to experiment performed by Outinen (2007), the yield strength of structural steel begins to decrease significantly when the temperature is above 550 °C. When the temperature reaches 576 °C, a 60% reduction in yield strength is observed compared to yield strength at room temperature, which is assumed to be the failing point of structural steel. A comparison between yield strength of structural steel at elevated temperature is presented in Table 7. In addition, the impact analysis of fire on steel equipment is calculated based on thermal radiation received by equipment. The thermal radiation received by equipment is greatly dependent on the surface emissivity as well as convection heat transfer associated with it (Sjöström and Andersson 2013). The effect of thermal radiation can

**Table 7** Yield strength versus temperature for structural steel S355J2H (Outinen 2007)

| Temperature (°C) | Yield strength (MPa) | Reduction compared to 20 °C (%) |
|---|---|---|
| 20 | 566 | 0 |
| 500 | 368 | 35 |
| 576 | 226 | 60 |
| 600 | 181 | 68 |
| 700 | 102 | 82 |
| 800 | 42 | 93 |

**Table 8** Effects of thermal radiation (Sjöström and Andersson 2013)

| Radiant heat flux (kW/m$^2$) | Observed effect |
|---|---|
| 0.7 | Normal sunshine |
| 12.5 | Volatiles from wood may be ignited |
| 29.0 | Wood may ignite spontaneously |
| 37.5 | Steel equipment damaged |
| 52.0 | Fibreboards ignite spontaneously in 5 s |

be summarised in Table 8. Based on these values and criteria, the impacts of fire on steel equipment are being analysed.

### 3.7 Effectiveness Analysis

In step 7, the effectiveness analysis of PFP applied to equipment is performed. The effectiveness of PFP is determined based on its ability to protect a structure against temperature rise and reduce thermal load received by reducing heat transfer to the equipment being analysed (Tugnoli et al. 2012). This is done by assessing the wall temperature and thermal load on equipment after the fire and determining whether the applied PFP can succeed in preventing temperature escalation until the critical temperature of the building material is reached. By obtaining the effectiveness of PFP, the amount or level of PFP required in a certain area is determined.

## 4 Results and Discussion

In this section, the results obtained from CFD simulation are discussed and compared based on the maximum heat radiation and wall temperature obtained for bare or/ unprotected (without PFP) steel and PFP coated equipment.

### 4.1 Mesh Independent Analysis

A mesh independent analysis is performed to determine the optimum mesh size for the scenario. During mesh independent analysis, wall temperature is chosen as the responding variable as it will be the main factor in determining the effectiveness of PFP coating applied. Figure 3 presents the mesh independent analysis for the scenario. From Fig. 3, it is found that the wall temperature remains constant at 870 °C when the number of cells exceeds 900,000. Thus, mesh size of 0.79 m × 0.64 m × 0.65 m with 900,000 cells is utilised for further analysis.

### 4.2 Bare Steel Equipment

Based on the simulation results, it is found that the equipment adjacent to the fire source which is the propane deasphalting unit (PDA) has a maximum net heat flux of 55 kW/m$^2$ and a maximum wall temperature of 820 °C after 300 s of exposure. At this temperature, the yield strength of equipment has reduced by approximately 93%, which is well above the failure threshold stated in Table 1. Based on criteria stated

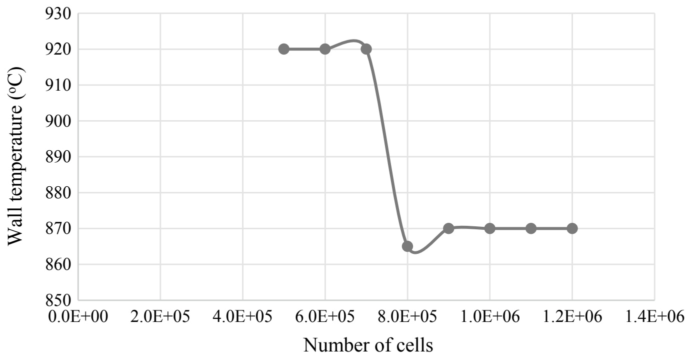


**Fig. 3** Mesh independent study

in Table 2, it is assumed that the steel equipment receiving 55 kW/m$^2$ of thermal radiation will ignite spontaneously causing severe damage, which ultimately leads to loss of containment. Based on these values, various PFP coatings are applied to the equipment to investigate the temperature variation. The results from the simulation are presented in Figs. 4 and 5.

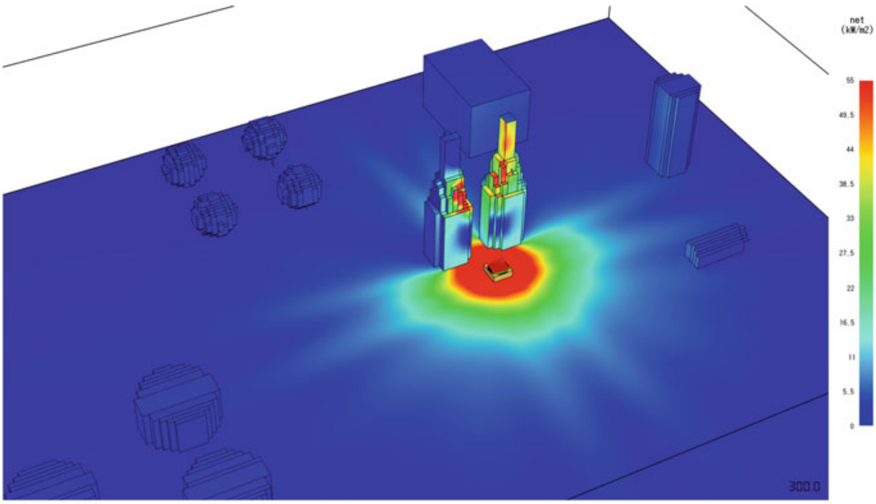


**Fig. 4** Heat flux contour (kW/m$^2$)

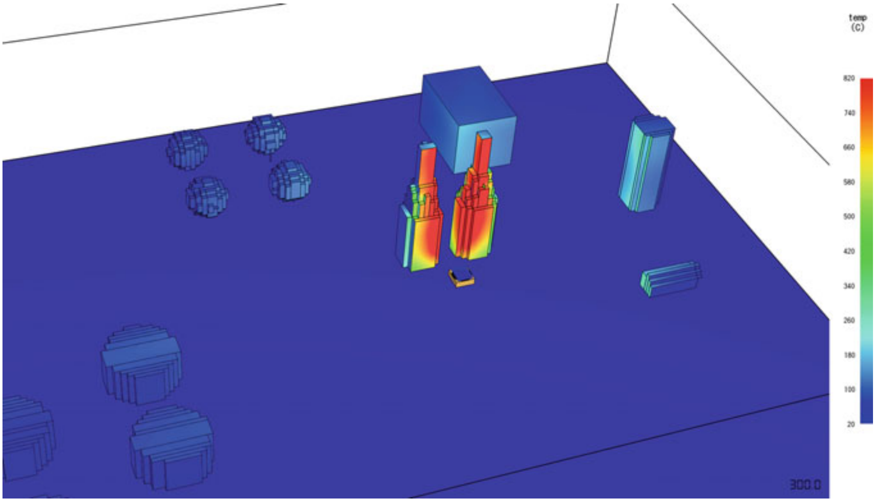


**Fig. 5** Wall temperature contour (ºC)

## *4.3 Heat Flux Comparison Between Bare and PFP Coated Equipment*

According to simulation results of various types of PFP, comparisons between heat flux received by equipment after 300 s are obtained, as illustrated in Fig. 6. According to Fig. 6, as a comparison to heat flux of 55 kW/m$^2$ received by the bare steel, all PFP coatings show a decrease in heat flux received by equipment when 10 cm PFP thickness are applied on the equipment surface. Fibre glass and cellular glass coated equipment have 25 kW/m$^2$ of heat flux received which is equivalent to a decrease

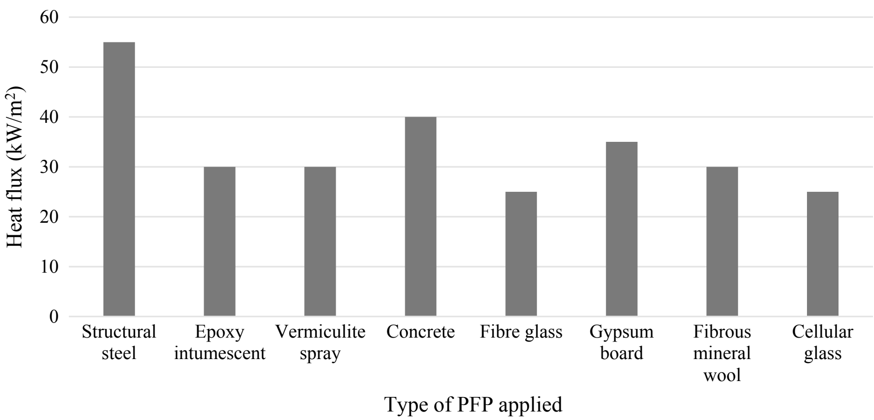


**Fig. 6** Thermal radiation received by equipment at 300 s (kW/m$^2$)

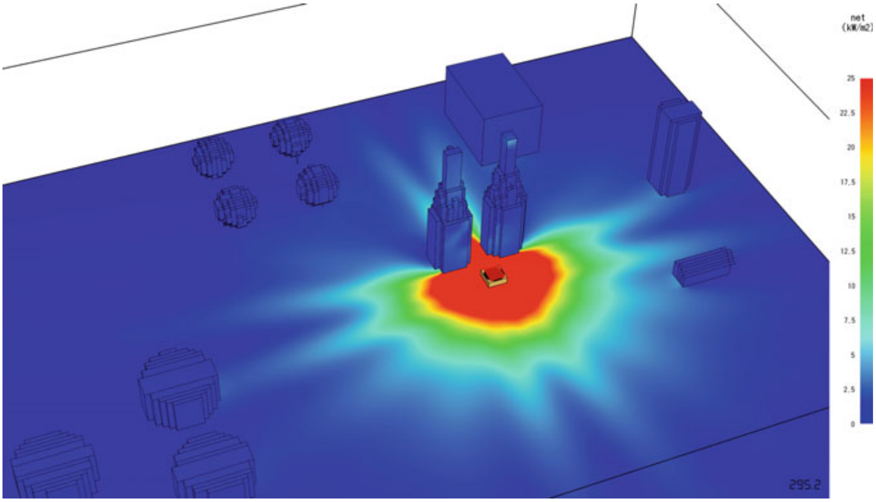


**Fig. 7** Heat flux contour for cellular glass-coated equipment (kW/m$^2$)

in 55% of heat flux received by equipment. With 25 kW/m$^2$ heat flux received by equipment, it is likely that the equipment will not fail according to criteria stated in Table 8. Heat flux contour of cellular glass-coated equipment is presented in Fig. 7.

### *4.4 Wall Temperature Comparison Between Bare and PFP Coated Equipment*

Based on the results obtained from PFP coated equipment simulations, wall temperature of equipment is examined and determines the capability of various types of PFP coating in maintaining the wall temperature below critical point. Figure 8 presents the wall temperature of equipment at 300 s for equipment with a different coating applied. Based on this figure, it is shown that concrete and cellular glass have maintained the wall temperature of equipment at 670 °C after 300 s which is significantly lower compared to 820 °C after 300 s of uncoated steel. However, based on the result obtained, it is shown that a thickness of 10 cm coating applied is insufficient to maintain the wall temperature of equipment below critical point of 576 °C when exposed to fire of this scenario. Thus, further analysis is required to determine the required thickness to maintain the wall temperature of equipment below critical point. Figure 9 presents the wall temperature contour of equipment coated with cellular glass.

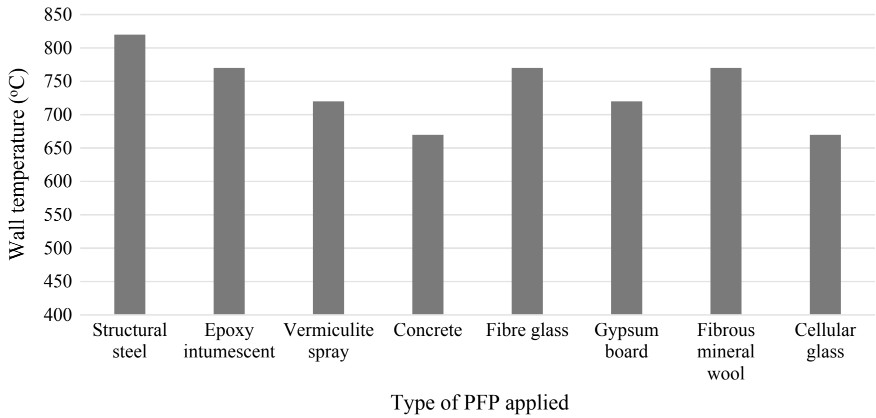


**Fig. 8** Wall temperature of equipment at 300 s (°C)

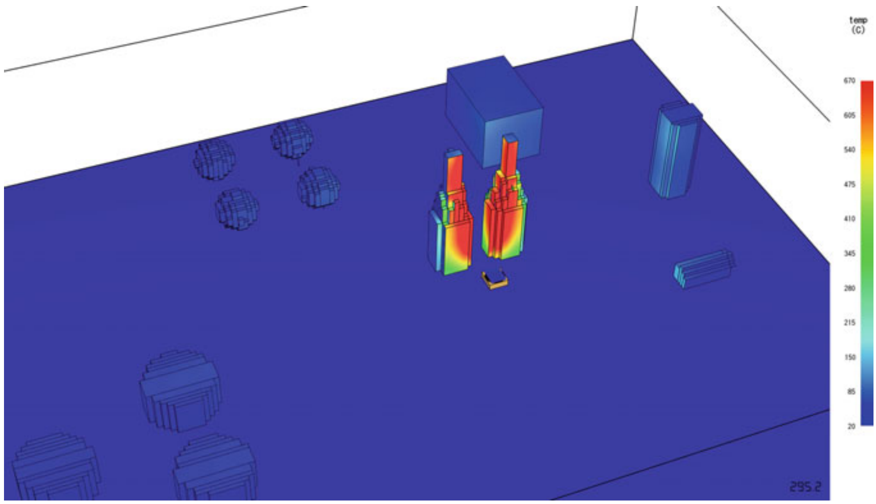


**Fig. 9** Wall temperature of cellular glass-coated equipment (°C)

## 5 Conclusion

In this study, a methodology is proposed for assessing the effectiveness of passive fire protection. An effectiveness study of various passive fire protection (PFP) systems is performed considering a case study. A total of 29 real fire accidental scenarios are considered, and the most credible fire scenario was identified using the Maximum Credible Fire Scenario (MCAS) method. The scenario was simulated in Fire Dynamics Simulator, and the thermal radiation received by equipment was used to assess the failure potential of equipment based on its temperature rise. It is found that without PFP, the equipment is subjected to failure risk having exceeded both radiation and temperature threshold limits. However, after applying PFP, thermal radiation on equipment was reduced below the threshold limit. From the simulation results, it is found that fibrous mineral wool is less effective for passive fire protection coating application as equipment coated with fibrous mineral wool has shown higher wall temperature than other PFP applications. On the other hand, it is revealed that cellular glass and concrete have prevented rise in thermal flux above the threshold value. However, further analysis and more scenarios are required to determine the required coating thickness to maintain wall temperatures below critical point in each case.

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# Evaluation of Equivalent Time of Fire Exposure for a Hospital Building: A Case Study

**Shubham Bakshi, Govardhan Bhatt, and Alfia Bano**

## 1 Introduction

The basic concept of performance based design is to provide the capability to design buildings that have a predictable and reliable performance in fire incident. The performance-based design allows the engineers to design a new building or upgrade an existing building for any crucial scenario with consideration of economical aspects. Performance-based design starts with selecting design criteria stated that may be of one or more performance objectives. The preferred reason behind the analysis of structure for fire incidence is to predict the behaviour of building's structure during the fire scenario, e.g. to evaluate performance of structure during the worst case of fire and building's resistance against fire. Each performance objective states the acceptable risk of incurring specific levels of energy losses and the consequential damage that occur as a result of this energy losses, at a specified level of fire exposure of structure. In performance-based design, as per FEMA guidelines, performance is defined as the probable damage and resulting consequences associated with building using the following performance measures (Eurocode 1 1991):

1. Casualties
2. Repair cost.

The intensity of fire that is experienced by the building during the fire condition causes damage to structural and nonstructural members. These include:

- Effects of fire on the structural member at the time of fire exposure condition and time of fire exposure.
- The behaviour of structural and nonstructural elements of building and their demand like deflection, moment.
- Structural member's vulnerability to their damage.

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- The quantity of combustible and noncombustible materials present inside a compartment or building during fire.
- Post-fire inspection of member, elements and all the components of building.
- The methods adopted in repair techniques.

The purpose of this evaluation is to calculate the equivalent time of fire exposure at the incidence of fire crisis, i.e. to check the performance of structural frame during incidence of fire. The result of this evaluation can be used to design a fire resistance structure. Fire exposure reduces the load taking capacity of structure and reduces the strength. Fire load increases the strain, stress and deflection which cause spalling, cracking and deterioration of the structural element which leads to the structural failure. Accordingly, the sections of structural elements are being assumed to include the fire resistant capacity.

## 2 Methodology

The fire load in a hospital building is the energy that is produced by combustible materials in the building during fire. There are two types of fire loads, i.e. fixed (dead) fire load and movable (live) fire load. Fixed fire load can be calculated by fixed combustible materials in building like floor, ceiling, fan, doors and windows. Movable fire load is evaluated by the combustible materials like tables, chairs, X-ray machines, etc. that are imposed in hospital. Fire load can be determined only by the combustible materials that are present in any building. Density of fire load can be considered as fire load per unit area of that compartment.

### 2.1 *Fire Load Density*

Total density of fire load can be evaluated using the equation:

$$q'' = \frac{Q}{A_{\mathrm{f}}} = \frac{1}{A_{\mathrm{f}}} \sum M.\, H_{\mathrm{c}} \tag{1}$$

$q''$ fire load density of room ($MJ/m^2$)
$Q_c$ fire load in room (MJ)
$A_f$ area of room ($m^2$)
$M$ mass (kg)
$H_c$ calorific value (MJ).

A typical building is designed with various components and materials to meet their legal obligations in the I.S. codes and to build a safe environment. The main purpose of the fire load survey is to calculate the mass of the material present inside the compartment ($M$), then evaluation of the calorific value of that material ($H_{c)}$, with

**Table 1** Calorific value of different materials used in hospital buildings

| S. No. | Material name | Calorific value (MJ/kg) |
|---|---|---|
| 1. | Wood | 19.6–21.6 |
| 2. | Rubber | 37.4 |
| 3. | Plastic | 22.1 |
| 4. | Paper | 15.4 |
| 5. | Clothes | 18.8 |
| 6. | Freezer | 28 |
| 7. | LPG | 49.9 |
| 8. | Chair | 19 |
| 9. | Office chair | 22 |
| 10. | Cotton | 18.3 |

measurement of the floor area ($A_f$) of that compartment. For conducting this survey, there are two techniques, first one is weighing technique and other one is inventory technique. Sometimes in complex type of surveys, combination of the both the techniques is used. In our survey, the inventory technique is used and some samples are surveyed using weighing techniques, such as chairs, tables and machinery. As the types of combustibles are identified through the survey, their calorific values are derived from the literature, as shown in Table 1.

## 2.2 Equivalent Time of Fire Exposure

The equivalent time of fire time exposure

$$t_{e,d} = \left(q_{t,d}.k_b.w_f\right).k_c \tag{2}$$

$q_{t,d}$ density of fire load (MJ/m$^2$)
$k_b$ conversion factor for no detailed assessment of thermal properties of material $= 0.07$
$w_f$ ventilation factor
$k_c$ correction factor (Table 2).

**Table 2** Correction factors for various materials

| Cross-sectional material | Correction factor $k_b$ |
|---|---|
| Reinforced concrete | 1 |
| Protected steel | 1 |
| Not protected steel | 13.7 |

## 3 Survey Scope and Hospital Building Details

The fire load survey is conducted in $G + 2$ hospital building. The survey is focused on all the important areas of hospital like common wards, operation theatre, USG, X-rays room, etc. In the ground floor, there are pharmacy, casualty, lobby, OPD, pathology, USG, labour room and most importantly ICU. In first floor, there are common wards, OT and private wards. Both the floors are surveyed properly. Other types of room like toilets, common toilets, lobby, and sitting area are included, and lift is excluded in survey procedure. Total surveyed area is 474.6 $m^2$ Approx (Table 3).

In ground floor plan, there is setting area which consists of chairs and pharmacy, lobby consists of wooden furniture which is combustible in nature, and lots of paper and plastic are also available there that increase fire. Two OPDs are there in ground floor covered with table, chairs and wooden racks, with lots of combustible materials like paper, and some amount of plastic is also there. One casualty room is there with three beds, clothes and many other combustible materials. In pathology, USG and labour room, there are beds, clothes, tables, chairs and some amount of combustible

**Table 3** Area of room under consideration in hospital building

| S. No. | Room under consideration | Area ($m^2$) | S. No. | Room under consideration | Area ($m^2$) |
|---|---|---|---|---|---|
| 1. | Lobby | 12.5 | 19. | PW-2 | 15.4 |
| 2. | Toilet | 9.3 | 20. | OT | 22.9 |
| 3. | Pharmacy | 10.4 | 21. | Scrub | 5.1 |
| 4. | Casualty | 16.4 | 22. | Toilet | 3.2 |
| 5. | OPD-1 | 8.6 | 23. | VIP room 1 | 22.8 |
| 6. | OPD-2 | 8.6 | 24. | Toilet | 3.7 |
| 7. | Pathology | 8.2 | 25. | PW-3 | 9.7 |
| 8. | USG | 14.9 | 26. | Toilet | 3.2 |
| 9. | X-ray room | 9.7 | 27. | PW-4 | 15.4 |
| 10. | ICU | 32.9 | 28. | Toilet | 2.9 |
| 11. | Labour room | 15.4 | 29. | PW-5 | 12.2 |
| 12. | Toilet | 3.7 | 30. | Toilet | 3.6 |
| 13. | Store | 2.4 | 31. | VIP room 2 | 17.4 |
| 14. | Female general ward | 46.1 | 32. | Toilet | 4.3 |
| 15. | Female common toilet | 10.8 | 33. | Pantry | 5.0 |
| 16. | Male general toilet | 10.8 | 34. | Male common toilet | 6.5 |
| 17. | Male general ward | 39.7 | 35. | Female common toilet | 5.6 |
| 18. | PW-1 | 9.7 | 36. | General ward | 46.08 |

plastic machineries with some amount of paper and plastic. In ICU, there are three beds, lots of clothes, wooden furniture and oxygen cylinders, which increase fire and fire load in ICU room. In the ground floor, one store is also there which is having maximum fire load density, because there are lots of combustible materials in a small area. Excluding staircase, lift area, windows, doors, total approx 237.3 $m^2$ of area is surveyed in ground floor.

In first floor, male and female common wards are there with lots of beds, clothes, curtains and some amount of paper and plastic with life-supporting devices. In private wards, there are two beds in each ward and some electronic devices, curtains and clothes. Operation theatre consists of lots of combustible materials with some electronic devices. A small scrub room with less combustible material is there in first floor. Fire survey is done in first floor by excluding lift, staircase, door and windows. Total area surveyed in first floor is approx 237.3 $m^2$.

In second floor, rooms under consideration are common ward, VIP rooms and private wards. Common ward is having large number of beds and devices with clothes and papers. Pantry is also there in second floor which consists of LPG cylinder which is having highest calorific value. Some amount of food combustible materials is also there. Area covered under fire load survey in second floor is 237.3 $m^2$ (Fig. 1).

## 4 Results and Discussion

Area surveyed is 439. The density of fire load in the various compartments of hospital building is given in Tables 4 and 5 (Figs. 2 and 3).

From the above data, the values of fire loads are found to be varying depending on the usage of the compartment and the nature and amount of the material stored. The average fire load is 233,242.7 MJ, and average fire load density is 472.92 MJ/$m^2$. Total average exposure time for hospital building is 35.6 min. During structural design to make the hospital building fire resistant, the criteria that are given in Eurocode 1991-1-2, for adopting the minimum section size that is given according to fire exposure time of structure is considered.

## 5 Conclusion

The fire load analysis of hospital building is carried out, and the conclusions are drawn based according to survey:

- The fire load for a typical hospital building compartment is varying from 330 to 30,170.8 MJ.
- The maximum fire load density is 1158.6 MJ/$m^2$ for general ward, where the combustible materials are more.


**Fig. 1** Detailed plan of typical hospital building

**Table 4** Equivalent time of fire exposure for hospital building

| S. No. | Rooms under consideration | Area ($m^2$) | Fire load | Fire load density ($MJ/m^2$) | Equivalent time of fire exposure (min) |
|---|---|---|---|---|---|
| 1 | Lobby | 12.5 | 5614.8 | 450.8 | 37.0 |
| 2 | Toilet | 9.3 | 770 | 82.8 | 6.8 |
| 3 | Pharmacy | 10.4 | 5682 | 544.7 | 44.7 |
| 4 | Casualty | 16.4 | 8860.6 | 541.9 | 44.5 |
| 5 | OPD-1 | 8.6 | 4229.95 | 245.6 | 20.2 |
| 6 | OPD-2 | 8.6 | 4229.95 | 245.6 | 20.2 |
| 7 | Pathology | 8.2 | 3640.8 | 444.1 | 36.5 |
| 8 | USG | 14.9 | 5283.6 | 354.7 | 29.1 |
| 9 | X-ray room | 9.7 | 9940.5 | 1024.9 | 84.2 |
| 10 | ICU | 32.9 | 18,246.8 | 553.9 | 45.5 |
| 11 | Labour room | 15.4 | 6828.2 | 444.4 | 36.5 |
| 12 | Toilet | 3.7 | 349.4 | 349.4 | 28.7 |
| 13 | Store | 2.4 | 2798.8 | 1158.6 | 95.2 |
| 14 | Female general ward | 46.1 | 30,170.8 | 654.8 | 53.8 |
| 15 | Female common toilet | 10.8 | 2250 | 209.1 | 17.2 |
| 16 | Male general toilet | 10.8 | 2316 | 215.2 | 17.7 |
| 17 | Male general ward | 39.6 | 27,530.9 | 695.2 | 57.1 |
| 18 | PW-1 | 9.7 | 5454.3 | 563.9 | 46.3 |
| 19 | PW-2 | 15.4 | 5483.9 | 356.9 | 29.3 |
| 20 | OT | 22.9 | 16,062.4 | 701.6 | 57.6 |
| 21 | Scrub | 5.1 | 1150 | 225.3 | 18.5 |
| 22 | Toilet | 3.2 | 330 | 102.7 | 8.4 |
| 23 | VIP room 1 | 22.8 | 9465.6 | 414.5 | 34.0 |
| 24 | Toilet | 3.7 | 1284 | 349.4 | 28.7 |
| 25 | PW-3 | 9.7 | 5454.3 | 563.9 | 46.3 |
| 26 | Toilet | 3.2 | 1284 | 449.0 | 36.9 |
| 27 | PW-4 | 15.4 | 5454.3 | 355.0 | 29.2 |
| 28 | Toilet | 2.9 | 1284 | 399.6 | 32.8 |
| 29 | PW-5 | 12.2 | 5230.3 | 429.8 | 35.3 |
| 30 | Toilet | 3.6 | 1284 | 356.7 | 29.3 |
| 31 | VIP room 2 | 17.4 | 9465.6 | 544.7 | 44.7 |
| 32 | Toilet | 4.3 | 1284 | 297.2 | 24.4 |

(continued)

**Table 4** (continued)

| S. No. | Rooms under consideration | Area ($m^2$) | Fire load | Fire load density ($MJ/m^2$) | Equivalent time of fire exposure (min) |
|---|---|---|---|---|---|
| 33 | Pantry | 5.0 | 1980.5 | 396.5 | 32.6 |
| 34 | Male common toilet | 6.5 | 1394 | 215.1 | 17.7 |
| 35 | Female common toilet | 5.6 | 1394 | 251.2 | 20.6 |
| 36 | General ward | 237.3 | 19,760.4 | 428.9 | 35.2 |

**Table 5** Exposure time and average exposure time in various floors in hospital

| S. No. | Floor | Peak exposure time | Average exposure time |
|---|---|---|---|
| 1. | Ground floor | 95.2 | 40.7 |
| 2. | First floor | 57.6 | 34 |
| 3. | Second floor | 57.6 | 32 |

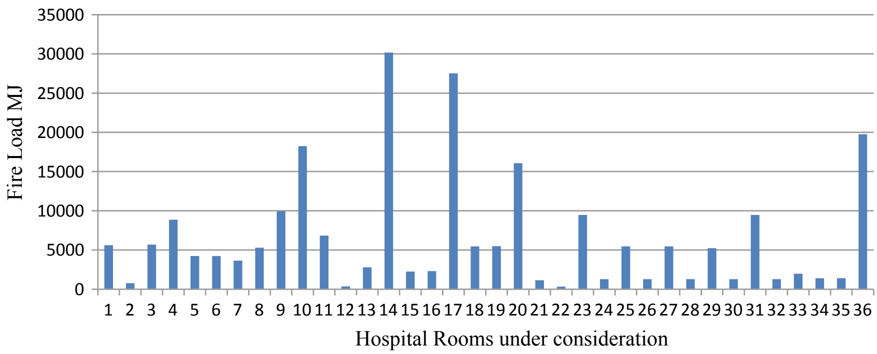


**Fig. 2** Fire load of rooms surveyed in a hospital building

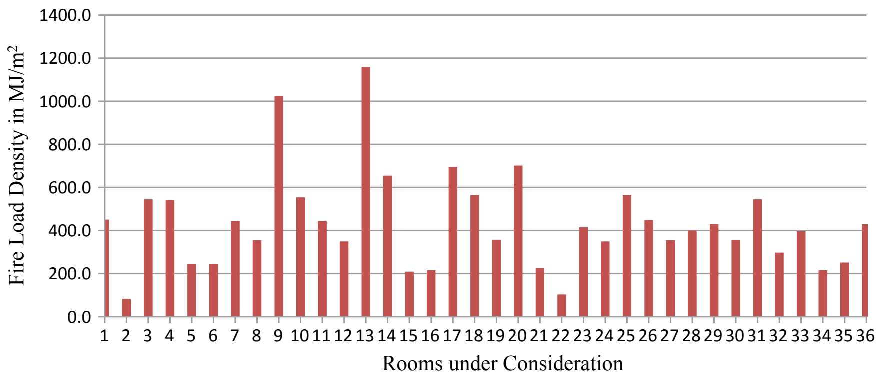


**Fig. 3** Fire load densities of rooms surveyed in a hospital building

- The peak equivalent fire exposure time for ground floor is 95.2 min, so one can assume and provide the sections and cover of the structural member.

## 6 Future Scope

- This study can be further considered to design fire-resistant building.
- Hospital building should be working during all kinds of natural or manmade disasters. According to performance-based design, hospital building should always be in immediate occupancy level during any failure scenario.
- Post-earthquake fire scenario can be studied.

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# Agricultural Water Demand and Management in India

**Ashutosh Pandey, B. P. Yadav, and Prasenjit Mondal**

## 1 Introduction

Water is a most basic input in agriculture and plays a significant role in determining the output of the cultivation. Better seeds and fertilizers cannot reach their maximum capacity to produce better crops if plants are poorly watered. Sufficient amount of water is essential for fisheries and animal farming as well. India represents about 17% of the total world population, yet it accounts for just 4% of the world freshwater resources which are also unevenly distributed in whole country. The ever-growing need of India's thriving population for water and reducing nature of prevailing water resources due to pollution and extra needs of industrial sector of India as well as agricultural sector has created a complex circumstance where utilization of water is quickly expanding while sources of fresh water stay pretty much steady. Almost 40% of the water needs of Indian cities are met by consumption of underground water, according to a survey conducted by Tata Institute of Social Sciences (TISS), which is why groundwater is depleting at a shocking rapidity of 2–3 m every year (Brown 2001). Water overuse can lead to water shortage especially in agricultural area which ultimately affects the soil quality. It leads to increased soil salinity, nitrate pollution, increased soil evaporation, etc. Indian agriculture utilizes 90% of available water due to rapid groundwater reduction and under-utilized irrigation system, and even now 70% of the net sown fertile areas are heavily dependent on rain Shah (2006). The main cause of it is not the unavailability of sufficient amount of water, but the incompetence in management of the available water which means lack of optimum utilization, expansion and conservation of water. The difficulties of Indian agriculture are closely linked with the use of available water in conventional manner. Even government schemes like crop insurance, rainfall insurance and reinsurance are not of much help to the farmers. With each passing day, food needs are rising

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but large area of lands continues to be unproductive. To maintain the current force of development, a cautious fiscal evaluation of various resources with water system is significant (Hans 2016). These resources like water should be managed by principles of optimum utilization with the commitment of each and every individual and the government. With this commitment in mind, this paper focuses on:

- Problems and challenges related to water in agriculture
- To throw light on the areas which are needed to be addressed for proper water management
- Initiatives taken by government to promote agriculture with water conversation
- Various new techniques which can be utilized for increasing crops per drop.

## 2 Water Resources Available for Indian Agriculture

### *2.1 Current Availability of Water*

India is not a very water-enriched nation, and additionally, she is tested by damaging effect of changes in environment; huge amount of wastage owes mostly to meager management and twisted water quantity estimation approaches. Ganga Basin in northern region has plenteous water resources, while the southern basin has insufficient resources filled with elevated amounts of pollutants. Rising populace and improving lifestyle have increased water need (mainly in irrigation sector) in urban as well as in rural regions. India constitutes 18% population of world but contains only 4% freshwater resources of world, of which nearly 80% is utilized in farming. India on an average receives around 4000 BCM of precipitation consistently every year. Nonetheless, just 48% is utilized in India's water bodies on surface as well as underground (Gleick 2000). A deficiency in storing capacity and methods, absence of sufficient framework, improper management of water has made a circumstance where water amount of nearly 18–20% is really utilized. Yearly precipitation in India is about 1183 mm, and in just four months from July to September, 75% rainfall is received. This results in floods and need for irrigation practices for remaining year. The populace in India is probably going to reach 1.6 billion in 2050, bringing about increased need for water, food as well as energy (Tilman 2001). This demands for improved infrastructure and enhanced resource consumption.

It should be mentioned that environmental change will negatively impact country's agricultural efficiency, going from selection of crops, cultivation time, strategies of irrigation and so forth.

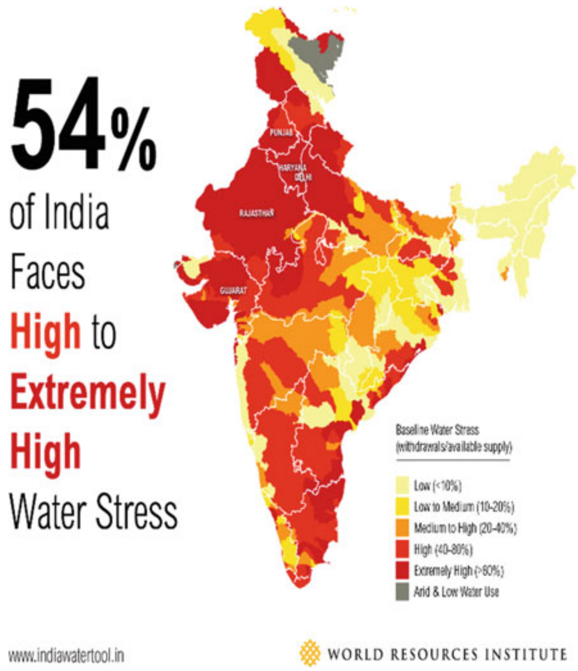


**Fig. 1** Current scenario of poor water stress in India

### *2.2 Availability of Water in Different Indian Regions*

The water availability and its need in India vary from one region to another in recognizable manner. There is a wasteful and unequal utilization and circulation of water. About 90% Indian populace live in places which have some type of water otherwise food deficiency. Water resources mainly underground have been generally plentiful in many Indian regions. Be that as it may, in a few districts, it is getting to be a grave resource issue. Circumstances of meager quality of water and water stress in different regions of India are shown in Figs. 1 and 2.

## 3 Water Use in Indian Agriculture

### *3.1 Underground and Surface Water Resources Being Used in Agriculture*

Although the evolution of groundwater as a whole (share of groundwater in total) is 62%, there is wide regional inconsistency. Over-reliance on groundwater, past practical dimension use has decreased the groundwater table considerably, particularly in northwest Indian region. The Central Groundwater Board ordered 16.2% of

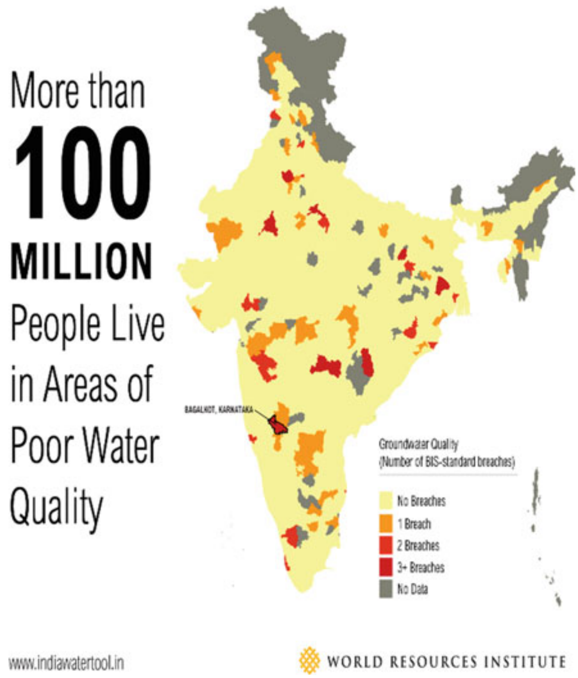


**Fig. 2** Current scenario of poor quality of water in India

total evaluated units which consist of Blocks or Talukas as "over-exploited" units. It also classified an extra 14% as "critical" otherwise "semi-critical" level. Commonly, a major number of over-exploited units are in northwestern region of India. The unsustainable exploitation of groundwater requires demand management as well as measures to improve efficiency of water utilization in agriculture. In eastern region, groundwater use is at limited level, and it offers wide possibility for the advantages of groundwater use to enhance crop output. Connecting Canals: Constructing reservoirs on every river and linking them to different regions can lead to drop in regional water disparities and can provide many benefits to irrigation system, household water supply as well as industrial water supply and also hydropower generation and so on.

## *3.2 Groundwater-Based Irrigation*

Around 40% irrigated water worldwide is provided by groundwater sources, while India has likely to be over 50% groundwater sources under irrigation use (Dhawan 2017). The common nature of groundwater to form a pool and the trouble of detecting it specifically, makes it hard to observe and direct, particularly in evolving nations. Groundwater resources continue to exhaust as a result of unsustainable withdrawal levels of groundwater that surpass natural energizing rates. Groundwater water system covers the greater part of absolute flooded zone (around 42 million ha) in

India. At present, irrigation system devours around 84% of all out accessible water. Modern and residential segments devour around 12 and 4% of all out accessible water, respectively (Dhawan 2017). With water system anticipated to be a leading factor of water use, “per drop more crop” is a most needed objective. The effectiveness of water utilization must be enhanced to increase the irrigation area while additionally saving water. Irrigation system base in India has gone through significant development throughout the years. Irrigation potential of India from large, medium and smaller irrigation system plans expanded from 22.6 million ha in the pre-planning years to 113 million ha by the 11th Plan end. Since this irrigation system potential accounts for 81% of final irrigation potential assessed at area of 140 million ha, the likelihood of additional development of irrigation system framework is largely limited. Over the years, irrigation sources have changed significantly. The water canal’s share of net irrigated area has deteriorated from 39.8% back in 1950–51 to 23.6% recently in 2012–13. At the same time, the part of groundwater expanded from meager 28.7% to an incredible 62.4% amid a similar period. The development like this shows the quality, reliability as well as advanced irrigation competency of 70–80% in groundwater water system in comparison with 25–45% of channel irrigation system. While turned out to be an important basis of irrigation system development, unwise usage of groundwater using so many tube wells has raised a few sustainability problems. The territory, generation as well as food grain yield in 2016–17 are shown in Table 1.

### *3.3 Efficiency of Water Usage in Agriculture*

Various approaches have been proposed for utilizing water effectively, some of which are mentioned below:

1. The irrigation technique used in India is flood irrigation, which always ends up causing water loss in huge amount. Superior irrigation competency has been attained by:
   - Appropriate planning of water system framework for dropping water transport loss.
   - Acquisition of water conservation technologies, for example, sprinkler as well as drip irrigation frameworks proved amazingly successful for water protection as well as for prompting higher yields.
   - New agricultural exercises like elevated bed planting, ridge–furrow method for planting, subsurface water system and precision farming that offer a great possibility for efficient use of water.
2. Efficiency of water can be enhanced by the notion of various use of water, which works past the traditional regional boundaries of the productive sectors. It gives high possibility for increasing income by diversifying crops along with the coordination of poultry and other industries in farming. This approach is capable in creating extra income advantages and can decrease helplessness by permitting

**Table 1** Food grains: area, production and yield during 2015–16 and 2016–17 in major producing states along with coverage under irrigation (Ministry of Agriculture & Farmers Welfare 2018)

| State | Area (m ha) (2016–17) | % of India (2016–17) | Production (million tons) (2016–17) | % of India (2016–17) | Yield (kg per hectare) (2016–17) | % of area under irrigation (2016–17) |
|---|---|---|---|---|---|---|
| Uttar Pradesh | 19.92 | 15.56 | 49.14 | 17.83 | 2467 | 80.40 |
| Punjab | 6.42 | 5.02 | 27.99 | 10.15 | 4360 | 99.00 |
| Madhya Pradesh | 17.03 | 13.30 | 32.98 | 11.96 | 1937 | 59.70 |
| Andhra Pradesh | 3.97 | 3.10 | 10.37 | 3.76 | 2610 | 66.50 |
| Rajasthan | 14.11 | 11.02 | 19.28 | 7.00 | 1367 | 35.90 |
| West Bengal | 5.98 | 4.67 | 17.06 | 6.19 | 2853 | 48.40 |
| Haryana | 4.59 | 3.59 | 17.16 | 6.22 | 3735 | 92.70 |
| Tamil Nadu | 2.99 | 2.33 | 6.22 | 2.26 | 2084 | 56.80 |
| Karnataka | 7.29 | 5.69 | 9.64 | 3.50 | 1323 | 27.30 |
| Bihar | 6.61 | 5.17 | 15.58 | 5.65 | 2355 | 69.80 |
| Maharashtra | 12.16 | 9.50 | 15.79 | 5.73 | 1298 | 18.00 |
| Odisha | 4.80 | 3.75 | 9.06 | 3.29 | 1887 | 29.00 |
| Gujarat | 3.80 | 2.97 | 7.42 | 2.69 | 1953 | 45.40 |
| Chhattisgarh | 5.05 | 3.95 | 9.23 | 3.35 | 1827 | 31.60 |
| Assam | 2.67 | 2.08 | 5.47 | 1.98 | 2049 | 10.40 |
| Jharkhand | 2.89 | 2.25 | 5.37 | 1.95 | 1860 | 8.80 |
| Uttarakhand | 0.88 | 0.69 | 1.87 | 0.68 | 2131 | 44.80 |
| Others | 3.59 | 2.81 | 7.69 | 2.79 | – | – |
| All India | 128.03 | 100.00 | 275.68 | 100.00 | 2153 | 51.30 |

progressively expanded business techniques and expanding the sustainability of environments.

3. Attention must be focused on water conservation by making watersheds in right zones and development of small structures for storing rainwater. Promoting water conservation has direct impact on availability of water resources, recharge of groundwater and financial states of country.
4. Effective management of water is basically connected with the performance of zonal-level water establishments. Thusly, institutional rebuilding for participatory management of water system and water user associations (WUAs) need to be bolstered.

### 3.4 Virtual Flow of Water

Virtual flow of water means the concealed water flow when different kinds of crop or other resources are traded from one place to another. The virtual flow of water from states such as Punjab is bringing up issues on sustainability of water, if we proceed using current techniques; groundwater consumption by 2050 may reach 75%. India sends out water exhaustive crops—rice is an example. It is assessed that in year of 2010, India traded around 25 km$^3$ water implanted inside its farming exports. This can be compared to the demand of population of almost 13 million. India used to be a "net importer" in terms of virtual water until 1980 s; however, with expansion in food exports, India turned into a net exporter in terms of virtual water—nearly about 1% of total water accessible per year (Economic Survey 2016). The export to import ratio of virtual water is around 4 for India and 0.1 for China. Along these lines, China is still a net importer in terms of virtual water. This likewise is apparent in trade designs of China and India. China imports crops which are water exhaustive such as soybeans, cotton along with oat grains, while trading vegetables in addition with processed foods. India sends out water exhaustive crops like rice, cotton and sugar.

## 4 India's Irrigation Scenario

India has capability of irrigation of around 139.89 hectares, from which 108.3 m ha (i.e., around 77%) is already under use (Hans 2016). The average yearly water accessibility per person is evaluated near around 1829 cubic meters at nationwide level. It is anticipated to decline to around 1341 cubic meters by 2025 and 1140 cubic meters by 2050, due to population expansion. The per person water accessibility limit in India is just around 207 cubic meters when contrasted with China's 1111 cubic meters. From whole water supply, 80% accounts for use in irrigation system. It is probably going to reduce to around 73% by year 2025 (Table 2).

Since water is crucial for producing and increasing productivity of various crops as well as for sustainable jobs and pay in agricultural area, appropriate planning and utilization of resources is necessary. Making proper infrastructures and implementing

**Table 2** India's available water resources (Hans 2016)

| | |
|---|---|
| Terrestrial area | 328 m ha |
| Cultivable area | 185 m ha |
| Precipitation/Rainfall | 4000 cubic km |
| Utilizable water resources | 1122 cubic km (including resources of 432 cubic km from groundwater) |
| Ultimate irrigation potential | 139.9 m ha |

appropriate management exercises will aid in expanding the utilizable water assets and enhance the productivity of the services.

### 4.1 Programs Supporting Irrigation

It should be noted that GOI has launched numerous programs before. From 1991 to 2007, India contributed (approx.) 4000 US dollars in canal systems available for public. However, the region irrigated using canals diminished by 38 lakh hectares amid that time, as canal infrastructures are old, water distribution is unreliable, and also no enticements are there. Even after 10 years of providing 50–90% grant for micro-irrigation, not more than 5% of developed territory of India got covered under grant scheme. In some states, the plans of Indian government were successful although struggled in other states. Electric controlled misuse of groundwater has in this way evolved into a unique combination of physical stress, policies and political issues that have caught numerous states in a horrendous circle of continuous reduction of groundwater, worsening water quality, dormant crop productivity, falling apart power sector and poor monetary strength of power generation companies. Majority of state governments give financed or cost-free power to farmers. It has been noticed that this has brought about more water abuse and brought about declining level of groundwater. It is evaluated that Indian agriculturists utilize water 2 to 4 times than Chinese or Brazilian farmers to produce same amount of food crop. 45% of it comes from cylinder wells, then canals and then wells. Various irrigational sources in India between 2013 and 2014 are listed below (Fig. 3; Table 3).

Significant importance by GOI has been given to the improvement of major canal irrigated areas. Earlier in 1950–1951, 8.3 MHA (million hectare) was the canal irrigated area which is presently 17 MHA. Nevertheless, overall position of canal irrigation has fallen to 26% in 2010–11 from 40% in 1951. Wells and bore-wells

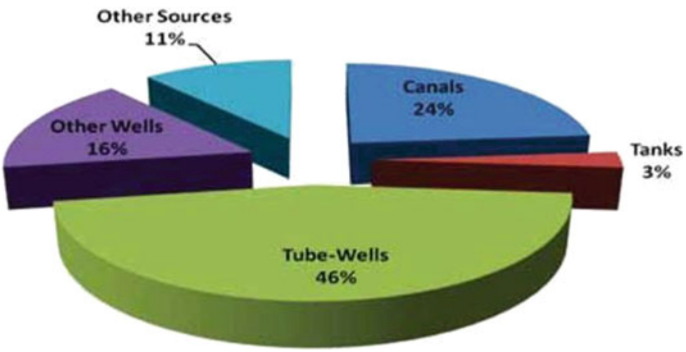


**Fig. 3** Different irrigation sources in India

**Table 3** Irrigation sources in India (2013–2014)

| Canals | Tanks | Tube wells | Other wells | Other sources | Total |
|---|---|---|---|---|---|
| 16,278 | 1842 | 31,126 | 11,312 | 7542 | 68,100 |

*Source* Ministry of Agriculture & Farmers Welfare (2018)

represented 29% absolute watered zone in 1951, and now they accounted for nearly 70% of the complete irrigated area in 2013–14.

## 4.2 Techniques Being Utilized to Improve Efficiency of Water Utilization

Different government endowment plans are trying to promote the introduction of new advanced proficient innovations, with varying level of accomplishments. One of the reasons behind this funding program is an expectation that the choice of water protection advancements can lessen groundwater extraction and balance out groundwater levels. In any case, groundwater is only occasionally managed or even evaluated in India, and power utilized for pumping water is available at subsidized costs. Lately, Madhya Pradesh government has introduced a program of planting soybeans on raised bed platforms. Cultivating soybeans on edges has resulted in saving water as well as increase in efficiency. Micro-level irrigation by means of sprinklers as well as dripping water has contributed to sensational changes in some areas of India, particularly in wavy geology and in desert areas where no other irrigation methods work.

## 4.3 Issues and Challenges for Agricultural System of India

### 4.3.1 Water Shortage and Water Use Efficiency

In India, water shortage is rapidly increasing day by day, frequently bringing about failure of crops, poverty, communal clashes and suicide by farmers (a normal of 15,000 each year). India, a member of World Trade Organization (WTO), is experiencing strain to allow world economy to use its market. Along these lines, the distressed poor farmers unquestionably will require help which should considerably be more than just some economical help. In dry land conditions of Gujarat and Rajasthan, Sadhguru Foundation's social workers made a few town-level cooperatives that thusly setup various SHGs, lift irrigation system groups, agriculture groups, seller groups and so forth. These groups helped in resource gathering and employment opportunities and, in the meantime, fill in as community network of municipal associations that challenge poverty, help in resolving social disputes and give chances for growth of whole community (Hsu 2015).

Remembering both, use and protection of qualities of water "proficiency" are the key vital factors. Ineffectiveness confines ability and consistency. Although this problem is physical, some financial problems are also there. The current investment plans and approaches of water pricing have their adverse financial results in line of production. A deficiency of water, which might be occasional or several times in a year, is a danger to a lot of financial exercises—public water distribution and sewage systems based on water, water-demanding enterprises and agriculture, clinics, hospitals, power stations, motels, mines and so on. It is conceivable that Departments of Irrigation become self-ruling and financially independent through expanded water costs, enhancing rate of storage and introducing lucrative tools and services to catch private sector interests under growth and the management program (Dewangan 2016). Reduced water costs reduce farmers' enthusiasm to think about the fundamentals of efficiency of water use and its preservation. Many rupees spent on grant of subsidized water for irrigation have prompted usage of more water resulting in decline in water level—to 75 from 15%, as stated by the researchers. Furthermore, India has institutional problems like weak organization base and weak water distribution systems, associated inputs and augmentation services (Mendhekar 2018).

### 4.3.2 Droughts

Drought also have severely affected economy, community and environmental conditions impacting crops, irrigation system, animal husbandry, wildlife, medical issues, soil, safety of public, in the end inducing extreme loss to human life. Drought has brought about a huge number of deaths in India through the span of the eighteenth, nineteenth and twentieth centuries. The most recent discoveries propose that while there were additional dry seasons and wet seasons in recent decades; recurrence of the event of dry spell or seasons in India has been expanded altogether. The period somewhere in the range of 1950–1989 faced ten dry season years, while five dry spells have been faced in the most recent 16 years (since 2000). As per meteorologists, this recurrence will increase further between 2020 and 2049. India has been encountering progressive dry spells from past several years. This particularly occurs in nine states of Andhra Pradesh, Karnataka, Telangana, Maharashtra, Chhattisgarh, Madhya Pradesh, Odisha, Uttar Pradesh and Jharkhand which faced a dry season in spell of 2015–16 as shown in Fig. 4b. Indian farming is essentially reliant on the regional weather conditions: Decent southwestern summer rainstorm is essential in providing water for crop cultivation. In few Indian states, the absence of rainstorm resulted in water deficiencies, achieving below normal harvest yields. India contains cultivable land of around 140 MHA in area, 42% of which are drought inclined regions. Besides, 54% of India's net sown regions subject to rain, rainfed sustained farming assumes a vital job in the nation's economy. The need of food security, at the present health level, wants an extra 100 metric ton (MT) food grains to be harvested or imported by year 2020. Reasonably, the overall contribution of irrigated farming

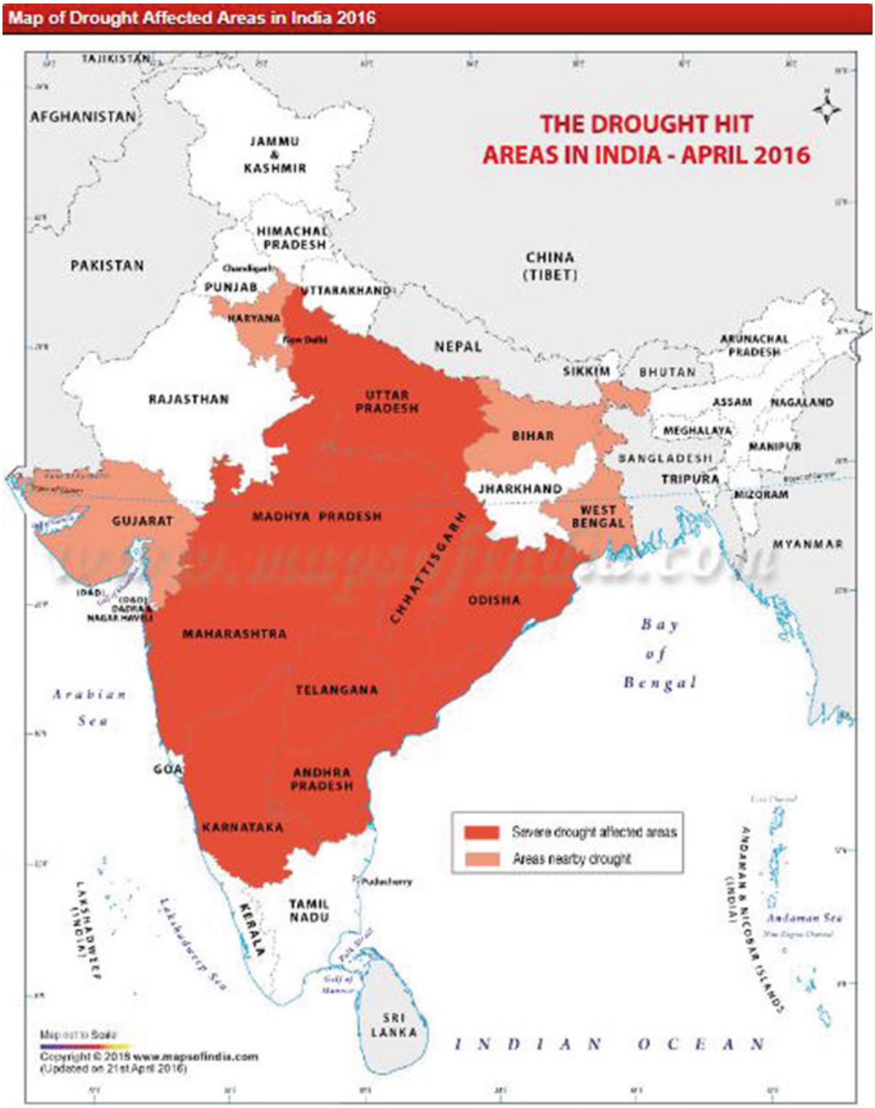


**Fig. 4** Map shows drought-affected area in 2016

to food generation from region development as well as yield enhancement would provide up to 64 MT by year 2020.

The rest of the 36 MT is obtained from rains or regions which are drought affected and from imports. Prior food deficiencies were principally because of the lack in supply of food not water. But today groundwater consumption is major reason we should be concerned about. All this shows the requirement for procedures for short and long periods to avoid dry seasons, alleviate the antagonistic impacts of dry spells and guarantee a superior and progressively productive water assets management. Building strong agriculture capable of withstanding climate challenges is the need of great importance (Dev 2016).

#### 4.3.3 Climate Change

One of the major difficulties in water sector as well as in food sector is change in climatic conditions. The expression "worldwide environmental change" alludes to the rising earth's temperature because of over expanded volume of carbon dioxide ($CO_2$) and various other greenhouse gases (GHGs). These phenomena of changing environmental conditions have turned out to be major cause of vulnerability of water accessibility, making it hard to enhance activities and their timings (OECD 2014).

#### 4.3.4 Various Other Causes

Natural resources are now vulnerable. Indian agriculture is in a strange circumstance of development but with weakness. A critical piece of the India's GDP growth varies annually over the previous century according to rainfall variations annually. Ocean level rise and exhaustion of consumable water level also current irrigation system potential are severe concerns. Evaluations anticipate that with rising temperature, by 2080–2100 the crop generation will likely reduce by 10–40% (Hans 2011, 2012). Today, greenhouse effect is a big challenge standing against green revolution.

In a few beach front zones of the nation, another issue is arising. Water table is getting affected and going down because of the sand mining and because of these farmers are using more power of their engines, again keeping the development, management and efficiency of irrigation system on line (Selvakumar et al. 2008).

## 5 Steps Taken by Government to Promote Healthy Agriculture

### *5.1 Watershed Development for Water Use Efficiency in the Agriculture Sector*

India's regular precipitation design paved the way for development of watersheds. India receives almost 50% of yearly rainfall in just 15 days giving over 90% stream volumes of a year. Numerous examinations demonstrate that the additional water provided by watershed advancement ventures is redirected toward water system, regularly while undermining the need of drinking water, particularly during dry spells. The table mentioned below features the Principal Watershed Management Content of the three World Bank-financed undertakings.

Principal Watershed Management Content of the three World Bank-financed projects

| | Karnataka | Himachal Pradesh | Uttarakhand |
|---|---|---|---|
| Overall WSM objective | • Strengthen limit of networks inside task cycle and of executing division for participatory administration inside a watershed arranging structure | • Application of watershed treatment exercises as arranged in Gram Panchayat Watershed Development Plans (GPWDP) | • GPs and other important local foundations have sufficiently grown ability to configuration, organize, actualize, work and keep up watershed maintenance |
| Hydrologic/water resource objective | • Re-energization of groundwater<br>• Management of water for producing crops (protection of soil dampness and managing water system) | • Application of integrated WSM framework using water as core basis for rural development | • Integrating goals of dampness maintenance and biomass generation into land and water utilization |
| WSM-related institutional objective | • Strengthening communities for participatory planning, usage, supervision and management<br>• To allow executive office work in a better socially comprehensive way inside structure of watershed advancement plans | • Institutions like Panchayati Raj and other local institutions have ability to plan, use, supervise and maintain the watershed treatments<br>• Awareness and building up level of competency of all partners also including line divisions involved in management of natural resources | • Assembling and organization of watershed and town development advances are done by communities<br>• Execution of watershed repair and town advancement speculations are implemented by GPs<br>• Strengthening of user groups |

(continued)

(continued)

| | Karnataka | Himachal Pradesh | Uttarakhand |
|---|---|---|---|
| Specific instruments to achieve WSM objectives | • Management of land<br>• Establishment of micro-WSM groups<br>• Development of WSM plans<br>• Training of local participants | • Conservation and recovery of land<br>• Enhance moisture content of soil<br>• Structures for harvesting water<br>• Improvement in efficiency of water use (irrigation, promotion of conservation)<br>• Starting common awareness groups<br>• Information, instruction and correspondence<br>• Enhancing capacity at local-level development of human resource<br>• Data management<br>• Coordination of watershed tactics at state level | • Implementation of SWC on cultivable lands<br>• Growth of non-arable terrains (jungles, fields, vegetative boundaries) |
| WSM-related indicators | • Re-energization of groundwater: expanded productivity, increased irrigated area<br>• Re-energization of wells and tube wells<br>• Soil disintegration diminished<br>• SWC techniques<br>• Research related to watershed and its expansion plans<br>• Remote Sensing Center helping with Geographic Information System (GIS) and preparation of treatment plans for ongoing projects | • Influencing policies of a state and issuing guidelines for developing watersheds<br>• Building up of 2500 UGs which are feasibly managing resources<br>• Tribal as well as nomads constitute two-thirds of GPs in watershed panels | • 15% expansion in accessibility of water for household as well as agribusiness use.<br>• Improvement of 20% in regulatory limit of GPs<br>• Water amount and quality pointers to be fused<br>• Percentage of exercises in neighborhood plans tending to water assets management |

## 5.2 Institutional Policies

In India, structuring appropriate institutional procedures to distribute rare water and river streams has been a huge test because of the complex legitimate, constitutional and social problems included. States like Andhra Pradesh, Madhya Pradesh and Maharashtra have made remarkable progress in reforming their water establishments and governance patterns by receiving enactments to advance participatory water system management. Water front faces the test of enhancing execution as well as water system foundation. There is minute understanding regarding suitable courses of action as well as criterions for effective organizational structure. From Punjab to Tamil Nadu, this prompted continuous exhaustion of water as well as bankrupted power services. In East, after having so many aquifers, farmland got powerless; and farming done by village people got hindered by elevated and increasing diesel expenses.

Many institutional game plans have advanced in course of the most recent couple of decades to utilize and deal with the expanding interest for water system. For instance, Participatory Irrigation Management (PIM) tactic is exercised generally by state governments, characterized with an arrangement of cooperation of recipient farmers with a small role in running the water system framework. Various changes are made in many Water User Associations (WUAs) set up in various Indian states, going from excess of 10,000 in state of Andhra Pradesh to under 100 in state of Bihar. Using PIM tactic, at times partial independence was offered to WUAs to mutually oversee primary and secondary irrigation system channels. Sometimes, a selected gathering of farmers or a panel works together with the states' water system office. In yet different cases, full self-governance is offered to farmers for managing the irrigation framework.

The accomplishment of organizational plans like PIM is unforeseen to mutual efforts at various dimensions of work and management of productive system of irrigation. However, infrastructures in most rural agricultural zones in India have remained unchecked, and there is a rising difference between the produced irrigation potential and potential under utilization. Without proper organizational help and exercise facilities for agriculturalists (bringing about low level of activity and up keep), WUAs were shaped and many of these associations do not utilize personnel to complete essential elements like managing water, support and record maintenance bringing about poor administration deliverance. Currently, government is sponsoring pumps powered by solar energy by providing 80–90% financial relaxation. Solar-powered pumps should be encouraged as coordinated power solution for water pumping.

## *5.3 Water Usage Rights and Pricing of Water*

### 5.3.1 Water Usage Rights

Water usage rights are associated with land possession in India. It basically means that an owner of the land owns the rights to obtain water by digging wells on his property. That is why land owners are urged for following rain water harvesting techniques.

### 5.3.2 Pricing of Water

Pricing of water and its related facilities sufficiently is able to urge individuals to squander less, reduce contamination, invest more money into infrastructures for water conservation and cherish watershed facilities. Water is available free of cost in various states or at a very low cost. Even many states allow electricity to be supplied free of cost for running pumps for agricultural use. These irregular prices of water are bringing about over abuse of this natural resource which will have bad effect in long term, for example, soil salinization along these lines causes increment of heavy metal content in soil leaving a highly productive cultivable land unfit for producing crops.

The state governments refrain from pulling back these pricing arrangements because farmers might think that high cost of water is denying them their rights on water, and this could prompt clashes and may likewise result in increment in food prices.

## *5.4 Rainfed Area Development (RAD): A Component of NMSA*

As Indian agriculture is largely dependent on monsoon rains, i.e., nearly 54% of the net sown area which accounts for over 40% of total production, the Indian government realized the key to fulfill ever-increasing demands of population is to focus on the conservation of resources as well as the development of rainfed agriculture (NMSA 2017). To meet this demand, the government launched National Mission for Sustainable Agriculture (NMSA) which has four components, i.e., Rainfed Area Development (RAD), Soil Health Management (SHM), On Farm Water Management (OFWM) and Climate Change and Sustainable Agriculture: Monitoring, Modeling and Networking (CCSAMMN).

To guarantee development of agriculture in the rainfed zones, NMSA propelled a new plan "Rainfed Area Development Program (RADP)" in the year 2011–12 as a sub-scheme under Rashtriya Krishi Vikas Yojana (RKVY). Its objectives are to improve the farmer's life, small- and middle-level farmers by offering many exercises for increasing their farm returns. RADP centers around Incorporated Farming System

(IFS) for improving efficiency and limiting dangers related to climatic variations. Amid 2011–12, RADP was steered in ten states with an expense of Rs. 250 crores (Department of Agriculture Cooperation & Farmers Welfare 2018). The expansive targets of the plan are:

- Expanding farming productivity of territories which receives heavy rainfall in sustainable manner by embracing proper methodologies.
- Reducing the negative effect of an unexpected crop failure because of various reasons like dry spell, flood or irregular rainfall, through enhanced and composite farming system.
- Rebuilding the trust of farmers in rain-dependent agriculture by making continued job openings through enhanced farm technologies and farming practices.
- Increment in farmer's salary and work support for reducing poverty in rainfed zones.
- Assembly of significant developmental projects in project zone for ideal usage of resources by setting up an incorporated and coordinated system network including different sector and various institutions.

RADP has been started in other 12 states as well in the year 2012–2013 with allotment of Rs. 150 crores. By March 2013 end, around 15,260 groups were included under coordinated farming system encompassing area of around 2.62 lakh ha. profiting about 4.0 lakh farmers. The yearly progress of RADP is as under (Department of Agriculture Cooperation & Farmers Welfare 2018):

| Expenditure incurred (Rs. in lakhs) | | Area covered (in ha.) | | Farmers benefitted (No.) | |
|---|---|---|---|---|---|
| 2011–12 | 2012–13 | 2011–12 | 2012–13 | 2011–12 | 2012–13 |
| 178.2 | 157.3 | 139,675 | 123,313 | 195,805 | 401,547 |

During 2013–14, the scheme was implemented in the states of Andhra Pradesh, Chhattisgarh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh, Jharkhand, Arunachal Pradesh, Assam, Manipur, Mizoram, Nagaland, Sikkim and Tripura with a budget of Rs. 250 crores.

## 6 Possible Actions

India is in dire need of reviewing its current policies regarding production of water-intensive crops like rice, sugarcane, cotton, etc. in water-scarce areas and their export to other countries. Improper policies and lack of enforcement weaken water governance.

Possible actions that should be taken are:

- Agricultural sector water pricing should be reviewed and revised to minimize water overuse.

- Laws should be enforced strictly to stop unsystematic sand mining and improper electricity use to save lots of water without affecting the agricultural productivity.
- Watershed production must be intended to protect the surface and groundwater restore systems.
- Aware people throughout the country about water use efficiency and ways to increase it.
- Awareness campaigns about water health and management must be launched, and training regarding sustainable agriculture, rainwater harvesting and water recycling must be given.
- Introduce incentive structure which is easy to understand, and that enhances the water use effectiveness in the agriculture part consequently guaranteeing long-haul maintainability of water.
- Solidification of inter-state water administration that also involves the water use in agricultural sector for a better management and resolving conflicts related to water between different states.
- Guaranteeing sustainable financing/funds to guarantee that current irrigation system is maintained.
- In western parts of India, strategy of solar pumps should aim toward:
  - Lessening subsidy burden on DISCOM
  - Lessening carbon content from underground way
  - Removing unreasonable incentives to over-abuse groundwater with government subsidized power.

## 7 New Techniques

The most important and difficult challenge in improving agricultural water management is to improve efficiency of water use and its sustainability. This can be accomplished through (I)

- an increment in crop water efficiency (an increment in marketable crop per unit of water utilized) through irrigation
- a decline in water losses resulting due to evaporation of soil that could somehow be utilized by plants for their development
- an increment in storage of soil water inside the plant establishing zone through better practices for management of soil and water.

Locating and quantifying water level at different agricultural regions can help greatly in water management, but it has always remained a great challenge due to interaction between various water resources from rainfall, irrigation, soil evaporation, plant transpiration, drainage losses from crop-growing areas, etc. There are few of the new techniques which can help in sorting out this problem and should be adopted are:

- Techniques such as Conservation Agriculture should be utilized to increase water efficiency and maintain soil quality.
- The cosmic ray-based neutron probes are used for surveying water movements at huge level for building up sustainable land-water use techniques.
- Isotopic marks of oxygen-18 and hydrogen-2% in the water taken from cultivating area of land help dividing irrigated water into two components: soil water evaporation and plant transpiration, hence giving data necessary to enhance the crops' efficiency to utilize water.
- The soil dampness neutron test perfectly estimates soil water near the roots of the crops, giving exact information on water accessibility. This helps in setting up ideal water system plans, and it is the most sensible tool for estimating soil dampness under salty conditions. Generally, it is used for calibrating traditional moisture sensors.
- The development of named nitrogen fertilizers in soil, water and plants can be monitored using isotopic mark of nitrogen-15. It is necessary for determining aspects that may influence the efficiency of nitrogen-based fertilizers as well as quality of water in cultivable regions. The collective isotopic marks of nitrogen-15 and oxygen-18 in nitrate help in recognition and isolation of nitrate contamination sources in cultivable regions.

## 8 Conclusion

Currently, our country is confronting problem of diminishing accessible water assets that have consequences on India's farming front. Water strain has become a cause of concern in certain areas. If the current efficiency of water usage does not improve, India could face water shortage in the coming decades. It has now become extremely necessary for our agriculture sector to help prevent this escalating situation by effectively utilizing the present resources to boost water usage efficiency. Another reason for this scenario is the ignorance and authoritative constraints which are making farming exhausted. Individuals involved in farming sector and associated activities ought to be perceived as assets management networks with knowledge and optimistic attitude of mind in the direction of a "coordinated way of dealing with the use of basic resources"—land, water and bio-diversity. It should not be a temporary methodology, but it should be a key coordinated effort toward sustainable eco system, agricultural livelihood and nutritional security. In addition, it must be solid in its quantitative and subjective measurements. Irrigation system must be created keeping in mind conservation of natural resources as well as area enclosure. Dispersal of dependable specialized ability with respect to water use, reuse and renewal also about dry season and disaster management should be made accessible even for little and minor agriculturists. Research laboratory works should contain data from field experiments so as to fulfill the needs of farmers and to improve their productivity.

A multi-branched procedure can be used for enhancing water management framework and its practices. Development of policies, procedures and administrative measures to keep the water abuse ought to be think about. Spreading awareness of water management and urging water users involved in the farming front to change toward more water efficient production schemes can help India in facing problem of water shortage. In addition, authorization of best tactics can help in advancement of current administrative structures by providing necessary data to present policy-makers and organizers. It can also aid in identification of key signs necessary for information based decision making. These difficulties are better linked, if there are ideal strategies and components which support people involved in farming front and also encourage them to increase their water usage efficiency.

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# Fire Load Estimation for a Medium-Rise Residential Building: A Case Study

**Vivek Jain and Govardhan Bhatt**

## 1 Introduction

Recent trends suggest that the number of fire accidents has increased in all over the world due to which an upward trend in loss of lives can be observed. Major problem with fire is that it provides less time to handle the situation. The most important aim of a fire–structure analysis is to predict the effects of fires in buildings and calculate the fire resistance time and performance of the structures under variation of temperature caused by fire. Fire–structure analysis results could be utilized in the design of protection systems and checking safety factor of structure against fire. The temperatures during an actual fire in the compartments can be specified in terms of fire loads, ventilation factors and thermal properties of the surface materials (Kumar and Rao 1995). The fire load data is essential for designing buildings against a fully developed fire. The methods which are utilized to evaluate the combustible energy of a specific compartment are measurement by: (i) mass along with the calorific value, (ii) volume along with the calorific value and (iii) energy release of an object by calorimeter. Past study reveals that no fire load surveys have been conducted particularly for medium-rise buildings. Generally, fire loads for mid-rise buildings are obtained by conducting the surveys. The challenges with doing this, however, include the fact that it would be time consuming to conduct the survey. There are also privacy concern issues that will need to be overcome. Also, a large number of dwellings will need to be surveyed to establish a meaningful data set for realistic analyses. The obvious alternative is to use data available from Web and from surveys that have already been conducted.

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## 2 Surveying Methods

The preliminary survey includes access to the building and listing out the contents along with their relevant characteristics. Also, architectural drawings are collected from various real estate promoters and builders. Based on the drawings and physical survey, fire load estimation has been carried out. From the review of the literature, several methods are used for estimation of mass of each combustible object, which are weighing, inventory, combination of weighing and inventory, questionnaires and website review. In this work, the surveys are conducted using the inventory method and architectural drawing-based survey for the residential dwellings. The data survey methods are defined as below:

- **Weighing Method**—Direct weighing method is utilized to obtain the mass, and mass chart is prepared.
- **Inventory Method**—The product of the calculated volume and standard density of the material gives the mass.
- **Combination Method**—Mass is obtained by opting both weighing method and inventory method.
- **Questionnaire Method**—Mass is obtained from standard tabular data based on self-administered questionnaires.

### *2.1 Uncertainties*

There is uncertainty in all the surveys irrespective of their methodologies because of numerous assumptions and errors made while calculations and measurements. The inventory technique which is considered as most accurate, measurement errors are reported around 10% (Zalok 2011), whereas the error variation between surveyors is around 15–20%.

## 3 Fire Load (FL)

The release of maximum heat due to combustibles present in a fire area provides the measure of a fire load.[1] Generally, the fire load in a compartment is defined as (Table 1)

$$q_c = \sum m_v \cdot H_v \tag{1}$$

where

$q_c$ = fire load (MJ)

[1]National Building Code Part IV, Bureau of Indian Standards.

**Table 1** Calorific value of various objects

| Objects | $H_v$ (MJ/kg) | References |
|---|---|---|
| Wood (raw) | 21.6 | [a] |
| Wood (scoured) | 19.6 | [a] |
| Rubber | 37.4 | [a] |
| Paper | 15.4 | [a] |
| LPG | 49.9 | I.S. Code (2005) |
| Clothes (average) | 18.8 | I.S. Code (2005) |
| Electric stove | 28.0 | [b] |
| Miscellaneous | 10.0 | [b] |
| Food stuff | 20.0 | [b] |
| Cotton | 18.3 | [b] |

[a]G. B. Menon, Handbook on Building Fire Codes, Fire Adviser, Govt. of India, CED-22 Fire Fighting Sectional Committee, Bureau of Indian Standards
[b]C.F Nielsen for calorific information https://cfnielsen.com

$m_v$ = mass of object (kg)
$H_v$ = object's calorific value (MJ/kg).

## 4 Calculation of Fire Load Density (FLD)

The total heat energy liberated due to combustion of fixed and movable combustibles present in a compartment is referred as fire load in this study. The fire load per unit floor area is referred as the fire load density (FLD). The fire load in case of industrial buildings and petroleum storage can be referred as fuel load. However, this survey is only concerned with non-structural components (i.e. doors, windows, furniture, etc.). The quantitative measurement of fire load density for numerous combustible objects is done as follows:

$$Q_f = q_c/A_r \tag{2}$$

where

$Q_f$ = fire load density (MJ/m$^2$)
$q_c$ = fire load (MJ)
$A_r$ = floor area of the room (m$^2$).

## 5 Fire Severity and Time Equivalent

Fire severity can be defined as the intensity and duration of a fire. It is also expressed as a fire potential to damage a structure or its contents. Generally, fire severity is considered in terms of the equivalent duration (Gross 1977). So, one way of quantifying the severity of a fire in a compartment is to measure or calculate the maximum temperature attained by an element of building construction in the compartment and find out how long it would take to achieve this temperature. This time is called as equivalent time of fire exposure or the time equivalent. The concept of time equivalent relates the standard test fire to the expected real fire and also utilized in estimation of fire resistance period required in the building, thereafter rating the fire-resistant capacity of the building as per the standard code. The mostly used time equivalent formula is proposed by Conseil International du Batiment (CIB) (CIB W14 1986), which is based on the ventilation factor and the combustible load. This formula was later modified by including the effect of horizontal openings and incorporated into the Eurocode (see footnote 1). The CIB formula for the equivalent exposure time is:

$$T_{\mathrm{e,CIB}} = K_{\mathrm{c}} \cdot w \cdot Q_{\mathrm{f}} \tag{3}$$

where

$T$e, CIB = exposure time (in minutes)
$K$c = correction factor to account for different compartment linings
$w$ = ventilation factor
$Q_{\mathrm{f}}$ = fire load density.

The equivalent exposure time formula according to Eurocode is:

$$T_{\mathrm{e}} = K_{\mathrm{b}} \cdot K_{\mathrm{c}} \cdot w \cdot Q_{\mathrm{f}} \tag{4}$$

where

$T$e = exposure time (in minutes)
$K_{\mathrm{b}}$ = conversion factor.

## 6 Case Study of a Residential Building

A six-storey residential building is considered in this study. It is an idealized form of what a typical apartment building might look like. The building has a floor area of 76.50 $\mathrm{m}^2$ for each residence and a floor height of 3 m. The building consists of twelve residences of total floor area of 821.56 $\mathrm{m}^2$. Each residence is having a floor area of 11.03 m × 7.56 m and consists of two bedrooms, a drawing room, a kitchen, a washroom, balconies, a toilet and a bathroom. The kitchen and balcony are connected to the living room via door, and the balcony to a lobby shared by other residence.

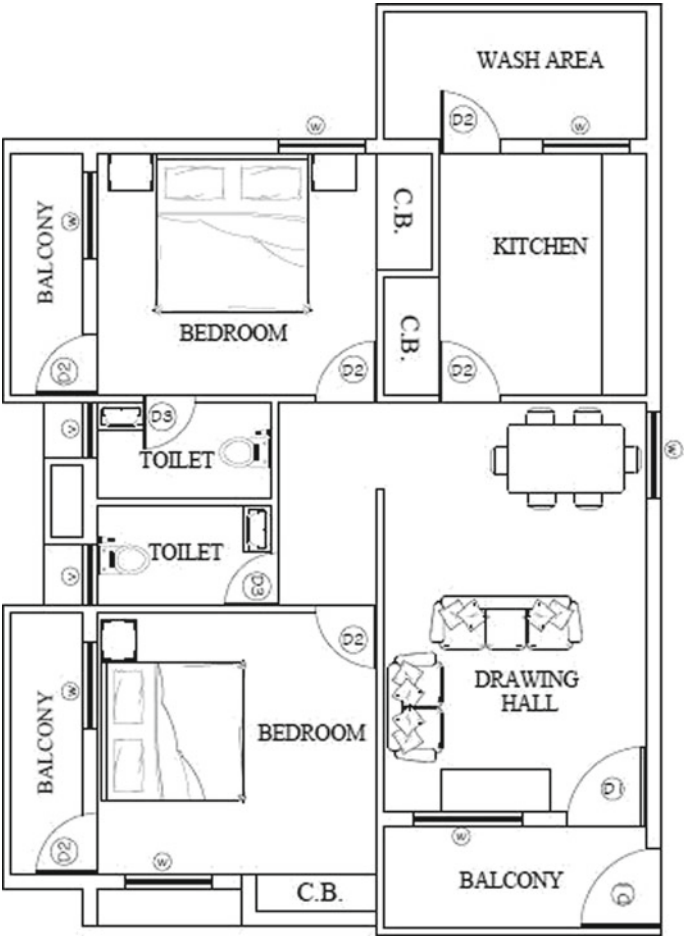


**Fig. 1** Detailed plan of surveyed residential block

Each door is having 2.1 m × 0.9 m dimensions, and each bedroom has a window measuring 1.2 m × 1.2 m connecting it to the outside. Figure 1 shows dimensions for each residence. There are total of one hundred and twenty spaces in the apartment.

## 7 Results and Discussion

An area consisting of two bedrooms, a kitchen, a drawing room, three balconies, a wash area and a bathroom of 821.56 m$^2$ is surveyed, and a summary of floor area obtained is shown in Table 2.

**Table 2** Evaluation of floor area

| Room use | Number of rooms | Floor area ($m^2$) | Total floor area ($m^2$) | Percentage of total area (%) |
|---|---|---|---|---|
| Drawing room | 12 | 20.34 | 244.08 | 29.71 |
| Bedroom 1 | 12 | 12.95 | 155.37 | 18.91 |
| Balcony | 36 | 4.02 | 48.24 | 5.87 |
| Kitchen | 12 | 9.55 | 114.57 | 13.95 |
| Wash area | 12 | 3.42 | 41.04 | 5.00 |
| Bathroom | 24 | 6.44 | 77.27 | 9.41 |
| Bedroom 2 | 12 | 11.75 | 140.99 | 17.16 |
| All rooms | 120 | | 821.56 | 100.00 |

**Table 3** Influence of fire load on various components

| S. no. | Components | Fire load density (FLD) ($MJ/m^2$) | Fire load (FL) (MJ) | Ranking based on fire load density | Ranking based on fire load |
|---|---|---|---|---|---|
| 1 | Drawing room | 283.93 | 5775.10 | 5 | 4 |
| 2 | Bedroom 1 | 561.97 | 7276.20 | 3 | 1 |
| 3 | Balcony | 195.02 | 784.00 | 6 | 7 |
| 4 | Kitchen | 668.92 | 6386.50 | 1 | 3 |
| 5 | Wash area | 410.53 | 1404.00 | 4 | 5 |
| 6 | Bathroom | 137.28 | 884.00 | 7 | 6 |
| 7 | Bedroom 2 | 574.63 | 6751.20 | 2 | 2 |

The floor area value of different compartments is found. The maximum percentage of a floor area of a residence is covered by drawing room as shown in Table 2.

The fire load influence of different types of rooms is shown in Table 3.

The maximum value of FL 7276.2 MJ is found in Bedroom 1, and the lowest value of FL is obtained in Balcony. The maximum FLD of 668.92 $MJ/m^2$ is found in kitchen, and the lowest FLD is found in bathroom. Based on FLD and FL, ranking is assigned to all components as shown in Table 3.

Graph is plotted between fire load density and room under consideration (Fig. 2; Table 4).

The FLD as specified in the National Building Code (NBC): part 4 for a residential building is 25 $kg/m^2$ for a residential building (I.S. Code 2005). The average FLD obtained in this survey is 23.04 $kg/m^2$ and is lesser than the value obtained from NBC part 4.

The exposure time of various components of residence is found and given in Tables 5, 6, 7 and 8.

Graph is plotted between temperature and time to obtain time–temperature curve (Fig. 3).

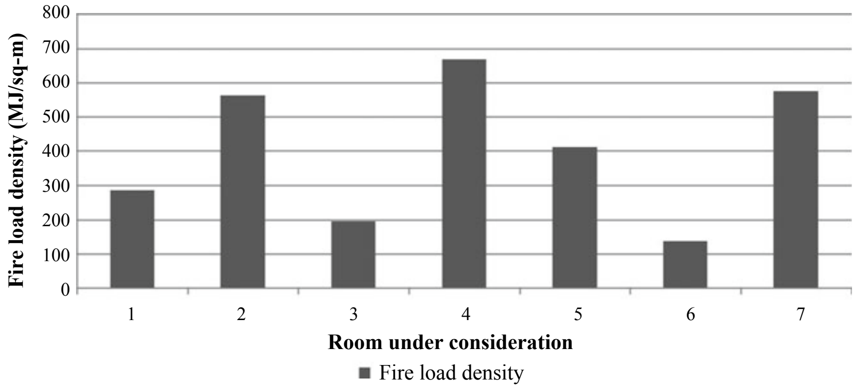


**Fig. 2** Fire load density of various rooms

**Table 4** Typical values of fire load density (see footnote 1)

| S. no. | Building type | Fire load density (expressed as wood equivalent kg/m$^2$) |
|---|---|---|
| 1 | Residential | 25 |
| 2 | Institutional and educational | 25 |
| 3 | Assembly | 25–50 |
| 4 | Business | 25–50 |
| 5 | Mercantile | Up to 250 |
| 6 | Industrial | Up to 150 |
| 7 | Storage and hazardous | Up to 500 |

**Table 5** Equivalent time of fire exposure of various components

| Room use | Equivalent time (in mins) |
|---|---|
| Drawing room | 23.77 |
| Bedroom 1 | 47.05 |
| Balcony | 16.33 |
| Kitchen | 56.01 |
| Wash area | 34.37 |
| Bathroom | 11.49 |
| Bedroom 2 | 48.11 |

## 8 Conclusion

A study has been done on mid-rise building to calculate the fire load. The following conclusions can be drawn based on survey results:

**Table 6** Estimation of gas temperature in the various fire compartments using standard temperature–time curve

| Room use | Gas temperature (°C) |
|---|---|
| Drawing room | 807.08 |
| Bedroom 1 | 909.00 |
| Balcony | 751.19 |
| Kitchen | 935.05 |
| Wash area | 862.09 |
| Bathroom | 699.00 |
| Bedroom 2 | 912.33 |

**Table 7** Estimation of gas temperature in the various fire compartments using external fire curve

| Room use | Gas temperature (°C) |
|---|---|
| Drawing room | 679.77 |
| Bedroom 1 | 680.00 |
| Balcony | 677.56 |
| Kitchen | 680.00 |
| Wash area | 679.99 |
| Bathroom | 668.53 |
| Bedroom 2 | 680.00 |

**Table 8** Estimation of gas temperature in the various fire compartments using hydrocarbon curve

| Room use | Gas temperature (°C) |
|---|---|
| Drawing room | 1099.94 |
| Bedroom 1 | 1100.00 |
| Balcony | 1099.12 |
| Kitchen | 1100.00 |
| Wash area | 1100.00 |
| Bathroom | 1094.82 |
| Bedroom 2 | 1100.00 |

- In mid-rise residential building, the magnitude of fire load density depends on the floor area. As the floor area decreases, fire load density increases.
- The fire load also depends on room use. The maximum fire load in a mid-rise building is encountered in the compartment where combustible form of materials is large in numbers such as bedroom having a fire load of 6751.20 MJ and maximum fire load density is encountered in kitchen having 668.92 MJ/m$^2$ for the present building considered.
- The time equivalent is estimated for all the compartments, and relative gas temperatures are estimated based on the different fire curves.

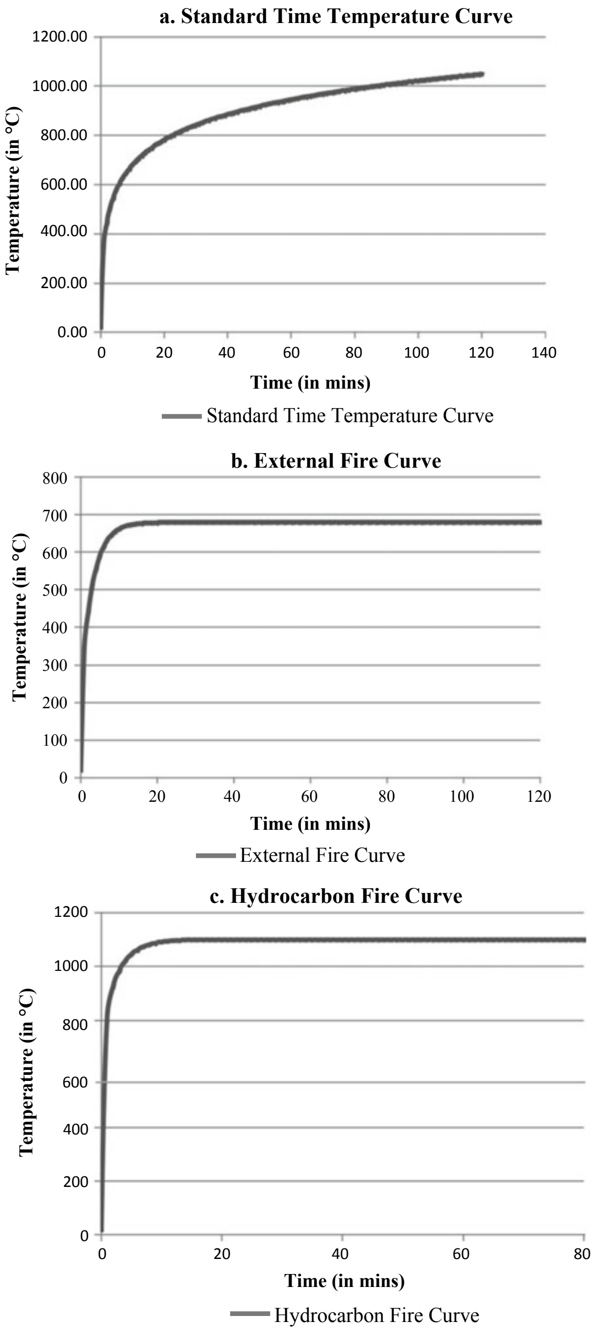


**Fig. 3** Different fire curves representing temperature versus time

## 9 Recommendations for Further Work

- Structural design based on fire safety has to be established.
- Codal provisions have to be verified for Indian standards.

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# The Perk of Safety Management System: A Meticulous Description

**D. Laxmi Ramanan, N. Pragadeeswar, and B. P. Yadav**

## 1 Introduction

Management culture improves the condition for working and at the same time guides the employees' characteristics and etiquette in minimizing the accidents and hazards in the workplace. The inadequacy of a safety management system became the main ground for a great deal of industrial calamities and accidents during the early times. After investigating the Bhopal disaster, it was said that three types of errors constituted to the tragedy which were the man-made error, technological error and system error. (Bowonder and Linstone 1987). The management for safety associates with the plan of purpose, practice and steps involved to be safe (Vinodkumar and Bhasi 2010). The main motto is to speculate the outgrowth like, loss time injuries and accidents such that rectification can be done by the companies so that the safety of the employees is improved a lot (Cox and Flin 1998; Mearns et al. 2003).

OHSM systems have no peculiar definition in terms of managing systems. This is mainly the lack of clear partitions between OHS proceedings, OHS management and OHS systems (Robson et al. 2007). Safety management systems are either obligatory or honorary. The obligatory OHSMSs emerge from government laws which impose their use by fines, inspections, etc. The voluntary or honorary OHSMSs rises by private organizations, groups of employers, agencies of the government, professional enterprises, etc., which may or may not be inter-linked to the administrative requirements. But the honorary OHSMS plans and schemes promoted through public agencies keep an eye even on smaller companies apart from their large company stalking (Frick 2000).

In all the countries in the world particularly developing countries, small and medium organizations are more important (Unnikrishnan et al. 2015). These make up 7% of India's overall domesticated products or GDP—gross domestic products.

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They comprise of 90% of the industrial sectors and units in the country and also pave way for nearly 35% of the exports in India. The SME is called the pillar of Indian economy which has contributed to industrial result of 45% and for the employment to nearly 60 million employees, constituting 1.3 million jobs each year and nearly 8000 products are manufactured for the Indian and international markets (Dhar 2014).

Safety performance is the most important issue for industries to grow into a world-class giant for this rapid globalization. Occupational accidents might pose to permanent/temporary disabilities and may even lead to deaths and/or economic loss or even both (Dağdeviren and Yüksel 2008). These accidents can be mitigated through measures that could prevent them like training, assessment of hazard, proper house-keeping and good protective equipment (PPE). To promote a good safety culture, the behavior of the workers and their mentality should be refurbished by acquiring changes in work culture and practices. Managers find it very easy in formulating the organizational policies by predicting the various types of accidents and hazards. This can mainly improve the safety performance (Beriha et al. 2012).

The foremost intention of this study is to look into the methods and the extent of safety management practices in SME's. A peripheral thought has been to analyze the practices in safety and to hold onto the leading practices in that specific sector.

## 2 Behavioral Safety

This safety model was presented by (Neal and Griffin 1997) mainly proposing theories depending on performance of a job (Borman and Motowidlo 1993; Campbell et al. 1993). It individualizes all the types of components based on their performance. In the aspect of safety, pliability of safety and participation of safety can be considered to be behavioral safety (Griffin and Neal 2000). In another study, (Pousette et al. 2008) restrained three safety behaviors to achieve self-related safety behavior. They were called as structural behavioral safety (linked with the involvement of organized safety behavior), interactive behavioral safety (linked with communication between the co-workers and the board of management regarding daily work-related safety activities) and personal behavioral safety (linked with the measurement of behavior with personal protection).

The constituents of safety performance are assumed to be taken from the safety behaviors like safety compliance and participation in safety. The employee's behavior which might have the prospective to increase their own safety and health is safety compliance. The behavior of an employee which has the capacity to increase the safety and health of the organization as well their fellow workers are meant to be safety participation (Hagan et al. 2015). Since, these measures outline the same result and the authors have compiled them into a single behavioral safety measure.

## 3 Practices for Safety Management

Management in terms of safety is related to the true operation, duties and tasks linked in being safe (Kirwan 1998). These are generally considered to be an auxiliary structure of the whole management for an organization. They are perpetrated through the industry's system of management in accordance with safety and health. Hence, they are said to be the systems that are contraptions cohesive within the organization that have been contrived to control anything that might be a peril to the workman's safety and health (Labodová 2004). These practices mainly denote the scheme, plan, program and approach aimed in promoting safety for the workers which have been followed and enacted by the organization for long periods of time. These maybe the necessary ingredient allowing the management to be vital and are said to satisfy with the ongoing legislations which are said to apply for the organization. The point till which these practices can be brought into an organization will be expressed by the different types of actions and deeds of the management and can be transparent to the people within the company. Hence, these systems can be considered as precursory of the company's climate of safety.

Many attempts have been seen in order to find out the practices for specific management and their performance. Many companies with minimal accident rates have been distinguished with few factors like: high ranked safety officers; safety activities had the involvement of the management personally; new employees were trained by their superiors; the existing workers had to undergo regular training frequently; all hazards were properly displayed in the form posters; the employees and their supervisors had a daily communication regarding the hazards and safety; regular inspections; in-depth analysis of accidents; emancipation of workforce (Cohen 1975; Griffiths 1985; Shannon et al. 1997; DePasquale and Geller 1999; Cohen 2013). The participation of workers, training, practices, systems that give incentives and rewards, feedback mechanisms should be started for giving better results in terms of safety and health (Vredenburgh 2002).

Among the first analysis concerning safety climate, it was found that the commitment of the management regarding safety affects the rise of an organization (Zohar 1980). The involvement of the hierarchy of the company in safety must not only be verbal but it should also prevail through their actions (Hofmann et al. 1995). An employees' point of view will exactly depict the value of safety in an organization (Griffin and Neal 2000). The involvement of the management in high risk and hazardous environments is continuously emphasized (Flin et al. 1996; Cox and Cheyne 2000). The adherence of the management as a part of the management practices is also included in this study. It is calculated with the ternaries associated with the management's priority for safety, the rectification actions, safety meetings attended by the safety manager, analysis of near miss/accidents and providing proper PPE's.

Safety training is the priority element for any reigning organization for preventing accidents. It helps in improving the behavioral expertise, knowledge related to them and/or point of approach. It helps to make accidents more predictive. For maintaining a healthy work environment and hazardous threats to workers, all employees and members of the management should be implemented with this training by bringing a mentor and by using buddy system for orienting fresh employees regarding the works, health and safety. Organizations with less accident were found to be undergoing proper safety training (Ostrom et al. 1993; Lee 1998; Tinmannsvik and Hovden 2003). So, training in safety is said to be a management implementation were several practices and training were given to new and old employees regarding emergency conditions and situations. They were encouraged to join in this training regularly and to attend these programs'.

To promote the motivation aspects, various types of communications are used to amplify its effect toward the employees. The most effect way of communication may be toward the system of two-way or double-way communication where its coverage and influence are higher. There should be routine communication on the event of issues regarding safety between the management, managers, supervisors and employees for a healthy environment and to maintain a safe workplace. Feedbacks should be welcomed and additional communication in the form of surveying by interrogation for different categories of employees helped to form an organized work system. This has made to accept that feedback and communication have been forms of safety management by this study. It has been restrained by using reports related to hazard system, safety issues in terms of open door theory, safety targets and achievements among managers and co-workers and discussion of issues in safety during meetings.

Among all of the supreme elements with regard to management of safety is the point to which the company is able eradicate the use of drugs and liquor consumption during a workers shift and hours of work (O'Toole 2002). But in this study, it has been totally removed due to the difficulty of the fact that only honest response can be considered from the particular employee rather than the actions that show them. Hence, all these above-mentioned practices for safety management are contemplated to be the precursors for the safety performance in an organization.

## 4 Safety Culture (SC)

It is a constituent ingredient regarding an organizational refinement, which takes major responsibility in affecting employees' behavior and attitude to a company's performance based on health and safety (Cooper 2000). Safety culture is often recognized, for example, by injuries from disaster, etc., which mainly contains behaviors, attitudes, responsibilities which are personal and also for HR features for training and development (Glendon and Stanton 2000). This concept is gaining its reputation as it takes in the concept of learning from numerous sources of research and organization. Hence, this is proving to stimulate others in learning its complex systems through adaptation and interactive features. This also unveils the progress underway and the obstacles that have to be dealt with as many analysts and specialists have made ample efforts hoping that the conception is made significant for organizations that tend to take behavioral transformation as a method for developing and improving the safety performance ( Baram and Schoebel 2007).

Workplace safety improvisation with behavioral-based approach was done by (Komaki et al. 1978) which says that behavioral-based safety programs provoked and made them act safely. Similarly, studies were made by (Cooper et al. 1994; Krause et al. 1999; O'Dea and Flin 2001) showing that safety leadership can be motivating to team members making them work harder and also to promote high levels of safety performance. Hence, without an exceptional leadership there cannot be any kind of safety performance. The Federal Safety Commissioner has highlighted that senior managers can gain safety leadership only through planned safety culture which can gain effectiveness in elevating organizational safety (Lu and Yang 2010).

## 5 Safety Climate (S. Cl)

It is basically the exhibition of culture in safety fund in the attitude and behavior expressed among the employees (Cox and Flin 1998). There can be an intellectual confusion when it comes in differentiating safety culture and safety climate in terms of management systems. (Kennedy and Kirwan 1998) uphold that management of safety and climate of safety are at gradations low of presumption. They are taken up to be the exposition of the whole culture of safety. Generally, it is the safety culture that rescues from boundless level of conjectures, operable safety like this has led to an escalation in scales and each has posed to analyze the climate of safety. The aggregate of facets for S. Cl still is said to be impugn, but recurring chapters among safety climate surveys have been commitment of management, adequacy of supervisors, over production priority in safety and pressure because of time (Cox and Flin 1998; Flin et al. 2000)

S. Cl elements rise up to be forecasters for accidents or unsafe behavior in a number of versions (Guastello 1989; Tomás et al. 1999) and has been undertaken that a fitting S. Cl is required for carrying out any maneuver safely. Mainly this is by promoting safety awareness and also by carrying safe behaviors in the presence of supervisors. This is a strategy which helps to give way for involvement of management. Hence, the decision-making has been made clear because of the involvement of workforce (Simard and Marchand 1994). These notions had led in the philosophy for safety of higher management and the SMS. In this aspect, attitudes of management and behavioral safety impregnate from the industry or organization onto the employees.

## 6 Safety Management Questionnaire (SMQ)

This is mainly set out to be a tool for audit. It was mainly formulated to analyze and evaluate the management procedures on each installation. The indicators called leading and lagging were able to sort out the performance. The weaknesses were identified due to the advantages of leading indicators which could easily exhibit the risks before they breach out as accidents. Many such significant indicators have been found out in organizations as weakness in safety practices (Blackmore 1997; Fuller 1999).

The grasp of the workers about the practices for management of safety and the behavioral safety must be calculated by terms of questionnaires. This should be constructed in regard to the evaluation of the literatures and theories that they had been guided with. It must contain questions must overlay the field of commitment with management, training, involvement of the workers, rules and steps to be taken in safety, communication of safety and its feedback, behavioral safety and safety policies (Cheyne et al. 1998). So they should be organized using certain themes like:

### 6.1 Policy Regarding Health and Safety

It includes the disclosure on safety and health, the position and number of the staff for safety and, conveying the policies of safety and health, corrective actions.

### 6.2 Organizing and Categorizing Safety and Health

Mainly the goals for safety and health have been the major topic. Office visits, allotment of responsibilities, evaluation, registering and gathering training necessities, rewarding for performances are the sub-topics to be taken into note then and forth.

### 6.3 Managerial Adherence

The safety performance of the management and its contractors, the cause and amount of senior panel visits, the precedence of safety during scheduled managerial meetings are some of the topics.

### 6.4 Involvement of Manpower

Percentage of workers getting orderly training in assessment of risks, the number of workers attending safety meetings, persistence of distinctive training or orientation disposed to all the representatives of safety, connivance of manpower in mounting objectives toward safety and health, analyzing risk control methodologies, etc.

### 6.5 Audit of Health and Safety

The proportion and number of audits performed, the evaluation process, rectification closed out after analysis, number of goals attained and targets in safety inspection reached.

### 6.6 Health Monitoring and Propaganda

The amount of ongoing health aid programs, discussion related to health issues and the point until any health plan gets achieved.

### 6.7 Connection Between Organizers-Operator

Clarification of all the shared operations both by the organization and also by the third party companies helping the organization in health and safety schemes, agreeing to a much unified proposition that administers the names and titles of all the staff based on their jobs in a company or a particular department showing how they are linked with each other, initiate key liabilities and also their responsibilities, conventional communication agreements, analyzing hazards to health for the combined activities, corroborate proficiency of the staff concerned with the shared pursuit and the aggregate contract company visits to the organization.

These maybe some of the themes regarding the questionnaires for safety management and these are very useful of any kind of job during audits and investigation. The grasp of the workers about the practices of management in safety and the behavioral safety must be calculated in terms of questionnaires. This should be constructed in regard to the evaluation of the literatures and theories that they had been guided with. It must contain questions must overlay the field of commitment with management, training, involvement of the workers, rules and steps to be taken in safety, communication of safety and its feedback, behavioral safety and safety policies (Cheyne et al. 1998).

## 7 Conclusion

This study has given an insight on the safety management techniques for organizations, elaborating a more valid and trustworthy measure in managerial safety across miscellaneous sectors. As an administrative tool, the scale of safety management can be used to benchmark the various activities of the company or industry. A cluster of practices is captured by these tools to analogize the safety performance positively so that it does not lack in its performance. These are as a checklist through the questionnaires by the managers by granting them scores 1–5 depending on the frequency of its occurrence and existence. These scores can be used to compare with other organizations and could help them to develop their own firm knowing where they stand. Furthermore, applying these scales simultaneously with safety climate can give a better perception on safety culture in the organization, also seeing an advance toward operationalization of the notion of the results because of these management systems will be able to provide organizations with inducement so that the working conditions are improved. Correspondingly, the engagement of the safety management concept helps in introducing them into more immense models, inspecting antecedents and the outcomes of these systems. Hence, it might be possible to learn about the association between the behavior of the individuals and the management system with the attitudes of the world wide, organizational degree, determining whether the systems are definitely a predecessor to that of the safety climate of the organization. At last, the organizational factors could be analyzed with the scale developed during the work that may be benevolence or restrict the enforcement of safety management system in the organization.

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# Carbon Nanotubes—A Novel Approach to Oil Spill Cleanup

**Kartik Kohli and Naman Bhatt**

## 1 Introduction

Oil spill cleanup techniques that have been used for containing the spill or to reduce the immediate effects of an oil spill include bioremediation, in situ burning of oil on water, mechanical equipment like skimmers and booms, spraying of chemical dispersants and oil sorbents (Majed et al. 2012). But these techniques are not very effective. The industry requires a more novel technique in order to combat oil spills. Some oil spill cleanup techniques along with their limitations and impact on the environment are discussed below.

### *1.1 In Situ Burning*

This is one of the techniques which have been used a lot. This method involves burning of oil on the site where oil spill has occurred. Oil spill should not spread to a greater area. For the in situ burn to be a success, layer of oil on the sea surface should be at least 2–3 mm thick in order to counter the cooling effect of sea winds and to sustain fuel source (Majed et al. 2012). Oil spill if spread to a greater area will need to be contained against a barrier. Ignition is incorporated using variety of devices like diesel-soaked rag to more advance equipments like helitorch. Helitorch is kind of a flame-thrower which is suspended beneath a chopper. A huge amount of smoke is generated as the oil is burned which results in contamination of land, water table and environment. The viscous residue has the ability to sink and get accumulated which

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would adversely affect the marine life-forms. Carbon monoxide and sulfur dioxide are frequently formed as toxic compounds when oil is burnt on the sea surface.

### *1.2 Booms*

Booms are temporary floating mechanical barriers used to contain marine spills and assist in recovery. Booms are available in various shapes and sizes as per the coverage area. A boom includes a containment partition that floats on and extends above the water surface to prevent water from splashing over, and a "skirt" or "curtain" that sinks into the water which prevents water escape from below.[1] Booms may be deployed in various configurations, depending on winds and other environmental conditions. Booms also facilitate the containment for in situ burning. However, oil drainage is still a problem for spills over greater area.

### *1.3 Thickeners*

Thickeners are often referred to as herding agents. They are deployed to increase the viscosity and increase the surface tension between oil and water. This leads to a better containment and eases the oil recovery as the spilled oil will not spread in larger area after the deployment of thickeners. However, thickeners are expensive as well as toxic. The affected oil with thickeners will sink soon. Hence, the problem may be increased while containing the oil spill.

### *1.4 Dispersants*

Dispersants are chemically active agents that assist to break up an oil droplet on the sea floor into further smaller droplets by lowering the surface tension between oil and water. But the chemical constituents of the dispersants pose a threat to the natural habitat because of their toxicity. Dispersants are sprayed on the area of spill by specially equipped boats or planes (guidelines on implementing spill impact mitigation process (SIMA) 2017). Dispersants can lead to contamination of water table. However, in the present scenario, the use of dispersants has been minimized.

[1] http://www.oilspillprevention.org/oil-spill-cleanup/oil-spill-cleanup-toolkit/booms.

### 1.5 Skimmers

Skimmers represent a variety of mechanical equipment that facilitate oil removal. An important aspect to be noted is that only lighter oils can be separated effectively.[2] Some skimmer technologies involve suction to recover spilled oil, while weir skimmers work on the principle of gravity to gather skimmed oil into underwater storage tanks. Skimmers are generally effective when used in calm water, and suction skimmers are prone to clogging by floating debris (guidelines on implementing spill impact mitigation process (SIMA) 2017). However, skimmers leave much of the recovered oil mixed with water, thus making this process expensive and economically impractical.

### 1.6 Bioremediation

It is a technique that involves biological agents that attracts microorganism which speeds up the process of biodegradation at the contamination site. This process is usually deployed in areas near shoreline. Nitrogen and phosphorus-based fertilizers are dropped in the contaminated area in order to enhance the growth of microorganisms (Wadhwani 2017). Bioremediation is not effective when sunken oil is involved. This method cannot be used in areas with low temperature and insufficient oxygen.

### 1.7 Sorbents

Sorbents are used for sorption and are the most popular technique that have been applied for the treatment of oil spills. Principle of adsorption is involved in the process. A variety of sorbent materials have been tested in order to determine the best one. Sorbents must be oleophilic and hydrophobic in order to combat oil spills (Wadhwani 2017).

### 1.8 Natural Organic Sorbent

These type of sorbent materials are abundant either in nature or as a by-product of an industrial process. These materials include straw, moss, etc., and are environmentally friendly as they do not harm the environment and the habitat. The limitation posed by use of such materials is the cost involved in recovering the oil-soaked sorbent after removing the oil and later re-using it again (Majed et al. 2012). Organic sorbents can

[2] http://www.oilspillprevention.org/oil-spill-cleanup/ocean-oil-spill-cleanup-toolkit/skimmers.

adsorb around 3–15 times their weight in oil. Many sorbents loose particles and are difficult to collect. These problems are countered by the use of floatation devices.

### *1.9 Inorganic Sorbents*

These sorbents are very fine grained, highly dense, natural or processed. They are used to sink the oil floating on the surface. These sorbents contaminate the sea beds and are harmful to the flora and fauna. Due to low retention capacity, they release large amount of adsorbed oil while sinking. They are not economically viable. Examples of inorganic sorbents are fly ash, zeolites, silica, activated carbon and graphite.

### *1.10 Synthetic Sorbents*

This category of sorbent is the most efficient and effective in recovery of oil. Polyurethane and polypropylene are the most widely used polymers in sorbents. They are known for their significant oleophilic and hydrophobic property along with their high adsorption capacity. Some synthetic sorbents include cross-linked polymers and materials like rubber. Most of these sorbents can adsorb up to 70 times their own weight. However, these substances fail to adsorb the chocolate mousse which is formed when the spilled oil is pitched and rolled on waves. If these sorbents are not recovered, ecological problems may arise.

## 2 Carbon Nanotubes—Structure and Properties

Carbon nanotubes are one of the best examples of the nanoscale materials that are derived from the bottom-up approach in chemical synthesis. The CNTs are a prime example of the advancements that the modern science and technology has undergone (Wang et al. 2013). The carbon nanotubes are tubular form of carbon which is composed of hexagonal lattice of carbon atoms. These tubes have a hollow core with diameter in the range of 1–50 nm and thickness much less than that of a human hair. These nanostructures exhibit some very unique and effective properties which makes them an ideal material to be used in the fields of electronics, optics, material sciences, nanosciences, etc.

The CNTs are allotropes of carbon and their structure can be easily understood as a one carbon atom thick sheet of graphene which is rolled at certain specific and discrete angles to form long and seamless tubes (McNeish 2008). The angle at which the sheet is rolled is known as the chiral angle. CNTs possess several interesting properties such as an extremely high aspect ratio which is nearly 1,000,000:1, ultra low density, extreme mechanical stiffness, tensile strength as well as elasticity. The value of Young's modulus of elasticity −1700 gigapascals is about eight times that of steel. The tensile strength of a CNT can range up to 100 gigapascals (approx. 15,000,000 psi). The density of carbon nanotubes varies around 1.3–1.4 g/cm$^3$ which is far less than the value of density for steel that ranges up to 7.8 g/cm$^3$ (Gui et al. 2013) (Fig. 1).

This strength of the carbon nanotubes is a result of the $sp_2$ hybridization found in between the carbon atoms, wherein each carbon atom is bounded to the nearby atoms via one double and two single covalent bonds. Hence, they are stronger than diamond which involves $sp_3$ hybridization among the interlinked carbon atoms.

## *2.1 Structure of CNT*

Based on the structure, carbon nanotubes are broadly classified into two categories—single-walled carbon nanotubes (SWCNT) and multi-walled carbon nanotubes (MWCNT).

A single-walled nanotube consists of a one carbon atom thick sheet of graphene which is rolled into a seamless cylinder with a diameter of nearly 1 nm (McNeish 2008). The structure of SWCNTs may be arm chair, zigzag and chiral depending upon the angle at which the graphene sheet is rolled (Fig. 2).

Multi-walled carbon nanotubes comprise several coaxial cylinders, each of which is made of a single graphene sheet surrounding a hollow core. The outer diameter of MWCNTs is in the range of 2–100 nm, while the inner diameter varies between 1 and 3 nm, and their length is one to several micrometers (Lee and Parpura 2010).

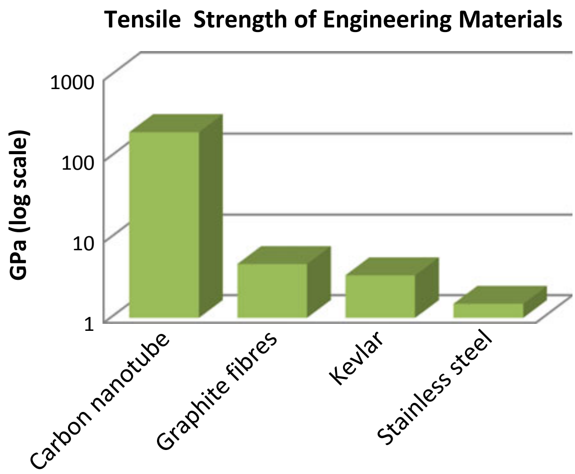


**Fig. 1** Comparative study of tensile strength of engineering materials. Source: https://worldofnanoscience.weebly.com/nanotube--carbon-fiber-overview.html

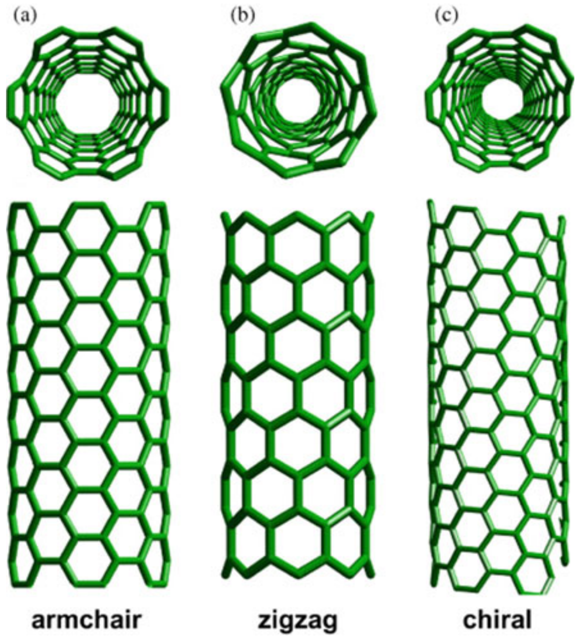


**Fig. 2** Different types of CNT based on their structure. Source: Karthik et al. [2014]

## *2.2 Carbon Nanotube Sponge—An Ideal Material for Oil Spill Cleanup*

CNT sponge is a three-dimensional framework of the carbon nanotubes. In contrast to the parallel arrangement of the individual nanotubes, a CNT sponge comprises an interconnected, cross-linked network of the nanotubes. This interconnected framework makes the material strong in three dimensions rather than the parallel arrangement of nanotubes whose strength is restricted only in the axial direction of tubes (Gui et al. 2011). The cross-linking is achieved by adding boron atoms during the synthesis.

Introduction of a foreign atom inside the hexagonal carbon lattice which is composed of a network of thin tubes, leads to disruption in the arrangement of the network since the foreign atoms do not wish to be a part of the same (Deng et al. 2013). Boron, being next to carbon in the periodic table, has one less electron in its valence shell. So, due to the addition of boron atoms, the curvature of the material changes, thus initiating a different type of growth. This encourages the formation of "elbow" junctions that enable the nanotubes to grow into a three-dimensional network (Varshney 2014). The individual threads are tangled together into a complex network, and thus a macroscale, spongy block of nanotubes is obtained which is thick and large enough to be used as a sorbent material in an oil spill cleanup (Wu et al. 2014).

The main highlight of this sponge is that it exhibits excellent hydrophobic and oleophilic properties. Owing to the superhydrophobicity, it floats on water and adsorbs only oil from an oil–water interface. It possesses high sorption capacity as much as 93.2 gm of oil adsorbed by 1 gm of the sponge. A CNT sponge provides an enormously large specific surface area whose experimental value is found out to be 253 $m^2$/gm, thus enhancing its sorption capacity and making it an ideal material for adsorbing oil (Gui et al. 2011).

An additional feature of CNT sponge is that they are robust, highly flexible and can withstand a series of compressive forces, without their properties getting affected (Kharisov et al. 2014). The above properties prove to be extremely useful for recovering the oil and also add to the reusability of the material. The adsorbed oil can be removed just by mechanically squeezing the sponge. This resistance to cyclic strains is achieved due to the inter-connecting cross-linkage in between the atoms. Incineration of the material causes absolutely no change in the internal network and structure. Upon the adsorption of oil, if the sponge is put to fire, only the adsorbed oil burns and the CNT sponge is recovered unaltered. The reusability of the sponge is further enhanced owing to this exclusive property (Golnabi 2012).

Along with the above-mentioned properties, it also shows salubrious magnetic properties which are produced due to the metal catalyst used during the synthesis process (Liu et al. 2007). Thus, the movement of the sponge on the sea floor can be controlled by the use of appropriate magnets and the sponge can be recovered back after the cleanup process. This gives it an additional advantage over other sorbent materials which cannot be recovered again after their use, are left behind after the cleanup and cause environmental degradation.

## 3 Experiment

The MWCNT proves to be the best sorbent material that can be used in oil spill cleanup due to its excellent selective adsorption capacity and its reusability (Wu et al. 2014). For the experiment petrol, kerosene and diesel were used. The CNT was gratefully provided to us by the UPES R&D Center.

To investigate the sorption capacity and its variation with the number of reuses, simple experiments were performed. 0.2 gm of CNT was put in an injection syringe (used in medical practices) for the oil absorption process.

The removal of oil from the CNT was realized using two different techniques.

1. Extruding the oil by pushing the piston of the syringe against the CNT to remove the oil.
2. Incinerating the CNT to burn the oil.

The steps for the experiment were as follows:

1. 0.2 gm was loaded in a 5 ml syringe.
2. The piston was pushed to extrude air from the sponge.
3. The oil was then sucked into the syringe by drawing the piston upwards, which was then taken out.

4. The extra oil was allowed to drip out by hanging the syringe for over 2 h.
5. The oil loaded CNT sponge was then weighed to determine the amount of adsorbed oil.

## 4 Results and Discussion

The adsorption capacity and reuse performance of the CNT were checked for all three oil samples (petrol, kerosene and diesel). The observations have been plotted in the following graphs (Fig. 3).

The results in the following graphs clearly show that the adsorption capabilities of the CNT tend to decrease in both the methods and then later acquire a near constant value. The adsorption capacity of the incinerated CNT is found to be higher than that of the extruded CNT.

For the extruded CNT, the adsorption capacity decreases with the no. of reuses but later reaches a stable value. The decrease is due to the deformation of the nanotube and hence decreases in its pore gap. Moreover, the value of the adsorption capacity is more for heavy oils, which are denser and have longer carbon chain (Liu et al. 2015). The decreased tube radius and increased viscosity (in heavier oils) of the oil assist adsorption. This makes them suitable for adsorbing crudes.

In case of the incinerated CNT, although the initial adsorption capacity is higher, but its repeated use induces a cooking process within the nanotube which decreases the internal gap and available adsorption sites. The extent of coking is more for heavier oils, i.e., oils having longer carbon chains (Liu et al. 2015). This makes the incinerated CNT less effective in the case of crudes.

Thus, it would be much more effective and efficient to utilize the extrusive reusability of CNT sponges in oil spill cleanup processes rather than incineration, wherein the oil is lost to combustion.

### *4.1 Deployment Strategy*

The natural sorbent materials used for oil spill cleanup do not possess selective adsorbtivity, and thus adsorb water too. The synthetic adsorbents like polyurethane have good amount of oleophilicity but that is very low as compared to the MWCNT sponge. The CNT sponge has superhydrophobicity which makes it an excellent material to be used effectively in areas with very thin oil spill layer.

The CNT sponge can be conveniently used to adsorb the oil by physical contact of the sponge with the oil spill surface. This helps to restrict the spill radius and the same method can also be employed at places where the small quantity of oil floats far away from the spill (Gui et al. 2013).

The technique used to extract the soaked oil from the CNT sponge includes a conveyer belt system that is mounted on the deck of a container ship. The sponge

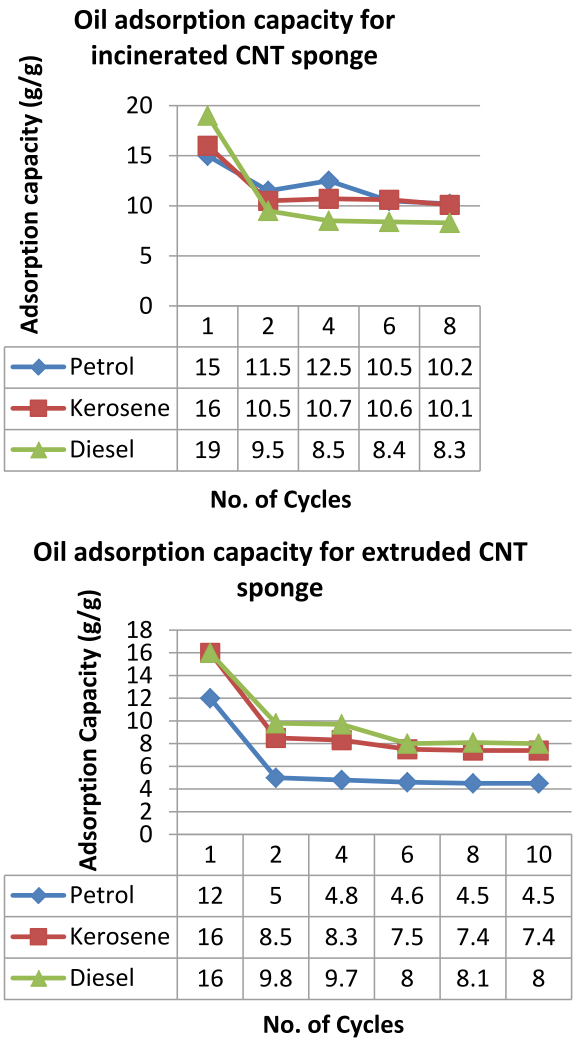


**Fig. 3** Comparative study of the performance of the CNT sponge on extrusion and incineration to recover the oil

is attached to the outer, coarse surface of the conveyer belt, which is then squeezed by a roller press to extract the oil. This system efficiently utilizes the reusability of CNT sponge for continuous and efficient recovery of oil (Fig. 4).

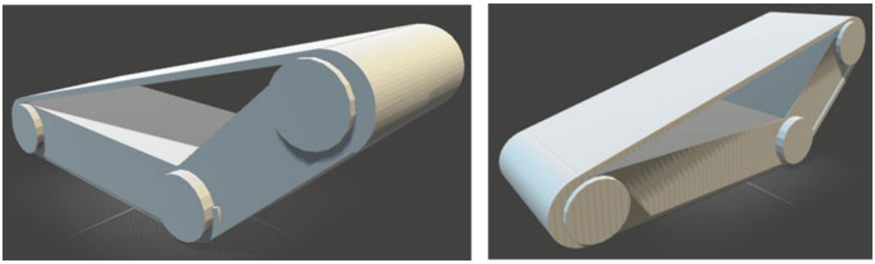

**Fig. 4** Illustration of the conveyer belt system

## 5 Conclusion

The commercial viability of any technology in an oil spill cleanup largely depends upon the production cost, oil adsorption capacity, environmental friendliness, reusability as well as disposability.

The use of CNT sponge is extremely efficient and eco-friendly. The sponge can be reused a number of times and can also be recovered back after the cleanup (Gui et al. 2011). Moreover, the CNT sponge surpasses aerogels in the recovery of oil due to its less production cost. The average cost for the production of 1 kg CNT sponge varies around 6–10$, whereas it takes 2870$ in the synthesis of aerogels by supercritical drying.

Thus, it is evident from the above factors that the CNT sponge shows enormous potential to come out as an innovative solution for the oil spill cleanups.

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# Scenario Evaluation of Domino Effects in Process Industries: A Review

**Nishita Vishwakama, P. A. Arun, Abhishek Nandan, and B. P. Yadav**

## 1 Introduction

Recent reviews shows accidents in process industries involves various disturbances in environment and due to human factor around 24.6% of the accident has occurred (Darbra et al. 2010). Accidents are well-defined as unexpected incidences which may lead to injury, fatal accident, property damage and production loss. Without knowing reason behind any accident, it is very difficult to implement preventive measures, therefore this review concentrates mainly on cause of accidents and sources which includes fire and explosion. Chain of accidents can be understand by discussing various theories developed for accident prevention and investigation. Due to the combination of behavioural and environmental reasons many accidents become catastrophic. Some of the behavioural factors which may contribute to an accident such as poor physiological condition, inactive mental condition, inadequate attitude, poor technical skills and knowledge. In process industry, Unsafe acts and unsafe practices majorly contribute to an catastrophic incidents. In order to overcome from these problems, there are several theories came into existence such as domino theory and multiple causation theory (Figs. 1 and 2), which is an product of domino theory, developed by W. H. Heinrich in 1931. As Domino accident is the string of many new accident which follows the game of toppling of each wooden block above the next one starts a sequence in which every toppling follows other block and so on, which is called "domino effect".

Although, many definition and analysis are published by authors earlier, but recognition of probable risk has not discussed by them. Recognition of the probable risk of domino effect is firstly addressed in its Directive 82/501/EC and further hazard identification and its consequences has been also addresses in its successive versions Directive 96/82/EC and Directive 2003/105/EC. It also recommends protective measures

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**Fig. 1** The domino theory

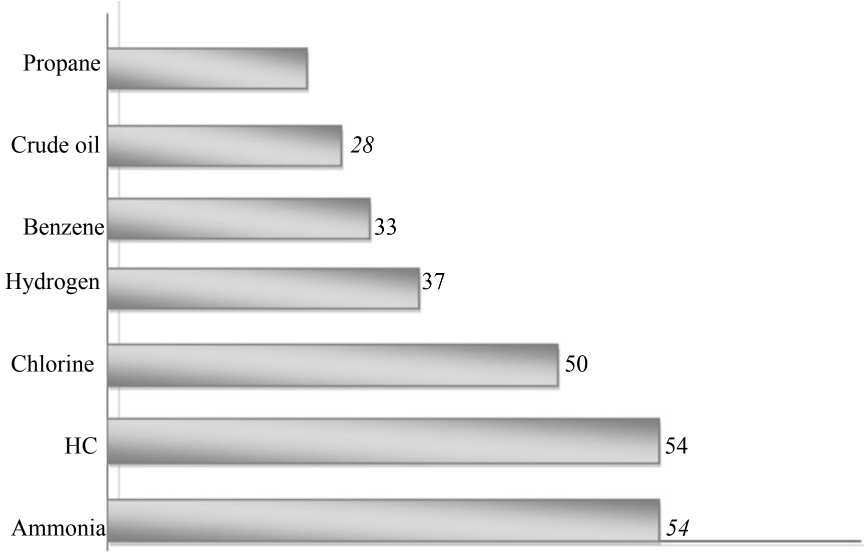


**Fig. 2** Number of accidents took place due to toxic release (Khan and Abbasi 1999)

like safe distances between equipments, storage and transportation techniques. To know the reason behind the accidents and to create their control measures along with their prevention, it is important to understand about and find out from history of past accidents.

Following are the results found by inventory of past domino accidents (Table 1).

**Table 1** Past accident data

| Past causes and areas of accidents | Percentage affected (%) |
|---|---|
| Explosions | 57 |
| Fire | 43 |
| Storage areas | 35 |
| Transportation of hazardous materials | 19 |
| *Combinations* | |
| 1. Explosion-fire | 27.6 |
| 2. Fire-explosions | 27.5 |
| 3. Fire-fire | 18 |

## *1.1 Rationale Behind Domino Effect*

Several authors give their interpretations related to domino effect. As per Lees, Dangerous occurrences can be obtained by the leakage of any hazardous material which may be considered as a factor for increasing potential of any hazard. He also included about consequences of domino accident which may cause an initiating event in any separate element (Lees 2012).

Bagster make clear report on domino effect which is based on management loss of a plant as severe accident always take place on a nearby plant or an equipment (Kadri and Châtelet 2013).

Delvosalle gave his explanations based on type of installations as consequences of domino effect are different for different type of installations. It may be primary installation, where major accident cant take place or it may be secondary installation, where accident must be severe one and its extend causes major damage and it may lead to the source for primary accident. According to As chain of accidents may take place with numerous type of installations, that’s why Delvosalle defines domino effect in 1996, like a chain which involves many kinds of installations (Delvosalle 1996).

Gledhill and Lines told about this effect, according to Controls of Major Hazards (COMAH), by considering adjacent or nearby severe hazard installations. He proposed his logic for domino effect by considering loss of primary containment and its associated failure on any severe hazard. He preceded his work along with the COMAH regulations (Kadri and Châtelet 2013).

A domino effect is a series of accidents which consists of accidents due to fire, explosion, missile, projection or any other hazardous matter. According to Khan and Abbasi (1999) its catastrophic consequences affect one operational section of a process unit which further affects secondary accidents in other operational units. This has the potential in which it has the maximum probability of dangerous occurrences in major chemical and process industries, generated by an incident happened in one section which affect secondary section of same unit (Khan and Abbasi 1999).

Article 8 of SEVESO—II tells about the existence of domino effect by its likelihood or probability of occurrence with the possible consequences. It also tells about its effect which is increasing day by day, lead to dangerous occurrences in any form of accidents because of the area and proximity of these type of establishments which play very important role in inventories of dangerous substances. Basic Guidelines related to severe accidents with its preventive measures are stipulated in the second version of SEVESO in Europe (Kadri and Châtelet 2013).

According to AIChE-CCPS, domino effect is a chain of an incident which start ignited in one material and transfer its affect to the other item by means of heat, blasts or its section impact which can increase in its severity and their consequences which may also effect its failure frequencies (Kadri and Châtelet 2013).

Some of the author have also explained domino effect by mentioning various parameters like type of accident, type of equipment used, location, temperature and many more. As per Reniers explain domino accident as internal domino, deals with occurrences of accident within the boundaries of a single organisation while External domino explain occurrences of multiple accident at a time which may take place outside the boundaries of the plant where primary accident occurs. Severity of consequences of external domino is more than that of internal domino, as it depends on the exposed area and the equipment involved (Reniers 2010).

A recent rationale defines domino effect in such a way that a primary incident propagates to nearby equipment which may trigger its primary or secondary unit, results in more severe effect than those of the initial triggered event (Reniers 2010).

Features of Domino System are:

1. Collaboration or connection between environment and its associated system.
2. For the generation of accidents in the form of chains, overall source is the only reason which can generate accident sequences; it can be control from the source only.
3. Organisational system along with the influence of human factors may also trigger the effect of domino system.
4. There are various physical parameters upon which source and aimed targets may depend, such as temperature, concentration or pressure with the variation of time intervals.

## 2 Historical Reviews on Domino Effect

In the historical review of domino effect, in this review paper catastrophic effects of some chemicals in various refineries, petroleum industries and chemical industries shall be discussed as follows:

In India, its very common to find many clusters of process industries in which they have common marginal walls 0f one or more than one operational industries. Various chemicals affects industries due to various reasons like fire, explosion, toxic release and its combination. According to many surveys, Ammonia is the most responsible chemical for the major hazards. Up to 1997, Out of 1744 accidents, accidents was due to their combinations.

One of the most important reason for catastrophic effect in industries is Toxic release which involves in fire and explosion. This is the only reason for Bhopal disaster which was happened in 1984 in which MIC (methyl iso-cynate) was responsible for the severe damage because toxicity of MIC is very high as it undergoes in an exothermic reactions when it comes in contact with water (Khan and Abbasi 1999).

Some more severe accidents happened in several refineries and chemical industries as follows:

- In 1996, BLEVE was the reason which destroys refineries in France and killed many firemen and workers who were working in that refineries as Propane vapour spreads all over the area and some major undesired events has been occured (Khan and Abbasi 2001).

- In 1997, More than 55 people were killed and many people got injured in huge fire expansion in Hindustan Petroleum Corporation Limited where many terminals, containers and tank farms were devastated at operational unit of Vishakhapatnam.
- In 1921, Oppau Works covered with cloud of explosion in a extent of 3 s, had the capacity to destroy all over plant in a span of 3 s with a very huge earthquake like shock. This explosion caused by the ignition of ammonium sulphate and ammonium nitrate which converts its physical nature from blasting powder into a baked cake in the storage section (Khan and Abbasi 1999)
- In 1987, In Purification column of Ethylene oxide, decomposition of $C_2H_4O$ took place due to which chains of blasts and missiles has been formed and a catastrophic explosion took place in a process industry of Belgium (Lees 2012).
- In 1978, During filling of LPG in Storage vessels got over pressured due to breakdown of a relief valve and pressure gauge. These vessels got cracked and leakage of LPG got started in the city of Texas in one of the petrochemical factory which got ignited and results into a huge fire ball which shattered all the storage containers with its projectile shot (Vilchez et al. 1995).

## 3 Inherent Sources of Domino Effects

Probable sources of domino effect depends upon their nature and are also connected with their commencing events. It may be initiated by many contributed events like fires, explosions and toxic releases. Fire consists many catastrophic sources like diffusion flame of volatile liquid called pool fire, ignited fire by a mixture of air and dispersed flammable substances called flash fire, a ball consists combustible or explosives called fire ball and with a release of hydrocarbon flames called jet fire which can produce disastrous damage. As like fires, Explosion have a capacity to produce projectile shots like a missiles which can cause extensive damages with the influence of flammable material produces Confined vapour cloud explosions (CVCE), Vented explosions, Dust explosions and vapour cloud explosions. To prevent these explosions, Chemical and process industries give explosion venting to protect indoor's equipment or buildings from extreme internal pressure. One of the most dangerous sources of domino effect is the toxic release having an immediate release of toxic air-gas mixture, liquid-gas mixture or liquid-liquid mixtures.

### *3.1 Fire and Explosion in Process Industries*

As per National Fire Protection Association, an average of 37,000 cases occur in Chemical and manufacturing industries every year.

Main causes of large fires are flammable liquid and gases, hot work, faulty equipments and its components, Pipe work and its fitting breakdown, amalgamating operations and some other factors. Flammable materials has higher contribution (17.8%)

for the exposure of fires in chemical industries while Release of hot materials which causes overheating contributes 15.6% and Maintenance works involves piping and fittings which contributes 11.1%, Electrical breakdown contributes 11.1%, Cutting-welding process contributes 11.1% and other factors contributes 28.7% (NFPA 1852).

Based on the frequent location of occurrence, Explosions may take place as per location like enclosed process areas, Outdoor structures, Yards, Tank farm, Boiler house and others. Different proportions for fire exposure as per location such as Enclosed process area in chemical industries contributes 46.7%, Outdoor structures contributes 31.7%, Boiler house contributes 3.3%, tank farm contributes 3.3% and others contribute 8.3% (Lees 2012).

There are many other contributing factors like equipment breakdown (26.7%), flammable liquids or liquefied gases (8.3%), human actions (18.3%), undesirable events (18.3%), faulty design (11.7%), blockage (11.7%),), long replacement time (6.7%), inadequate control of combustion (5%), insufficient relief of explosion (5%), etc. (Lees 2012).

## *3.2 Accident Analysis*

Characteristics of accidental release depend upon many factors such as location type, site status, material released and material phase.

### 3.2.1 Application Area

It consists of different locations like refuelling station, Tank area, chemical plant, processing plant, factories, warehouses, and others having different number of incidents like 278 incidents covered under chemical plant, 96 incidents covered under refinery, 187 incidents covered under factory, 47 incidents covered under storage depot, 28 incidents covered under tank yard, 15 incidents covered under fuel station, 38 incidents covered under other sections and 232 were unknown (Khan and Abbasi 1999).

### 3.2.2 Work Site Analysis

Site work also affects the different types of operations and may cause damage at workplace. It includes standard operations, Storage and Handling, Loading and Unloading facilities, Modification, testing, safeguarding, start up, shut down and some unknown process. Their contributes differs according to situation at workplace in which 343 incidents took place under normal operations having high contribution, 103 incidents took place under Storage and handling department, 33 incidents come under loading or unloading, 146 incidents took place under modification and maintenance work, 18 incident took place under contractor work along with 5 testing incidents, Also many Incidents took place when shut down and start up process were going to take place as start up contributes 42 incidents while shut down contributes 18 incidents and 128 incidents were unknown (Khan and Abbasi 2001).

### 3.2.3 Released Material

Based on the material released, many toxic substances are responsible for immediate accidents which demands pre investigations for risk assessments. There are many gases which are accountable for disastrous damage such as Crude oil, Steam, petroleum $NH_3$, HC, $Cl_2$, $H_2$, $C_6H_6$, Natural gas, $C_3H_8$, $C_4H_{10}$, Styrene, Naphtha, Fuel oil, HCl, $H_2SO_4$, $C_2H_4$, $H_2S$, $H_2O$, $N_2$, $O_2$, Vinyl chloride, LPG, etc. Major contributor for fire and explosion in terms of toxic release are Hydrogen, ammonia, crude oil, chlorine, hydrocarbons, Benzene and propane. Their contribution in accidents shown in graph as follows:

### 3.2.4 Unignited Materials

Based on Dispersion of Unignited material there are substances having different behaviour such as many materials come up from flammable sources which are not corrosive but may be irritant. They are also responsible for destruction in chemical industries as they are classified as with the number of accidents:

1. Flammable substances
2. Toxic materials
3. Materials having both characteristics flammable as well as toxic
4. Unignited gas
5. Vapour cloud
6. Ignition of material by spill
7. Ignition of material by Jet
8. Ignition of material by the influence of Spray
9. Corrosive substances (Fig. 3).

According to some reviews, fire or explosion or its combination are the most responsible factor for the dangerous occurences which takes place due to fires, flash fires, pool fire, jet fire, BLEVE, explosions followed by fire and flash fire. Loss of containment for different kinds of equipment is also one of the major reason for domino accidents in process industries.

Their contributions are different as per type of accidents (Lees 2012) as shown in Table 2.

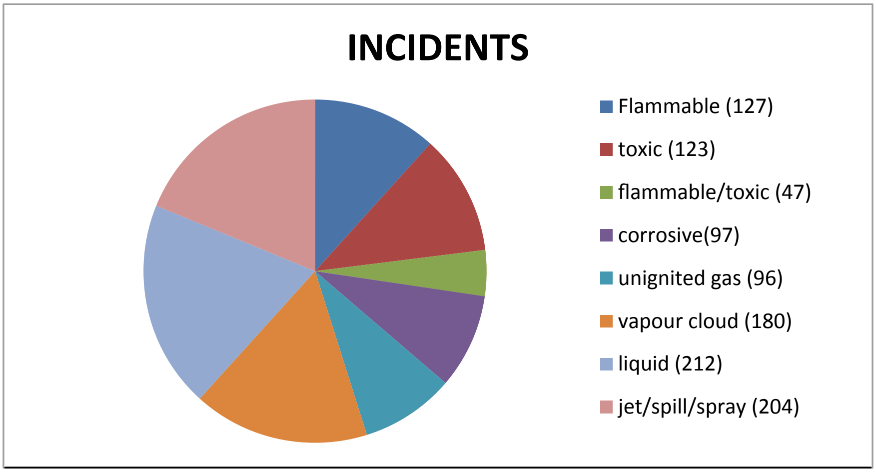


**Fig. 3** Accident contribution with respect to different section (Vilchez, Sevilla et al. 1995)

**Table 2** Resons for various accidents

| Reason behind fire/explosion accident | Number of accidents |
|---|---|
| Due to fire and its flashes | 156 |
| Due to pool fire | 4 |
| Due to jet fire | 1 |
| Due to fire ball | 7 |
| Due to BLEVE | 4 |
| Explosion → fire | 77 |
| Explosion → flash fire | 2 |

## 4 Causes of Domino Effect

### *4.1 Root Causes*

By identifying the causes of accidents, with the help of MHIDAS database, there are various techniques to prevent them from occurring again. According to (López López 2017), categories may use for common causes: external events, mechanical breakdown, errors produced by human actions, failure due to impact reaction, failure due to violent reaction, equipment and its component failure, disturb process state and service break down. Contribution behind accidents are vary from situation to situation. As there are two main causes of accidents such as 29.2% accidents covered under external events and 35.2% accidents covered under mechanical failure. As like two, 24.6% of the accidents were due to human error and these contribution had increased as per Darbra et al. survey (2010). As according to his detailed studies, generic causes were human errors or external events but along with failure due to impact reaction, failure due to violent reaction, equipment and its component failure and service failures were also responsible for domino effects in chemical industries. As accidents connected with human factor had significantly increased from 24.6 to 33% in industrialized countries which shows the poor health and safety culture with worse safety induction trainings in the organisations of many developing countries. Most of the service failures has occurred due to deviations in operation as loss of containment is one of the cause for component failures. As per many reviews there are several reason for loss of containment such as ruptures of containers, welding failures, vibration, overstressing, corrosion, internal and external explosions and many more.

## *4.2 Peculiar Causes*

There are many causes which are particularly indicates some of the specific section of an industry like leakage areas, maintenance works, etc. As discussed above there are some main causes by which domino effect got ignited and started making more chains of accidents such as Mechanical failure, external events, impact failure, violent reaction, instrument failure and service failures (Hemmatian et al. 2014).

### 4.2.1 Mechanical Breakdown

Mechanical Failures is the general cause in which 35.2% accidents were occurred in which there are some specific areas due to which severe damages may take place like overpressure, overheating, other metallurgical failure, Leaking coupling. Leaking valve, Hose, Corrosion, Fatigue, etc. Moreover, many operational failures may also take place like weld failure, brittle failure, use of incompatible materials, overloading, etc. According to his studies, 16.1% accidents were due to Overpressure only. It is a foremost root cause of domino effects according to his studies (Delvosalle 1996) 16.5% of domino accidents happened due to overpressure. As per MHIDAS database, Out of 105 accidents, 66 accidents were caused due to explosion involving nearby appliances, moreover it was due to overpressure (López López 2017).

### 4.2.2 External Agents

Somewhere, External agents or events are also possible causes of domino accidents in which fire and explosion had took part at large scale in most of the industries. External events includes various causes specifically fire, explosion, lightning, earthquakes, flooding, sabotage, design error, etc. Somehow, many operative events also come under this such as general maintenance, general operation, management, draining accident, overfilling, connection failure. In this, highest contribution had came from Fire, explosion and lightning. 49% of the domino accidents occurred due to fire and explosion each. As like both, 14% accidents occurred due to lightening (Darbra et al. 2010).

#### 4.2.3 Failures Due to Impact Behaviour

Accidents occurred under the influence of shock applied over short span of time or a force having a high intensity, those accidents come under the impact of such entity or force that may lead to severe damage. Impact failure includes rail accident, heavy object, road accident, ship-land clash, ship-ship clash, confined outburst, instrument breakdown, etc. Accidents due to trip, failure of controller and indicator also come under impact failure. Due to the high impact, rail accident is the foremost cause of domino accident as 70% of accidents were occurred under such failure (Wu et al. 2015).

#### 4.2.4 Service Breakdown

Service failure includes services associated with electricity and water supplies. By name, its very easy to get higher contribution for domino effect as electricity connected with most of the risky or dangerous occurrences. 80% of the accidents happened due to electricity.

### *4.3 Origin*

According to the MHIDAS database, There are many classification for the area or event from which origination of any accident took place such as Transportation, Loading-unloading, storage areas, process plants, warehouses, waste storage areas, etc. Some cases were unknown as they were almost 176 in numbers in which cause of origination of accidents were not found. According to Vilchez and Sevilla, there were specified number of accidents which was responsible for the origin of domino accidents as mentioned (Fig. 4).

Above distribution shows the maximum contribution were due to transportation only with 39.1% of accidents followed by Process Plant (25%) and Storage plant (18%) (Vilchez et al. 1995).

## 5 Estimation and Prevention

Now-a-days, in chemical processing industries, computer-aided tools has been used to find the likelihood of accidents involving domino effect. To evaluate and prevent domino accidents which includes fires, explosion or hazardous material

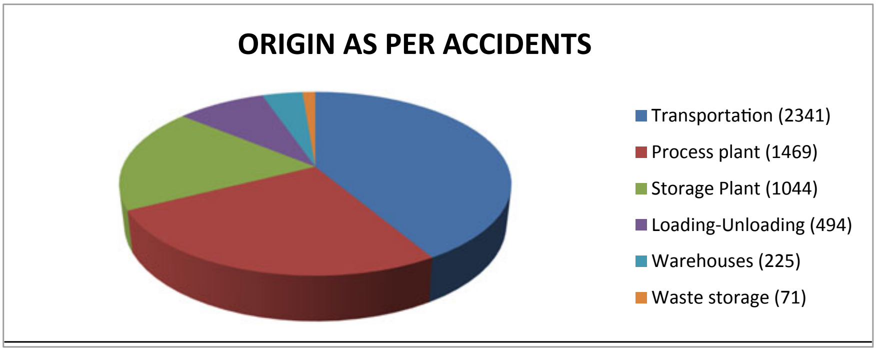


**Fig. 4** Origin of accidents (Vilchez, Sevilla et al. 1995)

release in storage areas and chemical based process areas. In this paper, there are many programmed based tools and hardware based analysis has been done by using MAXCRED, DOMIFFCT, ARIPAR, ATLANTIDE, GeOsiris, MiniFFECT, DomPrevPlanning and Vulnerability assessment which are reviewed here on the basis of historical surveys.

## *5.1 MAXCRED*

MAXCRED (MAXimumCREDible rapid risk assessment) encoded in C++ language developed in object oriented architecture, which allow to demonstrate accident models and harm probable estimation. This tool attuned with DOS and WINDOWS operating system.

Main menu of MAXCRED consist of many options such as data, accident scenario, analysis, graphics and file having module box of different cases by which severe damage may occur.

Following are the procedures which depicts five important steps of MAXCRED (Khan and Abbasi 1998a, b) (Fig. 5).

There are many models used in MAXCRED such as Box model and model plume path for heavy gas dispersion, flare model for flash fire, Gaussian dispersion model for light gas dispersion, etc. Also, Second version of MAXCRED can use in chemical


**Fig. 5** Procedure for MAXCRED

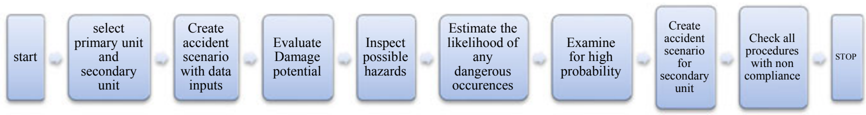


**Fig. 6** Procedure to carryout DOMIEFFECT

process area which simulates each and every accidents in a quantitative manner (Khan and Abbasi 1998a, b).

## 5.2 DOMIFFECT (Domino Effect)

Same panel of authors also prepared one of the tool based on methodical domino method called DOMIFFECT. It is use in chemical processing plants and in many industries also. It is computer based tool operates with object-oriented architecture which was encoded in C++ language. Basically it contains six elements on which simulation of accidents can be done such as data related to accident scenario, accident analysis, Domino, user interface and graphics. It is a menu driven software which is capable of evaluating possible hazards, handling different events according to the situations, moreover, it estimates probability of domino accident with their consequences. It is a software based on the method by which outcomes can be precisely determined with the help of probabilistic study (Khan and Abbasi 1998a, b)

Following are the important steps involved in DOMIEFFECT (Khan and Abbasi 1998a, b) (Fig. 6).

## 5.3 Aripar (AnalisideiRischiIndustriali E Portualidell'Area Di Ravenna)

The ARIPAR Project had worked on targeted quantitatively assessment where risks are connected with various type of processes, storage and transportation of various hazardous substances. It challenges to evaluate risks form several process plants for the calculation of various level of risks due to different type of installations. This is a software can be used on the basis of probit correlations. There is an upgraded version of ARIPAR which is based on probabilistic approach for risk assessment of complex processes which includes transportation also (Egidi et al. 1995).

### 5.4 ATLANTIDE

ATLANTIDE is a software had created to execute various models and to implement various consequences of domino accident that may occur in process or storage areas. It is used where location is allotted for Storage of highly flammable liquids or gases like LPG and for processing plants where heavy gas dispersion which involves hazardous process like BLEVE and fireball. This software used to evaluate all possible framework with the help of lagging indicators which indicates primary accidents according to different releases, features or mode of operation of any plant. By the help of coding, substances which are considering by this software are LPG, Propane and Butane with their chemical and physical properties such as density, flammable range, vapour pressure, etc. After that once user starts operating these points of interest with relevant operating conditions then meteorological situations are introduced to start the analysis which includes temperature, velocity of wind and relative humidity (Ditali et al. 2000).

### 5.5 DPP Toolkit

DomPrevPlanning is a tool used to determine the effects of domino system according to the order of priorities in an industrial plant on different levels of work. Depending upon the various experiments performed by authors, tool comes with an aim of preventing domino accidents in a chemical industries and various manufacturing industries. This software basically works on three components such as Guidelines for quantative risk assessment, reference manual for failure frequency figures and instrument domino effect (IDE). On the basis of above components, it also analyzes risks associated with domino system, installation in industrial facilities along with the various classifications (Reniers and Dullaert 2007).

### 5.6 Vulnerability Assessment

It is an evaluation technique which is used to examine safety parameters of plant items if a failure occurs in a nearby item. This is usually performed by placing 3D grid over the layout of the plant and specifying a grid coordinate for all process items by providing distances between items. The possible hazards of the various process items need to be identified along with their effect on other process items.

## 6 Results and Conclusion

In recent years, research interest on domino effect and its consequences has increased but research work is still less as compared to other portions of problems in process industries. As domino effect happens in many major incidents in various industries and has been increasing significantly. But still some of its main features are unknown.

In this paper, the study on domino accidents are covered from various databases and past accidents with different parameters such as its root causes, includes different kinds of failures, and peculiar causes which includes different kind of breakdowns and operation failures due to fire and explosions. In our work, some of the aspects has also discussed, includes its origin which quantifies the accidents as per different area such as transportation, storage, disposal and prevention techniques to find the likelihood of accidents which involves Domino effect.

There are various operation failures took place during Loading/unloading operations and in storage facilities which caused a major number of domino accidents. By providing improved version of training and guidance, all came to know that human error is also one of the main causes of accidents which has been identified while operators are working in industrial plants.

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# Effect of Biorhythm on Work-Related Accidents in Industrial Sector

**V. Babu and S. Umamaheswari**

## 1 Introduction

The task of a Safety Professional is to reduce the hazardous exposures to people or property. One method of accomplishing this is to develop an accident prevention program. A single program is not enough, so the Professional is constantly looking for new and better ideas. Some companies have used biorhythms in accident analysis, and others have used it in their accident prevention program. The concept of biorhythms can be a constructive tool for the industry as a means to warn employees and make them more safety conscious during their critical periods (34) Retrospective studies of accidents have found that the number of accidents occurring on a biorhythmically critical period range from 20 to 97% . Experimental research in industry has found that in some cases the accident rate decreased from 42 to 62% after the use of biorhythms in the workplace. The biorhythm cycles are believed, by most, to begin at birth. It is at this traumatic time that the 23–day Physical, 28–day Sensitivity, and 33–day Intellectual cycles begin to rise from the midline and fluctuate in each of its respective frequencies.

The physical cycle is believed to control strength, energy, endurance, confidence, and resistance to disease. The sensitivity cycle governs the feelings, nerves, intuition, and creative ability. The intellectual cycle affects memory, mental alertness, reasoning power, and ambition. The days of accident-proneness are suggested to be where the cycles pass across the midline. The body is changing from a plus phase to a negative phase or vice versa. During the critical day, the body is in an unsteady

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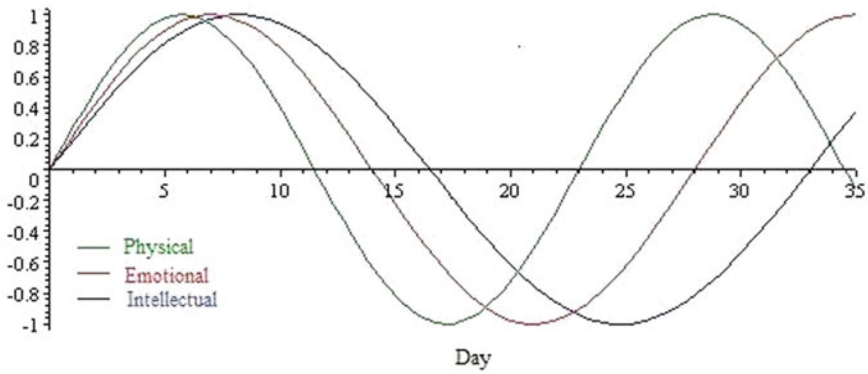


**Fig. 1** Biorhythm cycles

state. The unusual stress on the person increases his/her chance of error that may lead to an accident.

It takes fifty-eight years and sixty-six days to complete a biorhythmic lifespan. The lifespan covers 4 twenty-one thousand two hundred and fifty-two days. During this time, there are four thousand and six times a single curve crosses the midline creating a critical day. There are three hundred and twelve times that two cycles cross at the same time creating a double critical day. There are only eight times that all three cross together.

The amount of critical days during a year is only 20.4% of the total days. Using a 48 h critical period, the percentage is increased to 37.8% and a 72 h critical period is 51.5% of the year. Any accident is unwanted, no matter how small. Safety Professionals are beginning to look at biorhythms as a tool to reduce accidents (Fig. 1).

## 2 Objective of the Paper

The problem of this study is to investigate the possible relation between the biorhythm cycles and accident occurrence in an industrial setting. This study was designed to answer two questions. The first is there a relationship between the biorhythm physical. Sensitivity and intellectual cycles and the occurrence of industrial accidents took place in various industries. The second what will the difference in levels of significance and percentages be using 24, 48, and 72 h critical periods.

## 3 Review of Literature

G. Robert Schwarz, Portland Area Safety Manager, Bureau of Indian Affairs, stated that everyone is accident-prone in a general sense because there are potential tasks that no human being can perform without an accident. He goes on to say "the validity of biorhythm is usually more pronounced when the person is engaged in an activity that is stretching him to his greater capacity." This is why R. K. Anderson, former President of Russell K. Anderson Associates, Safety Engineers, believes biorhythm should be applied "to those places where there is a possibility of a far-reaching and serious accident: the chemical industry, a nuclear plant, a stamping or forging pant, and so forth.

The National Safety Council conducted a survey to substantiate claims by biorhythm proponents that the theory is widely used in occupational safety programs. Very few 15 replied and those that did were not all that eager to shed any more light on the subject. Bernard Gittelson believes that until the theory is proven beyond the slightest doubt, government and industry will be reluctant to reveal whether or not they are experimenting with the method.

R. K. Anderson has analyzed over one thousand accidents from many companies over a two-year period. He found 90% occurred on critical days. Otto Tope, Chief Engineer with the Department of Sanitation in Hannover Germany found that 83% of the accidents the street cleaners and shop workers had been on critical days.

## 4 Data Collection

The study carried out in various industries registered under the factories act and medium and small scale industrial sector of 80 work-related accidents during 1985–2015. The required information was collected from available documents in HSE unit. Based on the data available from the company biorhythm charts calculated based on a date from the company using natural Biorhythm Software V3.02 Conduct. For Biorhythm investigation and the impact on the accident 'extract was data date of birth' date accident incidence.

## 5 Method of Data Analysis

The tally system is used most frequently to group the data in this study into meaningful categories. The tally system is used for the following items; To derive frequencies for body part injured, accident type, accidents and days of the week, accidents and months of the year, accidents and company and department and location, and cycle days. A Chi-square and percentage are calculated to test each hypothesis for its

**Table 1** Alternative critical day definition

| Biorhythm cycle | Critical days in cycle definition 1 | Critical days in cycle definition 1 |
|---|---|---|
| Physical | 1,2,11,12,13,14,23 | 1,12,13,17,18, 23 |
| Intellectual | 1,2,16,17,18,19,33 | 1,17,18,25,26, 33 |
| Emotional | 1,2,15,28 | 1,15,21,22,28 |

probability and level of significance by comparing the persons birth date and the biorhythm cycle on the date of injury.

Four definitions and their related critical days for each cycle are shown in Table 1. A separate data for serious accidents were collected to determine if there was a relationship between critical days and more serious accidents, because some people argue that biorhythm theory predicts only those days on which an individual is at greatest risk.

## 6 Results and Discussion

A test of the relationship between critical days and industrial accidents requires the calculation of expected frequencies of accidents on these days if accidents were occurring randomly. Looking at the occurrence of accidents on biorhythm cycle days, contain patterns that become apparent. For this study, the most frequent physical cycle day is around the second and twentieth day of the twenty-three-day cycle. The most frequent sensitivity day is around the fourth and twenty-seventh day. The intellectual cycle days that are most frequent are around the seventh and sixteenth days of the cycle. By knowing some fundamental information obtained from the data and other sources, a better understanding can be formulated about the study sample.

## 7 Relationship to Critical Days and Periods

Four different sets of information were used in analyzing the sample of accidents and critical days. Set I contains those accidents that occurred on a critical day. Set II contains those accidents of Set I plus those accidents that occurred the day before. Set III contains Set I and those accidents that happened the day after the critical period. Set IV includes the critical day and both the day before and day after the critical day. Set I is twenty-four hours in length. Set II and Set III are forty-eight hours in length and Set IV is seventy-two hours long. Table 2 describes the actual biorhythm cycle days counted in each of the critical periods.

The findings of the study are such that none of the nine null hypotheses could be rejected. The best level of significance achieved was only $p$, 10 which was achieved four times. All four times they were in sets III and IV. Two times in the self were

**Table 2** Statistical comparison of actual versus expected injury frequencies for individual cycle

| Cycle position | Actual | Expected |
|---|---|---|
| *Physical* | | |
| Positive | 195 | 210.92 |
| Critical | 66 | 40.16 |
| Negative | 201 | 210.92 |
| **Chi-square 18.3 p *P* < 0.05** | | |
| *Emotional* | | |
| Positive | 180 | 214.5 |
| Critical | 51 | 33 |
| Negative | 231 | 234.5 |
| **Chi-square 16.6 p *P* < 0.05** | | |
| *Intellectual* | | |
| Positive | 198 | 217 |
| Critical | 51 | 28 |
| Negative | 213 | 224 |
| Chi-square 20.6 | | |
| **p *P* < 0.05** | | |
| $\chi^2 = 5.99$ for d$f = 2$ and $p < 0.05$ | | |

A chi-square analysis of significance $P < 0.05$ was used to compare the observed frequencies with those expected frequencies of the accidents. In this case, chi-square statistic can be shown as

caused group and two times in the intellectual group. The worst level of significance was a $p > 0.99$ which came from Set Its self caused group. The findings achieved with analyzing the percentage of hits also followed closely with what was expected by chance. Set I expected frequency was 20.4%. The observed was 17.1 and 18.5%. Set II and III expected frequency accidents happening during a forty-eight hour critical period is 37.8%. The study yielded from 33.7 to 37.1%. Set IV is a seventy-two-hour critical period. Its expected frequency is 51.5%. The observed was 41.8 and 44.2%.

The data and the outcomes of this study are not capable of rejecting any of the nine null hypotheses. Definite items were looked at to see what the industries safety program should look at one of the objectives of this study was to take a set of data and manipulate it around in all the forms found in the review of the literature. This was accomplished by using the four sets of information. Many researchers have tried different ways to manipulate the type data contained in this study. Only one variation was not attempted directly. Some researchers use a forty-eight-hour critical period that contains the critical day plus and minus twelve hours. By adding the twelve hours to either side of the critical day more hits can be recorded because it really covers the full seventy-two-hour critical period. Only when, a researcher has the persons' time of birth can biorhythms be used with an accuracy of less than one day. Each cycle is specific and unless you know the place and time of birth, the biorhythm calculation is only accurate to one day.

## 8 Conclusion

Study was undertaken to determine whether there was a relationship between biorhythm critical days and industrial accidents among the industrial workers. The results of the study confirmed that biorhythm theory is serious accidents because of the mixed responses of the results. Current study has an edge over the findings 67.5% of total number of accidents falls on critical days and also 72.8%, definition two may be used for predicting the accidents occurrence and workers may be stayed away from the hazardous work on these critical days for reducing the number of accidents in industries. The use of biorhythm theory in preventive work connected with industrial safety in industries and strict adherence to this theory makes it possible to reduce the incidence of industrial accidents and ensure safe and productive work. At times, the increasing of time from a critical day to a critical period may yield more hits but this does not mean the correlation is any better between biorhythms and accidents. The act of informing workers of their off days, and having more contact with the worker can bring the employee and employer closer together. This act promotes the feeling that “management really cares.” When employees feel good about their company, they develop a better work attitude which could lead to less accidents in the workplace, and that justifies biorhythms use in industry.

## 9 Recommendation

Statistical and analytical methods used with retrospective studies of this type. For this to have been a more meaningful study several things should have been tried. The first is to find out where they were born and the time of birth. This is essential for providing the most accurate representation of a biorhythm cycle on a date of injury. The second recommendation is to obtain a larger sample. But at the same time, it becomes essential that the researcher goes through a painstaking process to assure the correctness of the information and calculations made. The best recommendation would be to begin the next phase of actually performing an experimental research with a company.

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# Electrical Accident Scenario in India: A Review

**V. Venkata Krishnakanth and Akshi K. Singh**

## 1 Introduction

Electricity became one of the basic amenities of modern world and has rampaged growth of human kind since its discovery. The world's electricity production by 2015 has increased almost four times (International Energy Agency 2017) of 1973 energy production and highest growth rate in developing countries. Net electricity generation in developing countries like China, India, etc., increases by a mean rate of 1.9%/year from 2015 to 2040, compared to 1.0%/year in developed countries (Energy Information Administration 2016). As per predictions, the consumption of electricity increases in residential and commercial installations over the period of 2015–2040 as personal incomes rise and emigration to cities continues (U.S. Energy Information Administration 2017).

This rapid growth in consumption has been contributing not only for economic development, but also for the rapid increase in number of fatalities, even in developed countries such as USA, UK, etc. This is due to its nature of invisibility and light speed of travel (Bowers 2001) it poses a threat to surrounding life, if handled improperly. Thus, national governments and many international bodies such as Occupational Safety and health Organization (OSHA), International Electro-technical Commission (IEC), National Fire Protection association (NFPA), Health and Safety Executive (HSE), Institute of Electrical and Electronics Engineers (IEEE), etc., put efforts in framing standards to improve workplace electrical safety. Due to these efforts, the fatality rates reduced by 40% in USA—the home of OSHA and NFPA (Campbell and Dini 2015) but still electricity is one of the top most causes of fatalities. In India, fatalities due to electrocution, however, are increasing particularly in construction sector. Despite several legislations in place to ensure workplace safety (such as Indian

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Electricity Act-2003, Factories act and rules, etc., and regulations and bylaws made there under) in India death toll due to electrocution is increasing.

In this paper, an attempt has been made to review the workplace electrical accidents in India across various industrial sectors and overall death toll.

## 2 Electrical Accidents in India

Very few studies (Kumar et al. 2014; Mukherjee et al. 2015) are carried out regarding "electrical accidents in India," however, are limited to specific area/region. Hence, this paper entirely based on official reports of governmental bodies. Injuries/deaths and incidents/accidents in India are reportedly increasing as evident from the death toll (fatal injuries) figures given by National Crime Record Bureau (NCRB) (2001–15) (a statutory body under Central Ministry of Home Affairs (MHA)), under crime head "electrocution" (deaths due to electricity) for the period of 2001–2015 are as shown in Fig. 1.

However, Indiastat (2001–15) provided the same data along with no. of accidents collected from MHA. These numbers give an overall death toll estimate based on data collected from local police records, hospitals, etc. It is to note that deaths mentioned under crime head "electrical short circuit" are not considered, as that is a sub-category

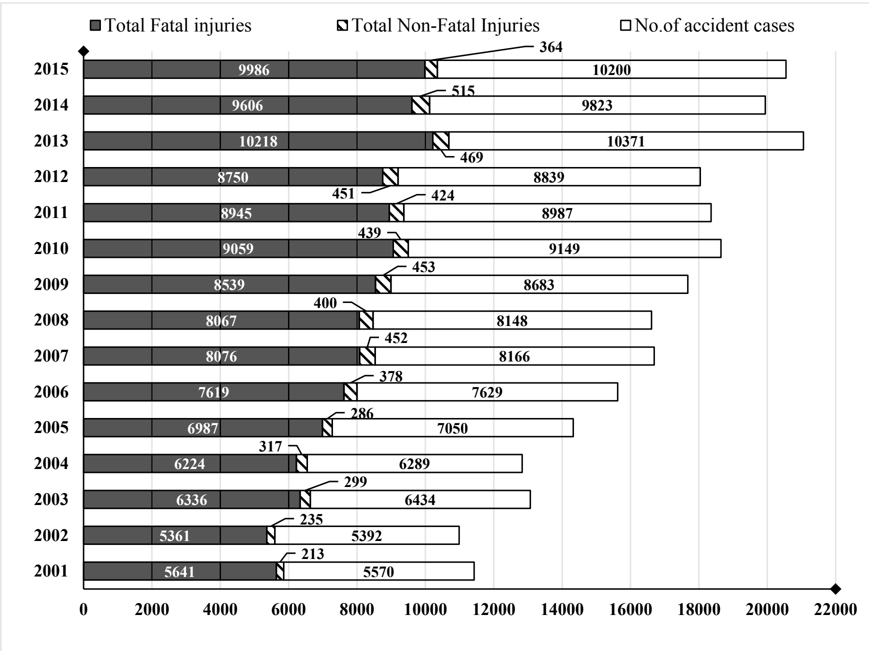


**Fig. 1** No. of deaths due to electrical accidents in India

under crime head "fire." From 2001 to 2013, the graph is increasing with maximum death toll of 10,218 (2013) and hauled around ten-thousand for 2014 and 2015 and data of later years (2016 onwards) is unavailable.

## *2.1 Industrial Scenario*

To understand the industrial scenario, the workplace fatality statistics are necessary. The electrical accident/incident/injury data of various industrial sectors has been provided in the following three categories and is explained in subsequent sections.

- Industrial accidents/incidents (excluding mines and power sector) (DGFASLI 2006–2016)
- Accidents/incidents in coal and non-coal mines (Director General of Mines Safety 2005–14, 2010–15; Director General of Mines Safety)
- Accidents/incidents in power generation, transmission, distribution and/or utilization (Central Electricity Authority 2001–15).

### 2.1.1 Industrial Accidents (Excluding Mines and Power Sector)

Ministry of Labor and Employment (MoLE) is the nodal ministry for workplace safety in Indian industries through Director General of Factory Advisory Service and Labor Institutes (DGFASLI) that ensures compliance of acts, rules, regulations and bylaws made for wellbeing of employees. The industrial injury (fatal and non-fatal) data 2003–2013 has been collected from Standard Reference Letters published by DGFASLI 2006–16 published by DGFASLI and labor stats by MoLE together with injury data for 2001–2003 collected from secondary source mentioned under "electricity" are used to portray the industrial scenario for the period of 2001–2013. However, cause wise injury data after 2013 and number of incidents/accidents is unavailable (Fig. 2).

As per these stats, almost one quarter of total injuries caused by electricity and about thirty percent of total electrical injuries are fatal in nature. The injury graph (both fatal and non-fatal) has shown both positive and negative variations alternatively; however, with maximum number (92) of fatalities in 2010 and non-fatal injuries (205) in 2006. It is clear from the graph that both fatal and non-fatal injuries reduced considerably from 2011 and attained minimum values in 2013. On an average out of 691 injuries per annum, 116 occurred due to electricity causing about 51 fatalities, and in conclusion, the impact of electricity-related injuries is significant in industries. It is worthwhile to note that data mentioned under this section does not include information regarding nuclear, aviation and defense sectors.

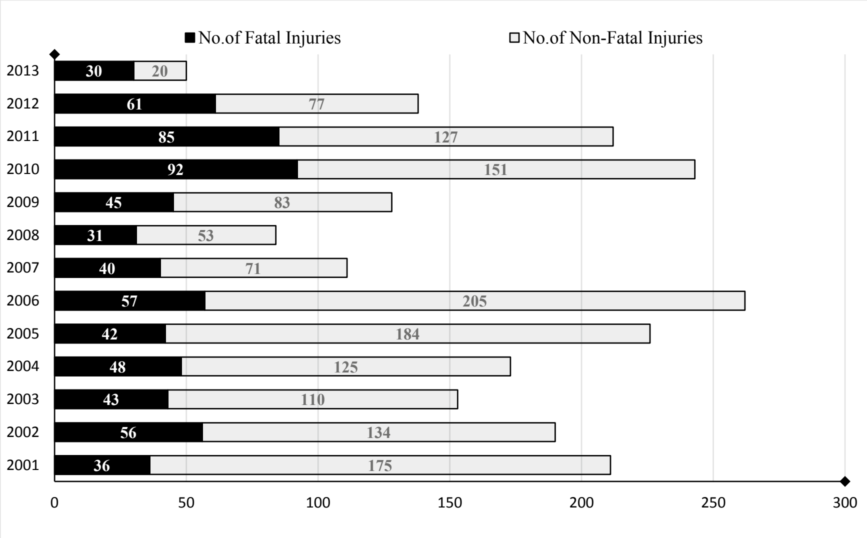


**Fig. 2** Injuries in factories due to electricity—2001–2013

### 2.1.2 Accidents/Incidents in Coal and Non-coal Mines

Accident data for mines collected from annual reports of Director General of Mines Safety (DGMS) a government agency under MoLE, looks after health and safety practices in mining industry. Accident/incident data has been collected from annual reports published by the agencies. The incident/accident data collected for the period of 2001–2015 presented here has been in the form of statistical charts (Figs. 3 and 4) and tables (Tables 1 and 2). Unlike DGFASLI that noted no. of injuries, DGMS presented (cause wise) no. of incidents and no. of resultant casualties for coal and non-coal mines. The electrical fatalities represented as percentage of total fatalities for easy understanding. Fortunately, in both coal and non-coal mines, the fatalities due to electrocution are less and particularly in non-coal mines it is almost zero. On an average:

- One fatal incident out of fifty incidents (total-fatal and non-fatal) is due to electricity, resulting almost one out of sixty fatalities, in case of non-coal mines.
- Almost four fatal incidents out of eighty incidents (total-fatal and non-fatal) are due to electricity, resulting into almost six causalities out of ninety-five fatalities, in case of coalmines.

It is to be noted that number of incidents/accidents and resulting fatalities/injuries are comparatively less than DGFASLI. However, electricity is one of the best sources of ignition in areas prone to fire damps and thus proper safety measures be applied to avoid/reduce fatalities.

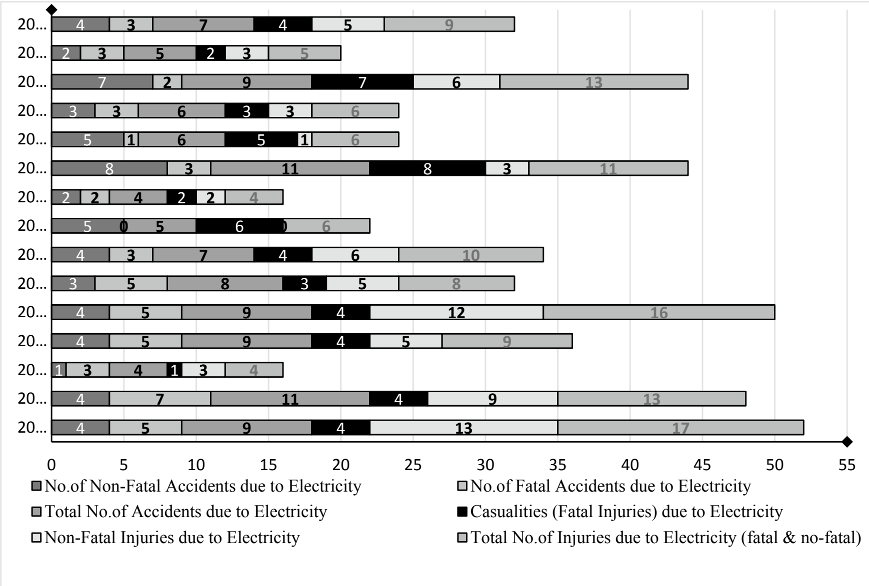


**Fig. 3** Accidents and injuries in coal mines

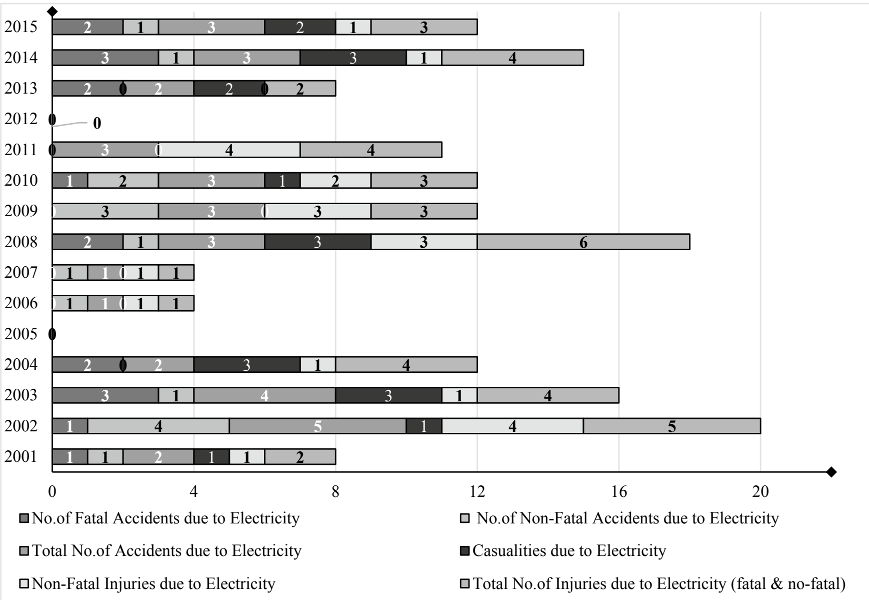


**Fig. 4** Accidents and injuries in non-coal mines

**Table 1** MHA versus CEA comparison of data components

| S. No. | Component of comparison | MHA | CEA |
|---|---|---|---|
| 1. | Data coverage | • The overall death toll, injury data against no. of accidents and fatalities/injuries due to electricity for entire India (i.e., every accident and injury occurred in India) | • The data regarding number of accidents in relation to electrical supply |
| | | • Covers data of entire India | • Excludes UTs |
| | | • Data for the selected duration 2001–2015 | • Data of 2003–2004 and 2011–2012 are missing |
| 2. | Type of data | • Number of accidents (sum/total of fatal and non-fatal)<br>• Number of injuries (fatal and non-fatal) | • Number of accidents (fatal and non-fatal) |
| 3. | Cause wise distribution of data | • All the accidents are "electrocutions" | • Categorized under seven causes as per CEA regulations |
| 4. | Source of data | • NCRB "accidental deaths and suicides in India" available from 1967 to 2015, gives death toll | • CEI and the cause wise distribution is available 2013–2016 only |
| | | • The number of accidents and no. of injuries derived from Indiastat | • The data prior to 2013 taken from Indiastat |

### 2.1.3 Accidents/Incidents in Power Generation, Transmission, Distribution and/or Utilization

Apart from industrial/occupational, data obtained from DGFASLI and DGMS Chief Electrical Inspectorate (CEI) [*the regulatory and reporting authority situated under CEA according to Indian Electricity, 2003, being surveillance of safety as one of its prime functions*] provided electrical accident stats for the period of 2013–16 (2013–14, 2014–15 and 2015–16). All these stats give the information about accidents that happened in relation to electrical supply, i.e., the accidents occurred in any premises, in relation to electrical supply lines, transmission and distribution equipment installed/maintained electricity boards. It is to appreciate that no. of fatal and non-fatal incidents affected humans or animals listed in detail against seven different causation factors as:

1. Snapping of conductors: Breakage of conductors due to short circuit, over loading, etc.
2. Accidental contact of the electric wire or equipment: Contact with live equipment

**Table 2** DGFASLI and DGMS versus CEA comparison of data components

| S. No. | Component of comparison | DGFASLI | DGMS | CEA |
|---|---|---|---|---|
| 1. | Data coverage | • The overall injury data against for *factories* (except nuclear, mining, defense and aviation sectors) | • Coal and other mineral mines data reg. number of accidents (fatal and non-fatal) and injuries (fatal and non-fatal) | • The data regarding number of accidents in relation to electrical supply |
| | | • Does not cover UT Lakshadweep and states Mizoram, Arunachal Pradesh and Sikkim | • Data covers entire India | • Excludes UTs |
| | | • Data available for duration 2001–2013 and for 2014 and 2015 yet to be published | • Data exists for entire selected period of study | • Data available for selected period except that 2003–2004 and 2011–2012 are missing |
| 2. | Type of data | • Number of accidents (sum/total of fatal and non-fatal) | • Number of accidents (sum/total of fatal and non-fatal)<br>• Number of injuries (fatal and non-fatal) | • Number of accidents (fatal and non-fatal) |
| 3. | Cause wise distribution of data | • All the accidents occurred due to “electricity” | • Categorization of causes found in statistical reports of DGMS as: accidents due to—overhead conductors, switch gears and other electrical accidents | • Categorized under seven causes as per CEA regulations |
| 4. | Source of data | • NCRB “accidental deaths and suicides in India” available from 1967 to 2015, gives death toll | • DGMS annual reports 2005–2014 | • CEI and the cause wise distribution is available 2013–2016 only |
| | | • The number of accidents and no. of injuries derived from Indiastat | • DGMS statistics of mines vol. I and II for 2010–2015 | • The data prior to 2013 taken from Indiastat |

3. Violation/neglect of safety measures/lack of supervision: Intentional violation of safe working procedures, for example, removal of safety guards while operation
4. Defective appliances/apparatus/tools: Improper or defective tool/appliance usage; for example, using uninsulated tools for repairing/maintenance
5. Inadequate/lack of maintenance: Improper maintenance of conductors/switchgear/any other equipment; for example, improper lubrication/cooling of equipment
6. Unauthorized work: Unauthorized access to live equipment; for example live line work without permit
7. Any other reasons: Other miscellaneous reasons.

CEA distributed accidents into three categories: Accidents in:

- Generating stations, transmission and distribution
- Industrial installations and
- Non-industrial installations.

With no mentioning of number of fatalities, i.e., no. of accidents are mentioned rather than no. of persons killed/injured. Both the categorization of accident under various causes and the format of statistical information collection are as per regulations set by CEA. About 24,030 total accidents in three-year duration (in which humans are affected) 14,907 are fatal accidents, i.e., about sixty-two percent. Among these, accidents/incidents due to cause-2 have maximum share with thirty-seven percent out of total fatal incidents occurred in three years. Prior 2013–2014, the detailed cause wise distribution of accidents and post 2015 accident data is unavailable (Fig. 5).

However, it is to note that the data does not include accidents of UTs and provide information of all accidents (industrial and non-industrial). Hence, exclusively industrial accident data is represented in Fig. 6; however, cause wise distribution is unavailable and accidents in which humans are harmed only considered. Total number of fatal accidents is more than double than that of no. of non-fatal accidents. It is to note that though all these accidents reportedly occurred within the industrial premises though related to electrical supply (lines and/or equipment) as previously mentioned and includes all sorts of industries. This means the CEA industrial accident data can be correlated with that of DGFASLI and DGMS data.

## *2.2 Critical Comparison*

The CEA data quoted as "number of electrical accidents in India"; also, there is variation in number of accidents and death toll given by MHA that it does not match the total of DGFASLI, DGMS and CEA figures. On the other side, the variation found in CEA industrial accident figures and those mentioned in DGFASLI and DGMS. Hence, a close examination of these variations presented in this section in two categories:

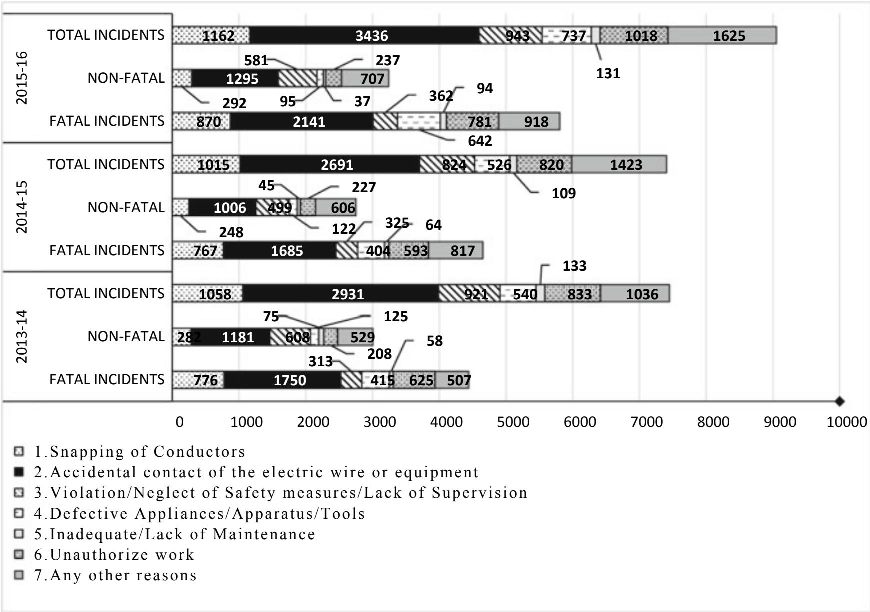


**Fig. 5** Numbers of accidents by CEA

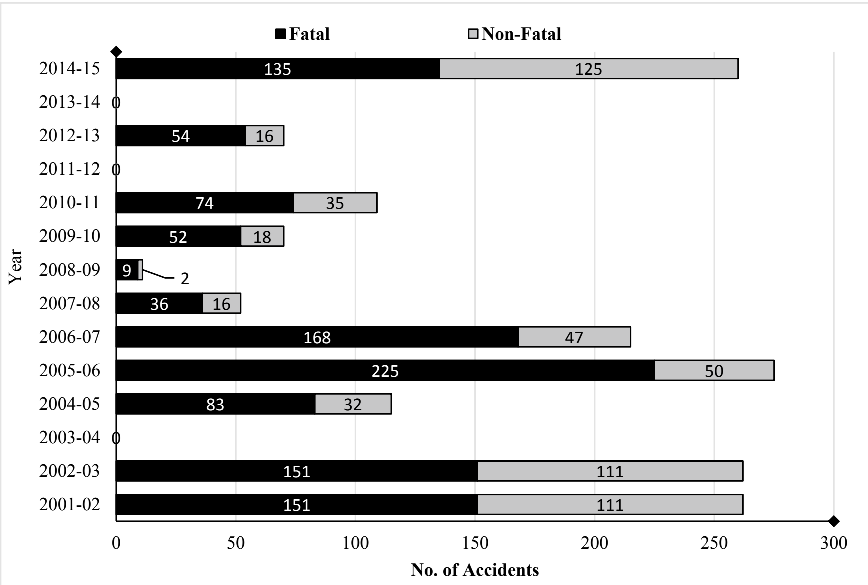


**Fig. 6** Industrial accident data-CEA

1. CEA data versus MHA data
2. DGFASLI and DGMS data versus CEA data on industrial accidents.

### 2.2.1 CEA Versus MHA

As mentioned previously, the figures quoted by according to statistics, available (Indiastat) only no. of incidents related to human fatalities are considered (Fig. 5), i.e., no information regarding fatalities has been provided. In contrast, as per the CEA's format (Format no. 19 of CEA's "Furnishing of Statistics, Returns and Information Regulations 2006") of statistics collection, mandates reporting no. of fatalities/injuries to note with no. of accidents marked in brackets; but, nowhere it is mentioned in this way. This raises confusion that existing data whether belongs to "no. of incidents/accidents" or "no. of resultant fatalities/injuries"; however, according to Indiastat, these numbers indicate number of accidents. A comparison of CEA and MHA accident figures is as shown in Fig. 7 and component wise comparison is presented in Table 1.

Apart from this comparison (Table 1), it is surprising to note that even with limited scope of monitoring, number of accidents quoted by CEA exceed that of MHA for years 2001 and 2002 (Fig. 7) and for rest of the years, they are less than that of MHA figures.

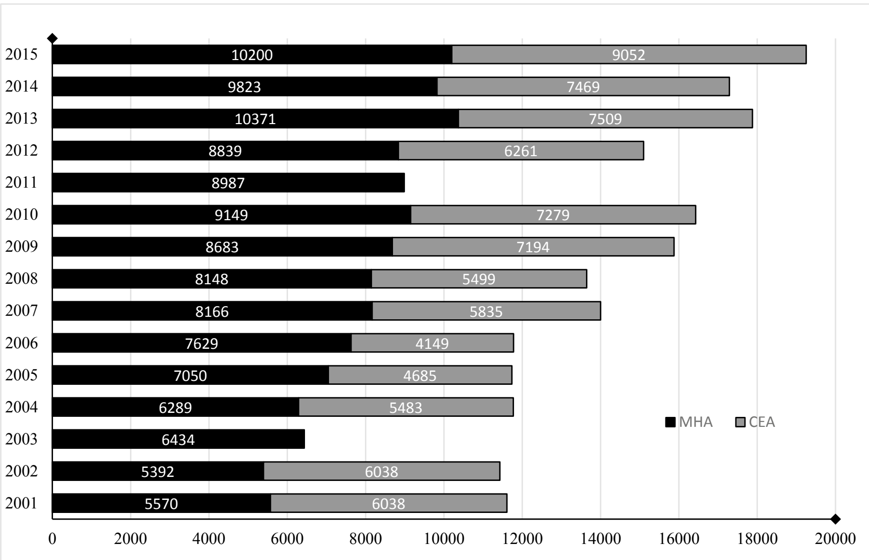


**Fig. 7** Comparison of accident data from CEA and MHA

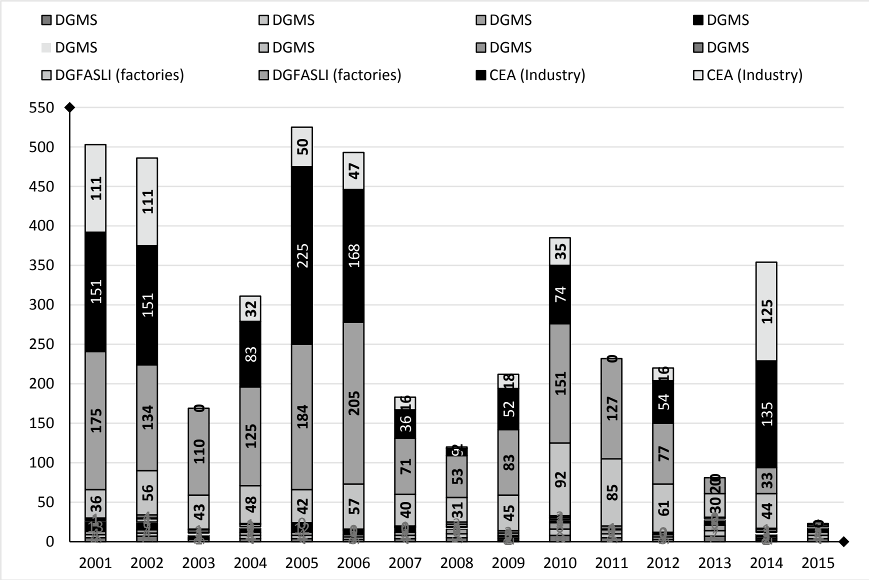


**Fig. 8** DGFASLI and DGMS versus CEA industrial accidents

### 2.2.2 DGFASLI and DGMS Versus CEA

As mentioned earlier, CEA data accounts industrial accidents too; and these figures can be correlated with that of DGFASLI and DGMS. However, DGFASLI provided information only regarding number of injuries, whereas CEA portrayed number of accidents. Unlike DGFASLI, both fatality/injury along with incident/accident data is available. Detailed comparison of these stats is given (Table 2 and Fig. 8).

It is clear that number of accidents and injuries/fatalities are relatively low in mines compared to factories and DGMS data is more complete in nature than rest two, i.e., in DGFASLI data information about number of accidents due to electricity is missing and in CEA number of fatalities/injuries. However, as CEA has wider scope than rest two, it can be concluded that number of accidents in industries is significant and if sector-wise segregated data provided by CEA or if DGFASLI could segregated number of accidents by cause, comparison could be done more effectively and efficiently. In addition, it is worthwhile to note that the format of collection of accident stats (Central Electricity Authority 2007) of CEA mandates mentioning of fatalities/injuries in parenthesis along with accidents/incidents; however, the same is missing in CEA reports.

## 3 Summary

A review of electrical accidents in India for fifteen years duration (2001–2015) carried out by collecting analyzing and comparing accidents and/or injuries from official reports of various governmental bodies-MHA (NCRB), DGFASLI, DGMS and CEA. However, the format of data collection followed is different and thus in-depth comparison of these stats is necessary to know the actual accident scenario. The overall accident data of CEA is comparable with that of MHA; similarly, the correlation in industrial stats could only be possible all the stats have at least same basis; for instance, if injury data of CEA available, one can compare it with DGFASLI and conclusion can be drawn on actual scenario in industries. The no. of accidents and injuries in mines relatively lower than occurrences in factories. All these figures show the need of "electrical safety" in India.

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# A Probabilistic Risk Assessment of Offshore Flaring Systems Using Bayesian Network

**Md. Alauddin, Faisal Khan, Syed Imtiaz, and Salim Ahmed**

## 1 Introduction

Following the Piper Alpha disaster (1988) (Gordon 1998) and Deepwater Horizon catastrophe (2010) (Graham et al. 2011), the commitment for inherent safety in the design of offshore platforms producing oil and gas is becoming increasingly complex. These platforms are vulnerable to fundamental hazards such as fire, explosion and oil release on the sea surface. According to the Worldwide Offshore Accident Databank (WOAD), 6543 accidents resulting in 2288 fatalities have been reported since 1970 (DNV.GL 2016). The offshore platform comprises of manifold systems, e.g. drilling mechanism, high-pressure separator, low-pressure separator, storage and transportation system.

Flare system plays a vital role in oil and gas production, refining and processing facilities (Zadakbar et al. 2008). Gas flaring systems are installed on onshore and offshore platforms production fields, transport ships port facilities, distribution pipelines and storage tanks. They are generally used to handle materials vented during normal operations, startup, and emergency conditions. The flaring system is primarily applied to ensure safe and efficient handling of gases as per the safety requirements. They also find extensive applications in handling toxic, corrosive and other flammable gases. The World Bank reported that 150–170 billion $m^3$ of gases are flared annually (Emam 2015). The gas flaring and venting are frequently employed for scheduled startup and shut down of a plant for maintenance. Thus, they are equipped with a safe and reliable method for burning gases in the emergency release. Primarily, the flaring system represents the last line of defence in the safe emergency clearance of undesired products released from emergency relief as shown in Fig. 1.

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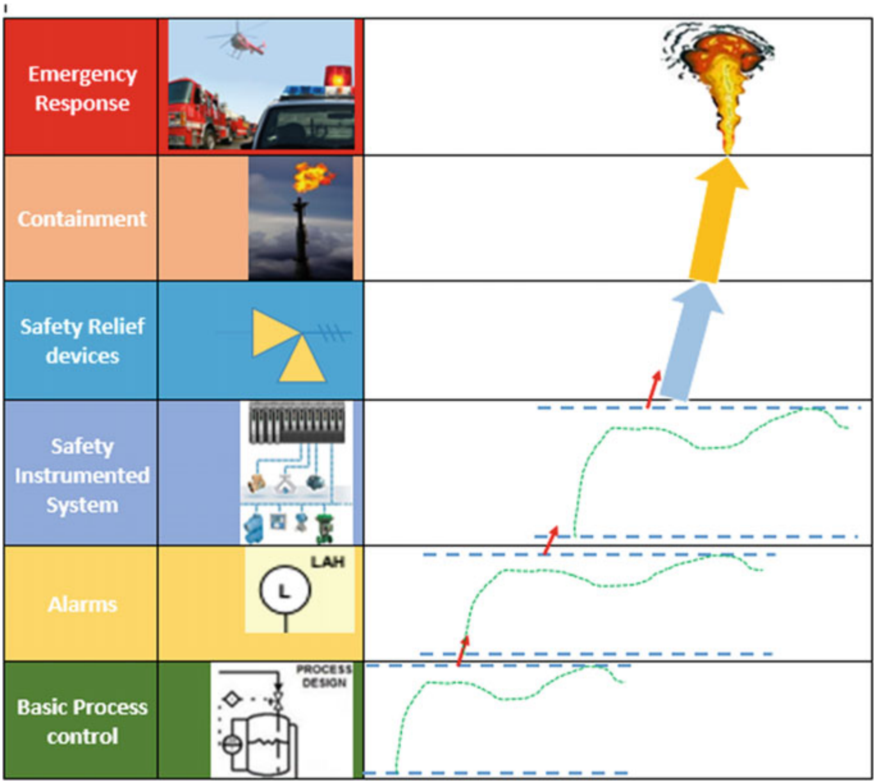


**Fig. 1** Hierarchy of safety measures

Thus, the design of the flare system is of paramount importance for ensuring safety and minimizing risk.

Risk can be estimated using the frequency of an event and the severity of its consequences (Ellingwood and Kinali 2009; Lathrop and Ezell 2017). The risk assessment includes hazard identification, identification of the consequences and estimation of the likelihood of the distinct consequences (Deacon et al. 2010; Abuswer et al. 2013). Many risk assessment methods have been applied to the offshore processing and flaring system. For instance, Deacon et al. (2010) developed a method for handling the human error in the offshore emergencies. Berrouane and Lounis (2016) exploited the fault tree analysis (FTA) for the safety assessment of the flare system. The FTA is based on top to down, deductive logic to build the relationship between the abnormal condition and the root causes. The consequences are modelled using event tree analysis (ETA). The combination of fault and event trees forms a bow-tie (BT) risk model which represents a logical relationship between the causes and consequences through basic events and safety barriers (Abimbola et al. 2014). These methods have been used as effective risk analysis tools due to their simplicity and quick inferences. However, they suffer from the limitations of static structure and uncertainty handling which are of profound significance. They are also unable to model the interdependency among the basic events.

This paper has exploited the inference of the Bayesian network for the probabilistic risk assessment of an offshore flaring system. The remaining part of the report is structured in sections viz—the flaring system, the methodology followed by the results and discussion.

## 2 The Offshore Flaring System

The flare system consists of the following elements (Bader et al. 2011):

- Flare collectors: Pipes that collect the gas from principal discharge component (safety or relief valve, blowdown valve) and extend up to the component to final disposal.
- Knockout drum: It is a vessel that separates liquid droplets from gaseous. The drum is a liquid–vapour separator which has tremendous applications in process industries.
- Tailpipes: They play an essential role in handling the maximum allowable back-pressure of the relieving devices.
- The flare stack: This is usually an elevated pipe pointing upwards. It causes the back-pressure in the flare system.

The P&ID and bow-tie diagram of the flare system is shown in Fig. 2 (Platvoet et al. 2012) and Fig. 3, respectively. The knockout drum is equipped with a level indicator. In case of a process upset, the level switch (LSH for high and LSL for low) transfers the signal to the pumping system which regulates the volumetric flow rate accordingly. The failure of pumps will result in the excess liquid leading to the overflow which has the potential for severe consequences such as fire and explosion. The damaging consequences are minimized by employing a series of safety barriers, e.g. level indicator, field operator inspection and monitoring station.

## 3 Bayesian Network

Bayesian network (BN) is an effective approach for safety and risk analysis. It can incorporate multi-state variables, conditional dependencies and real-time information to update prior beliefs. The Bayesian framework provides accurate probabilistic information of the updated model from the uncertain and incomplete information (Dogan 2012; Briggs 2000). It is constructed by combining process historical data and expert knowledge (Zhang and Thai 2016). Owing to its diverse nature, BN has emerged as the leading algorithm for the recombination with other process monitoring and fault diagnostic methods.

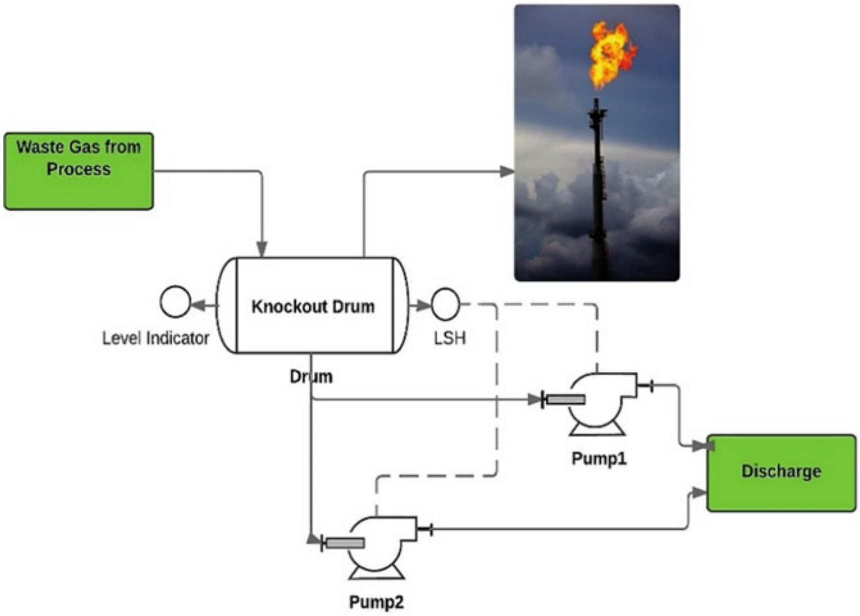


**Fig. 2** The P&ID of the flare system

A Bayesian network is a directed acyclic graph (DAG) comprising of nodes and arcs (Fig. 4) (Korb and Nicholson 2010). It employs Bayes theorem to generate the posterior based on updating the prior occurrence probabilities of events and new information. Each node represents the probability distribution of a random variable, while the arc determines the probabilistic relationship between the two connected variables. The arc is generated at the parent node and directed to the child node. The node which does not have any child node is called a leaf node. An intermediate node serves as both a parent and a child node in the network (Yu et al. 2015). A BN works by propagating the belief in the entire network and termed as a Bayesian belief network (BBN) (Mallick and Imtiaz 2013).

Equation (1) represents the joint probability distribution (JPD) of the network in the form of the product of all likelihood probabilities (Mallick and Imtiaz 2013). By using Bayes theorem, the posterior probability can be calculated by prior as given by Eq. (2) (Khakzad et al. 2011) for a given new evidence, $E$.

$$P(U) = \prod_{i=1}^{n} P(A_i|Pa(A_i)) \tag{1}$$

$$P(U|E) = \frac{P(U,E)}{P(E)} = \frac{P(U,E)}{\sum P(U,E)} \tag{2}$$

where $Pa$ $(A_i)$ is the parent set of $A_i$.

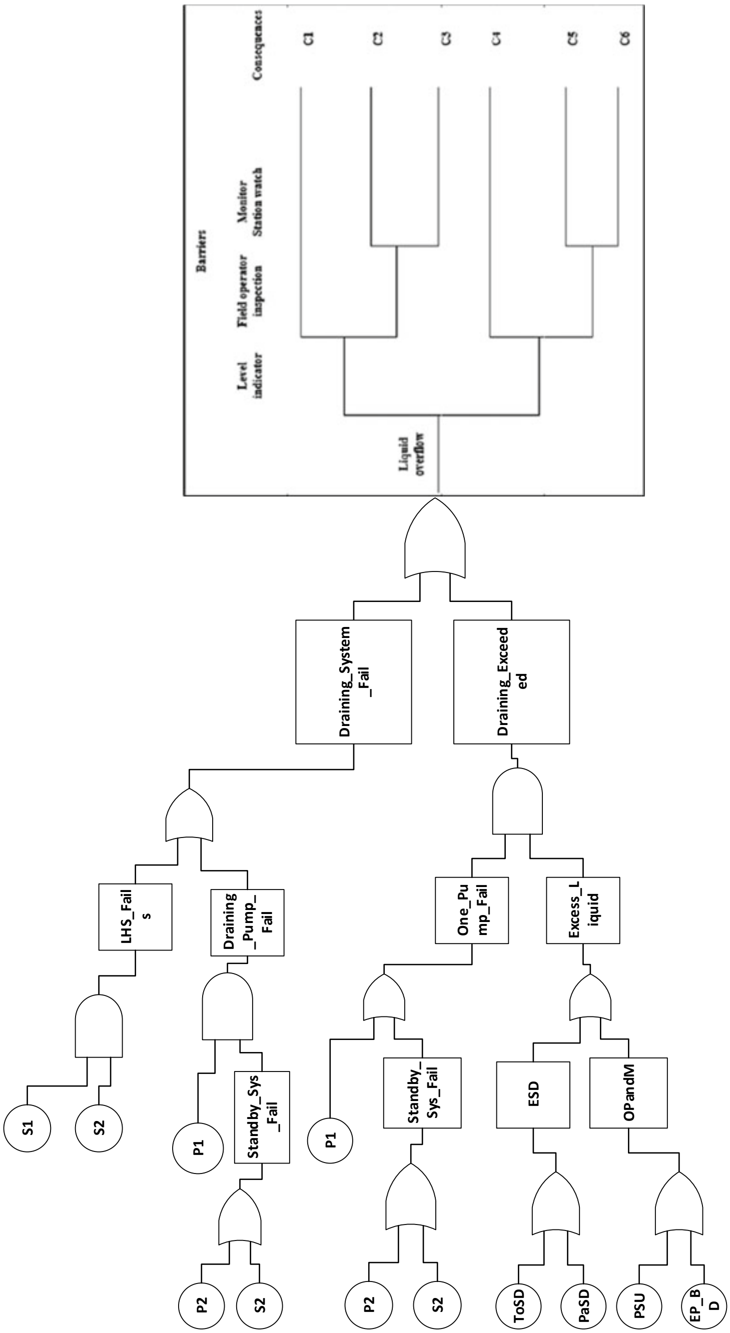


**Fig. 3** Bow-tie diagram of the overflowing liquid for the flare system of offshore platform. ToSD—total plant shut down; PaSD—partial plant shut down; PSU—plant startup; EP_BD—equipment and piping blow down; C1—overflow with no loss (controlled); C2, C5—flammable liquid overflowing with low damage to moderate damage; C3, C6—flammable liquid overflowing, pool fire and high damage; C4—flammable liquid overflowing with low damage

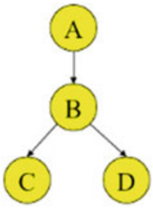


**Fig. 4** Basic representation of Bayesian network

## 4 Result and Discussion

Figure 5 represents the Bayesian network for the overflowing liquids of the offshore flaring system. It models the basic events and the consequences of the overflowing of the knockout drum. The probability of the basic events is expressed in Table 1 (Talebberrouane et al. 2016; OREDA Participants 2002). The dependencies of the events were realized by changing the conditional probability table (CPT) of the basic events as shown in Table 2. For instance, the LHS would fail when both S1 and S2 fail. However, the failure of any one of the S1 and S2 with influence the

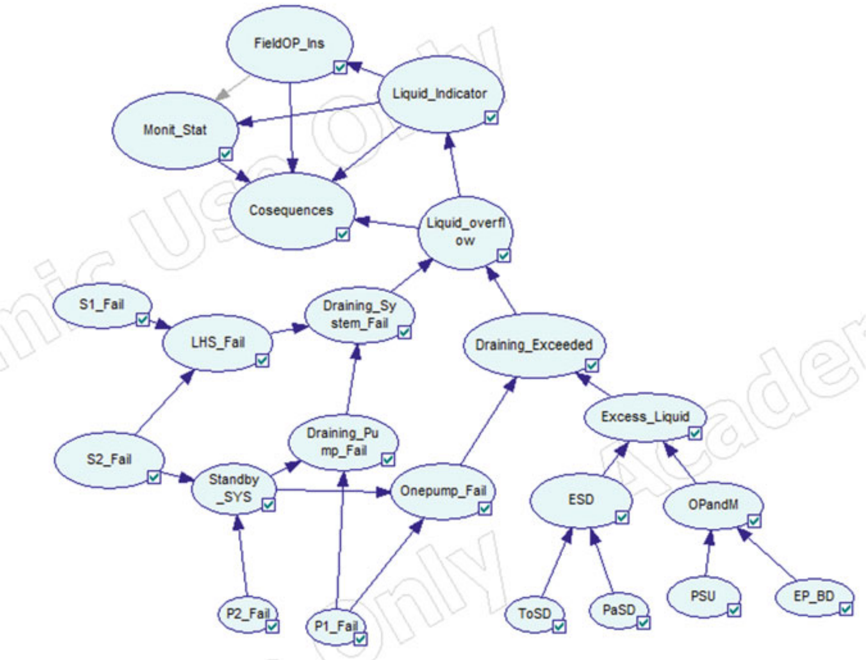


**Fig. 5** Modeling of consequences of overflowing liquid in the offshore platform using a Bayesian network

**Table 1** Probabilities of basic events for the overflowing liquids of the offshore platforms (Talebberrouane et al. 2016)

| Basic event | Symbol | Failure probability |
|---|---|---|
| Total plant SD | ToSD | 1.90E−05 |
| Partial plant SD | PaSD | 2.85E−05 |
| Plant startup | PSU | 3.26E−05 |
| Equipment and piping blow down | EP_BD | 2.28E−05 |
| Pump 1 fails | P1 fails | 5.70E−07 |
| Pump 2 fails | P2 fails | 5.70E−07 |
| Sensor 1 fails | S1 fails | 4.00E−07 |
| Sensor 2 fails | S2 fails | 4.00E−07 |

**Table 2** CPT for LHS_Fail

| | LHS_Fail | | | | |
|---|---|---|---|---|---|
| | S1_Fail | Fail | | Work | |
| | S2_Fail | Fail | Work | Fail | Work |
| Without dependencies | Fail | 1 | 0 | 0 | 0 |
| | Work | 0 | 1 | 1 | 1 |
| With dependencies | Fail | 1 | 0.1 | 0.1 | 0 |
| | Work | 0 | 0.9 | 0.9 | 1 |

other. The conditional probability table (CPT) of the consequences has been shown in Table 3. The consequences of the system under the normal condition and after the overflow have been reported in Table 4. The probability of failure for the barriers level indicator, field operator inspection and monitor station were 0.02, 0.2 and 0.05, respectively. The operation is mostly safe and under controlled situation with the given values of the basic events. The probability of the occurrence of C2 and C3 is zero, whereas those of C4, C5 and C6 which are potential hazard have very low values. However, the probabilities of the damaging consequences C4–C6 increased significantly by incorporating dependencies. It can be noticed that the probability of the abnormal events is increased by fifth order by imbibing dependencies of the first order. Table 4 also exhibits that the damaging consequences become critical after the occurrence of the overflow.

The sensitivity analysis and the influence diagram of the system have been presented in Fig. 6 with the corresponding sensitivity values of the events in Table 5. It can be observed that the pumps (P1 and P2) and sensor S2 are the most critical for safe operation of the flaring system with the average sensitivities of 0.042, 0.042 and 0.06, respectively. The other components, total plant SD (ToSD), partial plant SD (PaSD), plant startup (PSU), equipment and piping blow down (EP_BD), and sensor S1 are also influential. The safety barriers level indicator, field operator inspection

**Table 3** CPT for consequence node

| Consequences | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Liquid_ Overflow | Overflow | | | | | | | | No overflow | | | | | | | |
| Liquid_ Indicator | Fail | | | | Work | | | | Fail | | | | Work | | | |
| FieldOp_ Ins | Fail | | Work | | Fail | | Work | | Fail | | Work | | Fail | | Work | |
| Monit_stat | Fail | Work | Fail | Work | Fail | Work | Fail | Wor k | Fail | Wo rk | Fail | Wor k | Fail l | Wor k | Fail l | Work |
| Safe | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $C_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $C_2$ | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $C_3$ | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $C_4$ | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $C_5$ | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $C_6$ | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 4** Probability of distinct consequences caused due to the overflowing of the system

| Consequences | Probability of the consequences with the given basic event probabilities | | Probability of consequences given the overflow |
|---|---|---|---|
| | Without dependencies | With dependencies | |
| Safe | ~1 | 0.9999892 | 0 |
| C1 | 1.629 E−10 | 1.051 E−05 | 0.98 |
| C2 | 0 | 0 | 0 |
| C3 | 0 | 0 | 0 |
| C4 | 2.659 E−12 | 1.716 E−07 | 0.016 |
| C5 | 6.317 E−13 | 4.076 E−08 | 0.0038 |
| C6 | 3.325 E−14 | 2.145 E−09 | 0.0002 |

C1: overflow with no loss (controlled), C2, C5: flammable liquid overflowing with low damage to moderate damage, C3, C6: flammable liquid overflowing, pool fire and high damage: C4: flammable liquid overflowing with low damage

and monitor station are also crucial for intact working of the system. The liquid indicator is the most critical component with an average sensitivity value of 0.071.

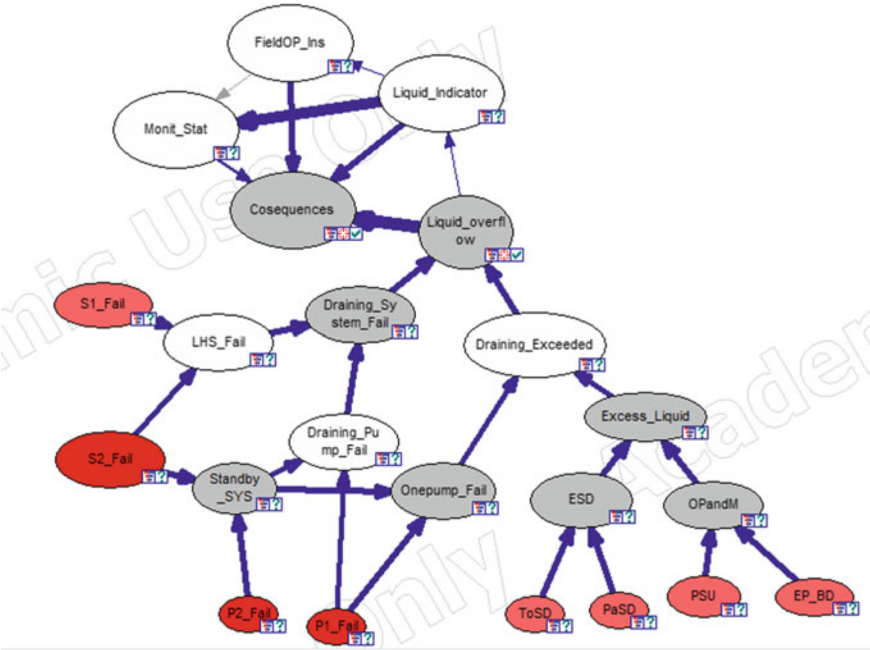


**Fig. 6** Sensitivity analysis and influence diagram of the overflowing liquid in the offshore platform

**Table 5** The sensitivity value of distinct components of the offshore flaring system

| | Component | Max sensitivity | Min sensitivity | Avg. sensitivity |
|---|---|---|---|---|
| Sensitivity of the components with the given basic event probabilities | S1_Fail | 0.100 | 0 | 0.022 |
| | S2_Fail | 0.271 | 0 | 0.060 |
| | P1_Fail | 0.190 | 0 | 0.042 |
| | P2_Fail | 0.190 | 0 | 0.042 |
| | ToSD | 0.100 | 0 | 0.022 |
| | PaSD | 0.100 | 0 | 0.022 |
| | PSU | 0.100 | 0 | 0.022 |
| | EP_BD | 0.100 | 0 | 0.022 |
| Sensitivities of the barriers given the overflow are realized | Liquid_Indicator | 1.000 | 0 | 0.071 |
| | FieldOP_Ins | 0.020 | 0 | 0.001 |
| | Monit_Stat | 0.004 | 0 | 0 |

# 5 Conclusion

This paper presents a probabilistic risk assessment of an offshore flaring system using a Bayesian network. The analysis was carried out on the knockout drum of the flaring system for the overflow and non-overflow cases.

It was found that the probability of the abnormal events significantly increased by incorporating interdependencies among the events. Sensitivity analysis was also carried out to study the impact of imprecision of data and find the critical components of the system. Thus, pumps (P1 and P2) and level indicator safety barrier were found to be the most crucial for the damaging effects.

The Bayesian network can be an efficient approach for safe mitigation of the unwanted process conditions in the flaring systems.

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# State of the Art Review of Accidents Due to Moving Parts of the Machinery in Industries

**Ambika Yadav, Bhaskar Arora, Surendar Varadharajan, and Bikarama Prasad Yadav**

## 1 Introduction

Machines are hazardous in nature and exposure to the hazards may cause accident that could be fatal accident. Objective of this paper is to suggest techniques and technology in order to make machine activities safe and bringing the hazards to the acceptable level. Before suggesting any technique and technology to make machine activity safe, it is necessary to find out the causes of accident that are due to moving machine parts. Moving parts of the machinery can be operated anytime so the risks of accidents are likely to happen frequently (Chinniah 2015). Lots of accidents occur from moving parts of machinery. With the system as well as technology advancement, the frequency of the accident has increased. The reason behind it is unpredictable motion of the machine due to the command from its control system. There are standards and regulations on the machines control system. For the safe functioning of moving parts of machine, it is necessary to follow these standards. Before talking about the accident and the prevention of accident from moving machine parts, it is necessary to define what a machine is.

A machine is an apparatus that uses mechanical power and also have many components that have desired task to perform and components all together perform a particular job. There are various types of machine. A lot of hazards are associated with the moving parts of machinery which results into day by day increasing fatalities and deaths which includes injuries of entanglement from rotating shafts, cutting from sharp edges of machines, crushing of hand, arms and fingers from hard surfaces of machines which move together, puncturing, sudden impact, etc. (Dźwiarek and Latała 2016). Each accident has three phases: first phase is pre-accident, second phase is accident phase and the third phase is post-accident (Hoła and Szóstak 2017). When

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a person is working near moving machines without proper safeguards and safe work practices, they can be struck and seriously injured or it may lead to fatal accidents. Sometimes, due to not having control on machines as well as sudden start or stop with change in speed due to system failure also led to harm to the life of people. The conditions which pose a threat to such accidents are installation of machines and equipment, operating machines and equipment, maintenance or repair services and cleaning services. Crushed hands, arms, fingers and legs are the possible injuries caused by the moving machines. Sometimes, the parts of the machines can be so hot and cold that it leads to burns. A condition such as when the screws, nuts, bolts or other fixed guards used in the machines loose and comes out during work performance; it is also responsible for injury or accidents to occur. Before talking about prevention of the accident, it is important to go to the depth of any accident and to reach out to its root cause. These causes can be from manufacturer end or the user end. Manufacturer causes of the accident are incorrect definition of safety functions, incorrect formulation of safety requirement, manufacturing fault in the machine, incorrect power and phase rating as well as user manual error. User causes of the accident are poor training/untrained worker, poor maintenance and not following the safe work practices. There are various sectors of organization in which large amount of fatality occur every year due to moving machinery. Majorly, construction sector, agriculture sector, wood industry, metal manufacturing industry and industry using robots are the major sectors where most of the accidents occur due moving parts of machine.

To prevent the accidents from moving machine parts, it is necessary to identify the root cause of accident. Elimination of root cause of accident prevents it in occurring in future. To prevent the accident and to find out the root cause, there are various techniques that have been adopted till now. Some of the effective techniques reviewed are safety climate and communication, sensor-based technology, injury survey, accident investigation method, safety assessment system, HAZOP-UML method, fault diagnosis method, logic analysis data, simulation model technique, failure mode and effect analysis (FMEA) and fault tree analysis (FTA). Now to prevent the increasing fatal accidents and injuries from the machinery, it is necessary to adopt safe working practices, devices and safeguards. Some of the safe working practices include training plan outlines, process of ensuring compliance, orientation of new and returning worker, following up the standard operating procedures, use of personal protective equipment, reduce workplace stress, report unsafe conditions to the supervisor, keep emergency exits accessible, take regular breaks and be aware of your surroundings. Some of the safety devices includes safety light curtains, safety controller, two-hand control device, indicator lights, safety scanner, safety interlock switches and enabling devices, tower light and emergency stop and stop control. Some of the safeguards include fixed guard, distance guard, adjustable guard, tunnel guard, fixed enclosing guard, interlocking guard, automatic guard, trip devices, two-hand control guard and reaching over guard.

Currently, sensor-based technology, machine guarding, training and use of PPE are the most effective measures taken by most of the industry to prevent accidents from moving parts of machine. Still the accidents from moving machine part are at high rate. So, in this paper, various new technologies and methods are available or they are in research phase to reduce the accident rate. Behaviour and attitude towards the safety, i.e. safety culture also plays a vital role in accident prevention in any organization. 88% of accidents occur due to the unsafe act. So the method of job rotation has been adopted by many organizations to prevent accident from unsafe act. It is challenging to control or modify the behaviour of any person towards safety and that is one of the major reasons of the accident.

## 2 Various Sectors Involving Machinery Accidents

### *2.1 Construction Sector*

Backström and Döös (2000) analysed that there were accidents despite the use of machine safeguards. According to them after using the machine safeguards, accidents were not prevented as according to them safeguards cannot stop all the machine movements. They concluded that safeguards do not function adequately because every safeguard cannot be considered as safe for same type of machines every time and different installations have different safeguards which work or perform up to a set range.

McCann (2006) identified that the contact with the heavy machines and the equipment with the workers at the construction area was considered as the most dangerous event which caused nearly 253 deaths in work industries because of backhoes and rollovers. Heavy loaded equipment caused the sudden jerk to the workers. Even some of the workers were barefoot and without proper personal protective equipment. As a result, LOTO procedures were used. Restriction to the specific zones was made where heavy equipment was installed. Setting of spotters at nearby places where such kind of activities was carried out.

Baksteen et al. (2012) found that lots of risks are associated to the workers working in the close proximity of the moving machines. A risk assessment was done to determine the risk. Identification of the reasons of the accidents led by these moving parts was conducted to determine the possibility of accident. They concluded that the accidents have categorized according to the different working conditions with the machines. For example, it could be anything related to cleaning, operating and maintaining machines. Measures were taken to decrease the fatality and permanent as well as temporary injury risk.

Choe and Leite (2013) found that sensor-based proximity warning technology in equipment helped in preventing back-over accidents in construction zones. This includes the selection of generic sensor system and performance is tested. This is implemented in work zones which can prevent injuries and fatalities. Back-over accidents are due to the limitations in the visibility. Technologies which have been added to remove this causality are video cameras, micro-cameras, tag-based cameras, radar and ultrasonic which gives the clear view and prevents the accidents.

Poisson and Chinniah (2016) observed that there is risk related to machinery in sawmills. So they worked on eight sawmills containing machines such as hydraulic equipment, vertical and circular saws and chain conveyors. Workers could be crushed easily. Even there are chances of entanglement of body parts as well as cutting of body parts during cleaning, dismantling, repair, adjustment, set up, production disruption, installation, maintenance, unjamming, sharpening of blades, etc. Seven lockout programs were followed. Basically, this paper tells us how the logout procedure is implemented in proper way. Fifty-seven lockout procedures were also observed with the energies that are hazardous and controlled by circuit breakers usually (isolating), switch gears, pneumatic and hydraulic valves. Use of padlock was also implemented. Chemical and radiation energies were also used.

### 2.2 Agriculture Sector

Kumar et al. (2008) analysed and found agriculture sector is one of the most illiterate and unorganized sector. The sharp turn taken by the operator, uneven land conditions, sudden applying of brakes while moving in high speed, poor functioning of brakes, accelerators and handle, and excessive load carried by the tractor are some of the causes of the accidents. But still the majority of the accidents happen because after suggesting techniques, still there is no effectiveness. Accidents are not recorded and there is no recorded data for the past accidents. In agriculture sector, maintenance and repair job are done by untrained person with time constraints and this is not done periodically. So, this result into a large number of injuries.

Narasimhan et al. (2011) evaluated that the machinery entanglement is one of the injury for the Canadian farmers during adjustments of machines parts, handling of products, clothes stuck with the sharp pointed parts of the machine or their attachments, during handling harvesting equipment for grains as well as seeds. The reasons were that the machinery was not operating properly, there was no proper guarding, there was no repair and maintenance, there was no safety sign, working hours were more than 20 and farmers were under time pressure. So this could be prevented by the safety attitudes, proper knowledge, changing perception towards safety, following the safety standards, farming procedures as well as maintenance.

Pawlak and Nowakowicz-Dębek (2015) observed that the most of the accidents occurred due to being struck by the heavy machines, misuse of the machines, such as automatic in row weeder, olive harvester, carrot harvester and separator, tractors, baler, cotton picker, loader and threshing machine, in agricultural holdings. As a result, farmers should know about the importance of learning safety instructions and safety regulations and even to get the vocational training.

Poisson and Chinniah (2016) discussed the smart machines which use sensor technology as well as robotic technologies in agriculture field for activities like seeding, harvesting, spraying, etc. Modern technology can prevent injuries by implementing advances in sensing hardware, software algorithms, data structures, smart systems and smart equipment. This is done for diagnosing the fault in the system of machines, monitoring the work progress and safety of workers from the fatalities and injuries through safety driven-based old technique machines. It improves the efficiency of workers working with the new advanced machines with their high tech boosting system with the help of hybrid engineering and integrated systems applied to them. This reduces the worker's risk of entanglement and serious injuries.

## *2.3 Wood Industry*

Pavlovic and Fragassa (2016) observed that the relation between the workers and machines is uneasy and quite risky during woodworking where the machine can do cutting, shearing as well as drilling. Technology makes the machine safe. Manual machines may harm operator by its moving parts. Manual, automatic and computerized numerical control (CNC) machines are dangerous in their aspect. Accidents related to machines mostly comprises of removing swarf, taking measurement, unloading and loading components. In this, machines have sensing devices which creates an invisible layer of sensing field around the machine and it prevents the body parts of worker from getting caught in the moving machine. As soon as the machine detects the presence of human, machine stops immediately.

Osakwe et al. (2017) discussed the processing activities at wood workshop which comprises of lifting, cutting and stacking. Out of these, the major accident occurs due to revolving and reciprocating cutting tool used for wood processing activities. It may cause injury or death. Here, to prevent accidents, a new technology has been created. They have used human shields as a barrier for face, internal and external organs, skin as well as bones for protection against moving parts of the machine, coming into contact with the rollers, slip and trip. Fault tree analysis and Lagrange's multiplier were used to determine the fault in wood workshop which causes fatalities.

## *2.4 Robot Related Workplace Accidents*

Jiang (1987) analysed 32 accidents from the robots and studied the type of injuries, degree of injury and categorized it into design of robot, design of workplace, error of human and he came into the finding that the line workers were in more risk as compared to maintenance workers and programmers. Accidents from robots occurred due to poor workplace design and human error. 56% accidents occur due to pinch point and 44% are impact accident.

Vasic and Billard (2013) discussed that the robots apart from being the best technology to help the human can also harm the humans. There are two possibilities of accidents from the robots: due to robot-robot collision or robot-human collision. Robot-robot collision occurs when two robots operating in the small area collides. Robot-human collision occurs when operator comes in close proximity or on the path of movement of robot's arms. The three major causes of the accident through robots are engineering fault, human error and working condition. Robots are programmed with software for safe working, but still accidents occur because the robots are not tested at lower speed at different working conditions before using it practically.

### 2.5 Accidents Investigation on Ships

Schröder-Hinrichs et al. (2011) carried out the accident investigation on ships using Classifying the system and human factor analysis for the causalities as well as incidents from the machines which leads to fire and explosion due to poor machine designs, poor techniques, failing of engines, wrong decision taken during the operation, faulty equipment, poor machine layout and improper space given to machines for their working. This also includes lack of organizational factors, lack of resource management, environmental factors, unsafe supervision, etc.

### 2.6 Various Accidents Due to Model and Technology

Bellamy et al. (2007) a research project was taken to build a casual model named as "story builder" for the scenarios which are mostly occurring and which has caused injuries to the workers. The tool classifies the data from accident reports. It also tells us the details of the failure of barrier to prevent accidents. A number of task groups have been allotted to identify and analyse the actual reason of the accidents apart from the other pathways. The result was that there should be selection of effective strategies to reduce the risk which takes into account the costs of accidents and proper measures should be taken. A proper ladder to analyse the accidents should be used which includes how the accidents occurred and at what time, failure of the accidents, number of risks involved during the work and type of work conducted during the accidents.

Backström and Döös (2007) found the data that comes from two engineering plants. They analysed the severity of the injury and the body part injured between advanced manufacturing accidents (AMT). Automated machines improve the production efficiency and also it makes working environment better. With the help of technology development, conventional reasons of the accidents are eliminated but new kind of accident arises. They concluded that AMT accidents are more harmful as compared to the other accidents because of the day by day growing technology, and these accidents were considered to be the most serious ones.

Caputo et al. (2013) observed that safe machines contribute to safety in workplaces. Safety of machines is in the hands of safety devices. In this conclusion, there is reduction of mechanical hazards of the machines used in the industries. Proper safety devices are used for different machines because every machine has different safety devices which resulted in decline of accidents. Devices were checked by the decision makers based on expert opinion and keeping safety factors in mind.

### 2.7 Accidents Due to Machine Design

Driscoll et al. (2008) aimed to give a statistics of the contribution of fatal work-related injuries. The results were that the 37% of fatalities at workplace had machinery design-related issues like improper guarding; improper protection from the fall heights, improper seat belts and failure of lifting. Design plays a vital role in the accident prevention that is related to moving parts of machine. Lack of incident data from accidents is one of the limitations of this study. Apart from this, even the design of machinery and leads to serious accidents in an increasing number. Proper safety should be considered while designing any machines, plant layout as well as equipment.

Dźwiarek and Latała (2016) analysed 1035 serious accidents out of which 341 were minor injuries. Moving machinery can be made safer by the manufacturer by using protective devices, safe design and safeguarding. On the other hand, machine can be safe by the user end, if the operator follows standard operating procedure (SOP), i.e. written and verified procedure to use the machinery safely. SOP plays the vital role in every industry having moving machineries in minimizing accidents due to wrong or unsafe work practices. Here, nine types of machine operations were used for different tasks with the help of rotating working elements of the machine and moving transmission parts in manufacturing sector.

### 2.8 Techniques Adopted to Prevent the Accidents from the Moving Parts of Machinery

The major objective of this review paper is to find out the main causes which lead to accident and injuries and also to suggest what other preventive measures can be taken by adopting effective and suitable methods. The studies have been made by adopting certain methodology to improve the statistics of increasing number of accidents which occurs during dismantle of the machinery and equipment, operating machine and equipment, providing maintenance or repair services, cleaning services, production from the different industries, etc. Accident investigation finds out the root cause of the accidents. There could be occupational factor (culture, environment, equipment, workload, working hours), human factor (motivation, training, physical and mental capability, medical conditions, alcohol and drugs) and technical factor (poor functioning of machines, no guarding, no warning signs, no warning devices, no warning signals, no complementary protective devices, etc.). Now there are certain areas where different methodologies have been used to prevent accidents.

### 2.9 Safety Climate and Communication

Hofmann and Stetzer (1998) observed that the underlying cause of any machine accident is necessary to be identified correctly in order to prevent the accidents occurring in future. In this adopted methodology, two types of surveys for the interpretation of accident such as safety climate and communication were carried out. Safety climate measures the importance of safety to the management, priority of the safety to their supervisor, availability of the safety equipment, strength of the safety policies and awards for achieving the safety standards. Safety Communication measures the extent to which workers are comfortable talking about safety with their supervisors.

### 2.10 Sensor-Based Technology

Roca (2006) suggested the machine protection system and method for rotating equipment which tells about the new alarming features and use of sensors to get the information such as thermal information, chemical, motion and force. Here, the amplitude vibrations are sensed and phase data is stored on a minute basis and hour basis for short term and long term by calculating the average of vibration amplitude baseline. If the alarm gets triggered on exceeding the sensed vibration amplitude from baseline vibration amplitude or through current deviation, the rotating machine will stop or shut down immediately.

Zhang et al. (2017) investigated and provided a review on the technology which was sensor based on advanced construction of safety management for accidents. There are few technologies which are used nowadays such as vision-based sensing technology, sensor-based technology, location sensor-based technology, wireless sensor-based technology, etc. In this paper, the use of different types of sensor-based technology has been identified and reviewed. Identification of radio frequency, network based on wireless sensor, system that provides pre-warning, and Zigbee was used to prevent accident.

## 3 Injury Survey

Robert et al. (2008) analysed and suggested a methodology to prevent the accidents from machinery. It is necessary to do the injury survey. To conduct this, questionnaires were made that are specific to machines and 201 injured persons were interviewed on the basis of categories of machine and the circumstances at the time of accident. This method helps in finding out the shortcomings that may be machine related or machine part related or safety measures related to machine.

## 4 Accident Investigation Method

Katsakiori et al. (2009) evaluated that the accidents from the machines were investigated but it is necessary to evaluate the effectiveness of the current investigation method. Investigation method is considered to be effective if it clearly specifies immediate and underlying cause. Evaluation of current accident investigation is one of the methodologies to prevent machine-related accident in future. Evaluation of the current accident investigation is based on the accident model, safety improvement recommendations, detailing of the machine accidents, validation of the accident investigation method, training and education required in order to conduct the investigation.

## 5 Safety Assessment System

Kim et al. (2016) observed that despite the safety guidelines, workers do not follow safety rules every time. So through this paper, an onsite safety assessment system was adopted based on computer vision and fuzzy interference for the accidents which occurred due to strucking from moving objects. Safety level will be shown as numerical value. Through this, current working condition of the workers can be improved.

### *5.1 HAZOP-UML Method*

Guiochet (2016) identified a new method HAZOP-UML. HAZOP method was combined with the system modelling language, i.e. (UML—unified modelling language). A prototype was originated to provide the better ease to HAZOP table and UML models. HAZOP-UML table consists of guide word line number, attribution, deviation, real-world effect, use case effect, every possible causes, severity, remarks, safety recommendation and hazard number. But there was a drawback related to this method that it is difficult to determine hazard as three columns represent the hazard such as deviation, use case effect and real-world effect. Apart from this, there is no method available to determine the actual environment conditions of the execution.

### *5.2 Fault Diagnosis Method*

Shao et al. (2017) developed a method for detecting the rotating machinery fault. This method is applied to rotating as well as bearing applications. It is a method in which raw vibration data is taken and after that we can detect the fault diagnosis result. We do not have to be dependent on signal processing techniques and to extract manual features.

### *5.3 Logic Analysis Data*

Jocelyn et al. (2017) found that logical analysis of data (LAD) was a great idea to prevent the accident that is related to moving parts of machine, when the belt conveyors were used. LAD is a computational technology. With the help of LAD, accidents of different natures were categorized with an accuracy of 72–74%. LAD provided the different patterns generated in a logical way by using this as algorithm to prioritize the risk factors and this thing helped the operators as well as practitioners to make decisions regarding safety.

### *5.4 Simulation Model Technique*

Hoła and Szóstak (2017) analysed that the construction site was prone to the accidents that cause injury or death. There are various causes of accident at construction site out of which one of the reasons was the accidents from moving parts of the machine during operating, transporting, servicing, etc. The proposed methodology had majorly five steps: collecting the data sources, acquiring the protocols of accident investigation, creating a database, constructing a stimulating model and testing of the models. The overall objective is to develop a model for stimulation of the accident and test the derived model.

### *5.5 Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA)*

Kan et al. (2018) evaluated that large no. of accidents and injuries occur from cranes that are used at construction. Most of the accidents are related to the bolts, pin, safety device, hook, twisting part of the machine such as coiling, hoist and load indicator. Now there are two types of methods used to prevent accidents and to know the reason of crane failure, i.e. fault tree analysis (FTA) and failure mode and effect analysis (FMEA). FMEA tells about the failures which are related to the machine failure but FTA tells about the failures which are related to the machine, human errors, environmental factors as well as factors related to the reliability. FMEA takes the help of data and humans that are expertise and thus they prevent the crane failure but FTA concentrates more on the results that occur in the end and at the last finds out the causes which lead to the accident.

## 6 Result and Discussion

Machine design-related issue causes 37% of the fatal accidents. The effective strategies can reduce the risk and in turn will reduce the cost of accidents and injuries. At construction site, workers getting in contact with moving machines cause most accident. Proximity sensors play vital role in backover accident prevention at the construction sites. Sawmill is one of the dangerous industry. People may suffer from cut, crush from machines of sawmills. Different types of safeguarding should be done for the different types of machine for getting the effective isolation from the moving machines. The technology such as sensing, hardwares, software algorithms, data structures, smart systems and smart equipment are modern techniques for the accident prevention and fault diagnosis. Wrong and unsafe practices can be prevented by standard operating procedures while working with moving machineries. Robots fall under the category of moving machines and most of the accidents from robot occur because of the poor workplace design and human error. Safety devices installed in the machines prevent many accident from moving machines. Other measures to reduce accidents from moving machines are less working hours, machine maintenance, adequate training, changing the perception towards safety and following the safety standards.

If the hazard cannot be controlled at the source, personal protective equipment work as a barrier between the worker and the hazard. In the case of machines, coming in contact with the moving machine parts is the hazard which may lead to injury or fatality. There should be 2D barcode on the every personal protective equipment and workers should get scan all the personal protective equipment in the barcode scanner machine where barcode needs to get access and then only the machine will get start. It should be software-based automatic system. Machine should get on only once the mandatory personal protective equipment barcode is being scanned.

## 7 Conclusion

Although most of the industrial sectors that comprise machinery with moving parts form a major source of productivity, agriculture and construction sector are the most prone to accident from moving machineries. After reviewing the papers, certain measures can be concluded that human error is one of the major causes of accidents from moving parts of machine. Effects can be from minor injuries to fatal accident. Other reasons that resulted in accidents are machine fault, design fault and poor safety culture. The hierarchy of control is applicable to any found hazard in the workplace and the relevant control strategy can be implemented depending on the type of hazard and the work floor environment. Most of the machines the elimination and substitution of the hazard are not possible as it is a part of the inherent design so engineering control, administrative control and personal protective equipment plays a major role. These accidents from moving parts of machine can be prevented by technology like guarding and guarding devices, implementing standard operating procedure (SOP) or by behaviour change towards safety and also correct mode of accident investigation prevents accident from reoccurring.

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# Overview of Road Safety Management Scenario in India

**Mahadevan Shankaren, Michael Reagon, Nihal Anwar Siddiqui, and Bikarama Prasad Yadav**

## 1 Introduction

An enhanced study on road safety found that an overall 90% of the accidents, 57% of the accidents are due to human errors, 2.4% of the accidents are due to the mechanical fault and 4.7% of the accidents are due to environmental factors. There are a large number of issues in road accidents happening and the main issue in transportation is due to energy efficiency and environmental protection which plays a major role and these accidents have the potential to harm the property, environment and other factors. Also, these accidents can cause serious impacts and disturbances to the transportation network. There are several errors which result in an accident and some of the errors are recognition errors, decision errors, performance errors and non-performance errors and the recognition errors are due to the distractions and other concentration by the driver, decision errors are due to the avoidance of seat belts and helmets and improper lane driving and overtaking in an irregular manner, performance errors is due to the driver's poor performance on the roads such as over-speeding and so on and non-performance errors are mainly due to the drunken driving so these types of errors mainly contribute to the big catastrophe and apart from the above errors some other accidents happen due to silent running of some motor vehicles which lead to injury on the person walking on the pedestrian crossing. Several research studies related to road accidents suggests that slow driving and conservative defensive driving could probably enhance safety. Genuine damage or demise changes lives perpetually—for families, companions, networks and collaborators as well. Human misfortune and enduring are unfathomable. Wounds and sickness can incite a noteworthy emergency for families in which they happen. The human mistake is frequently observed as the reason for street mishaps. While it may not be conceivable to prevent individuals

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from committing errors, these slip-ups need not result in fatalities. The traffic condition must be created so that human mistakes do not prompt genuine results. Street wellbeing implies security for all street clients. Mishap chances out and about, amid both business-related driving and relaxation time driving, include dangers to the driver, travelers and other street clients. The present consistently changing traffic condition requires steady sharpness with respect to street clients. Traffic guidelines are proposed to diminish the danger of mishaps. Improving street security includes managing issues identified with street clients, the traffic condition and the state of the vehicle (Wiethoff et al. 2012).

## 2 Literature Review

Road traffic accidents are the most important growing health problems, in developed as well as developing countries (Bener et al. 2003). Recently, the accident statistics show that many countries are suffered maximum due to road accident problem and many of the cases are left unreported (Naji and Djebarni 2000). In the view of all the cases, only some of the cases are near misses, mostly many of the accidents are reportable injuries and some of the cases are fatal. The road conditions also play a major role in this and some of the criteria lead to accidents are an improper construction of roads, unorganized pavement construction, lack of proper safety sign boards along the roads and many more. Proper signage should be kept in case of narrow roads and in speed breakers etc. Using tangents and circular roads, the speed prediction model is built and it can be monitored periodically to avoid the accidental loss due to the over-speeding (Esposito et al. 2011). Safety road committees and safety staffs should be allocated in every country separately to enhance the self-safety of the individuals and so that personal safety of every individual can be monitored and the several factors pertaining to the accidents could be monitored immediately. Many accidents happening around the corner of each part are due to the negligence of the individuals. This paper mainly deals with the negligence of every individual and careless act. Though the above-mentioned findings should be personally taken care by every individual, proper protective equipment have to be used to bring down the accident rate from high to zero.

## 3 Factors Associated with Road Accidents

There are several factors pertaining to road accidents and a detailed study has done in the roads of Dehradun and many references are taken from the road transport officer; also, some of the references were taken from the previous studies held;

- **Over-speeding**—Almost in most of the developed countries, 30% of the accidents happen due to over-speeding, and in some of developing and under developing countries, speed plays a major factor for the majority of the road fatalities. Determination of "safe speeds" involves consideration of several aspects like types and objectives of the road, the kind of catastrophe happening over the roads which finally results in an increase in road traffic.

- **Drunken driving**—It deals with the blood alcohol concentration and surge the level of the clash and results in high chances of death and it plays a major role in overall accident statistics. It also results in a longer loss sometimes, because the severity of the accidents occurring is very high and it sometimes irreversible and leads to death than minor injuries.
- **Nonusage of helmets**—It is another main factor in which 18% of the accidents occur due to non-usage of helmets or usage of poor quality helmets. Because quality plays a major role. Wearing a helmet could reduce the occurrence of an event by 40% and the risk of serious injury by 70%. The good quality standard helmets should meet the safety standards and it should be properly worn by the person riding the vehicle.
- **Visibility**—In very mechanized nations, terrible perceivability assumes a solid job in three principle sorts of accidents: calculated or head-on impacts, vehicles that backside or keep running into sides of moderate moving or stationary vehicles and backside crashes.
- **Improper roads**—Due to the improper roads around the country, the cause of accidents is higher and it has been increased by several factors such as poor construction of roads, potholes, etc. The stability of the roads plays a vital role in minimizing the number of accidents from maximum to minimum. While constructing the roads, it should meet the government road safety regulations as well as the safety standards in order to avoid the severity rate of the accidents.
- **Distraction while driving**—This is one of the main factor and around 35% of the accidents are happening due to the deviation while driving and use of mobile phones such a talking over the phone, use of navigation and one hand driving leads to accidents and which sometimes may be serious. Anything that takes attention while is the distraction, one cannot drive safely unless the task of driving has one's full attention.

Driver affectability relies upon reviews of road incident genuine examinations and police disaster reports and examinations. The higher the affectability pointer, the more thought drivers will pay to the security trademark and thusly the more the event of road incidents can be cut down. For example, it has been represented that consistently in excess of 97% of road setbacks (both fatal and singular harm) occurred on boulevards. This finding may be elucidated by the extra mindfulness or alarm drilled by drivers in poor black-top conditions. The additional caution or alert practiced by drivers in poor asphalt conditions could clarify this finding. It also shows that speed must be lower on poor-condition asphalts, although on high-condition asphalts, higher mishap rates could be the result of both speed and lower slip opposition as well as other safety factors.

## 4 Effect of Transport Complex on the Economy

Street crashes are turning into a worldwide wellbeing emergency and, all things considered, require exhaustive measures to forestall them, including a superior comprehension of the social effects of street related passing and wounds.

A few pointers expect to show the effect of car accidents. The most widely recognized ones are the number of fatalities and wounds. All inclusive some 1.3 million individuals kick the bucket out and consistently and up to 50 million endure wounds. Furthermore, by and large, financial expenses of street crashes go from 2 to 5% of GDP in numerous nations. These financial expenses give a premise to transport security improvement undertakings, for example, danger area medicines, street reviews, school zones and other preventive measures.

Street mishap does not extra any area of the general public whether an individual is poor or rich, untalented or exceedingly gifted. The dominant part of them are in the age gathering of 20–40 years and are normally the bread workers of the family.

I likewise trust that wellbeing, training and sustenance are the central needs of any individual. As we are aware, our country is attempting to meet the essential needs like health, instruction and nourishment. The streetcar crashes are exhausting the assets implied for these essential needs. The wounds brought about by street incidents are causing physical inability as well as causing a monetary handicap.

After the car crashes, everyone ends up less fortunate than what the individual in question was before. 50% of the families are either obtaining cash from somebody or selling their benefits like land, house, cows, vehicle and adornments and so on for the treatment of their cherished. Be that as it may, tragically, notwithstanding the best accessible treatment in our nation one-fourth to half of the mishap exploited people remain briefly or for all time debilitated and sadly yet for all intents and purposes turn into a risk to their family.

Over-speeding, surpassing and overstacking are likewise in charge of expanding the number of streetcar crashes. It has additionally been experimentally demonstrated that when speed expands the number of mishaps will in general increment. As indicated by a police report three-fourth of vehicles on the road had been observed to be over-speeding. As indicated by a police review directed in the mountain State of Uttarakhand, the significant reasons for street mishaps are over-speeding or overstacking. The general population is attempting to spare time by over-speeding and overtaking to squander the time on online networking. The expanding want to remain associated on social stages has turned out to be so addictive as of late that individuals have the inclination to utilize it even while driving vehicles. This is extremely perilous as has likewise been distributed in numerous reports that express that cell phones are the reason for lethal mishaps with the quantity of such accidents rising step by step.

## 5 Methods to Prevent or Minimize Road Accidents

The methodology for the choice and prioritization of the underlying arrangement of wellbeing measures is exhibited and talked about, in view of a mishap examination. To start with, the general methodology is depicted, at that point, the technique is displayed including the meaning of a situation, and how mishap insights are utilized as a beginning stage, the age of wellbeing measures, and the strategy for choice of security measures. Street wellbeing surveys ought to be attempted by a group of individuals who have involvement and exceptional mastery in street security building and crash examination and anticipation, connected to a comprehension of traffic the board and roadway structure.

Road surfaces must ensure an adequate element of pounding at the tire-black-top interface to oblige safe movement of vehicles. Black-top surface structuring properties can be described by two parameters: microtexture and macrotexture. Microtexture gives direct tire-black-top contact; however, macrotexture gives leakage limit. The insurance from slipping on a road surface is, as it were, managed by the microtexture of the surface aggregate. It is a component of all-out mineralogy and coordinated effort with traffic moreover, climate factors. Lacking contact of black-top surfaces may speak to a perilous space for interstate security. In any case, this factor is on occasion scarcely detectable by drivers since it cannot be physically watched or envisioned.

Frameworks and strategies to quantify slip opposition and street surface fluctuate generally from nation to nation. It has been accounted for that 84 distinct gadgets have been utilized for estimating asphalt contact and surface. Asphalt type and climate conditions have appeared to large affect street mishap relationships. The climate condition investigation demonstrated that 79% of the lethal clash and 79.7% of individual damage mishaps occurred in "clear or radiant" conditions (Glendon and Litherland 2001). Lethal and damage mishaps that happened in "stormy" climate conditions were under 9.9 and 12.4%, individually, while lethal and damage mishaps that occurred in conditions portrayed as "snow/solidifying precipitation/slush/hail" happened at the rates of 9.1 and 6.9%, respectively. Examination of street mishaps needs an extensive comprehension of the considerable number of components related to vehicle mishap events, what is more, their intelligent connections. From the previous measurable reports, it might be effectively yet wrongly inferred that street mishaps were not the result from terrible climate and surface conditions. The point is that despite the fact that asphalt condition represents a low level of mishaps, in total terms this does, notwithstanding, speak to a significant number of mishaps. The important factors of the accidents are speeding and it leads to maximum deaths and injuries, most of the accidents are happening due to the over-speeding and in overall accident percentage, 40% of the accidents are due to the speeding of the vehicles. According to the information accessible for the past numerous years likewise, the fundamental driver for mishaps is speed and more than 0.5 lakhs passing has happened on our streets in the previous a few years (Ranganathan 2016). It can be effectively controlled and little decrease in speed can spare a few life.

Some other factors which could prevent road accidents are;

- Overwhelming punishment ought to be forced on each one of the individuals who cross speed limits. If this is carefully actualized, no one will set out to go at a fast.
- Carefully designed speed controllers ought to be made obligatory in every single overwhelming vehicle and new substantial vehicles ought to likewise be made with sealed speed controller.
- Automobile manufacturers should manufacture the vehicle with the speed limit of 50–60 kmph, so as to avoid accidents due to over-speeding and also suitable speed limit to be set according to every country.
- Modern devices for crash counteractive action should be manufactured and installed on all vehicles. Research associations should be approached to develop such contraptions on a war equilibrium.
- Ahead defender should be made vital by law in all states or power a lower speed limit for the people who do not use a top.
- Law ought to be altered to such an extent that the individual who made the mishap needs to hold up under 0–10% of the protection claims, contingent upon the seriousness of carelessness. Likewise, the remuneration ought to be made tremendous.
- Kids beneath a specific age ought not to be allowed to drive in occupied streets/where substantial vehicles are utilizing.
- Permit of the individuals who are engaged with mishaps ought to be suspended right away.
- The soundness of vehicles ought to be carefully upheld.
- Streets ought to be legitimately marked. Proper sign sheets ought to be introduced.

Escalated street fixes where important ought to be taken to make traffic smooth and safe. Rash driving and driving in an intoxicated state ought to be restricted. The inebriated drivers' licenses ought to be dropped. There ought to be a fixed speed limit for driving on all expressways which ought to be shown noticeably at critical spots and intersections. Any violator of this breaking point ought to be seriously managed with. It will be extremely beneficial if street wellbeing weeks are sorted out in all schools and universities as often as possible to inform the youthful understudies from the earliest starting point of the possibility of street safety. All infringements on vital parkways ought to be evacuated and a few street paths at standard interims might be developed to streamline traffic. This thought may appear to balance against diminishing the quantity of street—dividers however it is not. In extremely essential urban areas where street traffic is high, a detour ought to be built to redirect or guide through traffic to other towns. The street traffic workforce ought to be exceedingly prepared to control the traffic in a superior way. If every one of these means is taken as one, the diagram of street mishaps is probably going to demonstrate a descending pattern.

## 6 Conclusion

This paper endeavors to add to the assortment of learning on street security. It is trusted that it will motivate and encourage expanded collaboration, advancement and duty to avoiding road accidents around the world. Road accidents are unsurprising and in this way preventable. So as to battle the problem, though, there should be close coordination and cooperation, utilizing an all-encompassing and incorporated methodology, crosswise over numerous areas and numerous controls. Car crashes are a noteworthy reason for passing in India and everywhere throughout the world and it has influenced countless of the components, for example, asphalt systems, climate factors, over-speeding, drunken driving, non-utilization of protective caps and because of these elements, numerous mishaps happen and the minimization of the street mishaps as for the different elements is resolved and it ought to be pursued to convey the mishap level to low. Consequently, it turns out to be vital that everybody ought to carefully pursue the traffic governs and ought to dependably drive securely with regarding different individuals and vehicles out and about. We ought to keep away from rash driving, tanked driving and hopping red lights. Wearing protective caps and safety belts could profoundly diminish the number of causalities amid a mishap. A harmony exertion from each and everybody could lessen the number of mishaps and make our streets safer. Street clients wherever merit better and more secure street travel.

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# Design of Fire and Gas Detection System in Process Industry

**Udbhav Srivastava, Ashish K. Gangola, Yash Dhiman, and Rishi Dewan**

## 1 Introduction

Process industry is a place which contains enormous number of hazards: firstly, general physical hazards such as noise, vibration, and fall from height; secondly, chemical hazards such as fires, explosions and toxic leakages (Crowl 2002). When a potential hazard is released due to leak, then it may pose danger to people as well as asset. By installing fire and gas detection system (FGS), we can easily detect the source of leak and isolation is done for that area and indication is given to the people to escape from the escape routes from the place, and immediately active protection takes place to stop the fire (Fig. 1). It is used for detecting a fire at early stage of escalation. The fire and gas detection system along with alarm system is to be focused during the design stage that contributes to enhanced safety (2006) (Benmebarek 2006).

Fire and gas detectors are the major components in FGS. The placement of the detectors is important to detect leaked gas and thereby implement further control measures. The position of the gas detector affects the reliability of the gas. The FGS systems in existing facilities have been traditionally designed with conventional method without any modeled simulation design (Shabaka 2006). The performance of such conventional designs is questionable where the detectors are placed randomly based on experience.

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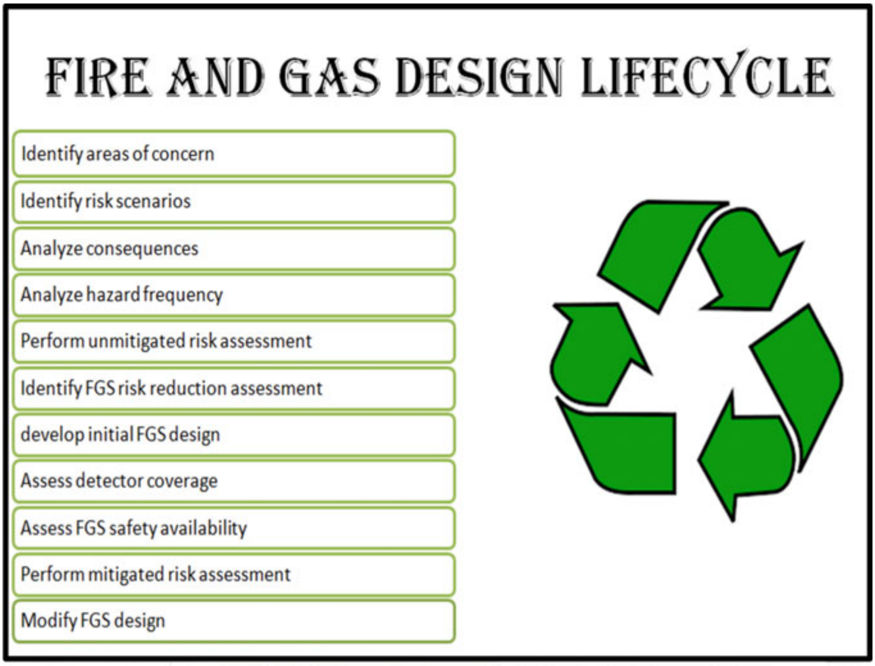


**Fig. 1** Fire and gas design lifecycle

The relevant codes and benchmarks, for example, NFPA 72 arrangement, especially NFPA 72E, BS 5839 and EN54 gave an extensive learning on choice, establishment and support of se gauges address the necessities of FGS and flame alerts in structures, but fall short for the mitigation of fire and toxic hazards in process industry. Industrial designers identified a need of more information particularly for design and placement of FGS in a process plant layout. Current standards provided only general considerations and recommendations for design of gas detector. These data are based on rule of thumb and do not addresses the complexities involved in the detector placement (Legg 2012).

## 2 Fire and Gas Detection

The fire detection system consists of the fire detector, control unit, and control devices which activates from the signal of control unit. When the fire breaks out, two things come into picture, one is saving life and the other one is safeguarding assets. The main objective of the fire detection system is to monitor for the potential leakage of flammabi2 or toxic gas and triggers the personnel by alarms thereby allow for further control measures. By and large, they are a piece of a completely programmed framework which alarms defensive gadgets, for example, steam blinds, or discharges firefighting operators. In different cases, in any case, the capacity of the location framework is constrained to giving a caution flag to the work force, who needs to translate and actualize control measure, for example, crisis shutdown, ventilation, start source control, and putting out fires framework. There are a few explanations behind not continually making the framework completely programmed. One is that location frameworks are subject to give false cautions, another is that it is not in every case simple to characterize ahead of time correctly what is required.

FGS configuration comprises of different sorts of locators, tuned to various set focuses and caution rationales; therefore, numerous components must be considered before introducing FGS like kind of identifier, number of indicators, area, set focuses and alert rationale. At the point when spillage of gas happens, it tends to be either structure a steady cloud or be dispersed relying upon elements like the hole rate, wind, thickness of the gas and condition present around the break. Every one of the elements are to be considered for planning of FGS for a procedure plant design. For the most part, modern discovery is required for loss of control (holes) and flame.

Three types of gas detectors can serve for detecting the loss of containment; they are flammable gas detector, hydrogen gas detector, and toxic gas detector.

In case of detection of fires, three detectors can serve the purpose; they are fire indicator, heat locator, and smoke finder.

## 3 Criteria for Detector Selection

Detectors are basically of two types fixed or portable. Fixed detectors are permanently installed in a given location for continuous monitoring of process plant. Fixed detectors are useful in enclosed spaces and are less reliable in open spaces. Portable gas detectors are small handheld device which are used for testing gas at confined space and emergency response. While utilizing fixed location framework, one can pick between two identification standards which are point discovery and open way recognition.

Point identifiers measure the grouping of intrigued vapor/gas at inspecting point. They cover limited area and are often used near to single equipment. Gas concentrations are measured in % lower flammability limit and toxic gas in ppm or ppb (Bafjord 2011). For detection coverage over large areas, multiple point detectors are needed. Many industrial detector types like infrared, catalytic, acoustic, semiconductor, and electrochemical detectors are based on this principle.

Open path detector contains infrared source and separate receiver. The target gas when passes through the infrared beam is detected through receiver. The advantage of path detector over point detector is that a single point detector can monitor large area instead of several point detectors. Gas/vapor concentration is measured in path length multiplied by %LFL or ppm. The issue with way indicator is that it is hard to recognize a little piece of gas with high focus and a huge one with less fixation. Since the open way indicator covers substantial region of recognition, it is hard to discover exact area of gas. Climate conditions and residue can have genuine impact on working of the open way identifiers. Election of detector type depends on type of target gas/vapor. Before deciding the detector, one should have sound knowledge on type of gases to be detected on process plant and applications of various detectors, for example, catalytic bead sensors are suitable for detection of combustible gases, whereas electrochemical sensors are useful for detection of toxic chemicals (CCPS 2009). Moreover the designer should aware of gases that cannot be detected, for example, infrared sensors cannot detect hydrogen. Some type of detector is susceptible to particular type of gases. All such required data should be reviewed before choosing detector.

Expected concentration of gas is a determining factor for choosing a detector. Both catalytic bead detector can and ionization detector can monitor flammable gases, but their range of detection varies significantly. Catalytic bead sensor cannot measure below LFL of flammable gases; however, ionization detector can measure as low as 1 ppm (CCPS 2009).

## 4 Factors Affecting the Design of Fire and Gas Detector Systems

There are many environmental and operational factors which can impair the performance of the FGS, so the designer should evaluate all the responsible factors before designing the FGS to a process plant (API 1991).

### *4.1 Density*

The density of the measuring gas is one of the prime factor of importance, gases with higher density than air locates more toward ground, whereas the gas with lower density than that of air disperses fast and rise upwards. Before installing, the designer has to check for the type of the gas to be leaked and its density for deciding the position of the detector, i.e., near to ground or at certain height at ceiling.

### *4.2 Wind Speed*

The speed of the wind can affect the dispersion of the released gas. In case of calm weather, the leaked gas behave according to density but at higher wind speeds, the gas movements are abnormally. Take an example of placing detector near to ventilation may not give desired output, even in case of leaked gas behaves like the air because of quick mixing with local air. These factors are to be considered especially in case of offshore installations.

### *4.3 Temperature*

Selection of detector is based on the ranges of operation of temperature; generally, it varies from manufacture to manufacture and also on type of technology. Operating FGS at upper and lower limits allowable temperatures may lead to drift in reading of 5–10% than the actual lower flammability limit concentration (API 1991).

### *4.4 Obstructions*

There are many chances of obstruction in process plant especially in case of open path detectors ranging from personnel, piping, equipment, dust, and particulate matter which deteriorates the detection capability and lag in response time. In order to prevent this, constant inspection is needed for FGS during both installation and operation.

### *4.5 Vibration*

Even though vibrations of higher frequency do not have significant effect on sensor, low frequency and high vibrations create a problem in FGS. High vibration is responsible for disabling the electrical circuit hence fail the detection mechanism. Care should be taken to avoid the mounting of detector on vibrating structures such as rotating equipment.

### *4.6 Miscellaneous*

The sensitivity of the detectors generally decreases with time due to aging. Proper installation and maintenance make the sensors to work for a period of 3–5 years. Check for calibration of detector regularly. The frequency of calibration is based on experience. Higher levels of humidity (>95%) are the factor which can affect the sensitivity and response time. Manufacturer has to be consulted.

## 5 Detector Placement Methods

Detector placement plays an important role for achieving the objective of FGS to give quick and reliable detection for early mitigation of major hazards. There is no guarantee of cent percent safety for detector positioning always a better way exists for detector placement. Heuristic placement for detector layout is simple and completely depends on past experience in similar applications. Any sort of numerical modeling is not used in this approach for determining detector coverage. Most of the times, heuristic method falla short for achieving safety goals because it puts more emphasis on source of gas leaks rather than gas accumulation. On other hand, prescriptive placement is used for placing detector which is strictly based on predefined standards. In this method, design engineers locate detectors solely based on rules of thumb or prescribed standards.

Semi-quantitative method for detector mapping is one of the most common methods to determine coverage (DET-TRONICS 2011). It considers factors like type of hazardous chemical, equipment used, process parameters, and level of occupancy. After evaluation of these factors, risk value is estimated, and based on the level of risk (NORSOK 2008), the place is classified into zones. After zonal classification, each zone's plot is loaded into the mapping application to determine the detector coverage which is based on the rules of thumb. Before loading, each application must be carefully considered based on toxic or flammable gas detection. Mapping application gives the percentage of detected and undetected coverage. Finally, decision has to be made by design engineer to whether to accept the level of coverage.

Full quantitative mapping or a risk-based approach is developed in recent years. Initially, a set of all possible release scenarios are defined and all the required input data such as release rate, grid set, and environmental factors are considered. In second step, dispersion modeling is done to identify the maximum distance of exposure (Defriend 2008). In third step, the risk of every possible scenario is calculated similar to semi-quantitative method. Then risk-based objective function is developed which is to be solved by using any iterative approach to get the optimum detector layout.

## 6 Set Point and Voting of Detector

As mentioned in the previous sections, the objective of the FGS is to monitor the hazardous gas and alert the personnel; in most of the cases after detection, the alerting mechanism is alarm system.

After measuring the gas concentration, the set point should be present for sending signal to alarm. For toxic gases, the set point is OSHA permissible exposure levels and for flammable gases maximum of 50% of lower explosion limits for a minimum of 30 days. Review the frequency of alarms and average concentration of gas leaks to adjust the set point downwards until minimal set point is reached to avoid nuisance alarms (CCPS 2009). According to NORSOK standard, the set point for low alarm and high alarm is 20% LEL and 30% LEL for point-type detectors (Health and Safety Executive 2003).

To avoid situations like emergency shutdowns because of alarm signal obtained from one detector due to small gas leakage at that particular detector, voting logic is employed in industries. Voting logic is deciding of number of gas detectors has to monitor the gas out of N detectors. Suppose if voting logic is 2 out of 5 (2oo5), then two detectors should detect the gas for the alarm to give signal. Voting of detector results in change of effective coverage and time of response because a gas cloud must grow to come in contact with multiple detectors. Many mapping applications do consider voting logic on gas detection coverage.

## 7 Methodology for FGS Design

The overall design procedure for FGS is shown in Fig. 2. Process industry poses a wide range of hazards because of its inherent nature of dealing with flammable and toxic chemicals. FGS system should not be used for good facility system and maintenance. Whenever potential leak of flammable or toxic gas cannot be eliminated, there arises the need for fire and gas detectors. One should always remember that installing FGS does not fits the purpose until proper control actions are installed along with FGS.

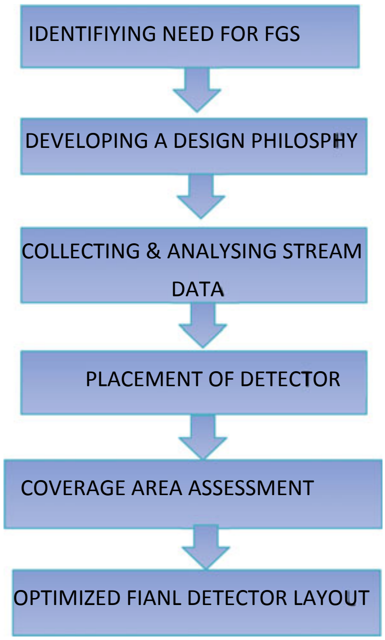


**Fig. 2** Methodology for fire and gas detection design

Verify that release of concern can be detected with a relatively high probability of success especially in case of open areas.

Detection philosophy shall cover the design requirements of FGS systems, and to what extent, the coverage is needed. There is no straight forward answer to answer this some interpret the risk in FGS with arbitrary calculations of SIL which may lead to some over engineered systems. Design philosophy varies with companies as well as type of plants. It is based on previous experience and knowledge in their domain. It is also based on the amount of funds allocated to FGS and to what level of safety systems are needed for the specific plant.

Once the design philosophy of FGS is developed, one shall collect all the required input data which is required for design of FGS. Equipment plot layout of the unit, all the equipment list, process flow diagram, process data sheet, heat and material balance sheets and site topographical data and wind velocities (Miyata 2011).

Once the preliminary collection of data is completed, start collecting properties of all chemical components involved in the process. The properties like flash point auto-ignition temperature and density of the pure components. Then start analyzing every stream of the process and identify the components in each stream which are greater than 5% volume in composition. Based on the design philosophy, identify which type of detector is needed for specific equipment.

Segregate the plot plan into zones based on the similar type of equipment in one zone. Start placing the detector in equipment plot plan from the previously identified. Place the detector by considering the wind directions. Coverage area assessment is needed to validate the detector layout and optimize it. It can be of two types, geographical assessment and scenario assessment. For flame detectors based on the vendor specifications, check for area coverage in three-dimensional plot. For scenario assessment, carry out dispersion modeling using available mathematical CFD tools and thereby optimize the layout of the detector for cost effective detection (Roman 2016). As mentioned in previous sections, the signal from the detector is properly linked with control equipment like alarm signaling, emergency shutdown, and activating fire water pump, etc. for the mitigation of risk.

## 8 Redundancy and Cost

Based on experience review of past case studies ,it is aware that there are one or more detectors which do not have any extra value of safety. These redundant detectors can be removed from mapping layouts; however, there should be no compromise on effectiveness of safety. A balance should be maintained between cost of the detection and safety offered by the FGS. All risk mitigation measures should be employed unless there is a negative effect on gross disproportionate to the benefits (Vinnem 2007).

## 9 Traditional 2D Versus 3D Detector Mapping

Conventional 2D mapping is drawn on a paper or utilizing plant design PC programming which thinks about two-dimensional perspectives. There are many problems involved in using 2D mapping and one of the main problem is elevation and orientation issues during 2D mapping process. After completion of detector mapping a walk throughout the plant is necessary to identify for any deviations. Walkthrough needs sound knowledge and experience in detector mapping. Consider the factors like ease of maintenance, cleaning, and calibration during the walkthroughs. After the detector mapping is completed, review it multiple times for any deviations.

## 10 Conclusion

A definitive point of any security framework introduced in the process plant is to ensure the life of work force and forestall harm to resource and condition. Proper detector selection and various performance factors are to be considered for improved placement of detectors. By carrying out dispersion analysis and coverage area assessment, one can validate the detector layout. Quantitative detector mapping is advantageous over heuristic approach for enhanced effectiveness of safety. Optimization of detector layout yields the better safety performance and reliability at low costs.

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# Assessment of Accidental Release of Ethanol and Its Dangerous Consequences Using ALOHA

**Rishabh Yadav, Shubham Chaudhary, Bikarama Prasad Yadav, Surendar Varadharajan, and S. M. Tauseef**

## 1 Introduction

Due to rapid industrialization, chemical demand has been increased tremendously, which poses a major threat to safety in industries. Process industries are always susceptible to major fire, explosion and accidental dispersion of hazardous chemicals. Most of the industrial chemicals are toxic, corrosive, flammable and poisonous in nature, unexpected or accidental release have adverse effect on human as well as for environment, and sometimes, it can lead to major catastrophe like Bhopal gas tragedy (Khan and Abbasi 1999). In distillery industries, ethanol is the extraction of sugarcane molasses, barley, wheat, etc. from fermenting it which further used in petroleum products, pharmaceutical companies, etc. (Horn et al. 2000). Ethanol can be directly blended with gasoline, reacted with isobutylene to form the oxygenated fuel additive ethyl tert-butyl ether (ETBE), or burned directly as a clean fuel. Blends of either ethanol or ETBE with gasoline force engines set for gasoline to run lean and can substantially reduce carbon monoxide emissions; so nowadays, the use of ethanol in gasoline is quite common (Wyman and Hinman 1990). There are many studies which shows the flammable characteristics of the ethanol and if not handled properly could lead to catastrophe, the heat generated due to ethanol is 26.78 kJ $g^{-1}$, and the closed-cup flash point is 16 °C (Hurley et al. 2015; Lyondell Chemical Company 2003). Some studies show that more than 20% of ethanol in any mixture is enough to form fire load (Fischer et al. 1987).

In this study, the Areal Locations of Hazardous Atmospheres (ALOHA) model has been chosen to simulate the scales of impact (threat zones) in the event of toxic chemical release (Hillairet et al. 2009). ALOHA is the program which is widely used in modeling the potential hazard of chemical releases in industries. Dispersion model is applicable for the fluid flow system which are classified as heavy gases (heavier

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than the air) and volatile chemical vapor cloud (Inanloo and Tansel 2015). ALOHA 5.0 provides user a choice of several accident scenarios, then uses a suitable source algorithm to release material into the air over a period of time (Shao and Duan 2012).

The simulation results based on Emergency Response Planning Guidelines (ERPG) and corresponding immediately dangerous to life or health (IDLH) values. The results and assessment of the simulation used for improvisation of safety during the handling of such types of chemicals and further used to analyze the potential harm and damage hence improve the risk assessment of the industry (Curran 2012).

Emergency response planning is a method which gives complete guideline for safe evacuation in case of fire and explosion (Tseng et al. 2008). Failure of which could lead to huge losses. Hence, the main objective of this study is to simulate the consequence modeling of toxic gas dispersion and evaluate the radius or area of the dispersion. This study quantifies the thread zones and areas which can be affected due to accidental release (Arunraj and Maiti 2009).

In this simulation, Aloha software helps to determine the dispersion of gases into the atmosphere whether it is leaking from pipes, spilling from tanks and a pool fire from puddle. It also predicts the concentration of gases at a different location and depicts the result in the form of graphs. So, it is easy to calculate the dispersion of vicious gases in the surrounding after an escaping of any chemical releases. Moreover, ALOHA can evaluate the instant area which is immediately dangerous to life and health or level of concern LOC. In this assumption, we can trace the footprint of gas with it. The Areal Locations of Hazardous Atmospheres (ALOHA) model has been chosen to show the results in the form of the graphs giving the approximation idea about the hazardous atmospheric location and its severity level which helps industries to carefully perform a risk assessment and improve the emergency response planning (Tseng et al. 2008).

In this study, ALOHA is used to simulate the toxic release of ethanol from storage tank and predict the impact zones considering the recent accident happened in sugar industry during loading of ethanol, ALOHA estimate the threat zone area where the results help to identify the contributors of the accidents and help other industries to improve the safety while handling ethanol.

## 2 Research Methodology

### *2.1 Description of Location and Atmospheric Condition*

The city of Uttar Pradesh, Meerut, has been selected for the study. In order to identify detail analysis, here are some atmospheric condition of Meerut; it lies between 28° 58 longitude and 77° 42 latitude. In this study, we took two seasons, i.e., summer having a temperature of 40 °C and winter having a temperature of 20 °C. Its wind speed varies between 3 and 6 m/s.

## 2.2 ALOHA Dispersion Model

The Areal Location of Hazardous Areas is a freeware software tool developed by the National Oceanic and Atmospheric Administration Office of Response and Restoration (NOAA), Chemical Emergency Preparedness and Prevention Office (CEPPO) and US Environmental Protection Agency (USEPA). The Gaussian model of dispersion has been used to model the dispersion of methane gas as it is neutrally buoyant and will spread with the downwind direction (Jones et al. 2013). ALOHA tool is adopted to simulate the accidental release of ethanol from storage tank and the simulation results are shown in Table 1.

This simulation is approaching the toxic material ethanol which is colorless and has a boiling point of 78.5 °C (Cowart and Boruta 1995). This makes the chemical hazardous to human being and environment. Ethanol is widely used in industries for making perfume and paint. Any mishandling and leniency may lead to catastrophic. Hence, this simulation helps workers and industries to closely analyze the risk involved in handling of ethanol and prepare emergency response according to it and in a more systematic way. It has been observed that most of the accidents occurred during high rush time, so emergency response was not followed in a systematic manner; this study gives a brief idea about threat zones involves which may help industries to formulate their risk assessment and emergency planning to save people and property.

**Table 1** Ethanol release scenario for simulation

| Hypothetical scenario of simulation fixed parameters | Scenario 1 (Summer) | Scenario 2 (Winter) |
|---|---|---|
| Temperature | Summer: 40 °C | Winter: 20 °C |
| Relative humidity | 50% | 20% |
| Elevation of wind speed measurement | 737.07 ft | 737.07 ft |
| Total amount burned | 4226 lb | 4365 lb |
| Model of release | Direct release | Direct release |
| Model | Heavy gas dispersion | Heavy gas dispersion |
| Cloud cover | 5 tenths | 5 tenths |
| Terrain roughness | Urban or forest | Urban or forest |
| Manipulated parameters | – | – |
| Atmospheric stability level | B | C |
| Wind speed | 5 m/s | 3.6 m/s |
| Total duration burn | 28 min | 28 min |

## 3 Limitation

ALOHA's simulation is not able to detect exact release of chemical; it assumes the chemical is mixed with air immediately but is not happen in actual; that is why it shows bell-shaped curve of any concentration. ALOHA's simulation is not able to determine the end products, i.e., smoke, particulate matter, radioactive particles. In this simulation, it is not able to determine the flying debris of container while having an explosion.

The concentration estimates by ALOHA can be inaccurate at very low wind speeds especially less than 3 miles per hour as the pollutant cloud is unable to mix with the surroundings quickly and ALOHA is unable to predict the concentrations especially near the source. ALOHA assumes the wind speed and direction to be constant throughout simulation. But in reality, wind speed and direction change with respect to time.

## 4 Result and Discussion

ALOHA model was used to simulate the release of ethanol chemical from a tank in the distillery plant. This simulation has been tabulated in Tables 1, 2 and Figs. 1, 2. The transport of ethanol is a complex process and in case of any loss of control, can prompt an accident; therefore, the simulation results from this study can prove to be very helpful in determining the affected distance over which injury can occur. Additionally, the results seem to be helpful in construction of an effective response plan during such situation.

### *4.1 Scenario 1*

Figure 1b shows the graphs which ALOHA simulation gives after putting all the atmospheric conditions and geographical data. Figure 1a shows thermal radiation threat zone are in which categories the area according to their severity, the parameter taken to define the threat zone is the heat energy flowing per unit area per unit time, i.e., heat flux density. From the scenario 1, it has been observed that threat zones are classified in three categories based on heat flux density. The maximum threat

**Table 2** Threat zone of chemical substance ethanol

| S. No. | Toxic in effect | Scenario 1 (threat zone in summer) | Scenario 2 (threat zone in winter) |
|---|---|---|---|
| | Ethanol | ERPG 1 (1800 ppm): 21 m<br>ERPG 2 (3300 ppm): 16 m<br>IDLH (3300 ppm): 12 m | ERPG 1 (1800 ppm): 12 m<br>ERPG 2 (3300 ppm): 16 m<br>IDLH (3300 ppm): 23 m |

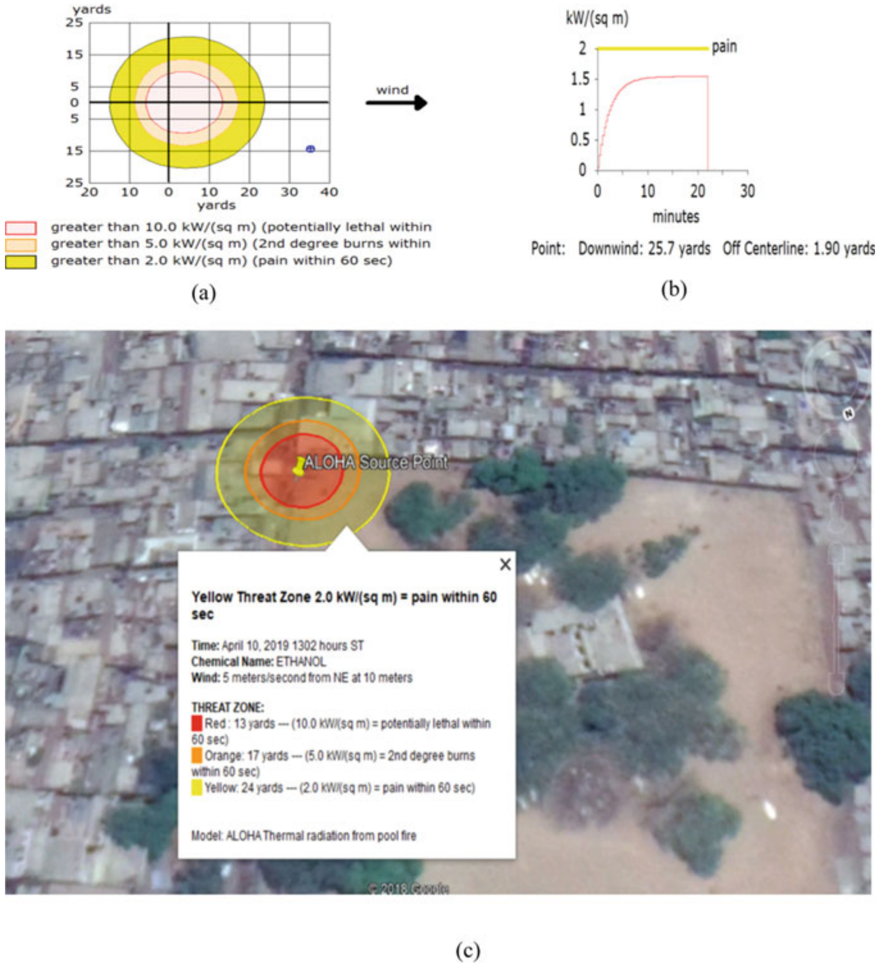
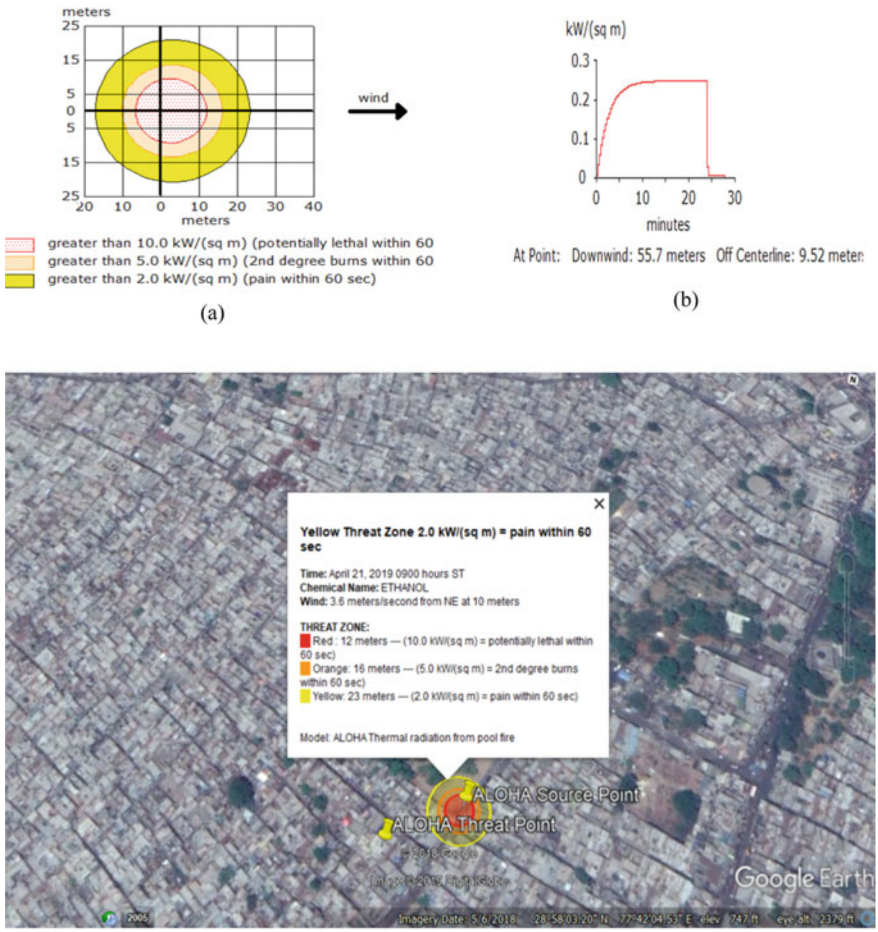



**Fig. 1** Flammable, toxic area and thermal radiation due to dispersion of ethanol, wind speed 5 m/s

or risk factor involves in the location where flux is 10 $kW/m^2$ and it covers areas which are close to the storage tank and distance up to 12 m. The pink area shown in graph Fig. 1a lies under moderate threat zone where heat flux density is greater than 5 $kW/m^2$ but less than 10 $kW/m^2$, covers distance up to 16 m and has a potential to cause second degree burns. The region marked in yellow shows the area where flux is greater than 2 $kW/m^2$ but less than 5 $kW/m^2$, covers distance up to 21 m and can cause pain within 60 s of exposure time. In this scenario, ERPG-1 constitutes of 1800 ppm concentration, ERPG-2 and IDLH value is 3300 ppm.




(c)

**Fig. 2** Flammable, toxic area and thermal radiation due to dispersion of ethanol, wind speed 3.6 m/s

## *4.2 Scenario 2*

Figure 2b shows the graphs which ALOHA simulation gives after putting all the atmospheric conditions and geographical data. Figure 2a shows thermal radiation threat zone are in which categories the area according to their severity, the parameter taken to define the threat zone is the heat energy flowing per unit area per unit time, i.e., heat flux density. From the scenario 1, it has been observed that threat zones are classified in three categories based on heat flux density. The maximum threat or risk factor involves in the location where flux is 10 $kW/m^2$ and it covers areas which are close to the storage tank and distance up to 10.93 yards. The pink area shown in graph Fig. 2a lies under moderate threat zone where heat flux density is greater than 5 $kW/m^2$ but less than 10 $kW/m^2$, covers distance up to 15 yards and has a potential to cause second degree burns. The region marked in yellow shows the area where flux is greater than 2 $kW/m^2$ but less than 5 $kW/m^2$, covers distance up to 24 yards and can cause pain within 60 s of exposure time. In this scenario ERPG-1 constitutes of 1800 ppm concentration, ERPG-2 and IDLH concentration is 3300 ppm.

## 5 Conclusion

From the simulation, it can be observed that the primary causes of accidents are atmospheric stability level, wind speed and season of the year. As aloha simulation performed for two scenarios, i.e., summer and winter season, the results show that due to different atmospheric condition and other factors such as wind speed, temperature, etc. plays an important role in the dispersion of any toxic release. The results of simulations have shown that there is significant in IDLH, ERPG-1, ERPG-2 zones as atmospheric conditions change. The results obtained in summer season the ILDH zone cover 12 m, whereas in winter season, it covers 23 m, which gives a clear picture that the dispersion distance is more in summer as compare to winter. The difference in dispersion region is due to high wind velocity which increases the dilution of gas in the atmosphere rapidly. This gives clear evidence that impact due to threat zone depends on atmospheric and geographical conditions of the area. Further, this study enables the industries which are handling ethanol to plan their risk assessment and management to cope up with any kind of discrepancies in the future. If industries perform ALOHA in the initial stage to predict the future mishappening, it would not only give a reference for safety officer of the rescue operation but also help to notify the areas which are near to that industry which enables them to take necessary precaution to ensure their safety.

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# Analysis of Industrial Accidents in a Public Sector Power Company—Causes and Preventive Measures

**N. N. Pisharody, Kanchan D. Bahukhandi, Prashant S. Rawat, and R. K. Elangovan**

## 1 Introduction

Accidents are unexpected events resulting in unwanted or undesirable outcomes. Unwanted outcomes can include harm or loss to personnel, property, production or nearly anything that has some inherent value. These losses increase organization's operating cost through higher production costs, decreased efficiency, and long-term effects of decreased employees' morale and unfavourable public opinion (U.S. Department of Energy 2012). All accidents need not cause loss. Depending up on the consequences, types of accidents are classified as near miss, first-aid injury, non-reportable injury, reportable injury and fatality.

Near misses are harmless disruptions from normal operation without any personal injury or property loss. First-aid injuries are accidents in which the victim is returned back to workplace after treatment at first-aid centre. Non-reportable injuries are accidents in which victims are send to hospital with or without treatment at first-aid centre for further medical examination and victim returns to workplace within 48 h of the event, and Reportable injuries are accidents in which the victim is send to hospital with or without treatment at first-aid centre for further medical examination and victims returns to workplace after 48 h of the event and fatality are accidents with loss of life to one or more persons as consequence of accident.

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Consequences of accidents vary from nil to loss of life. Near misses, first-aid injuries and non-reportable injuries are accidents with low consequences and high frequency, when compared with reportable injuries and fatalities which are with high consequences and low frequency. Therefore, accidents of low consequences give more opportunities for corrective measures to prevent accidents of high consequence. In order to develop a strong accident prevention system, reporting of accidents of low consequences and correction of causes should be imbibed in organizational safety culture. Studies also show that whenever line managers had shown increased focus in reporting and correcting of causes of accidents of low consequences, there were reductions in accidents of high consequences (Geoffrey 1991; Taylor and Lucas 1991; Lucas 1991; Masson 1991; Van der Schaaf 1991a, b; Jones et al. 1999; Phimister et al. 2003; Sonnemans and Korvers 2006; Sonnemans et al. 2010, NASA 2011). This implies that while organization shall take corrective measures to prevent reportable injuries and fatalities, it is equally important to promptly address causes of near misses, first-aid injuries and non-reportable injuries also (National Safety Council 1981; Lees 1996). Accidents are prevented by effective hazard control programme. This is achieved by means of engineering controls, administrative controls and personal protective equipment or human inference.

In this paper, analysis of 2179 accidents comprising of 1539 near misses, 366 first-aid injuries, 161 non-reportable injuries, 95 reportable injuries and 18 fatalities; occurred at 22 operating plants and 7 construction projects in a public sector power company in India during the period of 10 years from 2006 to 2015 with reference to IS-3786 "Method for the Computation of Frequency and Severity Rates for Industrial Injuries and Classification of Industrial Accidents" is described (IS-3786 2002).

The number of accidents is given Table 1, and proportion of each category of accident is given in Fig. 1. The paper brings out causes and recommendations to prevent accidents.

**Table 1** Number of events during the period from 2006 to 2015

| Year | Near miss | First-aid injury | Non-reportable injury | Reportable injury | Fatality | Total |
|---|---|---|---|---|---|---|
| 2006 | 39 | 0 | 0 | 7 | 3 | 49 |
| 2007 | 46 | 0 | 2 | 18 | 3 | 69 |
| 2008 | 69 | 15 | 6 | 12 | 1 | 103 |
| 2009 | 93 | 11 | 17 | 10 | 1 | 132 |
| 2010 | 103 | 27 | 27 | 11 | 2 | 170 |
| 2011 | 172 | 53 | 17 | 6 | 1 | 249 |
| 2012 | 188 | 48 | 25 | 14 | 1 | 276 |
| 2013 | 241 | 80 | 22 | 8 | 3 | 354 |
| 2014 | 282 | 54 | 18 | 4 | 2 | 360 |
| 2017 | 306 | 78 | 27 | 5 | 1 | 417 |
| Total | 1539 | 366 | 161 | 95 | 18 | 2179 |

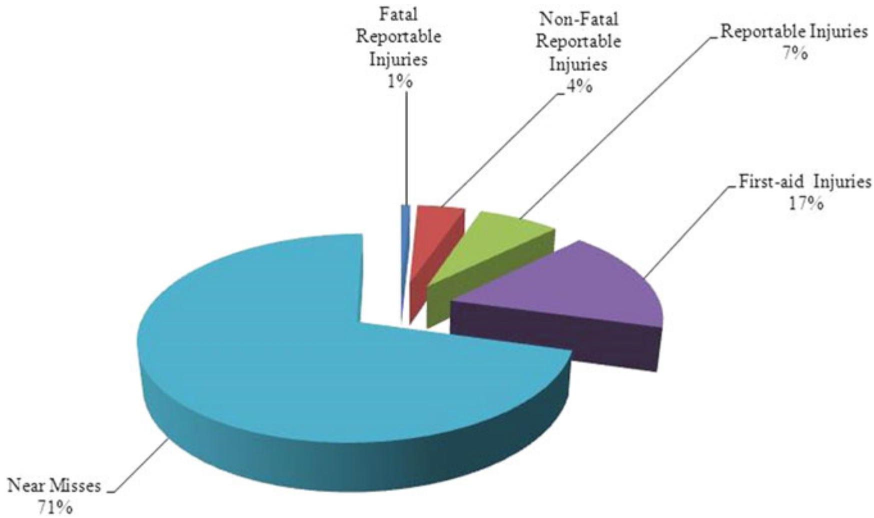


**Fig. 1** Industrial accidents during the period from 2006 to 2015

## 2 Taxonomy

The paper comprises 12 sections. Section 1 presents Introduction. Section 2 gives taxonomy. Section 3 deals with brief description of Indian Standard IS-3786 applicable to the analysis. Sections 4–10 are on Analysis of Industrial Accidents based on IS-3786 as per "Agency", "Unsafe Mechanical or Physical Condition", "Unsafe Act", "Unsafe Personal Factor", "Type of Accident", "Nature of Injury" and "Location of Injury", respectively. Section 11 gives Discussion and Recommendations of analysis and Sect. 12 gives Conclusion of the analysis.

## 3 Indian Standard IS-3786

Bureau of Indian Standards (BIS) has issued IS-3786 "Method for the Computation of Frequency and Severity Rates for Industrial Injuries and Classification of Industrial Accidents" in the year 1983, and it was reaffirmed in the year 2002. Appendix-B of the standard gives guidelines for classification of accidents based on seven principal factors related to causation of accidents as given below:

B-1 Agency
B-2 Unsafe Mechanical or Physical Condition
B-3 Unsafe Act
B-4 Unsafe Personal Factor
B-5 Type of Accident

B-6 Nature of Injury
B-7 Location of Injury

Brief description the above factors is given below:

## *3.1 Agency*

"Agency" is the object or substance, which is most closely associated with the accident causing injury and with respect to which adoption of a safety measure could have prevented the accident. Examples are machines, means of transportation, flying objects, scaffoldings, ladders, lifting machines, electrical conductors, electric hand tools, chemicals, gases, working environment, live animals, etc.

## *3.2 Unsafe Mechanical or Physical Condition*

These are "Unsafe Mechanical or Physical Condition" related to Agency, which contributed to the causation of accident. Examples are improperly guarded agency, defects in agency, hazardous arrangement, procedure, etc. in or on apparel, improper illumination, unsafe dress or apparel, improper ventilation, etc.

## *3.3 Unsafe Act*

"Unsafe Acts" are deviation from accepted and laid down safe procedure, which contributed to the causation of accidents. Examples are operating without authority, failure to secure or warn, operating at unsafe speed, marking safety devices inoperative, using unsafe equipment, hand instead of equipment, or equipment unsafely, unsafe loading, placing, mixing, combining, taking unsafe position or posture, etc.

## *3.4 Unsafe Personal Factor*

"Unsafe Personal Factors" are anatomical, physiological or psychological characteristics which caused the unsafe act. Examples are unsuitable anatomical, physiological or psychological characteristics, lack of knowledge or skill, unsuitable mechanical or physical conditions, social environment, etc.

### *3.5 Type of Accident*

"Type of Accident" is the manner in which the object or substance causing the injury comes into contact with the person or the movement of the injured person which resulted in the injury. Examples are fall of objects, fall of person, stepping or striking against or struck by object, caught or in between the objects, over exertion or wrong movements, exposure or contact with extreme temperature or electric current or harmful substances, explosions, etc.

### *3.6 Nature of Injury*

"Nature of Injury" indentifies the injury in terms of principal physical characteristics. Since there is no injury to persons in case near misses, potential for the nature of injury is considered. Examples are fractures, dislocations, sprains and strains, concussions and other internal injuries, amputations and enucleations, wounds, superficial injuries, contusions and crushings, burns, acute poisonings, effects of weather, exposure and related conditions, asphyxia, effects of electric currents, effects of radiations, multiple injuries of different nature, etc.

### *3.7 Location of Injury*

"Location of Injury" is the part of the injured person's body, directly affected by the injury. Since there is no injury to persons in case of near misses, potential location for the injury is considered. Examples are head, neck, trunk, upper limb; lower limb, etc.

## 4 Analysis of Industrial Accidents as Per "Agency"

Figure 2 gives proportion of **Agencies** caused Industrial Accidents during the period from 2006 to 2015.

**52%** of the Industrial Accidents were due to unsafe conditions and unsafe acts while working indoor and outdoor "**Working Environments**". Agencies in indoor working environment (43%) are floors, confined quarters, stairs, traffic and working surfaces, floor openings and wall openings, environmental factors such as lighting, ventilation, temperature, noise; water, fire or other unsafe conditions in structures, systems and components within the plant buildings. Agencies in outdoor working environment (9%) are weather, traffic and working surfaces, water, fire or other unsafe conditions in structures, systems and components outside the plant buildings.

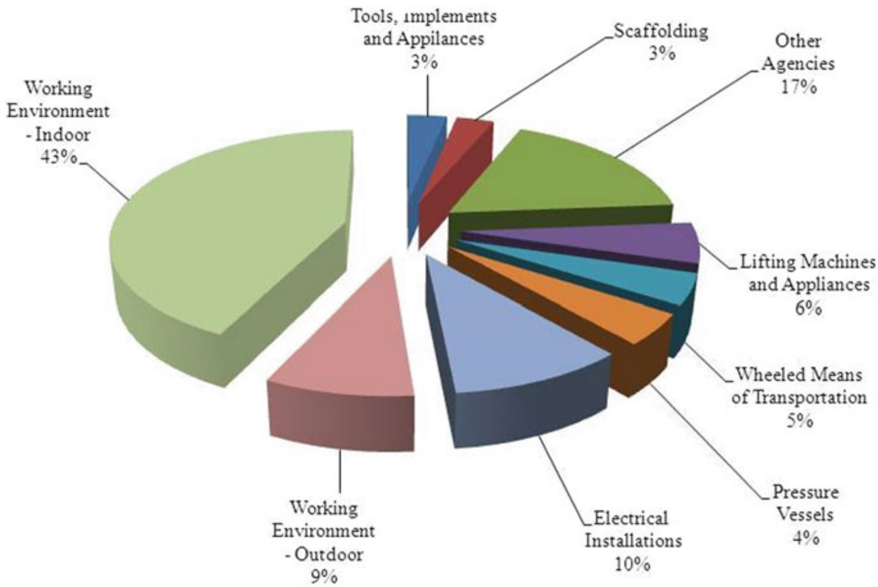


**Fig. 2** "Agencies" during the period from 2006 to 2015

**10%** of Industrial Accidents were due to unsafe conditions and unsafe acts while working on "**Electrical Installations**", such as motors, switchgears, circuit breakers, cables lighting circuits or lamps, causing electric shock or potential to cause electrical shock to persons involved.

**6%** of the Industrial Accidents were due to deficiencies in "**Lifting Machines and Appliances**" such as EOT cranes, mobile crane, tower cranes, forklifts, elevators, slings or other lifting tools and tackles, which have caused injuries or potential to cause injuries to persons while using these equipments.

**5%** of the Industrial Accidents were due to **Wheeled Means of Transportation** such as light vehicles, trucks or buses, due to unsafe conditions and unsafe acts while using these vehicles.

**4%** of the Industrial Accidents were due to deficiencies in "**Pressure Vessels**" due to unsafe conditions, unsafe acts and shortfalls in periodic inspection of pressure vessels, pressurized components and gas cylinders or lack of supervision.

**3%** of the Industrial Accidents were due to deficiencies in "**Scaffolding**" such as loosely placed working platforms, hand railings, absence of toe boards or mid railings, which had caused or had potential to cause injuries to persons due to fall of persons or fall of objects from height.

**3%** of the Industrial Accidents were due to deficiencies in the "**Tools, Implements and Appliances**" due to unsafe acts while using tools, improper use of tool or non-use of required tools.

**17%** of the Industrial Accidents were attributed to deficiencies in "**Other Agencies**" which comprised of miscellaneous equipment such as transmission machinery

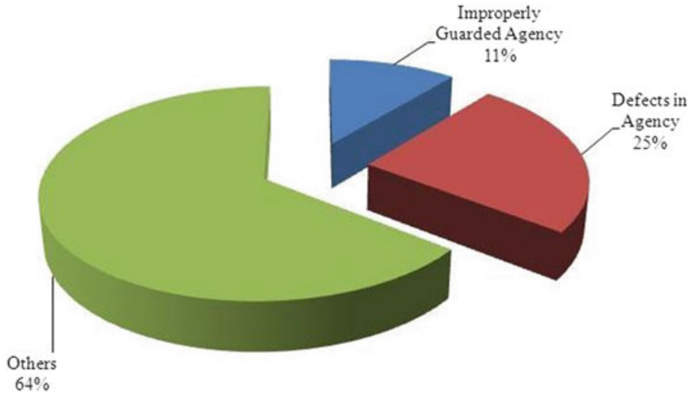


**Fig. 3** "Unsafe materials or physical conditions" during the period from 2006 to 2015

(0.6%), metal working machines (1.2%), electric hand tools (0.1%), ladders and mobile ramps (2.1%), other unclassified equipment (9.4%), flying objects (0.7%), other substances and materials (0.5%), dusts, gases, liquids and chemicals (2.4%).

## 5 Analysis of Industrial Accidents as Per "Unsafe Materials or Physical Conditions"

Figure 3 gives proportion of "**Unsafe Materials or Physical Conditions**" caused Industrial Accidents during the period from 2006 to 2015.

**64%** of the Industrial Accidents occurred due to reasons "**Others**" such as hazardous working arrangement, lack of caution signage, lack of safe working platform, lack of safety net, lack of training or awareness, unsafe condition due to poor housekeeping, inadequate design or lay out, improper installation, not securing the equipment, improper storage of materials, wrong procedure, selection of wrong equipment or tools, unsafe tools, wrong identification, tagging or labelling of equipment, unsafe personal protective equipment or unsafe working place.

**25%** of the Industrial Accidents occurred due to material condition "**Defects in Agencies**".

**11%** of the Industrial Accidents occurred due to "**Improper Guarding of Agencies**".

## 6 Analysis of Industrial Accidents as Per "Unsafe Act"

Figure 4 gives percentage of "**Unsafe Acts**" caused Industrial Accidents during the period from 2006 to 2015.

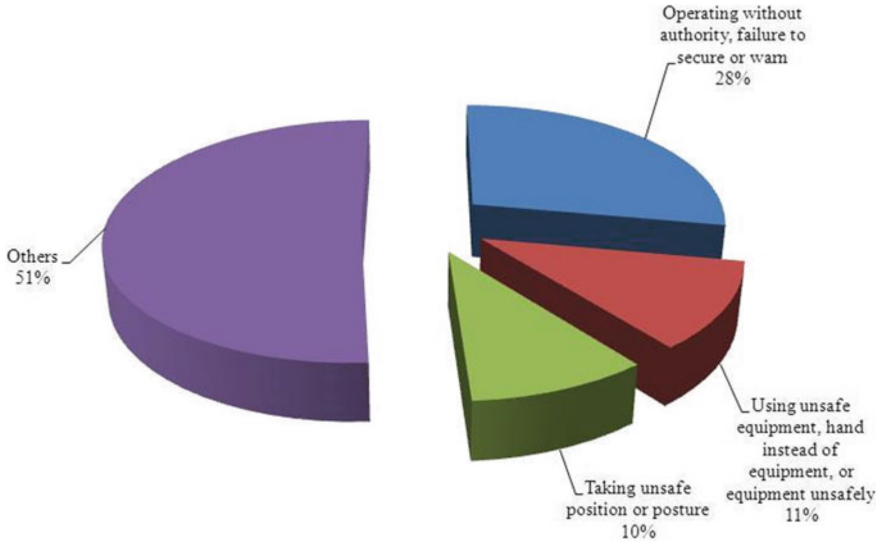


**Fig. 4** "Unsafe acts" during the period from 2006 to 2015

**51%** of the Industrial Accidents occurred due to reasons "**Others**" such as conditions not checked before the job, wrong procedure or performing jobs without procedure, improper use of tools or non-use of required tools, improperly completed job, inadequate design review, ineffective communication and coordination, lack of attention to the job, non-use of required personal protective equipment or improper use of personal protective equipment, overloading, storing the materials in unsafe manner, use of wrong equipment, weakness in inspection and correction, horseplay by the workers, wrong labelling/tagging, lack of awareness of employees or shortfalls in supervision and enforcement of safety measures.

**28%** of the Industrial Accidents occurred due to "**Operating without Authority, Failure to Secure or Warn**" such as performing job without work permit, guaranteed isolation or authorization, not securing equipment in work places; or lack of caution signage or warning by the coworkers or work supervisors.

**11%** of the Industrial Accidents occurred while "**Using Unsafe Equipment, Hand instead of Equipment or Equipment Unsafely**" due to equipment deficiencies or unsafe equipment.

**10%** of the Industrial Accidents occurred due to "**Taking Unsafe Position or Posture**" by the employees due to lack of safe access, lack of knowledge of workers, weakness in supervision or lack of attention of workers to unsafe conditions at work places.

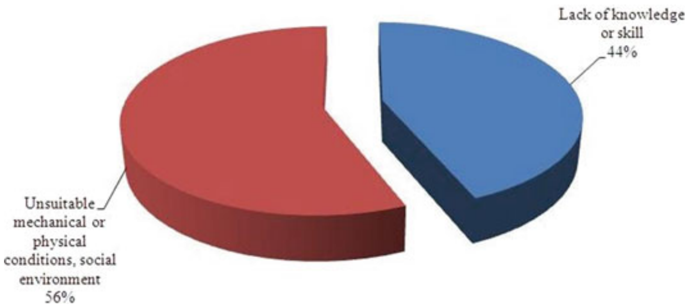


**Fig. 5** "Unsafe personal factor" during the period from 2006 to 2015

## 7 Analysis of Industrial Accidents as Per "Unsafe Personal Factor"

Figure 5 gives percentage of "**Unsafe Personal Factor**" caused Industrial Accidents during the period from 2006 to 2015.

**56%** of the Industrial Accidents occurred due to "**Unsuitable Mechanical or Physical Conditions, Social Environment**" attributable to deficiencies in design and layout, material condition deficiencies, improper storage of materials or shortfalls in inspection and maintenance of structures, systems and components.

**44%** of the Industrial Accidents were due to "**Lack of Knowledge and Skill**" leading to unsafe acts by the employees either intentional or unintentional.

## 8 Analysis of Industrial Accidents as Per "Type of Accidents"

Figure 6 gives percentage of "**Types of Accidents**" caused Industrial Accidents during the period from 2006 to 2015. In case of Near misses, since there were no injuries, potential for types of accidents is considered.

**27%** of the Industrial Accidents were attributed to "**Stepping on or Sticking against or Struck by Objects**" due to deficiencies in material condition, design, layout and ageing of structures, systems and components; tripping hazards, poor housekeeping, placing materials in unsecured manner, lack of caution signage or warning, ineffective communication, non-use of correct tools, non-use of personal protective equipment or lack of supervision.

**26%** of the Industrial Accidents were due to "**Falls of Objects**" from structures, systems and components due to deficiencies in material condition or ageing, unsafe procedures, poor housekeeping and placing materials at height in unsecured manner.

**14%** of the Industrial Accidents were due to potential for "**Fall of Persons on the Same Level**" due to deficiencies in material condition, design, layout or ageing of

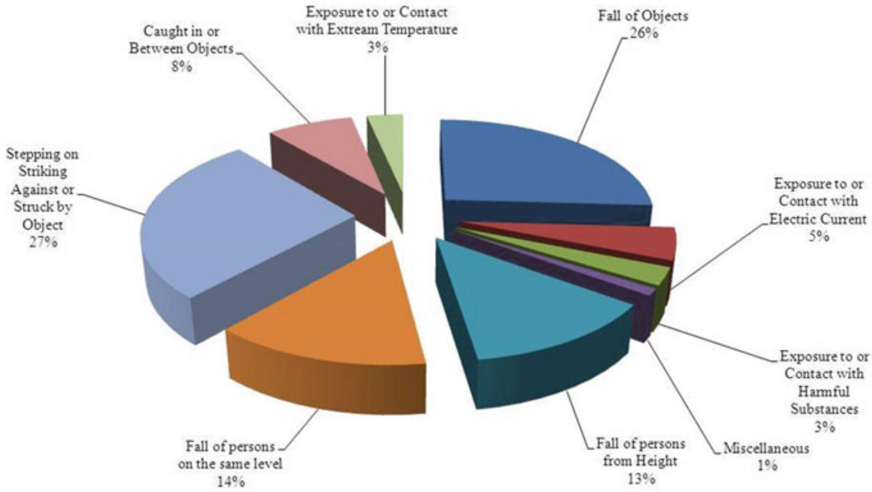


**Fig. 6** "Types of accidents" during the period from 2006 to 2015

structures, systems and components, slipping on the floor due to spillage of materials or biological growth, tripping hazards, use of unsafe personal protective equipment, taking unsafe posture by the workers, unsafe procedures, unsafe act by the workers, poor housekeeping, lack of caution signage or warning; or low illumination.

**13%** of the Industrial Accidents were due to "**Fall of Persons from Heights**" due to unsafe scaffolding, platforms and ladders; lack of safe access for working height, lack of hard barricading and caution signage at height, uncovered openings or openings covered with soft materials, unsafe design and layout, tripping hazards at height, deficiencies in staircases, deficiencies in material condition, aging, not securing ladders, low illumination, unsafe acts by the workers, non-use of personal protective equipment or fall protection measures, use of unsafe personal protective equipment, unsafe procedures, non-adherence to procedures and work permit system, slipping on the floor due to spillage of materials, poor housekeeping; or ineffective supervision and communication.

**8%** of the Industrial Accidents were due to "**Caught in or Between the Objects**" attributed to shortfalls, identification of hazards and implementing risk control measures, lack of hard barricading or guarding with caution signage, uncovered openings or pits, unsafe storage of materials during transportation, ineffective supervision and communication, unsafe design and layout, lack of procedures, unsafe procedures, non-adherence to procedures and work permit system, uncovered openings, unsafe acts by the workers, placing materials in unsecured manner, unsafe platform, non-use of personal protective equipment or use of unsafe personal protective equipment, lack of safe access for working or low illumination.

**5%** of the Industrial Accidents were due to "**Exposure to or Contact with Electrical Current**" attributed to ageing of cables, wrong identification and tagging of equipment, design, deficiencies in equipment, lack of guaranteed electrical isolation, lack of procedures, unsafe procedures, non-adherence to procedures and work permit system, ineffective supervision and communication, weakness in self checking and peer checking of equipment before the job, exposed live contacts of equipment and cable terminals, unsafe design and layout, non-use of personal protective equipment, lack of caution signage and markers for subsurface cables, use of cables with joints, lack of Earth Leakage Circuit Breakers in electrical circuits, lack of hard barricading with caution signage to restrict approach, low illumination or unsafe act by the employees.

**3%** of the Industrial Accidents were due to "**Exposure to or Contact with Extreme Temperature**" attributed to heating or sparks due to non-adherence to procedures and work permit system during hot works, unsafe procedures, sparks from damaged electrical cable by rodent attack or ageing, lack of arrangement for collecting welding and cutting spatters, ageing of equipment and components, storage of incompatible chemicals, use of cables with joints, un-insulated hot components of systems, lack of barricading and caution signage to restrict approach to hot components of the system and environment, water leakage on electrical systems, non-use of personal protective equipment, use of incorrect personal protective equipment, lack of supervision, shortfalls in design and layout, storage of flammable materials or oil leak at work places, overloading of electrical cables, lack of attention of workers to hazards in workplace or shortfalls in identification of hazards and implementing risk control measures.

**3%** of the Industrial Accidents were due to "**Exposure to or Contact with Harmful Substances**" due to deficiencies in material condition, design, layout and ageing of structures, systems and components; unsafe acts by the workers, ineffective supervision and communication, lack of procedures, unsafe procedures, non-adherence to procedures and work permit system, shortfalls in identification of hazards and implementing risk control measures, use of incorrect tools, non-use of personal protective equipment, use of incorrect personal protective equipment or lack of labels on chemical containers.

**Remaining 1%** of the Industrial Accidents classified as "**Miscellaneous**" were attributed to "Over Exertions or Wrong Movements" (0.4%), "Explosions" (0.2%) and "Others" (0.4%) which are not classified elsewhere.

## 9 Analysis of Industrial Accidents as Per "Nature of Injuries"

Figure 7 gives percentage of "**Nature of Injuries**" which caused Industrial Accidents during the period from 2006 to 2015. In case of near misses, since there were no injuries, potential for nature of injuries is considered.

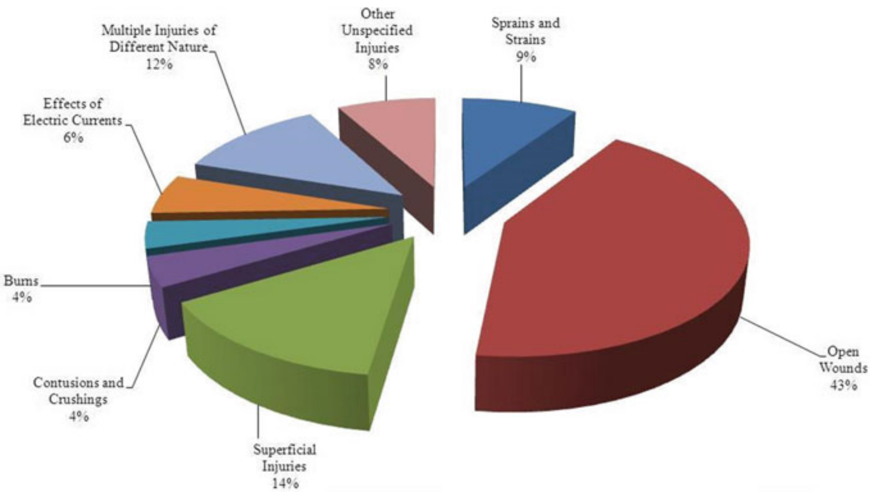


**Fig. 7** "Nature of injuries" during the period from 2006 to 2015

The injuries or potential injuries are caused due to occurrence of various types of accidents attributed to unsafe conditions, unsafe acts and unsafe personal factors associated with various Agencies.

## 10 Analysis of Industrial Accidents as Per "Location of Injuries"

Figure 8 gives percentage of different "**Location of Injuries**" caused Industrial Accidents during the period from 2006 to 2015. In case of near misses, since there were no injuries, potential for locations of injuries is considered.

The injuries or potential injuries are caused due to occurrence of various types of accidents attributed to unsafe conditions, unsafe acts and unsafe personal factors associated with various Agencies.

## 11 Discussion and Recommendations

The paper presents a generic analysis of 2179 industrial accidents comprising of 1539 near misses, 366 first-aid injuries, 161 non-reportable injuries, 95 reportable injuries and 18 fatalities occurred in a public sector power company during the 10 years period from 2006 to 2015 with reference to IS-3786 (IS-3786 2002). The analysis

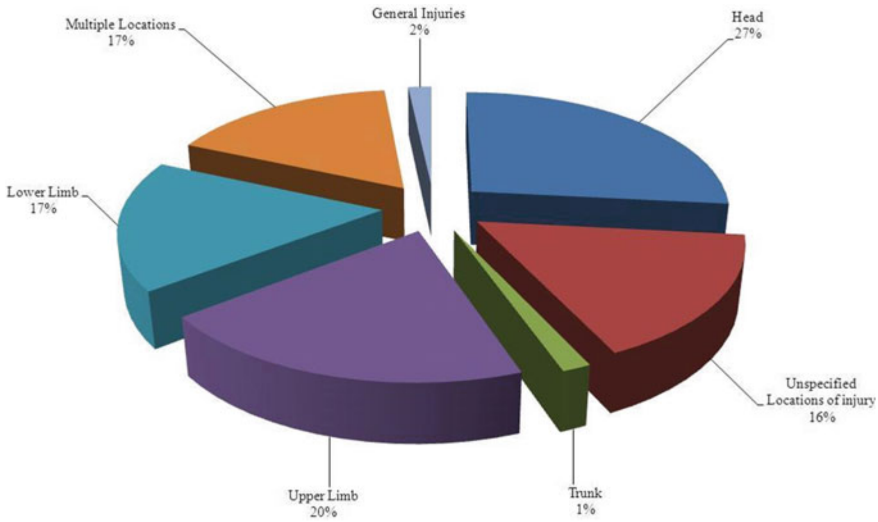


**Fig. 8** "Location of injuries" during the period from 2006 to 2015

indicates that accidents occurred due to shortfalls in engineering controls, administrative controls and use of personal protective equipment to prevent accidents. Effective control measures as described below to address these shortfalls could prevent recurrence of accidents of similar kind:

1. Inadequate review of design and layout either at the initial design or subsequent modifications have caused accidents due to insufficient guarding or hard barricading with caution signage to restrict approach of workers to hazardous system components and work environment. This should be addressed by:

**Engineering Controls:**

- Engineering design of machine guards.
- Installing fencing or railings around the pits
- Covering floor and wall openings with hard materials of requisite strength to prevent fall of persons from height.
- Providing protective covering over the system components carrying corrosive or high-temperature fluids.
- Insulating exposed power terminals of electrical equipment
- Designing equipment ergonomically.

2. Lack of safe access for working at height and unsafe scaffoldings and platforms have caused accidents due to unsafe acts and unsafe posture of workers while performing jobs at height. This should be addressed by:

**Engineering Controls:**

- Using scaffolding and platform materials manufactured as per national or international standards.
- Ensuring safe access to and egress from platform for performing job at height.

**Administrative Controls:**

- Imparting skill-based training on scaffolding erection to the employees involved in erection of scaffoldings and platforms.
- Strengthening inspection and certification process of scaffoldings and platforms before use by competent agencies.
- Providing "Green" tags on scaffoldings certified safe for use and "Red" tags on scaffoldings under erection or dismantling or unsafe for use.
- Deploying workers with valid height pass who are medically and physically fit and authorized for working at 2.5 m and above height.

3. Short falls in inspection, maintenance and testing of structures, systems and components have caused accidents due to unsafe conditions attributable tripping hazards, material condition deficiencies and ageing of structures, systems and components, poor housekeeping, improper installation, not securing equipment, improper storage of materials, non-compliance to required number of fire extinguishers at the fire points or low illumination. This should be corrected by:

**Engineering Controls:**

- Providing hard barricading and caution signage to restrict approach to hazardous work locations.
- Insulating hot components of the system to prevent burn injury to workers on contact or exposure.
- Securing materials firmly at work place.
- Safe storage of materials during transportation.

**Administrative Controls:**

- Strengthening periodic inspection, preventive maintenance and testing structures, systems and components, and rectification of deficiencies attributed to material condition and ageing.
- Maintaining good housekeeping of workplace before, during and after the job.
- Inspection of equipment before performing job.
- Ensuring positive isolation of process systems before taking up works.
- Periodic illumination survey and ensuring sufficient illumination at work places as per statutory requirements.
- Ensuring preventive maintenance testing of vehicles.
- Providing required number of fire extinguishers at the fire points and ensuring this during periodic inspection and maintenance.

4. Unsafe act by the workers have caused accidents due to lack of procedural adherence, lack of awareness, unsafe posture of workers while performing job, lack of attention of the workers to hazards in the area, inadequate hazard identification and risk assessment and implementation of control measures and work permit system; improper earthing of work pieces and lack of arrangement for collecting welding and cutting spatters during welding, improper insulation on electrical cable, use of unsafe personal protective equipment, unsafe tools, defective equipment for performing job, lack of supervision and ineffective communication or coordination. This should be addressed by:

**Engineering Controls:**

- Conducting Job Hazard Analysis for hazardous job to identify hazards and risk involved in the job and implementation of control measures before execution.
- Use of right equipment and tools for performing job and training of workers on correct use.
- Providing safety net and fall protection measures.
- Using mechanical means for material handling instead of manual means.
- Use of cylinder valve cap or guard while shifting of gas cylinders

**Administrative Controls:**

- Emphasizing compliance to safety measures, procedural adherence and work permit system, job specific hazards during safety induction training, pre-job briefing, tool box talks and enforcing safety measures during work execution.
- Compliance to work permit system and guaranteed isolation of equipment before starting the job.
- Performing job with approved procedures and valid work permits.
- Providing arrangement for collection of welding and cutting spatters during welding.
- Imparting training on defensive driving to drivers and instructing them to comply with specified speed limits while driving vehicles.
- Imparting training on loading and stability to mobile crane mobile crane operators.
- Providing intermittent rest to the workers involved in continuous job.
- Effective supervision, communication and coordination by line managers and work supervisors.

**Personal Protective Equipment:**

- Use of right type and safe personal protective equipment in correct manner such as anchoring lanyard of full body harness to a firm structure, wearing chin straps of helmets, use of eye protection during hot works and wearing ear protection measures in high noise area.

5. Use of cables with joints, lack of Earth Leakage Circuit Breakers (ELCBs) in electrical circuits, inadequate insulation of live contacts of equipment and cable

terminals, failure to de-energize discarded electrical circuit, overloading of electrical cables, damage to electrical cable by rodent attack and ageing of cables, wrong identification or tagging or labelling of equipment have caused electrical accidents. This should be addressed by:

**Engineering Controls:**

- Avoiding joints in cables.
- If joints cannot be avoided in cables, join the cables with insulated electrical connectors.
- Providing ELCBs in electrical circuits.
- Providing hard barricading with caution signage to restrict approach to exposed and charged electrical equipment.
- Ensuring visible double earthing of electrical equipment.
- Providing visible cable markers for underground cables at the surface level.
- Restricting entry of mobile cranes with extended boom to the area below overhead electrical transmission and distribution lines by providing goal post barriers.
- Designing cable trays with excess capacity to accommodate additional cables envisaging future field modification works.
- Restricting number of cables in cable trays, enhancing capacity of cable trays or rerouting of cables through less loaded cable trays. Cable trays should not be filled in excess of 40–50% of the inside area of the tray or of the maximum weight based on the cable tray specifications (NFPA-70 2017).
- Closing openings in electrical equipment against rodent entry and using cables with sheathing protected against rodent attach.

**Administrative Controls:**

- Ensuring guaranteed isolation of electrical equipment and compliance to work permit system.
- Training of employees on precautions to be taken while working in electrical systems.
- Deploying electrically authorized persons for works on electrical systems.
- Periodic inspection and testing of cables with respect to ageing and replacement of cables with damage and expired service life.
- Self-checking and peer checking during identification, tagging or labelling of equipment and before execution of job on electrical systems.
- Obtaining clearance from electrical department before carrying out any excavation works.

**Personal Protective Equipment:**

- Using arc-resistant suits, hand gloves and face fields while carrying out works on electrical switch gears.
- De-energizing discarded electrical cables and providing tags on such circuits.

6. Unsafe storage and transportation of materials, wrong labelling equipment and storage of incompatible materials have caused accidents or has potential to cause accidents. This should be addressed by

**Engineering Controls:**

- Segregating materials with incompatible chemical properties during handling and storage.
- Chaining or securing of gas cylinders during transportation and storage.

**Administrative Controls:**

- Controlling storage of flammable and hazardous materials in work places by permit system for transit storage of these materials.
- Self-checking and peer checking during identification, tagging or labelling of materials.

## 12 Conclusion

Causes for most of the accidents are repetitive and multi-disciplinary in nature. This could be due to shortfalls in identification of root causes and enforcement of foolproof corrective measures. Prevention and control of accidents is a big challenge. Continual efforts are required to control or reduce probability and severity of accidents.

All accidents should be investigated as it provides valuable information on the genesis of accidents and deep insight on accident prevention. In order to make an accident investigation unbiased, it should be carried out by an independent team, not related to the area and job in which accident occurred. Accident investigation involves finding answers to five Ws and one H, i.e. What? When? Where? Why? Who? and How? Of these, How' involves identification of root cause by using "Five Why Technique", in which "Why" is asked five times to determine root cause.

Accident prevention and control measures should be included in the design and subsequent operation to bring risk within the acceptable limits. Risk control shall involve judicial application of engineering controls, administrative controls and use of personal protective equipment in the respective order of hierarchy of effectiveness. This will help to achieve **zero accident** in an organization.

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# E-waste Management and Its Current Practices in India

**Susmitha Patibanda, Sharika Bichinepally, Bikarama Prasad Yadav, Kanchan Deoli Bahukandi, and Madhuben Sharma**

## 1 Introduction

The electronic industry is one of the largest and rapidly growing manufacturing industry in this world (Electronic Systems and Focus Sector 2020). In this industrialized world, quick growth results in discarded electronics, which is now considered as the largest and fastest growing wastes. Electrical and electronic equipment is classified as a broad range of goods which include small and large household appliances, cellular telephones, MP3 players, mobile phones, audio, and video equipment, etc. (Babu et al. 2008; Majumder et al. 2017). According to the Organization for Economic Cooperation and Development (OECD), when any appliance using electric power supply reaches end of its life, it is called as e-waste or Waste of Electronic and Electrical Equipment (WEEE). (Perkins et al. 2014).

Waste of Electronic and Electrical Equipment is a resource of used and valuable materials such as gold, copper, aluminium (Fornalczyk et al. 2013). When these materials are not recovered, these products are to be extracted and are processed to manufacture new materials which may result in loss of materials and damage to the environment. These are involved by transport, mining, manufacturing, and energy use (World Energy Resources 2016). The materials found in electrical and electronic waste are copper, aluminium, gold, iron, and other metals are around (60%), ferrous materials are (38%), non-ferrous materials are (28%), plastics is of (19%), glass is (4%), other including wood, rubber, ceramics, etc., is of (11%) and hazardous pollutants accounts for (2.7%) (Uddin 2012). Recovering these metals is a profitable business which results in transboundary trade and global trade. E-waste is an emerging problem nowadays in India, and also, volumes of e-waste generated and amounts of toxic and valuable materials are also high (The Global E-waste Monitor 2017; Bhutta et al. 2011).

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Waste is created out of generally expensive and basically strong durable items utilized in data processing, broadcast communications, and stimulation in private families and business (Wath and Chakrabarti 2012). Dealing with the expanding volumes of e-squander successfully and proficiently in expense and environmental effect is a tough task. Initially, exceptional calculated prerequisites are important for gathering e-waste. Furthermore, electronic waste contains numerous risky compounds that are very unsafe for human well-being as well as for nature. So their transfer requires uncommon treatment to prevent spillage and scattering of poisons into nature (Maheshwari et al. 2013). Use of these electronic devices is rapidly growing throughout this world. After some time, these will also satisfy the demand for cheap used equipment or second-hand electronic and electrical equipment.

## 2 Literature Review

### 2.1 E-waste Management—Scenario in India

After 1990, India started facing problems of e-waste after the initial stage in economic liberalization. Because of heavy competition in market price, brand, services, and quality between foreign and Indian companies, the electronic industry grew in India. After that due to a big boom in electronic industry and also due to cheaper rate, the purchasing capacity is also increased in India, mainly for household appliances like TVs, refrigerators, ACs, ovens, washing machines, computers, telecommunications (Consumer Durables Industry—Structure and Prospects Consumer Durables 2018). Then, the information technology (IT) came into India and has set the path in all the areas. Sales of PCs have increased tremendously. These evolutions with tremendous technological advancements caused an addition for a wide range of electronic waste from industries, public sectors, business, household availabilities to the waste flow (Mahajan et al. 2015).

Solid waste is a big problem in India. Now by invading the electronic waste, it has become more complicated. PCs wastes from other parts of world to India are a major problem (Begum 2013). The top states for the highest production of WEEE are Maharashtra, Andhra Pradesh, Tamilnadu, Uttar Pradesh, Madhya Pradesh, Karnataka, Gujarat, and Punjab. City-wise ranking is like Mumbai, Delhi, Bangalore, Bhopal, Chennai, Hyderabad (ASSOCHAM India 2018) (Fig. 1).

### 2.2 Present Scenario

India is one among of the top five countries in the electronic waste generation in the world. China, USA, Japan, Germany follow the next worldwide ranking. It is noted that 3 million tonnes of e-waste are produced in India until 2018, which is

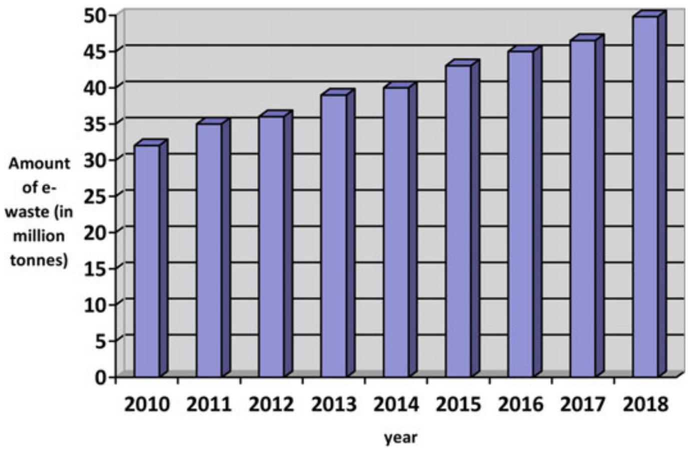


**Fig. 1** E-waste generation from 2010 to 2018

one of the largest and fast-growing electronics industries in the world. India's e-waste generation will reach to 5 million tonnes by 2020. Coming to Indian states, Maharashtra is the largest e-waste contributor of around (19.8%). But it recycles 47,810 tonnes with a capacity of 32 units. Tamilnadu has 14 units with (13%) e-waste, which recycles about 52,427 tonnes. Uttar Pradesh has 22 units with (10.1%) and recycles about 86,130 tonnes. Karnataka has 57 units with (8.9%) e-waste and recycles 44,620 tonnes. Gujarat has 12 units with (8.8%) of e-waste which recycles 37,262 tonnes. Delhi is of (9.5%) e-waste, and Madhya Pradesh is of (7.6%) e-waste. The volume of electronic waste is likely to touch 52.2 million tonnes or 6.8 kg per occupant by 2021 with an annual growth rate of 4–5%. Of all total e-waste produced in 2018, 20% is reported to be recycled and properly collected (ASSOCHAM India 2018). E-waste management involves reuse, repair of all electronic items, and finally reaches the end process to recover metals and also for disposal. This e-waste contains heavy metals and toxic substances like lead, mercury, etc. The recovering of these metals is important which reduces the environmental and human risks.

According to ASSOCHAM-NEC (2018) Consumer Durables Industry—Structure & Prospects Consumer Durables (2018)

- Recently, ASSOCHAM-NEC said that India recycles only 5% of its e-waste and reveals that India is one among the largest contributors of e-waste in the world.
- Electronic waste is referred to as electronic equipment that is being thrown away. It consists of headphones, chargers, LCDs, ACs, cathode-ray tube (CRT).
- India gives around 3 million tons per annum (TPA) of electronic waste in which 12% constitutes of telecommunication equipment alone.
- Recycling of e-waste is in very low quantities in India because of no correct legislative regulations and improper infrastructure.
- Pollutants released by e-waste cause harm to the environment and human health.

- More exposure to hazardous chemicals exposed by e-waste causes lung diseases, nervous system damage, respiratory problems, blood systems, liver, kidney damage, etc.,
- It is said that the computer equipment is of (70%) of e-waste, electrical equipment (7%), telecommunication equipment is (12%), and other household e-craps are around (4%).
- According to StEP, worldwide e-waste generated in the USA is (9.3) MT, in China (7.2) MT, in India is (2.75) MT, in Japan (2.74) MT, and in Russia is (1.4) MT.
- As of 2018, Mumbai tops the e-waste generation with (120,000) metric tons per year followed by Delhi-NCR (98,000), Bangalore (92,000), Chennai (67,000), Kolkata (55,000), Ahmadabad (36,000), Hyderabad (32,000), and Punjab (26,000).
- 5 lakhs child labours are engaged in e-waste activities between the age of 10 and 14 years, without any safeguards and correct protections for recycling.
- Noted that two-thirds of e-waste workers are suffering from irritation, coughing, and breathing problems.[1]

## 2.3 Global Scenario

**Europe (EU)**

Internationally, a different legal framework is developed and required to control electronic waste. In Basel convection of control of transboundary mobility of toxic waste and their removal is playing a crucial role for restraining e-waste stream from OECD countries to countries which are not involved in OCED. Europe is one among the other developed countries which took part to safeguard environment from all types of hazards from electronic waste. It has two firm directives to control e-waste, i.e. WEEE directive and restriction of the use of certain hazardous substances (RoHS). By seeing these, many countries incorporated the WEEE directive to reduce e-waste to protect the environment (see Footnote 1).

**United Kingdom (UK)**

WEEE directive done by EU directives transcribed the directive into their UK legislation in 2007. In this, it has the responsibility of financing treating compliance and reporting obligations on operators of private sectors. Having a register for all its members also should be done by the operators. The operator should check whether WEEE allotted has to be treated with best methodologies like recycling and recovery treatments (Wath et al. 2010a).

**United States of America (USA)**

Green National Electronics Action Plan (NEAP) was started by US Environmental Protection Agency to set environmental problems for e-waste management. The USA

[1] "Chapter 8 Status of E-waste Legislations."

has collected and recycled the e-waste from commercial and residential areas in an eco-friendly manner. California has started a law called **Advance Recycling Fee** (ARF) which helps to collect from the consumer when the new product is purchased. The ARF announced charges on electronic items like TVs, laptops from the US $6 to the US $10 (United States Environmental Protection Agency and Office of Inspector General 2004).

**China**

E-waste of China is under the Legislation for the Control of Pollution by electronic compounds. This design and manufacturing information have to meet the national industrial standards. It imposes penalties on importers, manufacturers, sellers (Kaur and Goel 2016).

**India**

Ministry of Environment and Forests (MOEF) is authorized to check electronic waste management and environmental protection. E-waste management has an objective of identifying the various source of electronic waste equipment and to provide steps for handling electronic waste in an eco-friendly way (Of 2008).

## 3 Strategies of E-waste

Reducing the volume is one of the best ways of managing electronic waste. Recovery of metals, plastics, glass, and other products decreases the magnitude of electronic waste (Long et al. 2016). The consumers, manufacturers, regulators, policymakers, and municipal authorities should take the matter seriously so that all problems associated with it can be addressed in an integrated manner. The strategies of waste management should include issues from the manufacturing of a product to final disposal. To complete this efficiently, proper training, legislation, and guidelines are needed (Fig. 2).

### *3.1 Educational Strategies*

Instead of following a traditional approach, integrated approach should be developed and executed by the world government. There are five different types of strategies for e-waste education (June and June 2017).

*Educational Strategy-1*

The methods of educating customer during purchasing the product form the first strategy. The companies which are involved in a mass purchase, this type of strategy is important. As they will be able to educate consumers on various options and the number of processes to reduce the impacts of e-waste (June and June 2017) (Fig. 3).

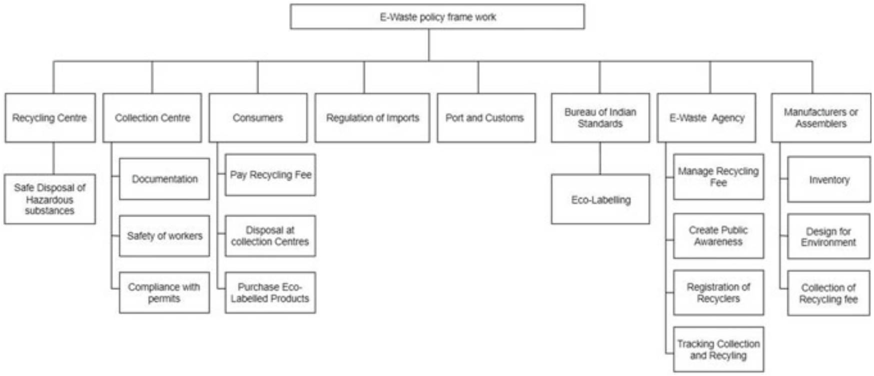


**Fig. 2** Flow sheet for electronic waste management in India

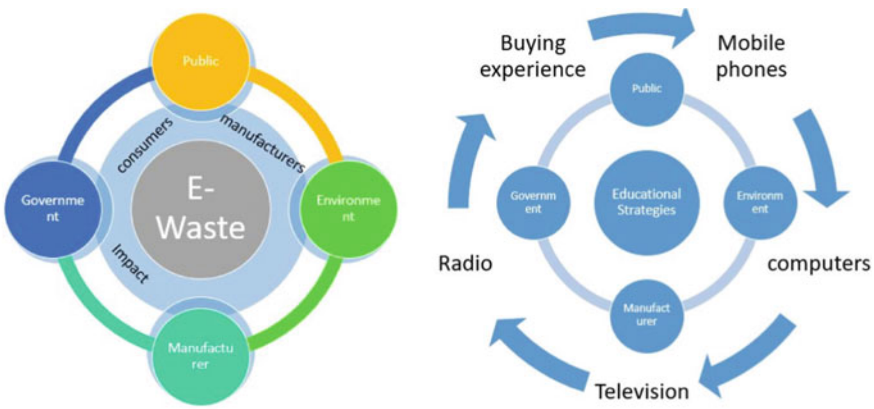


**Fig. 3** Educational strategy for reducing impacts of e-waste (June and June 2017)

*Educational Strategy-2*

This stage requires support from manufacturers that manufacture and sell the products. Responsibility is to enforce the process of education and valued solutions to all consumers and audience. Implementation of such additional processes results in additional costs to a product which can be offset by implementing a disposal or education retainer surcharge. So because of this, purchaser thinks twice before they dispose of the item (June and June 2017).

*Educational Strategy-3*

In this stage, we can use existing media like radio, TV, newspaper to create awareness on the effects of e-waste. Finance could be an issue for such advertising details, particularly on such a mass scale. However, the strategy will look to media companies to fulfil cooperate social responsibilities (June and June 2017).

*Educational Strategy-4*

This addresses about the use of Internet and social media network for creating awareness among the audience. Since the Internet is global, we can use it to convey the harmful effects of e-waste on the population worldwide (June and June 2017).

*Educational Strategy-5*

In the final strategy, we can involve high-level cooperation between the government of the world. A memorandum of agreement should be endorsed between countries and the government signatory to search the record will have responsibilities to educate and inspect process related to electronic waste (June and June 2017).

## 4 An Economy of E-waste Sector

### *4.1 Unorganized Sector*

92–95% of electronic waste is recovered in India by informal sector. Downtown slums of metros where incompetent persons use traditional methods for reducing recycling operations majorly contribute to the unorganized sector (Case Report 2015). A study by the Basel Action Network (BAN) in cooperation with the toxic substances revealed that electronic waste informal recycling techniques where similar to India and China. Unorganized sector mostly consists of informal business which is not controlled by any health and environmental regulations. Since workers will not be using personal protective equipment like gloves or masks, they face hazardous working conditions.[2] Toxic gases, smoke, and particulate matter are some of the most serious threats for employees and the environment. The labourers are endangered to workplace hazards which include physical injuries, skin diseases, and cancer. This sector mainly focuses on important components which are used for metal recovery, and the non-recoverable is disposed of in landfills (see Footnote 2). Since the workers are illiterate and have rural backgrounds of the country, children aged 4–6 years are employed.

### *4.2 Organized Sector*

Systematic recycling process of e-waste in our country is started in 2009. Only 10% of all the recycle process is organized (Ganguly 2016). The major drawback of this area is lacking in collection and dismantling procedures. Since there are no proper systems for collection, institutes and industries end up in storing large amounts of products in the store rooms and godowns. Mostly, these things are resold so only less percentage

[2] U. S. In and H. Issues, "CHAPTER—III UNORGANIZED SECTOR IN INDIA-AN OVERVIEW," pp. 56–76.

is sent for recycling. A major drawback of this sector is insufficient refineries for expensive metals recovery. Formal recyclers use environmentally friendly processes, and chemicals are not used. They include multinational companies which should compete with their new products and should not step into the black market. About 90% of electronic waste outcome is redeveloped, and rest is recycled (Ongondo et al. 2011).

## *4.3 Current Practices of Electronic Waste Management*

### 4.3.1 Extended Producer Responsibility (EPR)

This method expands the responsibility of the manufacturer to the post-consumer stage; i.e., they should take responsibility for disposal of that product. The companies which manufacture should financially or physically be responsible for those products after their useful life.

The main goal of this method is to coax the producers to control pollution. The lifelong goal is to develop eco-friendly products which require fewer resources and are easy to recycle and are economical.

EPR helps in

- Prevention of the overall waste
- The use of harmless materials
- Use of less hazardous process
- Development of new methods for recycling
- Manufacturing more reliable and durable products (Manomaivibool 2009)

These objectives help in product design, and most important step is to determine the quantity and nature of the resource and pollution emissions of products in the life cycles. The main aim is to set neat and better product design, not only a simple setup of the recycling system. Environmental regulations have been focusing on many years on controlling pollution with no regard to pollution depending on the life cycle (Wath et al. 2010b). This method is used widely in various countries, but it still has to be explored more. The only component for which we have environmental legislation is the batteries.

### 4.3.2 Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS)

The primary aim is to restrict toxic chemical substances in electric and electronic equipment so that they will not pose any harm to humans. According to RoHS, the electrical equipment should not contain the following harmful substances like

- Mercury

- Hexavalent chromium
- Lead
- Polybrominated diphenyl ethers
- Cadmium
- Polybrominated biphenyls[3]

The rules are applied to small and large appliances. The main goal of these restrictions is to protect consumers from hazardous substances; for example, brominated flame retardants cause cancer. The manufactures must make sure that their products are free from prohibited substances. The products that violate the restrictions are prohibited. Anyone who violates the regulation has to face a fine or may be sentenced up to 2 years. In fluorescent tubes, the use of mercury and in soldering materials usage of lead is permitted. European government can ask for exemptions but no possible technically and substitutes for dangerous substances cannot be replaced.

### 4.3.3 Effects of Informal Recycling

- E-waste is usually disposed and categorized into portions like printed wiring boards, cathode-ray tubes, cables, plastics, metals, condensers (Wath et al. 2010b).
- Unemployed people due to loss of ability, they are spoiling their health and surroundings also.
- Materials collected can be used directly after small processing, and few can be used as raw material to manufacture other electronic goods (Wath et al. 2010b).
- The stuff left behind is directly burnt open which results in fugitive emissions, and exposure to heavy metals causes respiratory problems due to shredding (Geiger and Cooper 2010).
- The employees of e-waste recycling are turning into small entrepreneurs whose enterprises are widespread and difficult to operate. But the wealth and benefits of their enterprises are unequally distributed.

### 4.3.4 E-waste Implications

In India, electronic waste is generated in large amount which does not have any systematic methods for handling the electronic waste in an economic and eco-friendly way. Electronic waste is deposited only as municipal waste. These are rich of plastics, toxic substances, ferrous products but has a major business opportunity to many people (Begum 2013). Different tools are used for the disposal process of removing hazardous materials and for recovery of reuse of the materials. Mainly, screening, magnetic separation, electric conductivity base separation techniques which depend on size, type, shape, and component are used for the recycling process.

[3] "PM 2/17: Study of a possible restriction of MCCP in electrical and electronic equipment regulated under RoHS."

## 5 Treatments of Electronic Waste

Treatment is needed to be done in three levels. Respective product for the first level is the reactant for the second level.

- First level
- Second level
- Third level (Begum 2013)

**First level**:

First level treatment is done in three stages. They are decontaminated, disposed, and sorted.

**Second level**:

Hammering, shredding, and special treatment processes like CRT, electromagnetic separation are done in this level

**Third level**:

In this stage, recycling and recovery processes are done. All the above level processes are based on material flow. First, it starts from the first level and goes to third-level treatment. All levels consist of unit operates where the product will be the reactant to the next level. After that, the residue is taken out in an incinerator. The efficiency of the first level and second level decides the number of residues.

## 6 Impacts of E-waste

E-waste causes very dangerous environmental issues due to toxic chemicals and manufacturing all different types of electronic goods. Hazardous chemicals like aluminium, zinc, lead, chromium, mercury, iron are present in different electronic items which primarily consist of liquid crystal display LCDs, electrolytes, capacitors, cathode-ray tube (CRT), mercury switches. Coming to the circuit board, cadmium and lead play a major role for toxic substances, mercury in switches, cathode ray tubes in switchboards, cadmium in computer batteries, and other materials in transformers, capacitors. PVC insulations also release toxic dioxides when but with copper from wires. All electronic equipment are hazardous because they have some content of lead, antinomy oxide (5–10% wt) flame retardants (1–2%) (Sivaramanan 2014).

### 6.1 Challenges and Problems

- The major problem in India is the installation of pipelines to bring waste from producer to recycler (Basha 2007).
- The major part of the material sent for recycling is reused, i.e. in an eco-friendly way.
- Another drawback is the recyclers face competition from informal waste handlers.
- Proper models should be developed in formal sector and informal sector.
- Further workable models should be developed which suits Indian conditions and are strongly supported by government policies.
- Since waste management is for social benefits government should provide facilities, medication, and incentives for the proper working of these models.
- Awareness programmes should be conducted to educate the masses and to make them accept new practices.
- Formal and informal sectors need to be assimilated to create practical recycling model.
- Unorganized sectors should be converted to organized sectors for better solutions for e-waste management in an environmental friendly way (Basha 2007).

## 7 Conclusions

Informal recycling sector is huge, and it adopts different processes to meet the demand and gain profit. It must be thoroughly inspected to identify the streams that are harmful for environment as it is the cheapest waste management practice. When it is combined with the steps that reduce the impact on environment, then the recycling of e-waste would be easy, and it generates significant profits. Recovery of plastics, glass, metals, and other materials should be done to reduce the impact on environment. New methods for recycling and recovery of electronic waste should be established. Criteria for the disposal of e-wastes are to be developed. In India, there should be a need for further research on how to adopt the correct methodologies for the reduction of electronic waste, in order to follow the best e-waste management systems. Restriction of the use of hazardous substances as first step and extended producer responsibility as the following step helps in reduction of e-waste generation significantly.

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# Comparison of Compressive Strength of Hardened Concrete Using Schmidt Rebound Hammer and Conventional Testing Method

**Susanta Kumar Sethy, Mopidevi Vijai Kishore, Vikas Garg, Raja, and Vivek Kumar**

## 1 Introduction

It would be difficult for us to imagine ourselves without concrete. Concrete is a visco-elastic moldable liquid consisting cement, sand, coarse aggregate, water with admixtures. It is fundamental building component for present day society. Each significant development venture utilizes concrete in some frame. Its wide use is governed due to its strength, durability, rigidity, low maintenance, resistance against water and fire, workability, economy, etc. With the use of concrete in infrastructural activities comes the parameter of safety that must be kept in mind and hence determining compressive strength is paramount which is done in order to judge concrete quality. Often, structures of concrete should be checked for its strength once the concrete has hardened for determining if the structure is serviceable. Various DT and NDT methods for determining strength of concrete have been suggested. The analysis of the concrete strength in existing structures by destructive method is costly, troublesome in some case and might not be possible in some cases. Hence, it is not always appropriate since they affect the physical characteristics of concrete whereas Non- destructive tests are reliable and time saving without undergoing any damage to the structure. The two tests that have been performed during the following work are compression test by compression testing machine and Schmidt rebound hammer test. DT investigates the mechanism of failure of material to determine its mechanical properties viz. yield and compressive strength. Non-Destructive techniques investigate properties without getting into the core of structure. The principle involved for Rebound Hammer Test is: The elastic rebound depends on surface hardness on which it strikes. When the

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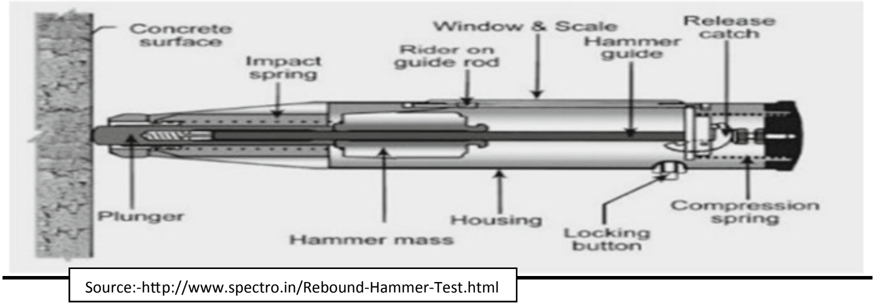


**Fig. 1** Schmidt rebound hammer. *Source* https://1.bp.blogspot.com/-6wa2pOhP47o/Xpx0Tc_LtUI/AAAAAAAAAXo/NAY8qT6hepQvN0V_vMraQdbZLxQwKBe5ACLcBGAsYHQ/s1600/rebound%2Bhammer.jpg

plunger of Rebound Hammer is punched against the surface of hardened concrete, spring controlled mass rebounds and degree of such rebound depends upon hardness of the surface, thus rebound is related to the concrete's strength. Value of rebound is obtained from the graduated scale and is assigned as rebound number or index. The strength of the concrete can then be read straight from graph that is present on the hammer body (Fig. 1).

## 2 Literature Review

A series of connected works of national and global journals have been contemplated. Out of these, portions of the significant works are mentioned below:

1. R. Balamuralikrishnan (2017) have attempted to show that the percentage variation in the average compressive strength from NDT 25–32 N/mm$^2$ having w/c ratio ranging from 0.35 to 0.50 and destructive testing 30–36.24 N/mm$^2$ of same water-cement ratio varies from 11.50 to 16.70% with respect to destructive testing. The variation of the values of not more than 16.5% is the evidence that NDT by rebound hammer shows reliability in monitoring the health of structural elements. The study also suggested that the increasing rebound number represents the higher compressive strength and the results are affected by factors such as smoothness of surface, moisture condition of the concrete and the type of cement used.
2. Malek and Kaouther (2014) presented the calculations of compressive strength and modulus of elasticity determined from nondestructive and destructive tests. The investigation supported the use of NDT due to its ease of operation and economic advantages. The different results of the testing were conducted using compression testing machine and rebound hammer test. The compressive strength determined by destructive test (compression test) and Non-destructive

test (rebound hammer test) at different ages of the concrete (7 and 14 days) showed that the resistances obtained by the compression test were higher than those obtained by the rebound hammer test and decreases considerably at the age of 28 days. The authors suggested that the rebound hammer test can be used to evaluate the compressive strength of old concrete and not young concrete.

3. Ali-Benyahia et al. (2017) have attempted to optimize the methodology of the calibration of NDT model on site. Combination of NDT techniques has been promoted in many studies but its efficiency remains controversial. The conclusions were centered around the enhancement of the significance and the viability of the NDT techniques in such operational circumstances.
4. Kumavat et al. (2014) performed a case study on condition assessment of concrete with NDT. A reduction of 5% in the minimum average compressive strength was found. It was presumed that the present strategies for ultrasonic testing of concrete require direct contact between the surface of concrete and the transducers. Since the contact is not always perfect, the air trapped in between may cause variable errors in the measurements.
5. Saleem et al. (2012) focused on non-destructive evaluation of a five-storied concrete frame structure to assess the existing condition. For this purpose, load tests and core tests were performed on four floors from basement to first floor. Test results showed that the structure has adequate strength for future use although it was unprotected against severe environmental conditions for several years. Study further confirms that a combination of tests, instead of performing just one type of test, provides more suitable results to confidently accept or reject the structure as a whole or its component for future use.
6. Shankar and Joshi (2014) compared the actual strength of a concrete by destructive test (DT) method and that by NDT method using Schmidt Hammer (SH) (or rebound hammer) and ultrasonic pulse velocity (UPV) as NDTs and test by compression testing machine (CTM) as DT. In this study, separate comparisons have been done for two NDTs and a procedure to follow while estimating strength of concrete by NDT has been recommended.

## 3 Methodology

66 Samples (Fig. 2) of concrete cubes were casted with the mix design of M25 and M30. The experimental procedure included the following steps to study the variation of compressive strength by NDT and DT. These steps include:(As per IS 516: 1979)

- 66 Cubes have been casted.
- All the specimens were cured before testing.
- Nomenclature is done for each specimen using a unique number with 10 points marked on each cube to facilitate Rebound hammer test and make identical testing for all cubes (Fig. 3).
- Specimens were then put at the center of compression testing machine and loaded to about 25.0% of their ultimate compressive strength.

**Fig. 2** 66 cubes laid in order on ground

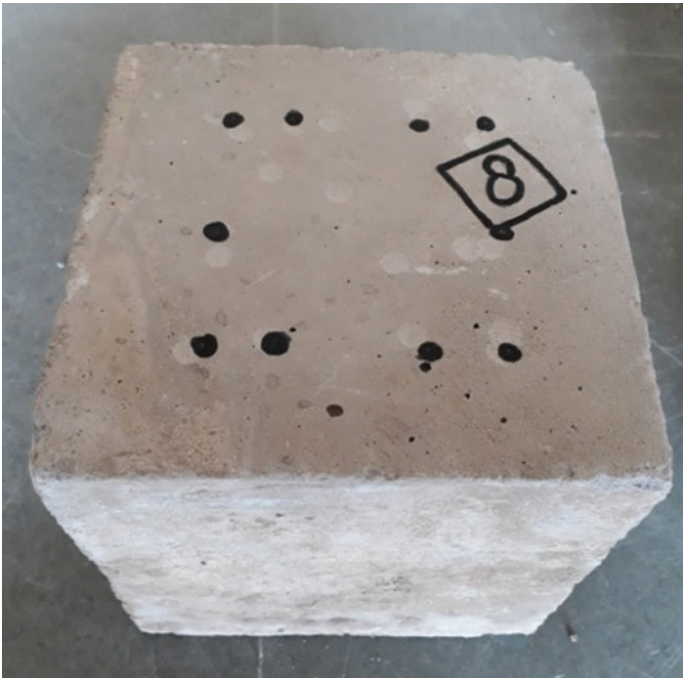


**Fig. 3** Detailing of 10 points on each cube with a unique number

**Fig. 4** The cube specimen placed in the testing machine

- Before commencing the rebound hammer test, the apparatus should be tested against the test anvil to get reliable results.
- Ten readings were then taken to estimate the average rebound number using ten points marked on each cube.
- After reading the rebound number, the applied load was increased at a rate of approximately 140 kg/sq cc/min until failure and then cube.
- The compressive strength of each specimen was calculated (Fig. 4).
- The values obtained from both the tests were compared and the variation is then obtained in the values of NDT with respect to DT values.

## 4 Result

66 cubes were experimented by Rebound Hammer and Compression Testing machine and the variation in compressive test results has been shown in Table 1 followed by graphical comparison (Fig. 5).

**Table 1** Variation between NDT and DT test results

| S No. | Grade | Rebound number | Strength by rebound hammer, N/mm$^2$ | Avg. compressive strength, NDT, N/mm$^2$ | DT compressive strength, N/mm$^2$ | Avg. compressive strength, DT, N/mm$^2$ | % Variation between NDT and DT |
|---|---|---|---|---|---|---|---|
| 1 | M30 | 51.7 | 25.5 | 25 | 27.26 | 28.43666667 | 12 |
| 2 | M30 | 57.7 | 21.5 | | 28.25 | | |
| 3 | M30 | 45.4 | 28 | | 29.8 | | |
| 4 | M30 | 41.8 | 21 | 22 | 22.63 | 24.81333333 | 11 |
| 5 | M30 | 57.7 | 25 | | 28.25 | | |
| 6 | M30 | 52.9 | 20 | | 23.56 | | |
| 7 | M30 | 47.3 | 27.5 | 25.33333333 | 30.93 | 29.74666667 | 15 |
| 8 | M30 | 46.3 | 25.5 | | 28.51 | | |
| 9 | M30 | 48.1 | 23 | | 29.8 | | |
| 10 | M30 | 51.8 | 40 | 38 | 40.43 | 42.46666667 | 11 |
| 11 | M30 | 51.4 | 38.5 | | 44.93 | | |
| 12 | M30 | 48.3 | 35.5 | | 42.04 | | |
| 13 | M30 | 44.8 | 35.5 | 38.5 | 42.86 | 42.04666667 | 8 |
| 14 | M30 | 57.4 | 38 | | 40.88 | | |
| 15 | M30 | 49.8 | 42 | | 42.4 | | |
| 16 | M30 | 44.8 | 25 | 27.66666667 | 32.01 | 32.07333333 | 14 |
| 17 | M30 | 52.1 | 30 | | 31.48 | | |
| 18 | M30 | 42.7 | 28 | | 32.73 | | |
| 19 | M30 | 48 | 32 | 32.16666667 | 34.14 | 36.35666667 | 12 |
| 20 | M30 | 50.5 | 33.5 | | 37.3 | | |
| 21 | M30 | 44.2 | 31 | | 37.63 | | |
| 22 | M30 | 61.6 | 49 | 53.83333333 | 60.17 | 60.78 | 11 |
| 23 | M30 | 50.5 | 56.5 | | 63.42 | | |
| 24 | M30 | 54.8 | 56 | | 58.75 | | |
| 25 | M30 | 59.8 | 45 | 42.66666667 | 50.35 | 48.71 | 12 |
| 26 | M30 | 49.3 | 44 | | 45.12 | | |
| 27 | M30 | 46.1 | 39 | | 50.66 | | |
| 28 | M30 | 55.2 | 36 | 39 | 45.15 | 46.06333333 | 15 |
| 29 | M30 | 53.9 | 42 | | 49.42 | | |
| 30 | M30 | 46.2 | 39 | | 43.62 | | |
| 31 | M30 | 60.8 | 62 | 61.66666667 | 66.8 | 69.27 | 11 |
| 32 | M30 | 55.6 | 58 | | 70.17 | | |
| 33 | M30 | 46 | 65 | | 70.84 | | |

(continued)

**Table 1** (continued)

| S No. | Grade | Rebound number | Strength by rebound hammer, N/mm$^2$ | Avg. compressive strength, NDT, N/mm$^2$ | DT compressive strength, N/mm$^2$ | Avg. compressive strength, DT, N/mm$^2$ | % Variation between NDT and DT |
|---|---|---|---|---|---|---|---|
| 34 | M25 | 45 | 21.5 | 23.33333333 | 25.24 | 27.64333333 | 16 |
| 35 | M25 | 49.6 | 25.5 | | 29.73 | | |
| 36 | M25 | 45.3 | 23 | | 27.96 | | |
| 37 | M25 | 48.2 | 20 | 20.5 | 22.72 | 23.94333333 | 14 |
| 38 | M25 | 50.6 | 17.5 | | 22.74 | | |
| 39 | M25 | 59.6 | 24 | | 26.37 | | |
| 40 | M25 | 46.2 | 24.5 | 21.33333333 | 24.04 | 24.37 | 12 |
| 41 | M25 | 43.1 | 20 | | 23.29 | | |
| 42 | M25 | 36.1 | 19.5 | | 25.78 | | |
| 43 | M25 | 43.1 | 30 | 30.5 | 37.62 | 35.56 | 14 |
| 44 | M25 | 46.8 | 28.5 | | 35.56 | | |
| 45 | M25 | 45.5 | 33 | | 33.5 | | |
| 46 | M25 | 54.2 | 39.5 | 38.66666667 | 43.14 | 42.32 | 9 |
| 47 | M25 | 52.7 | 41 | | 44.29 | | |
| 48 | M25 | 46.8 | 35.5 | | 39.53 | | |
| 49 | M25 | 44.3 | 30 | 32.16666667 | 37.15 | 36.05666667 | 11 |
| 50 | M25 | 56.7 | 31.5 | | 33.44 | | |
| 51 | M25 | 48.5 | 35 | | 37.58 | | |
| 52 | M25 | 47.7 | 42.5 | 38.83333333 | 41.86 | 41.09333333 | 5 |
| 53 | M25 | 43.9 | 39.5 | | 39.38 | | |
| 54 | M25 | 53.3 | 34.5 | | 42.04 | | |
| 55 | M25 | 45.6 | 28 | 31.83333333 | 38 | 38.53333333 | 17 |
| 56 | M25 | 50.2 | 31.5 | | 36.74 | | |
| 57 | M25 | 48.8 | 36 | | 40.86 | | |
| 58 | M25 | 51.4 | 43 | 48.66666667 | 53.07 | 50.29333333 | 3 |
| 59 | M25 | 51 | 48 | | 48.17 | | |
| 60 | M25 | 53.5 | 55 | | 49.64 | | |
| 61 | M25 | 50 | 47.5 | 49.33333333 | 65.33 | 59.47333333 | 17% |
| 62 | M25 | 54.1 | 55.5 | | 56.29 | | |
| 63 | M25 | 59.4 | 45 | | 56.8 | | |
| 64 | M25 | 52.8 | 56 | 48.33333333 | 53.06 | 51.55666667 | 6 |
| 65 | M25 | 48.8 | 46 | | 50.46 | | |
| 66 | M25 | 52.2 | 43 | | 51.15 | | |

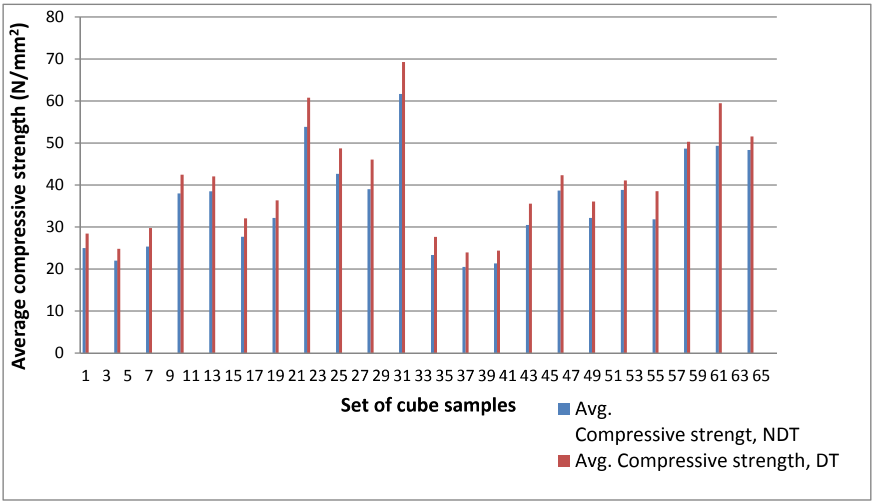


**Fig. 5** Variation in compressive strength obtained from NDT and DT

## 5 Conclusion

This experimental study suggests that the variation in the compressive strength obtained by Non- destructive test with respect to the Destructive test vary with a value ranging from 0 to 15% for most of the cubes samples.

Destructive and Non-destructive tests were performed on 33 cube samples of M25 grade and the average variation in values of strength using NDT with respect to DT is observed as 11.09% whereas in case of M 30 grade concrete, the average variation for 33 cube samples is 11.90%.

The result obtained suggests that the use of Non- destructive methods is reliable and can be used to estimate the compressive strength of hardened concrete. It can therefore reduce the number of cores taken from the structures to estimate the strength.

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# Shaping of Safety Conduct of Construction Workers Through Psychological Contract of Safety

**Kartikay Jha, Aarushi, Bikarama Prasad Yadav, Surendar Varadharajan, and S. M. Tauseef**

## 1 Introduction

Construction industry plays a dynamic role in contributing to economic growth (Jefferies). Projects undertaken by this industry are dynamic and full of risk. It (Sunindijo) **contributes to 30–40% of fatalities (about 38 fatalities everyday)** by employing **3–5% of workforce** (Pti. 48 2017). Regardless of technological advancement and applications of strong safety control system level of fatalities, injuries (Jones) and other issues related to safety and health are resistant to change because of this awareness of company safety management increased the interest in safety climate (Fig. 1).

Safety climate shapes the construction worker conduct through their expectation toward company value and rewarding system. The correlation between safety climate and safety conduct in researches and their results are known as safety result. The existing researches proposed that characteristic of company nature can lead construction workers to respond differently in terms of safety. The person responsible for translating the principal employer obligation of safety to construction worker/workgroup is the first line supervisor. This has put some light on factor influencing social exchange between construction worker and first line supervisor, and it arises as argument that if one person acts to provide benefit to another person an indirect duty is generated for future interdependence. Thus, psychological contact arises as the prominence which is used to capture the momentum between construction worker and first line supervisor and their nature in terms of safety.

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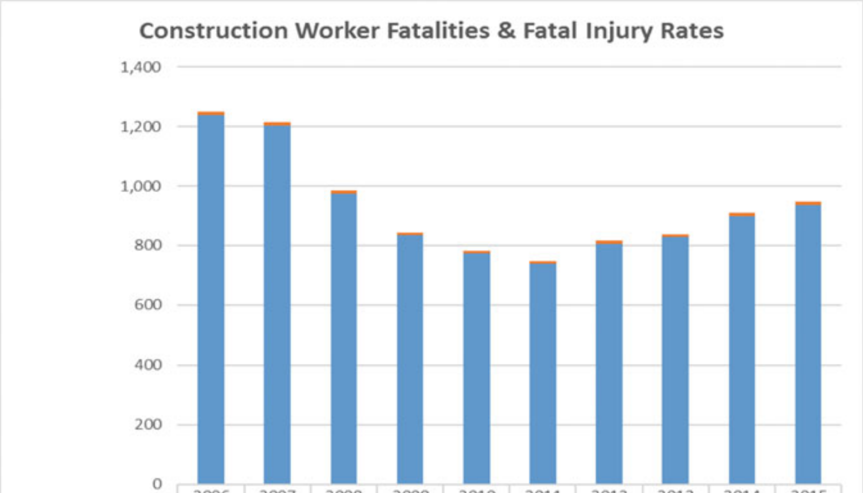


| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|
| Fatal Injury Rate | 11.2 | 10.8 | 9.7 | 9.9 | 9.8 | 9.1 | 9.9 | 9.7 | 9.8 | 10.1 |
| Total Fatal Injuries | 1,239 | 1,204 | 975 | 834 | 774 | 738 | 806 | 828 | 899 | 937 |

**Fig. 1** Accident trend in construction industry

## *1.1 Psychological Contact of Safety (PCS)*

PCS gives framework with respect to the view of people about corresponding safety duties and which it can be only achieved through promises (internal and external). Thinking about the impact of principal employer on construction sites, PCS could give the subjective hypothesis in the evolution of construction worker safety conduct emerging from first line supervisor safety conduct. This is a critical highlight of safety climate in evolution where first line supervisor plays the most crucial job to shape construction worker safety awareness. Consequently, a framework of the psychological contact, which explores the correlation between safety climate and safety conduct, is intermediated by the psychological contact of safety.

## *1.2 Safety Climate*

As per (Dedobbeleer 1991; Zhang 2015), the study gives exact proof to establish constructive connection between safety climate and safety accomplishments of construction company. The connection between safety climate and safety conduct has likewise been well established in safety study, and its results are recognized as increased safety result, which are important measure for improved safety on sites. There is a development to create construction-detailed safety climate determinant composition that empowers an understanding of practical and uncooperative results of safety vision. On going ahead, this distinguished factors surely impact the safety perception of construction worker existence, the principal employer (Heinrich)obligation, first line supervisor conduct, co-construction worker conduct, single construction worker participation, and safety guidelines.

As per researches done currently, safety climate included principal employer, sub-temporary construction worker, first line supervisor, workmate, and individual construction worker conduct. The acceleration of safety climate assessment depends on the job of safety personnel who assumes critical jobs in dealing with the suspicion of construction worker in regards to safety at construction sites. Thus, among the previously mentioned factors, thinking about the hypothetical foundation and point of the research, three factors (principal employer obligation of safety, first line supervisor safety conduct, and construction worker's safety conduct) are incorporated into study as parts of safety climate.

### *1.3 Principal Employer Safety Obligation*

It plays an important role in maintaining safety performances, but this happens only in large companies as small companies lack monetary resources and management obligation. It is basically a level to which a contractor and safety professional place safety as top priority, communicate, and act on safety issues successfully. It is a main measure of safety climate as it increases safety conduct and decreases injury rate over a defined scope (extent). When managers have safety as his/her priority, then first line supervisor and construction worker have to meet their expectations by adopting safety in their everyday life.

## 2 First Line Supervisor Safety Conduct

As construction industry is changing (non-routine activity), it is necessary for first line supervisor to interpret formal safety policies and procedures without offending anyone. Role of first line supervisor is to shape subordinates safety conduct which is of very importance in accordance with the routine production process as they are in frequent contact with the construction workers at different level and responsible for quality safety performances on site.

First line supervisor retaliates to safety as a key determinative in creating a construction worker's belief about the importance of safety. First line supervisor translates principal employer obligation into safety ethics and work practices among construction workers. This relationship between construction worker and first line supervisor is recognized more significant than other work activity setting.

# 3 Workmate Safety Conduct

Role of workmate is to significantly shape group-level safety climate. First line supervisor and workmate have close influence on safety climate as if these two are unsupportive to safety and safety issues, then there will be too many unsafe practices by construction worker. Group safety climate will show high safety performances in comparison with company-level safety climate. In large companies where construction worker have rare contact with the principal employer, they have immediate contact with their workmates or groups, and they are influenced with their immediate surrounding that includes workmates (first line supervisor, safety steward). Construction worker conduct is responsible for the fatalities up to a great extent as they are the one who conduct unsafe practices knowingly or unknowingly, and there are some images that will show construction worker's critical unsafe practice that may lead to fatality or severe bodily injury (shutterstock) (unsafe-worker-behavior) (Figs. 2 and 3).

## *3.1 Safety Conduct*

Conduct is something which is observable and measurable or in simple terms conduct that is what someone does or says. From accident investigation prospective, construction worker's unsafe practices are primary cause of accident/fatalities and are identified as 88% accident involves unsafe practices. Similarly, construction worker conduct with respect to safety can be predicted in similar way, and additional work conduct includes performances.

Earlier, safety performances are measured through lagging indicators (accident rate, TRIFR), and these measures are criticized as it includes reactive approach, but safety conduct predicts accident and injury rates.


**Fig. 2** Unsafe work behavior of worker

**Fig. 3** Unsafe work behavior of workers

### *3.2 Psychological Contact of Safety*

The role that first line supervisor performs is distinctive considering the role of first line supervisor and their correlation with construction worker, and it is argued that psychological contact serves as moderator between safety climate and safety conduct. The theory of psychological contact of safety (PCS) (Newaz 2019) implies promises and reciprocates obligations which are fundamental component, but expectation plays a vital role in establishing psychological contact. In practical sense, psychological contact is at best board build that determines conduct of construction worker and first line supervisor and helps employer to control their employees. Psychological is proposed as means of exploring corresponding relationship, and safety based on correlativity involves duty of employer to protect, whereas employee has duty to follow safety standard. Employer's forms expectation about workplace safety, and these actions will be responded; this forms a psychological contact of safety, and safety climate, safety conduct, and safety result (injury and fatality) depend upon level of attainment and violations of psychological contact of safety.

# 4 Assumptions

There are some hypotheses which are made to determine which factor of safety climate affects the safety conduct on construction sites. There are three types of hypothesis, and they are

- PCS serves as a moderator between principal employer safety obligation and construction worker safety conduct and determines the factor lagging from either side.
- PCS serves as a moderator between first line supervisor safety conduct and construction worker safety conduct and determines the factor lagging from either side.
- PCS serves as a moderator between workmate safety conduct and construction worker safety conduct and determines the factor lagging from either side.

# 5 Methodology

## *5.1 Sample and Procedure of Conducting the Survey*

The question were directly displayed on the screen read out by the facilitator only about 352 participants participates and completed the survey, and they all belong to construction sites which are advised by their employer and contractor to give their feedback (answer) in accordance with ethics, principle, and guidelines of authority conducting the survey (Table 1).

It was necessary to check the survey timely in accordance to safety point of view, so the safety experts viewed the content to maximize the content validity. These experts added some safety advisor with long experience of construction safety. All items or answer is given on the range of five point, except the other information. In range 1 = completely disagree to 5 = completely agree, here it was explained that 1 = completely disagree, whereas 5 = completely agree. The main facilitator of this survey ensured the understanding of the construction worker related to the psychological contract of safety range (Walker 2010) that this range is used to determine the degree of actuality of safety between the construction workers and the company in which they are working.

## *5.2 Safety Climate Factor*

Safety climate factors are used to determine the safety climate at the construction sites. There were items for safety obligation, items for first line supervisor safety conduct, and items for workmate safety conduct for determining the consistency, and reliability Cronbach's $\alpha$ (Cronbach's alpha: simple definition) is determined

**Table 1** Survey format

| Elements of questionnaire | | |
|---|---|---|
| Company factors | Personnel factors | Other factors |
| • Work load<br>• Inconsistent demands<br>• Ways to monitor construction worker safety | Personality—traits and characteristics | • Gender<br>• Age<br>• Nationality |
| Factor effecting supervisor performance | Psychological understanding—awareness and use of emotions | Employing company |
| Safety support—from colleagues or supervisors | Self-confidence of a personnel | Trade (type of work) |
| Visibility | Perception about the accident | Experience |
| Construction workers' safety conduct and psychological contract of safety | Factors (internal and external) serve as motivators of safety | Responsibility of operations |
| Safety climate factor | How person is involved in an accident | – |

$$\alpha = \frac{N \cdot \overline{C}}{\bar{v} + (N - 1) \cdot \overline{C}}$$

as

where

$N$ = the number of items (entries).
$\overline{C}$ = average covariance between item (entries)-pairs.
$\bar{v}$ = average variance of entries.

For survey related to principal employer safety obligation, it is 0.865, for first line supervisor safety conduct, it is 0.875, and for workmate safety conduct, it is 0.893.

## *5.3 Construction Worker Safety Conduct*

Construction worker safety climate is measured by items, and they are according to the safety conduct range. The measure was associated for the better safe work practices and reduces exposure to environmental stressor, and the presence of more safety policies and positive attitude of construction workers toward workplace in a company decreased accidents (Fig. 4).

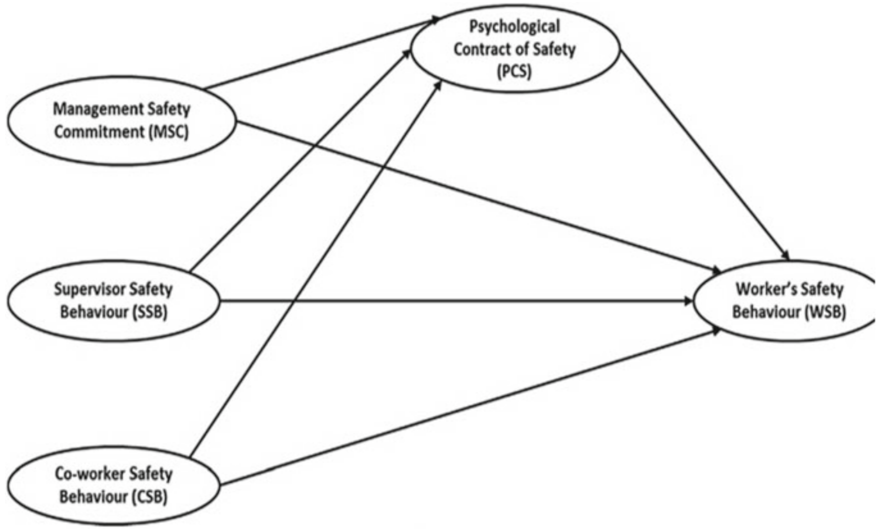


**Fig. 4** Proposed model

### 5.4 *Psychological Contract of Safety*

Psychological contract of safety based on correlative obligation between supervisor and the construction worker and employer while using this concept to consider safety. The safety conduct of construction workers is shaped by the psychological contract of safety between first line supervisors and construction workers which gives efficient safety outcome for example accident rates. The value of Cronbach's alpha is 0.923

## 6 Result and Discussion

The survey was completed among 352 participants out of whom 30 responses were not considered due to missing field after completion of survey. The reliability and consistency of data is tested using Cronbach alpha after that the data went to correlation and SEM process to decide the effect of safety climate factor on construction worker safety conduct directly or indirectly which one is more efficient in shaping the safety conduct of construction worker. Final result for safety conduct on construction site are achieved through obtained hypothesis. Hypothesis 1 concludes that there is no significant effect of principal employer obligation on construction worker safety conduct directly (beta = 0.00), but if the contact is made through psychological contact of safety, the effect will be significant (beta = 0.44), and it will determine the factor that are restricting to shape the construction worker safety conduct. Hypothesis 2 concludes that there is no significant effect of first line

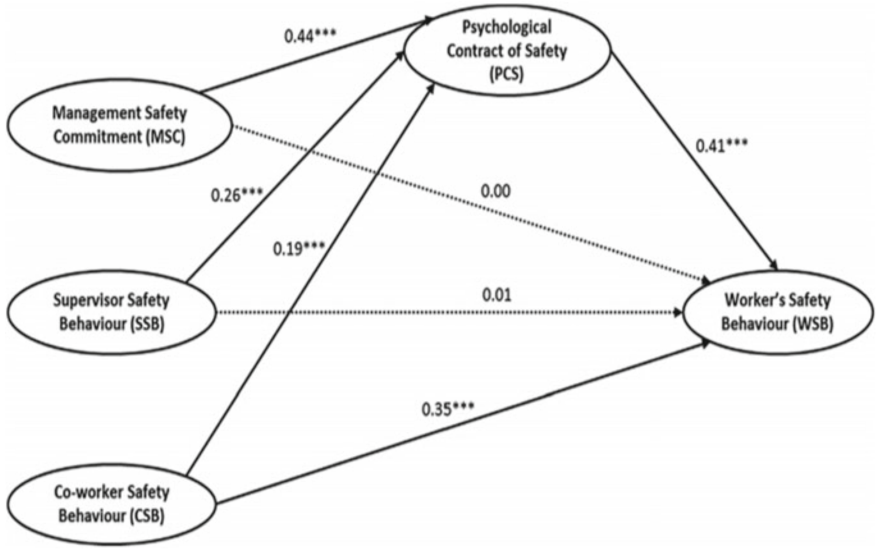


**Fig. 5** Hypothesis testing

supervisor on construction worker safety conduct directly (beta = 0.01), but if the contact is made through psychological contact of safety, the effect will be significant (beta = 0.41), and it will determine the factor that are restricting to shape the construction worker safety conduct. Hypothesis 3 concludes that workmate safety conduct significantly affects construction worker safety conduct directly (beta = 0.35), but if the contact is made through psychological contact of safety, the effect will also be significant (beta = 0.41), and it will determine the factor that is restricting to shape the construction worker safety conduct (Fig. 5).

Although the correlation between safety climate and construction worker safety conduct using psychological contact of safety as a moderator (on supporting and determining factor that restricts shaping of construction worker safety conduct) are understood. If the positive relationship is established, construction worker conduct will be changed, but this relationship works on construction site will depends on site conditions. The reactive level of safety climate factor is undoubtedly related to common obligation between construction worker & safety climate factor, high level of principal employer obligation and high psychological contract of safety that produces high safety outcome (by influencing construction worker safety conduct). Therefore, due to this, construction worker attaches safety perception to correlative obligation.

Due to this, relationship management knows how to translate management obligation into safety conduct. First line supervisor and managers through psychological contract of safety can easily determine the attainment correlative obligation and its impression on safety conduct of construction worker, and a better awareness of correlative obligation leads to safety conduct of construction worker. PCS also explains that how conduct of first line supervisor affects the safety conduct of construction worker who is site-based representation of principal employer, and its conduct determines the degree of attainment of safety obligations (commitment). Workmate also influences the PCS as he is the one who is closest to construction worker as they are working in group, and if workmate have the sense of attainment of obligation, then he will shape the safety conduct of construction worker.

## 7 Conclusion

The construction worker safety behavior is one which can change the rate of fatalities at construction site, but for that the safety climate should be efficient enough to promote all the parameter that influences the construction worker safety behavior and removes the factor which are affecting construction worker safety behavior, and to determine this efficient, there should be psychological contract of safety between factors of safety climate and construction worker safety behavior. Psychological contract of safety will be proved to be a great medium to change the behavior of construction worker in terms of safety and reduce the unsafe practices that serve to be the cause of fatalities. Psychological contract explorations are used to do 'real-life inspections' that reveal the level of attainment of correlative obligations and its effect on construction workers safety conduct. Using structural equation modeling (SEM), different relationship between key safety climate factors and psychological contact of safety was analyzed to describe the effects that they have on each other. This technique disclosed that how safety management system can be changed to sustain a safe working environment for construction workers.

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# Hazard and Risk in Mining Industry: A Case Study Based on Senghenydd Colliery Disaster

**Aayush Kumar, Shravan Nair, Bikarama Prasad Yadav, and P. A. Arun**

## 1 Introduction

The Occupational Safety and Health Administration (OSHA) in the USA defines combustible dust as a solid material which is made up of prominent particles or pieces, despite its size, shape, or chemical composition, which exhibits a fire or deflagration hazard when suspended in air over a range of concentrations. Dust explosion may occur frequently in many industrial environments where there is a presence of fine particles in air, like flour, coal, starch, sawdust etc. Mining and flour mills are the most susceptible to such dust explosions.

The National Institute for Occupational Safety and Health has given the following statistics of 623 coal mining disasters (with five or more fatalities):

| Date | Mine name | Type | Product | Fatality |
|---|---|---|---|---|
| 30–12–1970 | Finley Coal No. 15 and 16 | Explosion | Coal | 38 |
| 26–02–1972 | Buffalo Mining | Dam failure | Coal | 114 |
| 22–07–1972 | Blacksville No. 1 | Fire | Coal | 9 |
| 16–12–1972 | Itmann No. 3 | Explosion | Coal | 5 |
| 09–03–1976 | Scotia | Explosion | Coal | 15 |
| 11–03–1976 | Scotia (second) | Explosion | Coal | 11 |
| 01–03–1977 | Porter Tunnel | Flood | Coal | 9 |
| 04–04–1978 | Moss No. 3 | Suffocation | Coal | 5 |
| 07–11–1980 | Ferrell No. 17 | Explosion | Coal | 5 |
| 15–04–1981 | Mid-Continent CO | Explosion | Coal | 15 |
| 07–12–1981 | Adkins Coal Mine | Explosion | Coal | 8 |

(continued)

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(continued)

| Date | Mine name | Type | Product | Fatality |
|---|---|---|---|---|
| 08–12–1981 | Grundy Mining | Explosion | Coal | 13 |
| 20–01–1982 | RHF No. 1 | Explosion | Coal | 7 |
| 21–06–1983 | McClure #1 Mine | Explosion | Coal | 7 |
| 19–12–1984 | Wilberg Mine | Fire | Coal | 27 |
| 06–02–1986 | Loveridge Mine | Collapsed coal pile | Coal | 5 |
| 13–09–1989 | William Station No. 9 Mine | Explosion | Coal | 10 |
| 07–12–1992 | No. 3 Mine | Explosion | Coal | 8 |
| 03–09–2001 | No. 5 Mine | Explosion | Coal | 13 |
| 02–01–2006 | Sago Mine | Explosion | Coal | 12 |
| 20–05–2006 | Darby Mine No. 1 | Explosion | Coal | 5 |
| 06–08–2007 | Crandall Canyon Mine | Fall of face or rib | Coal | 6 |
| 05–04–2010 | Upper Big Mine | Explosion | Coal | 29 |

*Note* Owing to the extensive nature of the table, only the data of last 40 years are taken into consideration

As it can be seen from the above table, almost 73% of all the accidents which occurred in the last four decades had explosion as their type which indicates the presence of dust particles and the harm that it may cause in the mining industry.

Complimentary to the well-known fire triangle which needs fuel, oxygen and an ignition source for fire to occur, dust combustion has two additional components, namely dispersion of dust particles and confinement of the dust cloud. This dust pentagon when completed gives rise to dust explosions whose intensity may vary from time to time according to certain parameters. Combustible dust explosions are further classified as primary explosion and secondary explosion. In any typical dust explosion, due to the dust present in the confined space getting ignited (due to some ignition source) will cause a fire relatively small in nature. This is known as primary explosion. But the most destructive explosion type happens after this, which is the major problem. The primary explosion will cause the accumulation of dust forming a dense cloud in the confined area, which on getting airborne will get ignited resulting in a much more dangerous uncontrolled explosion. More often than not it is this secondary explosion which is the cause of a number of fatalities in any factory/industry it takes place.

Coal dust in this case is one of the major causes of dust explosions to take place in any industry, specially mining. Historically, majority of the fatalities and casualties have occurred due to coal dust explosions, namely Courrieres mine explosion in France (1907), Benxihu Colliery disaster in China (1942), Farmington coal mine disaster in USA (1968) and the one used for this study, i.e. Senghenydd colliery disaster. There is a certain range of concentration of dust and air mixture which will determine whether the explosion will occur or not occur. Upper explosive limit is the range above which the explosion will not take place whatsoever, whereas lower explosion limit is the lowest concentration of dust capable of causing an explosion.

It also has to be noted that the most unmanageable explosions are produced when there is enough oxygen content present in the dust cloud which results in complete combustion.

When a solid or liquid particle is finely divided and dispersed in air, it forms a higher degree of risk to explosions as compared to any other matter. When dispersed, its surface area increases by manifold as well as the space occupied by the dispersed material is expanded over many times. These conditions cause the material to burn more rapidly, and the energy which is liberated gets released suddenly along with the production of high quantity of heat energy. This heat energy produced exerts large amount of pressure on the walls of the area confining the dust cloud. All this along with some fuel leads to fire and explosions of high magnitude which further entraps the people working in these areas leading to their death.

## 2 Literature Review

Ben Harvey examined the Oaks Colliery Disaster which occurred in 1806 to understand the safety concerns related to coal industry in much more context. He explored different safety legislations that were enacted by the industry and how well it was followed by different hierarchies of management from management level to the workers. Although the disaster occurred following series of explosions which was caused by firedamp that ripped through the entire framework, he determined the root cause of this incident in terms of the behavioural management of the workers and staff that led to this mishap. It helped him to quantify safety duties and state regulations that need to be undertaken by the industrial workers and other parties (Harvey 2016).

C. Chu, R. Jain, et al., statistically analysed coal mining safety in accordance with the increasing advent of technologies in China. Different parameters used for this analysis were fatalities per million tons, labour productivity and fatalities per 10 000 exposure hours. Statistics Package for Social Science (SPSS) was used for this correlational analysis between the mining accidents and technology advancement. Direct connection was observed between the monetary investment, new technology with the coal mine safety from the year 2001–2010 in China (Chu et al. 2016).

Kenneth L. Cashdollar studied the explosibility of coal dust in order to determine improvement factors in mining and other industries with respect to safety where coal is used or is being processed. Minimum explosible concentrations, minimum oxygen concentrations, highest pressure rise rate, maximum explosion pressures and total required quantity of rock dust for inheriting the coals which are the few parameters were measured. Laboratory explosibility chamber (USBM 20 litre) was used for this purpose. The relation between coal explosibility and particle size was assessed, and it was observed that particles with fine size are more hazardous than particles of relatively larger diameter (Cashdollar 1900).

Robert G. Neville reviewed the second-largest colliery disaster known as The Courrieres Colliery Disaster, 1906, which happened in France. Although the exact initial cause of this explosion is unknown because all the witnesses of this catastrophe are gone, still he examined the two causes of the accident which were known after the investigation which were ignition of methane by the naked flame of a miner's lamp and handling of mining explosives (Neville 1978).

Irving Hartmann has conducted extensive research on industrial dust explosions, mine fire control unit, dust allaying in mines, alternate and healthy use of mining explosives, strength and compressibility of coal pillars, variations in humidity, temperature impact and development and control of coal mine explosions and other mine safety problems. He came into conclusion that dissemination of dust, adequate ventilation, use of flame safety lamps, large exhaust dust collectors on mining machine and rock dusting of all mine workings are few of the preventive measures that could be taken to prevent such explosion (Hartmann 1954).

Zhao Dai-ying, Nie Bai-sheng statistically evaluated the serious accidents in coal and mining industry in China. For this study, they took accident data of 30 years, i.e. from 1981 to 2010. Relative indexes according to time, employee and output were calculated by statistical method. They came into conclusion that in coal mines, the death of hundred thousand employees has reduced over a course of time by relative indexes analysis. According to type analysis, it was identified that not only gas but also flooding accidents are one of the dangerous kinds, whereas month-based analysis reveals that larger PSCA incidents occur from March till May and from November till December (Dai-Ying and Bai-Sheng 2011).

Michael J. Brnich, Kathleen M. Kowalski-Trakofker examined the changing trends in colliery disasters by capturing the past data of underground coal mine disasters in USA of almost 110 years. Different parameters of this study were frequency of fatalities, increase in behavioural-based safety concern, general types and the responses to those disasters. They emphasized on the fact that human behaviour plays a vital role with respect to the coal mining accidents. This research includes the leadership quality of a person in this situation, decision-making capability, communication, incident command centre issues, expectations training and issues related with the introduction of refuge chambers. They divide the coal disasters into three different time periods such as 1900–1909, 1910–1969 and 1970 to present. It was observed that as the period goes on, there was a notable downfall in the underground colliery explosions. Also, the main reason for this achievement was advancement in psychosocial and human behaviour factor and their recognition by the industries. Hence, it was concluded that behavioural science and psychology have a huge impact on mine safety and health.

E A Khamidullina, S. S Timofeeva, et al. took into account the safety quality parameter, i.e. risk indicators to identify the extent of accidents in the coal and mining industries. The purpose of this study was to analyse the social risks associated with the coal mining and represent it in the terms of F/N curve. For preparing this curve, he took past data of 70 years, i.e. from 1943 to 2012, and the nominal values for risks were evaluated. It was observed that cumulatively, all the accidents resulting in deaths were comparatively more than number of deaths in the worst conditions. Also, from the F/N diagram, it was visible that normative level was attained by the frequency of accidents with higher number of fatality, thus indicating larger risk values (Khamidullina et al. 2017).

Timothy hynes with the help of past researches has tried to examine different events that lead to the mining and explosion disasters in an organization. He related mock bureaucracy with the accidents and examined different factors leading to the violation of safety rules at a workplace. He came into conclusion that growth of mock bureaucracy is due to macro-environmental factors, managerial non-compliance, workers non-compliance, cultural factors and delegitimization of safety rules by external agencies (Hynes and Prasad 1997).

Metin Akgun studied different coal accidents and compared its impacts with the explosion in Soma Eynez mining quarry to determine the causes of these accidents and to evaluate various preventive measures for it. He realized that the main reasons for this disaster were spontaneous combustion of coal and the presence of methane gas. He further examined the respiratory emergencies in coal mines. Different aspects for this evaluation were the history of coal accidents, procedures undertaken while rescue operation, management of the emergencies encountered while the accident, precaution that should be undertaken prior the process and respiratory emergencies (Akgün 2015).

James C. Cawley conducted a study focusing on various electrical hazards in a mining industry. He studied 1926 electrical accidents which occurred between 1990 and 1999, where all these data were MSHA closeout data and few preliminary data. It was seen that electrical hazards contributed to fourth highest cause of mine disaster also 14th most cause of injuries. He analysed different factors such as circuit voltage, cables, grounding, circuit breakers, batteries, meter usage and working on energized circuits and came with some preventive measures to reduce such electrical hazards which were mitigation of likelihood and consequence of flash burn injuries, electrical injuries in maintenance work activities and of electrical shock injuries (Cawley 2003).

Letícia Couto Garcia, Danilo Bandini Ribeiro, et al. reviewed Brazil's worst mining accident of Samarco Corporation owned mine which was demolished. This disaster resulted in death of 20 people and affected biodiversity by degrading the local indigenous land, pollution of water and death of marine life. He further studied the steps undertaken by the organization to prevent reoccurrence of such accidents, compensation given, improvement brought in the monitoring system and the environmental bond (Garcia et al. 2017).

## 3 Causes of the Accident

Investigations into the incident were first opened on 2 January 1914 which ran for about three days before getting adjourned. Reopening again on the 27th of January of the same year, it continued for a period of 13 days. The report titled "Causes of and circumstances attending the Explosion which occurred at the Senghenydd Colliery on Tuesday, 14th October, 1913" was submitted by Richard Redmayne who was the commissioner of chief controller of mines and the assessors included Evan Williams, Chairman of South Wales and Monmouthshire Coal owners' Association along with Robert Smillie, President of miners' association of Great Britain to the Secretary of State for the Home Department, Great Britain on 3 March1914.[1] Various theories and their acceptance put forward by the committee were:

1. The only obvious way by which the start of the explosion could have happened was found to be spark from electric signal wire or sparks from the rocks brought down by the fall. This was supported by the experiments conducted with electrical signals having same voltage of the batteries which were present at the site where accident occurred.
2. There were very large falls on the road, exposing seams of coal and beds of hard rocks which may have caused the outburst of gases responsible for getting ignited and causing the explosion.
3. The theory of the falls being responsible was supported by Mr Watts Morgan who took a prominent part in the exploration work and also a member of the committee of control which was established after the explosion had occurred.
4. The mining engineers also put forward their theory that the ignition could have taken place due to the lamp present at the lamp cabin which was supported by the Manager, Mr Shaw.
5. Another probable theory which came up by Mr J. Winstone was that the gas existing in a cavity in the main West Level at the arch end and friction caused by a haulage rope rubbing against timbers near the roof resulting in the induction of spark. Though this theory was opposed by timberman Edwards, the most experienced man amongst the miners said that he had never seen a rope running in the timbers or the places mentioned by Mr Winstone.
6. There were also several features which opposed the lamp station as being the point of ignition. The cabin in which the lamp was present was whitewashed only two months previous to the explosion and showed no signs of discolouration, which should have occurred had the explosion originated in the cabin. Also an underground lamp was found lying on the table of the lamp cabin with unburnt paper inside it.
7. The primary cause being the ignition caused by sparks was further strengthened by the evidence of Mr Shaw who had frequently seen the sparks from falls of ground. An account of this incident was further supported by the overman (R.W. Evans) and a Fireman (J.Loyd), who had witnessed it.

Along with this, Dr Wheeler's report on experiment with signalling apparatus was also submitted in which a number of tests were carried out using one of the Sengenydd bells in the laboratory. The experiments were conducted in such a manner that either the bell or the signal wires were enclosed in a chamber containing an explosive mixture of methane and air. It was found that the ignition at the bell due to the maintained spark at the spring contact could be obtained with a battery of five cells, the current when the circuit was closed being at 0.70 amperes and voltage across the bell terminals being 7.5.

[1] Senghenydd-Explosion-Report-opt.pdf.

It has to be noted that as is the case with every inquiry report, this inquiry also failed to identify a definite cause for the explosion to occur, though the spark from the signalling gear igniting the coal dust–air mixture was considered as the most likely cause of the accident. Also, one of major reasons for the explosion to occur was the breach of the mining regulations which was considered as a failure on the behalf of the management. Additionally, disapproval was aimed towards the course of action in place in case of any emergency such as shortage of respirators and the shortage of ample water supply for firefighting.

## 4 Conclusion

After the careful study of the authentic investigation reports on this particular accident, it is now known that there were multiple underlying causes for this catastrophic accident, in which the main and preceded event is liberation of substantial quantity of gas by the falls. These hefty falls revealed the deposits of coal and hard rock beds, and a rush of gas attacked one of them. In there, the sole method of fire was a spark caused by the electrical signalling gadgetry. The possibilities of match and lamps as a means of ignition were remote, and no sufficient evidence was there to start discussion. Use of electric wires into the West Mafeking District were the existence of gas was reported previously to an accident and it has also revealed that the particular area of mine where inflammable gas was present already in appropriate amount had a suitable environment for fire aided by the presence of electrical signalling equipment in that area.

Making this electrical signalling apparatus as a primary means of ignition in the scene, investigators carried the experiments on type of electrical signalling apparatus which was used at the mine.

**Dr. Wheeler's report on experiments with signalling Apparatus**

His experiments showed that there were three Dania cells giving a current (on closed circuit) of 0.45A under a pressure (on open circuit) of 4.5 volts making conditions possible to produce a spark, by short circuiting the current, which exploded a mixture of air and methane when methane was present at 8.2%.

**Underlying cause/Root Cause**

Non-compliance with the statutory requirements of Sect. 62(3) of the Coal Mines Act, 1911. It was argued that according to the sub-sections, the cleaning of dust from the floor, roof and sides should be carried out "as far as practicable", which was lacking in the mine.

Non-compliance with the code of electricity Regulations 1905 which states that no bare wires shall be used for signalling circuits except in haulage roads and also no apparatus was permitted as per the code of 1905 to produce external sparks in places where gas might occur in amount which is adequate enough to be suggestive of the hazard which it possesses.

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# Environmental Impact of $SF_6$ and Investigation of Its Substitute: A Review

**Sandeep Kumar, S. Sanjay, Bikarama Prasad Yadav, N. A. Siddiqui, and Surendar Varadharajan**

## 1 Introduction

$SF_6$ has been extensively used in HV and MV industry because of its exceptional physical properties. Hence, it contributes on a very large scale to the global warming. Usage of $SF_6$ is not only limited to the GIS; it has been also adopted to electrical insulation in medical applications such as in X-ray machines, as a tracer gas studies, shock absorbers, and also provides special atmosphere for magnesium and aluminum protection and purification (Mantilla et al. 2014). However, modern switchgears' improved design allows them to minimal use of $SF_6$, as well as reduction of $SF_6$ leakages from the switchgears (Koch 2003).

Over the years, high-voltage industry is dominated by switchgears, whether it is gas-insulated or air-insulated. Generally, GIS uses $SF_6$ as its insulation media, whereas AIS uses air insulation in metal clad system; GIS uses $SF_6$, which is heavier than air and offers excellent arc extinction behavior. Air-insulated switchgears require more space as it can only be erected on outdoor. AIS does offer upfront cost savings, but require extra man hours in case of installations and maintenance, and because of its more susceptibility on the outer disturbances, it offers negative effects on the upfront cost (Nagarsheth and Singh 2014; Jeromin et al. 2010).

In terms of GIS, it is relying on the use of $SF_6$, because of its high reliability and short erection period at site. Fuji Electric has developed different types of $SF_6$ gas-insulated switchgear depending upon the rated voltage such as type SDF, i.e., for 170 kV and SDA514, i.e., from 72.5 to 145 kV. These are classified on the basis of rated voltage, rated $SF_6$ gas pressure, rated operating sequence of circuit breaker, etc. (Fuji Electric, no date). Preferably, GIS is exclusively used above 400 kV having the entire electrical component interconnected via compressed $SF_6$, i.e., bus bar, circuit breaker, potential transformer, current transformer, surge arrester, disconnectors and

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earthing switches (Dervos et al. 2011). It has been estimated that almost 80% of the $SF_6$ formed globally has been used by the electrical industry for the use of circuit breakers, transformers, substations and in transmission lines. The dielectric strength of the $SF_6$ in case of gas-insulated switchgears is extremely important under the condition of fast transient electrical stresses, switching and lightning impulse(Olthoff and Brunt 1994).

Environmental impact is the most significant downside of $SF_6$, and due to this, it has greenhouse effect on the atmosphere which creates high sensitivity to metallic protrusion and high cost. Due to this, GIS has many defects such as free metallic particles and protrusion from the electrode surface (Hwang et al.). One more drawback of GIS is the outage due to seemingly harmless conducting particles which result in around 50% of GIS failure. The occurrence of flashover in GIS is associated with longer outage comparatively to air-insulated substation (Kumar et al. 2014).

## 2 Development of Alternatives

The global warming potential of $SF_6$ has 23,500 times more than $CO_2$, and it has a atmospheric life span of 3200 years, thus placing it among one of the most potent greenhouse gases. Meanwhile, a large database needs to be monitored for the actual atmospheric condition, and therefore, the present study on finding of an alternative would be more helpful and reliable in current scenario. Despite the fact we can use atmospheric tracer for the $SF_6$ concentration on the environment, the potential climatic impacts of $SF_6$ are troubling.

The development of a suitable alternative has been in progress to replace $SF_6$ and to reduce its greenhouse effect from the environment. There are many methods of decomposing of $SF_6$, but none of them are as reliable as $SF_6$, whether is non-thermal plasma technique or RF plasma technique. There is a bigger problem in case of $SF_6$ abatement to also take care of the byproducts of it, and many of them have average toxicity of LC50. Fortunately, some of the byproducts are soluble to water, but those who are not need to be captured by either wet scrubbing or absorption (Dervos et al. 2011). Therefore, it was necessary to develop an alternative, but this was also not an easy task to develop. While developing the alternative, it was very necessary to keep in consideration of the physiochemical properties such as high dielectric strength, low boiling point, low toxicity, high vapor pressure at low temperature and to have a chemical stability. There are also some environmental factors that are very important requirement such as no ozone depletion potential, low GWP and minimal environmental impact. Since the electrical equipment is also used in various conditions of various ambient temperatures, it is mandatory to the material to remain in the gaseous form typically to at least −30 °C.

Traditional natural gases such as $CO_2$, nitrogen and pure air can be considered and have the advantage of low GWP, but it has less dielectric strength comparatively $SF_6$, and not only this, if it is being used as a insulation medium, it will lead to drastic change in the product design. Increase in pressure will also have impact on vessel

**Table 1** Comparison between hydrofluoroolefin (State 2008; Weight et al. 2008; Ether 2015; Abderrahmane et al. 2017)

| Hydrofluoroolefin | HFO-1234ze(E) | HFO-1234yf | HFO-1336mzz-Z |
|---|---|---|---|
| GWP | 6 | 4 | 2 |
| Toxicity LC50 4 h/rat (ppmV) | >207,000 | >400,000 | >102,900 |
| Flammability | Non-flammable | Slightly flammable | Non-flammable |
| Boiling point in °C | −19 | −29 | 33.4 |
| Molar mass g/mol | 114 | 114 | 164.05 |
| Dielectric strength Kv/cm (% of $SF_6$) | 85 | – | 220 |

that will also affect the safety measures and change in design. Initially, this will also increase the manufacturing cost (Ponchon and France 2015).

## 2.1 *HFO-1234ze(E) (Hydrofluoroolefin)*

Hydrofluoroolefin is a subclass of HFCs, and it was first proposed to be next-generation refrigerants, further it has considered as insulation gases, particularly HFO-1234ze(E). The HFOs used are alkenes; carbon chain having three carbon atoms, preferably $C_3H_2F_4$, because of its lesser environmental impact as well as it is non-toxic, non-explosive and non-corrosive. Dielectric strength of pure HFOs is better than $SF_6$, but it cannot be used as a pure form, because it cannot alone achieve the safety or other performance standards, and preferably, it is mixed with traditional gases or mixture of these gases (Bournay et al. 2016; Potential and Acid 2016).

The investigation of HFOs has been conducted for satisfying the technical specification with respect to replacing $SF_6$. Lightning impulse test considered to be more critical than power frequency test has performed, and the result appears to be satisfactory (Christophe et al). HFO-1234ze(E) is a good candidate to replace $SF_6$ as dielectric insulating medium in MV applications (Preve et al. 2017).

The comprehension of the thermodynamic properties of HFO-1234yf is better. The thermophysical parameters are very much similar to each other, but HFO-1234yf is extremely flammable. For this benefaction, HFO-1234ze(E) is selected (Katagiri et al. 2008). It can be most probably used as a replacement in medium-voltage applications to $SF_6$ (Table 1).

## 2.2 *Trifluoroiodomethane ($CF_3I$)*

Most of the $SF_6$ properties have been met with this gas; it also exhibits characteristics such as colorless, non-flammable and non-toxic. It has less atmospheric lifetime because it decomposes by solar light (Katagiri et al. 2008). It exists in gaseous form at room temperature with boiling point at −22.5 °C and melting point at −110 °C. Long-term stability test shows that $CF_3I$ rapidly degrades in the presence of copper, moisture and temperatures above 100 °C. It is used as an environmentally friendly gas in the electrical power industries. It also finds application as an extinguishing agent in fire-suppression systems.

Pure $CF_3I$ holds certain limitations such as high boiling point; therefore, it is not suitable to be used as pure form. Hence, it is merged with buffer gas like $CO_2$ or $N_2$, thereby improving its dielectric performance as $CO_2$ poses comparatively good interruption capability (Katagiri et al. 2008). As test conducted (Katagiri et al. 2008) for its interruption capability, both the mixtures, $CF_3I$–$N_2$ and $CF_3I$–$CO_2$, performed really well. However, the performance of $CF_3I$–$CO_2$ (30/70%) was better than $CF_3I$–$N_2$ and 0.2 times higher than the $SF_6$ (Kamarudin et al. 2014), and consequently, the dielectric strength of the mixture of $CF_3I$–$CO_2$ is 0.75–0.8 times higher than $SF_6$.

The characteristics of $CF_3I$ are such that though iodine has higher capability of destroying stratospheric ozone, due to the weak C–I bond, it is broken easily under the influence of water, hence bringing down the ozone depletion potential to near zero. The study at IPCC indicates the global warming potential over a span of 100 years to be 0.4 (Ar et al. 2012).

## *2.3 Perfluorocyclobutane $C_4F_8$–$N_2$*

Over the last few decades, a comprehensive investigation is carried out for efficient use of $C_4F_8$–$N_2$ as an alternative to $SF_6$. This gas mixture of $C_4F_8$ exhibits similar characteristics such as $CF_3I$ in its colorless, non-flammable and non-toxic. Due to its high boiling point, the use of pure $C_4F_8$ is impractical. Hence, the mixture with $N_2$ makes the gas mixture ideal for substituting $SF_6$. The choice for selecting a buffer gas should be suitable; otherwise, it may have adverse effect on its electrical properties as well as the mixing ratio is also crucial (Zhao et al. 2016).

The insulation strength of this mixture is approximately 1.13 times of $SF_6$ under an electric field which is uniform in nature. This gas mixture acts synergistically: The $N_2$ gas scatters electrons into the range of energies in which the electrons of electronegative gas are captured most efficiently (Wu et al. 2006). Like other fluorocarbons, it is very stable, even at elevated temperatures (Blodgett 2013). This gas mixture has a low GWP compared to that of $SF_6$ with only 36% of $SF_6$'s GWP and has a ozone depletion potential of nearly zero. The boiling point of the mixture is nearly −5.8 °C and a melting point of −40.1 °C. The $C_4F_8$ finds application as deposition gas and an etchant.

### 2.4 $G_3$ Mixtures ($(CF_3)_2CFCN$)

$G_3$ mixtures are basically the result of 3 M Novec 4710 and $CO_2$, because Novec 4710 has liquefaction at low temperature; hence, it cannot be used in pure form, and then, it is diluted with buffer gas for the suitable application. $(CF_3)_2CFCN$, heptafluoro-iso-butyronitrile compound, comes from the family of fluoronitriles. It is one of the latest investigated fluorinated compounds because of its lower toxicity and performance standards. The dielectric strength of this alternative is twice that of SF6, at atmospheric temperature, with a wide range of operating temperatures. Its high thermal transfer capability and low toxicity make it a very suitable candidate for replacing $SF_6$ (Ar et al. 2012). Kieffel (2016) has inscribed in his paper with respect to GWP savings, and a 145 kV 3-phase GIS bay contains of 60 kg of $SF_6$ which is equal to 1400 tons of $CO_2$, whereas G3 mixtures of same amount are equivalent to only 27 tons of $CO_2$ (Kieffel 2016). This gas has lesser impact on environment compared to $SF_6$. The gas has a good compatibility with metal and with most of the hard plastics. The substitution of this gas with $SF_6$ requires minor or no modifications (Kieffel 2016; Ponchon and France 2015) (Fig. 1).

The investigation is done by Nechmi et al. A mixture of 3.7% of fluoronitriles and 96.3% of $CO_2$ constitutes all the required environmental and physical properties to replace $SF_6$ in switchgears in the point of pressure and low ambient temperature (−30 °C). This strikes the balance between the operational pressure and temperature and also impacts on the environmental (Nechmi et al. 2016). Addition of dilution gases with fluoronitriles could be $N_2$, dry air or $CO_2$ having GWP either equal to 0 or

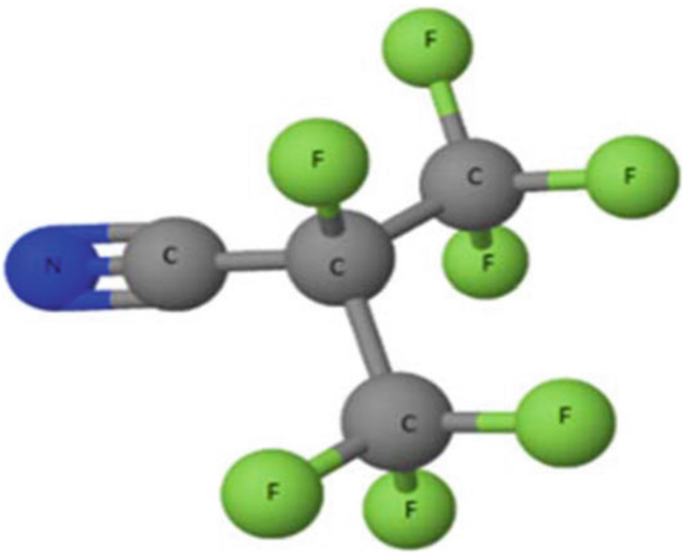


**Fig. 1** 3D representation of $(CF_3)_2CFCN$ dielectric fluid

1. The selection of dilution gas basically depends on two factors, firstly low boiling point that should be less than or equal to the minimum utilization temperature and secondly depends upon the dielectric strength that is greater than or equal to the $CO_2$ at under test conditions (Kieffel et al. 2015). In order to replace $SF_6$, it relies on many parameters to look on; then only, we may consider it as a possible substitute. Thus, fluoronitriles addition with dilution gas provides considerable validation toward electrical performance and reduces environmental impact (Table 2).

## 3 Conclusion

In this paper, we have discussed different possible substitutes for $SF_6$ with less impact on environment and possibly with the same working reliability. The discussed substitutes are HFO-1234ze(E) (hydrofluoroolefin), trifluoroiodomethane ($CF_3I$), perfluorocyclobutane $C_4F_8$–$N_2$ and 3 M Novec 4710 ($(CF_3)_2CFCN$). HFOs have better characteristics than $SF_6$, but it cannot be used in pure form; if we want to achieve better safety and reliability, it is mixed with buffer gases, and then only, it can perform as a possible alternative. $CF_3I$ is also one of the promising alternatives which has a very low GWP of 0.4 and atmospheric lifetime of less than 1 month which makes it one of the very lesser impacts on the environment. The only drawback of it is high boiling point which prevents it to function singularly; hence, it is mixed with traditional gases and then it comes into function as a substitute. $C_4F_8$ poses a very good dielectric strength, but its GWP is much greater than other substitutes. The 3 M Novec 4710 poses all the inherent merits that make it a better alternative among all. It has an advantage of being as eco-friendly nature which gives approx. 98% impact reduction from what $SF_6$ has on the environment.

**Table 2** Comparison of alternatives (Abderrahmane et al. 2017)

| Comparison between $SF_6$ and its alternatives | | | | | | |
|---|---|---|---|---|---|---|
| Sl No | Properties | $SF_6$ sulfur hexafluoride | 3 M Novec 4710 $(CF_3)_2CFCN$ | HFO1234ZeE (hydrofluoroolefin) | $CF_3I$ trifluoroiodomethane | $C_4F_8$–$N_2$ |
| | *Environmental impacts* | | | | | |
| 1 | Atmospheric lifetime (years) | 3200 | 30 | 16.4 Days | Less than 1 month | 2600 |
| 2 | Global warming potential (GWP) | 23,500 | 2090 | 6 | 0.4 | 8700 |
| 3 | Ozone depletion potential (OZP) | 0 | 0 | 0 | Very low (<0.08) | 0 |
| | *Physical properties* | | | | | |
| 4 | Molar mass g/mol | 146.06 | 195 | 114.04 | 195.91 | 228.04 |
| 5 | Toxicity LC50 4 h/rat (ppmV) | Non-toxic | >10,000 and < 15,000 | >207,000 | 160,000(CMR@3) | Non-toxic |
| 6 | Dielectric strength Kv/cm | 75 | 108.26 | 85 (%of $SF_6$) | 90.75 | 66 |
| 7 | Boiling point in °C | −64 | −4.7 | −19 | −22.5 | −36.7 |
| 8 | Flammability | No | No | Low | No | No |
| 9 | Liquefaction pressure at−30 Â°C | 0.52 | 0.0311 | 0.11 | – | – |

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# Occupational Hazards and Risk Exposures in Firework Industry: A Review

**S. Nandhagopal, K. Praveen Kumar, Bikarama Prasad Yadav, Abhishek Nandan, and Nihal Anwar Siddiqui**

## 1 Introduction

India is the second production of firecrackers after China, almost all of its domestic utilization. The biggest manufacture of matches and firecrackers located in Sivakasi, Virudhunagar District in Tamilnadu, South India. Area in Sivakasi, Virudhunagar almost all of its people and working employees directly and indirectly engaged with business of fireworks and crackers includes matches. There are around 750 factories and 80,000 workers are employed

in that area climatic condition for one of the reasons for firecrackers production. Climate in Sivakasi and Virudhunagar districts very hot and dry, so it is suitable for firework production. During firework production, more possibility of accidents and also workers health affect because more chemicals are manually handling by workers. Firecracker industry is a risky industry, from the place of fabricate, transportation and capacity of firecrackers which is a hazard to life and property. Non-stoichiometric proportions of ingredients in firecrackers cause accidents and health issues. Besides unhygienic conditions, improper training leads to dangerous worker. Lead poisoning, ulcers, damages to the central nervous system which is some major problems for workers working in firework industry. Child labour employment is major problem loss of lives at an early stage. So to reduce of accidents, workers welfare and child labour employment strictly enforced the Factories Act 1948 and PESO act in firework industries.

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## 2 Literature Review

From the paper (Sukumar and Subramanian 1992), trace elements in scalp hair of manufactures of fireworks, it is discussed Sivakasi Firework industry that 143 male and female labours of hair sample study test were taken. The methodology carried out in this is the hair is used as an indicator of elements pollution in the atmosphere. These samples were then analysed to find the presence of trace metal elements. And as result, it was found that higher level of chromium, magnesium and lead content. In that study, analysis of female workers had higher level of lead (Pb) and lower level of magnesium (Mn) as compared to the male workers. Due to higher-level exposure of magnesium (Mn), workers had a chronic headaches, dizziness and ulcers because of workers did not wear PPE.

From the paper (Padma 2014), agile augmentation of clean air in an around fire cracker industries located villages, we can observe that four common questions have been prepared and surveyed with the local peoples. The answer of each of these questions is interpreted and analysed in order to get a data. With the help of these data, they have concluded, that the awareness among was low and it is migrated by the help of proper training and self-motivation of the employees.

The paper (Li et al. 2014) "Urinary Perchlorate Exposure and Risk in Women of Reproductive Age in a Fireworks Production Area of China" focuses on the firework production area of Liuyang in China in accordance with the usage of perchlorate and its impact due to overusage is detailed. The methodology carried out in this paper is by the collection of various samples such as groundwater, surface water, farmland soil and urine samples of female workers in the respective industries. These samples of the research areas are compared with controlled areas, and the result is observed. The final result is seen to be that the concentrations of perchlorate in groundwater, surface water, and soil at the research area were all greater than that at the control area (Li et al. 2014), and also, the impact on female workers of reproductive age in the research area is higher when compared to others in controlled area. Thus, a conclusion detailed study regarding epidemiological should be carried out in the viewpoint of precautionary principle.

The study of perchlorate (Sugimoto and Isobe 2012) is further carried out in Sivakasi firework as well as safety match industries. The detailed study about this is carried out in paper "perchlorate contamination of groundwater from fireworks manufacturing area in South India" which focuses on the perchlorate contamination in the groundwater and surface water with reference to normal area. The result of this paper relives that the contamination is mostly due to these industries, and the contamination results in wastage to water and also engages to various diseases due to the usage of these water resources. The common mitigation strategy told in this paper is to make public awareness and low usage of perchlorate; antipollution measures are to be carried out.

# 3 Firework Manufacturing

## 3.1 Process in Firework Industry

Fireworks are made of pyrotechnic chemicals which have an ability of emitting heat, light, ‘sound, gas on ignition. Charcoal is commonly used in the firework industry. The distinctive chemical substances utilizing are sulphur, aluminium powder of various evaluations, barium nitrate, potassium nitrate, sodium nitrate, strontium nitrate, dextrin, charcoal, aluminium chips, iron chips, PVC powder, magnesium powder and boric acid. Strontium, barium and copper act as colouring agent. Binder carries the mixture together (Fig. 1).

Different stages of unit operations take place in firework manufacturing such as weighing, sieving, mixing, filling, fuse cutting, drying and finishing. All the mixing operations are done manually. Through the process of sieve by the help of wooden trays with meshed bottom, the chemicals are obtained in homogeneous mixture. Then the mixed chemicals are filled into the tubes or loading into the required boxes. Further, the fuses are kept inside and allowed to dry. Prepared platforms are used for drying the products. The drying process is carried out twice in the production line. Then manually the fireworks are packed in small boxes. It is done after drying process. Later these boxes are bundled together. In large bundles, the warning slips are placed.

- **Fuel**: Charcoal that is black powder commonly used fuel in fireworks.
- **Oxidizing Agents**: It is mostly nitrates, chlorates used. The function is to produce the oxygen needed in order to burn the mixture within the fireworks.
- **Reducing Agents**: The function of the reducing agents to burn the oxygen provide by the oxidizing agents. Sulphur and charcoal act as reducing agents, and these are react with oxygen to form sulphur dioxide and carbon dioxide, respectively.
- **Regulators and Colouring Agents**: To regulate the speed of the reaction and colouring agent’s metals can be added, that is aluminium, titanium, copper, strontium, barium.

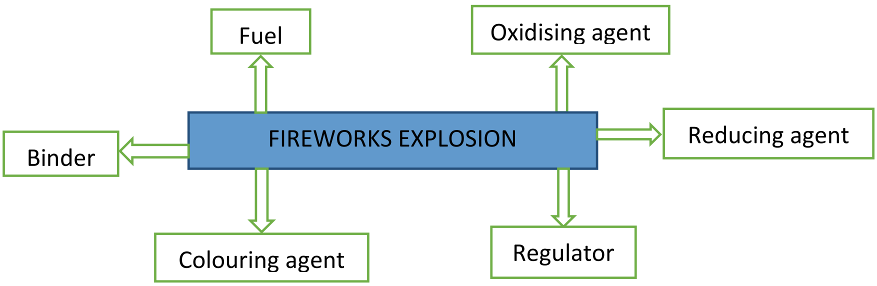


**Fig. 1** Requirements for fireworks explosion

**Table 1** Causes and hazards in manufacturing (Dhruv Katoria 2013)

| Cause | Hazards in manufacturing |
|---|---|
| Production phase | Manual handling chemicals, friction, static electricity, human errors |
| Drying on heating platforms stage | Dust accumulation, overheating |
| Transportation stage | Inattentive handling, impact of overloading, material movement |

- **Binders**: It is used to hold the mixture. The most commonly used binders are dextrin, type of starch.

# 4 Potential Hazards

## *4.1 Cause of Hazards During Manufacturing Process*

See Table 1.

## *4.2 Effects of Chemicals*

The major chemicals that are mostly used in the firework industries are aluminium, sulphur, barium nitrate, potassium nitrate, copper chloride, etc. In this, the impacts of these major chemicals are discussed below.

### 4.2.1 Aluminium

It is used as a fuel. It produces white sparks and flames. It causes irritation to eyes and skin and also causes metallic taste in the mouth, headache and fever. Fine dust exposes to cause scarring of the lungs with the symptoms of cough and shortness of breath.

### 4.2.2 Sulphur

It is used for white and colour smoke composition, flash and sound blend. When inhale, it irritates the nose, throat, and airways to cause coughing, wheezing, shortness of breath. Chronic exposure may harm the respiratory system.

#### 4.2.3 Barium Nitrate

It is used as oxidizer. It can produce white or silver effects with aluminium. High exposure can cause diarrhoea, irregular heartbeat, muscle weakness, tremors. It irritates the nose, throat and chest. Repeated exposure leads to damage to the kidney.

#### 4.2.4 Potassium Nitrate

It is used in safety fuse and lift charges. It causes irritation to nose and throat. Higher exposure can cause headache, methemoglobinemia, kidney problems and carcinogenic effect.

#### 4.2.5 Copper Chloride

Salivation, nausea, stomach pain and diarrhoea cause stomach irritation. High level of exposure can cause thickening of the skin and ulcers and may damage the liver and kidney.

### *4.3 Mode of Contact*

The various modes of intake of these chemicals into workers are by

- Injection
- Inhalation
- Absorption
- Ingestion.

On these ways, the major in way of the pollution into the workers is mostly due to inhalation.

The workers in fireworks industries are affected by asthma, eye infection, kidney failure and TB due to hazardous chemical pollution in air by fireworks industries which results among 90 per cent of communities/workers

#### 4.3.1 Reason and Cause for Pollution

- During improper chemical stacking/unstacking.
- Improper handling of decomposed material.
- Improper chemical disposal.
- Working in open roofing area and unclean the room.
- Improper storage.

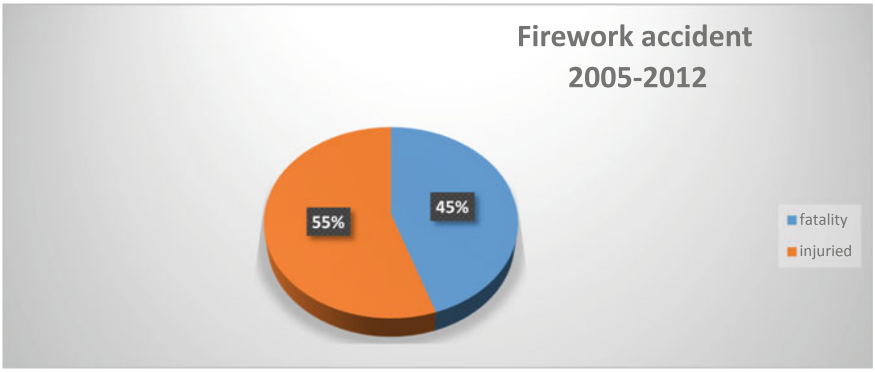


**Fig. 2** Firework accident

# 5 Materials and Methods

## *5.1 Data Source*

The accident data of fireworks accidents for the past seven years (2005–2012) were collected from the status of pollution abatement measures, Central Pollution of Control Board, Delhi. The total number of accidents was 23, fatalities 124 and injured 153 (Board 2017). The data were analysed for the reasons to which the accidents were occurred. Then the data are entered in the MS Excel format, and graphs were plotted against all the variables (Fig. 2).

Further, from the data provided from the paper (Board 2017) represented in the literature review, the detailed study and documents regarding the hair loss and other related diseases as well as the element traces are identified for both male and female workers and represented in (Table 2; Fig. 3).

# 6 Discussion

As a final, we are knowledge about the various chemicals and its impacts on the workers in Sivakasi firework zone. In sections such as filling and fancy, the chemicals are filled manually by the workers in the powder form. During this, the air dusts are accumulated leading to various risks and health effects. As the above data shows that most of the accidents lead in fatality.

Thus, we need to focus on the mitigation strategies to reduce these hazardous impacts as well as the occupational health effects on the workers. So some the mitigation strategies that are discussed here are:

**Table 2** Level of elements in hair of male and female (Sukumar and Subramanian 1992)

| Sample No | Male subjects | No of samples | Mean concentration (ppm S.E.)in hair | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Cadmium | Chromium | Copper | Manganese | Nickel | Lead |
| 1 | Control(nv) | 24 | 0.3 ± 0.1 | 2.8 ± 0.4 | 13.0 ± 1.5 | 3.5 ± 0.8 | 0.2 ± 0.06 | 6.5 ± 0.9 |
| 2 | Workers(nv,sm,h) | 14 | 0.4 ± 0.1 | 4.1 ± 0.4* | 13.9 ± 0.2 | 12.9 ± 3.3** | 0.4 ± 0.2 | 9.1 ± 0.6 |
| 3 | Workers(nv,sm) | 17 | 0.3 ± 0.2 | 4.4 ± 0.4* | 18.7 ± 3.9 | 13.7 ± 2.9*** | 0.4 ± 0.1 | 8.9 ± 1.4 |
| 4 | Workers(nv) | 21 | 0.3 ± 0.1 | 5.1 ± 0.8** | 16.5 ± 3.3 | 12.4 ± 1.5”” | 0.4 ± 0.2 | 8.9 ± 1.0 |
| 5 | Workers(nv,v) | 24 | 0.2 ± 0.1 | 4.9 ± 0.8** | 18.3 ± 3.2 | 12.8 ± 2.4”** | 0.6 ± 0.2 | 8.5 ± 1.2 |
| 6 | Workers(h) | 16 | 0.3 ± 0.1 | 3.9 ± 0.4* | 15.5 ± 0.6 | 12.8 ± 2.8”* | 0.7 ± 0.2 | 7.9 ± 1.2 |
| 7 | Workers with N.D. | 8 | 0.3 ± 0.1 | 5.7 ± 0.9** | 11.5 ± 5.4 | 13.0 ± 3.3” | 0.4 ± 0.1 | 13.1 ± 5.7* |
| Sample No | Female subjects | No of samples | Mean concentration (ppm S.E.)in Hair | | | | | |
| | | | Cadmium | Chromium | Copper | Manganese | Nickel | Lead |
| 1 | Control | 18 | 0.6 ± 0.06 | 1.9 ± 0.1 | 37.7 ± 4.2 | 6.5 ± 0.9 | 0.5 ± 0.1 | 13.1 ± 1.5 |
| 2 | Workers(1–15 year age group) | 10 | 0.8 ± 0.2 | 1.7 ± 0.3 | 35.2 ± 8.8 | 12.7 ± 1.9*** | 0.6 ± 0.2 | 10.4 ± 2.5 |
| 3 | Workers(16–30 age) | 64 | 0.8 ± 0.1 | 2.2 ± 0.3 | 33.4 ± 2.8 | 14.9 ± 1.9* | 0.9 ± 0.2 | 5.65 ± 0.8” |
| 4 | Workers(total) | 77 | 0.7 ± 0.08 | 2.2 ± 0.3 | 32.4 ± 2.6 | 14.5 ± 1.6 ** | 0.8 ± 0.2 | 6.2 ± 0.7”* |
| 5 | Workers(nv, h) | 63 | 0.8 ± 0.09 | 1.8 ± 0.2 | 31.5 ± 2.9 | 12.7 ± 1.5* | 0.7 ± 0.2 | 5.9 ± 0.7”* |
| 6 | Workers(other disease) | 9 | 0.3 ± 0.1 | 2.9 ± 1.1 | 44.5 ± 0.7 | 27.4 ± 6.8 | 1.0 ± 0.3 | 8.3 ± 3.4 |
| 7 | Workers (nv, ns, h) | 54 | 0.6 ± 0.2 | 1.8 ± 0.2 | 32.3 ± 3.2 | 13.6 ± 1.8 | 0.8 ± 0.2 | 6.4 ± 0.8 |
| 8 | Workers with chewing tobacco | 13 | 0.6 ± 0.1 | 1.65 ± 0.2 | 29.9 ± 6.2 | 8.7 ± 3.3 | 0.8 ± 0.3 | 4.6 ± 1.3 |

Nv-non vegetarian, v-vegetarian, sm-smoker, h-healthy, n.d-nervous disease(sustained headache and dizziness). Significance: between the controls and workers,*$P < 0.05$,**$P < 0.02$,***$P < 0.01$,” $P < 0.005$,”*$P < 0.002$,”**$P < 0.001$.”” $p < 0.0005$

Nv-non vegetarian, ns-non smoker, h-healthy, O.D. ulcer and asthma. Significance between controls and workers *$P < 0.05$,**$P < 0.02$,***$P < 0.001$,” $P < 0.0002$,”*$P < 0.0001$

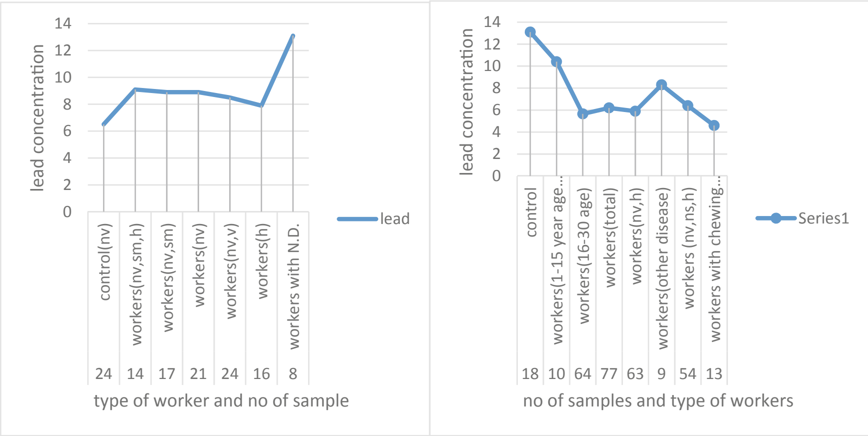


**Fig. 3** Lead concentration male and female

- Constant supervision and monitoring of employees activity to check their unsafe act.
- The main causative fireworks were whistles these fireworks should not be carried close to the body. Fuses are highly combustible since they are coated with gunpowder. As a consequence, required whistles should be equipped with safety fuses. They are covered with plastic, thereby allowing ignition only from the tip (Selvakumar et al. 2013).
- Usage of proper PPE such as mask and gloves.
- Fire extinguishers as well as fire protection systems are to be implemented as per standards and must be maintained regularly.
- The usage of the chemicals must be within the permissible limit and must be periodically checked.
- Awareness among the communities/workers must be educated in order to increase the personal safety.
- Rubber mat must be covered on the floor.
- Dragging of materials over the floor must be avoided.
- Separate places for all chemical mixture for mixing as well as filling process.
- Proper signage and board placement.
- Distance between filling and mixing zone must be 18 m.
- Manufacturing, transportation, storage and retail sales of fireworks must be carried out as per the rules and regulations implemented in the standard NFPA 1124 (Association 2012).

## 7 Result and Conclusion

Thus to obtain a successful health and safety program, it is necessary to make a strong management committee which focus on the welfare of the workers and also maintain a healthy workplace. The management must focus on the following hazards and should provide the necessary aids and control measures. Though most of the industries in Sivakasi are small scale, the workers are illiterate and are not aware of the hazards.

Though government provides required welfare, they must also provide additional focus on these hazards by periodic visit and generalizing the awareness among the workers as well the neighbours. Apart from the contribution of the government, the management must also focus on the occupational hazards of the employees.

The required safety regulations must be established, and these rules must include the permissible limit usage of all these hazardous chemicals. Further, most of the accidents occur due to rough handling of the chemicals which requires more care.

Human error plays a vital role in the accident that takes place in the industry. Thus, proper training and inspections must be carried out periodically. Additionally to reduce the fire accident incidents, the fire assessment can be carried out. As a result, life plays a vital role in the world, and thus, the industries must focus on the safety rather than in production.

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# Application of Integrated Risk-Based Approach to Safety Design of High Speed LNG Powered Vessels

**Rouzbeh Abbassi, Ushen Kam, Mohammad Dadashzadeh, and Vikram Garaniya**

## 1 Introduction

The shipping industry is facing increasing claims to meet restricted environmental regulations and escalating operation costs. To mitigate these problems, cleaner and more cost-effective fuels are required to power the new generation of vessels. Currently, the high speed ferry sector is using lightweight diesel engines burning distillate fuels. However, the increasing demand for higher installed power requirement in such vessels, coupled with fuel costs, has placed further constraints on this sector (Bennett 2011). Liquefied natural gas (LNG), which meets these new requirements, is now becoming popular as an alternative fuel in this sector.

Liquefied natural gas is obtained through natural gas liquefaction by cooling it to approximately 162 °C at atmospheric pressure. This process reduces the volume approximately 600 times; hence, it is more competent for transportation and storage compared to conventional hydrocarbon fuels (Ramos et al. 2014).

Due to the increasing the number of new generation LNG powered vessels hitting the market, the risks of accidents must be adequately addressed and mitigated to avoid a major catastrophe. Accidents involving offshore facilities or petrochemical plants have proved that the consequences on human lives and material by the release of LNG can be extremely severe. Catastrophic LNG accidents date back to the 1940s. In Cleveland, Ohio, an explosion and fire due to the release of LNG caused 128 deaths. A more recent Skikda accident in 2004 resulted in 27 deaths and 74 injuries,

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with material damages both within and outside the plant due to fire and explosion (Neves et al. 2008).

The release of LNG can result in a liquid pool formation followed by vapourization due to the ambient temperature. A pool fire is the result of an immediate ignition. Another possible scenario is the vapour cloud explosion (VCE). The VCE occurs due to the delayed ignition of flammable vapour clouds formed by dispersion of volatized flammable vapour over the vessel (Dadashzadeh et al. 2013). Proposed an integrated accident scenario through which the interaction between the VCE and pool fire, due to the release of LNG on an offshore platform, is addressed. It was concluded in (Dadashzadeh et al. 2013) that a delayed ignition causes the fuel vapour to disperse and form a vapour cloud in the process area, for which an ignition source on the vessel can lead to a VCE. Heat load caused by the explosion further enhances the vapourization of the liquid pool resulting in a pool fire.

The studies on modelling fire and explosion consequences due to LNG release range from empirical models to complex computational fluid dynamics (CFD) simulation. To estimate the heat radiation, (Rajendram et al. 2015; van den Bosch et al. 1996; Woodward and Pitblado 2010) employed the solid-flame model due to its simplicity and relatively accurate results. CFD codes have been extensively used to model the catastrophic consequences associated with the release of hazardous gases, amongst those which are using CFD codes are FLACS and FDS for gas dispersion modelling (Hansen et al. 2009; Dadashzadeh et al. 2016, 2013; Abbassi et al. 2012), using FLACS CFD code for VCE modelling (Dadashzadeh et al. 2013; Dadashzadeh et al. 2013; Gavelli et al. 2011), and using CFD code FDS for fire modelling (Dadashzadeh et al. 2013; Baalisampang et al. 2017). A more elaborate fire modelling can be conducted by using CFD codes. The benefits of CFD models over empirical models include the fundamental physics of fluid flow, their flexibility in considering a wider range of boundary conditions, and the ability to model accurately detailed geometries (HSE 2004; HSE 2010). According to (Turner and Sari 2012), the empirical model known as the multi-energy (ME) method has been proven to produce a relatively accurate description of the explosion and the subsequent overpressure.

The solid-flame model, CFD approach, and ME method are employed to model the fire and explosion consequences in this study. Upon completion of the accident modelling, a risk assessment is conducted to quantify the severity of the effects on a person in the vicinity of the affected areas. While many studies have assessed the fire and explosion scenario separately, the interaction of the two phenomena that may occur as an escalating scenario may have a different impact on the recipient, especially on a relatively small footprint vessel, e.g. high speed ferry. This study will investigate the appropriate LNG fuel tank location on a high speed ferry by implementing the developed integrated risk-based methodology of (Dadashzadeh et al. 2013) to assess the interaction of the two phenomena, i.e. explosion and fire, which aids in determining the severity of human impact in such accidents.

# 2 Risk-Based Methodology

Figure 1 demonstrates the proposed risk-based methodology developed in this study. A potential LNG release scenario is defined based on the release flow rate, prevailing wind conditions, ambient temperature and the release duration. The fire and explosion modelling are carried out to obtain values of the corresponding radiation heat flux and overpressure. Results obtained from the consequence modelling are applied to estimate the impact on a person. Probit functions are employed to calculate the probabilities of effects due to the radiation heat and overpressure. The score scheme of (Dadashzadeh et al. 2013) is used and integrated into the impact probabilities to calculate the severity index of each impact. The maximum severity index amongst the various effects of the fire and explosion is considered as the fire or explosion risk index. Finally, the total risk index at the affected areas of the vessel is obtained as a summation of the individual risk indexes. The overall risk profile on the vessel is developed which is used to determine the LNG fuel tank location.

## 2.1 Consequence Modelling

The release of LNG forms the LNG pool which vapourises due to the ambient temperature; hence, the fuel vapour is formed. Depending on the ignition time, the scenario is now twofold: dispersion of fuel vapour, formation of fuel vapour cloud and a delayed ignition which results in a VCE in confined and semi-confined area; and immediate ignition of the fuel vapour formed over the LNG fuel and the pool fire.

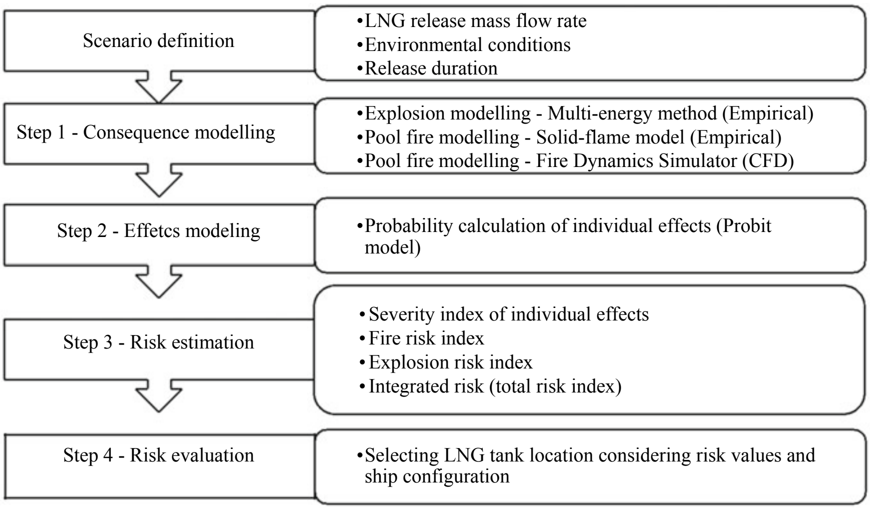


**Fig. 1** The developed risk-based methodology

To model VCE and pool fire, both empirical models and CFD tools are employed in the current study. The modelling details are explained in detail through the following sections.

### 2.1.1 Explosion Modelling

ME method is commonly used for calculating the overpressure due to a hydrocarbon VCE. This empirical model is confirmed as being practical in VCE modelling of confined or obstructed spaces and it is easy to apply and was used in similar VCE modelling studies (Beccantini et al. 2007; Mélani et al. 2009). The layout of a high speed LNG powered ferry is highly congested due to the presence of the cargo and other onboard facilities. Hence, the ME method is applicable which assumes that only part of the combustion energy of the flammable vapour which is confined participates in the pressure generation of the explosion (Turner and Sari 2012; van den Berg 1985). In this study, the vapour is idealized as a hemisphere and the radius of the hemisphere is used to estimate the area of dispersion.

First step in ME method is to define the vapour cloud dimensions to calculate the cloud volume and its dispersion area. In ME method, the blast severity is an effective player which is in the range of 1--10 for low to high congestion, respectively. The study assumes the dispersion of the fuel vapour in the process area which is confined and highly congested; hence the worst-case value of 10 is assigned in ME method. This helps to determine the explosion energy ($E$). The detailed procedure to calculate the explosion energy is not in the scope of this study and is available in (Assael and Kakosimos 2010). Equation (1) calculates the scaled distance ($r'$) as a function of explosion energy ($E$), distance from the centre of the explosion ($x$) and the ambient pressure ($P_a$). Considering the blast severity of 10 in this study, the scaled distance is then used in Eq. (2) to obtain the explosion overpressure at the distance ($x$) from the centre of the explosion (van den Berg 1985; Assael and Kakosimos 2010).

$$r' = x\left(\frac{E}{P_a}\right)^{-1/3}, \tag{1}$$

$$P_s = 10^{-b \log_{10} r' - c}, \tag{2}$$

For the blast severity coefficient of 10 which is the assumption of this study, Table 1 represents different values for coefficients $b$ and $c$, which are based on the range of scaled distance ($r'$).

**Table 1** Coefficients $b$ and $c$ used in Eq. (2) (Assael and Kakosimos 2010)

| Coefficient of | Range of $r'$ | $b$ | $c$ |
|---|---|---|---|
| *Strength of blast* | | | |
| 10 | $0.15 < r' < 1.0$ | 2.3721 | 0.3372 |
| | $1.0 \le r' \le 2.5$ | 1.5236 | 0.3372 |
| | $r' > 2.5$ | 1.1188 | 0.5120 |

### 2.1.2 Fire Modelling

To calculate the pool fire dimensions and the corresponding heat radiation, this study employed two approaches, i.e. the solid-flame model (Mudan 1987), CFD code FDS (NIST 2010).

According to (McGrattan et al. 2000), amongst the empirical models used for the pool fire modelling, the solid-flame model has the advantage of representing the fire as a solid cylinder emitting thermal radiation from its side. The method considers the flame as a solid body in which the amount of heat, $q'$ (kW/m$^2$), received by a target, e.g. human, is calculated as

$$q' = \text{SEP}_{\text{act}} \times F_{\text{view}} \times \tau_a, \tag{3}$$

where $\text{SEP}_{\text{act}}$ (kW/m$^2$) is the actual surface emitting power, $F_{\text{view}}$ $(-)$ is the radiation fraction which is received by the target at a certain distance from the surface of the flame, and $\tau_a$ $(-)$ is the atmospheric transmissivity which is a value between 0 and 1 which depends on the atmospheric humidity, soot formation, and the dissipation due to the distance (Heymes et al. 2013). The details procedures on modelling the pool fire, using solid-flame model, are available in (Assael and Kakosimos 2010; Khakzad et al. 2018). The burning rate value of the natural gas is used to calculate the flame dimensions and its actual surface emitting power ($\text{SEP}_{\text{act}}$). Having the flame dimensions (Fig. 2), i.e. its length ($L$), depth ($D$), the angle of tilt ($\theta$), one may calculate the $F_{\text{view}}$ as explained in (Assael and Kakosimos 2010; Mudan 1987).

Using CFD tools to model the pool fire can overcome the limitations of empirical models, e.g. to consider the detailed geometry, to take into account the area properties, etc.

In this study, FDS (NIST 2010) was employed to perform the pool fire simulation. The circular pool fire diameter and the burning rate are two parameters extracted from the solid-flame model calculations to be used in the fire simulation of FDS. Developed by the National Institute of Standards and Technology (NIST) of the US Department of Commerce, FDS uses partial differential equations to describe the transportation of mass, momentum, and energy for the fire and its impact in the surrounding area. For turbulence modelling, FDS employs Large-Eddy Simulation (LES) method. In a three-dimensional cartesian grid, FDS uses partial differential equations and solves the conservation equations of mass, momentum, and energy through a finite volume technique (NIST 2010).

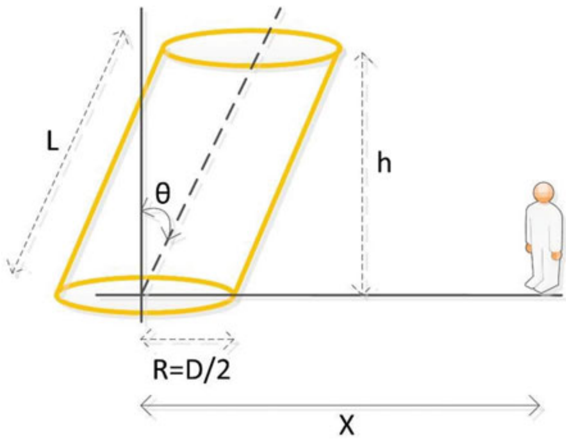


**Fig. 2** Flame as tilted cylinder (Assael and Kakosimos 2010)

## 2.2 Effects Modelling

Only the adverse impacts on the individuals on the vessel are considered in this study. Probit model is used to determine the probabilities of effects as Eq. (4): First degree burn, second degree burn and death due to the fire heat radiation; injury from eardrum rupture, death from lung damage, death from head impact, and death from whole body displacement.

$$\mathrm{Pr} = c_1 + c_2 \ln D, \tag{4}$$

The parameters $c_1$ and $c_2$ and the calculation procedure for the dose ($D$) depend on the effect and they are available in (Assael and Kakosimos 2010). The probit value (Pr) is then used in Eq. (5) to calculate the probabilities for each effect (Dadashzadeh et al. 2018).

$$P_{\mathrm{i}} = F_{\mathrm{k}} \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{\mathrm{Pr} - 5}{\sqrt{2}}\right)\right], \tag{5}$$

The subscript i denotes the individual effect due to fire or explosion.

## 2.3 Risk Estimation

The severity index ($\mathrm{Risk_i}$) for each individual effect is calculated as Eq. (6). $S_{\mathrm{i}}$ in Eq. (6) denotes the severity score of the mentioned seven major human effects which are presented in Table 2 (Dadashzadeh et al. 2013). The risk associated with fire ($\mathrm{Risk_{fire}}$), explosion ($\mathrm{Risk_{explosion}}$), and the total risk ($\mathrm{Risk_{total}}$) are realized through Eqs. (7), (8) and (9).

**Table 2** Scores ($S$) for seven major human effects caused by fire and explosion (Dadashzadeh et al. 2013)

| Hazard | Effects | Score |
|---|---|---|
| | First degree burn injury | 2 |
| Fire | Second degree burn injury | 5 |
| | Death | 10 |
| | Lung damage death | 8 |
| Explosion | Eardrum rupture injury | 5 |
| | Head impact death | 10 |
| | Whole body displacement death | 10 |

$$\mathrm{Risk_i} = S_\mathrm{i} \times P_\mathrm{i}, \tag{6}$$

$$\mathrm{Risk_{fire}} = \mathrm{Max}[\mathrm{Risk_{1st}}, \mathrm{Risk_{2nd}}, \mathrm{Risk_{death}}], \tag{7}$$

$$\mathrm{Risk_{explosion}} = \mathrm{Max}\left[\mathrm{Risk_{lung}}, \mathrm{Risk_{eardrum}}, \mathrm{Risk_{head}}, \mathrm{Risk_{body}}\right], \tag{8}$$

$$\mathrm{Risk_{total}} = \sum\left(\mathrm{Risk_{fire}} + \mathrm{Risk_{explosion}}\right), \tag{9}$$

### 2.4 *Risk Evaluation*

Developing the risk contour over the speed of the vessel, the value of the risk will be between 0 and 20. The developed scheme allows one to create an overall risk profile on a high speed LNG powered vessel which enables assignment of the safest location of the LNG tank on the vessel.

## 3 Case Study

In this modelling scenario, an LNG powered 99 m INCAT high speed ferry involved in a collision with another vessel is used. The collision resulted in the breach of the hull and a rupture of 0.1 m diameter to the LNG fuel tank. Assuming the discharge coefficient to be 0.62 (i.e. for a hole with sharp and steep edges), the LNG is released at a mass flow rate of 12.65 kg/s for 100 s at a wind speed of 5 knots (2.57 m/s) and an ambient temperature of 25 °C. LNG is vapourized and a flammable vapour cloud is formed at the process area. At 60 s, a delayed ignition occurs resulting in a VCE. Subsequently, the heat load generated from the VCE burns back to the LNG pool resulting in a pool fire at the release location. The pool fire continues to burn for a further 40 s. The accident scenario is assumed to be identical for each of the six

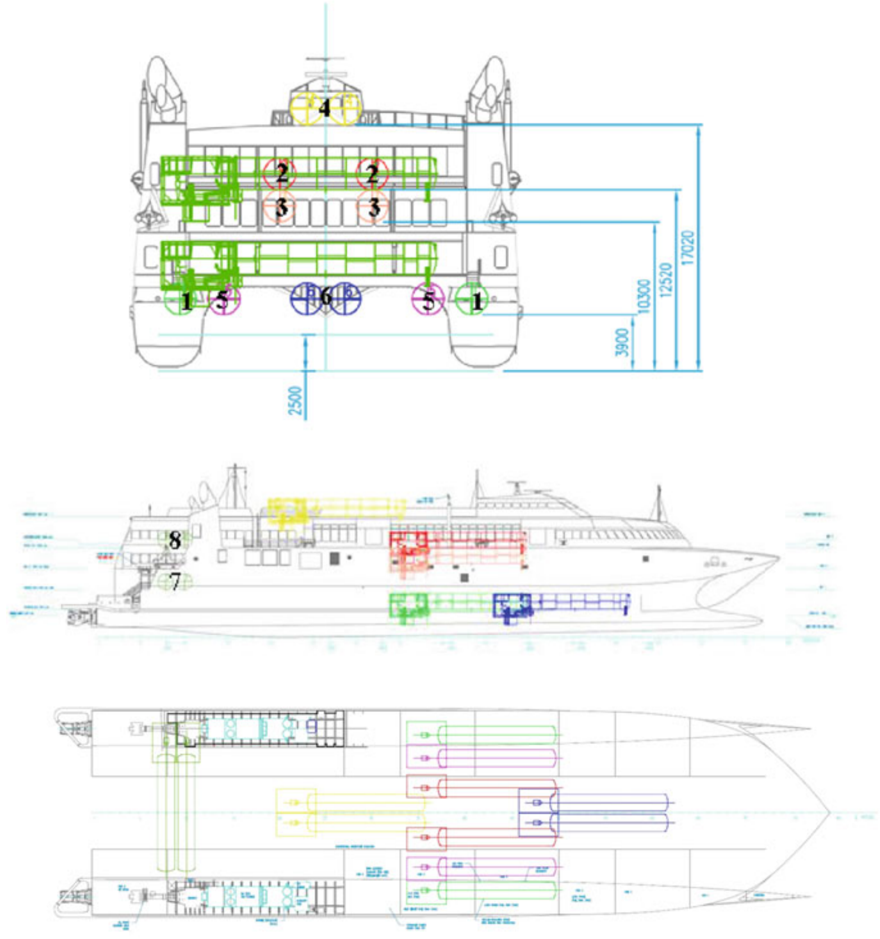


**Fig. 3** Proposed LNG tank locations on the vessel

different tank positions modelled in this study. The options for the tank location are demonstrated in Fig. 3. Tank positions 1 and 5 have been excluded from this study due to the unacceptable FCN values from INCAT's study.

## *3.1 Explosion Modelling*

The mass of LNG released was defined based on the leak duration. Using the approach provided by (Assael and Kakosimos 2010), the volume of the dispersed natural gas was then estimated. Based on the combustion reaction, assuming 100% of methane in natural gas, the volume of the cloud was estimated to be ten times the volume of the existing natural gas. The formed vapour cloud was assumed to be a hemisphere and the depression area was estimated. The energy of explosion was calculated. Assuming the volume of cloud to be equal to the available space (i.e. blast coefficient = 10), the overpressure and positive time phase of the explosion, with respect to the scaled distance, was calculated.

### *3.2 Fire Modelling*

In the solid-flame model, the LNG spillage taking part in the pool fire is assumed to be a function of the remaining release time after the occurrence of explosion. Assuming a pool thickness of 0.05 m, the pool diameter was estimated to be 5.4 m. The burning rate of the pool fire was determined, followed by calculation of the flame length. The maximum surface emitting power ($SEP_{max}$) was calculated which was used to obtain the actual surface emitting power ($SEP_{act)}$ of the pool fire. Employing Eq. (3), the radiation heat flux at different distances from the surface of the flame was calculated.

For the CFD model, a simplistic version of the vessel deck geometry was considered for each deck based on a vessel of similar type, the 99 m high speed vessel Francisco (INCAT Hull 069). A grid resolution of 0.25 m was used in the simulation volume obtained through a sensitivity analysis. The circular pool diameter and burning rate, calculated through the solid-flame model, were used as input parameters for the pool fire modelling in FDS. A lumped fuel mixture was created to better represent LNG which is often comprised of a mixture of gases. A constant LNG pool depth was assigned in the simulation due to the lack of a dispersion model. Finally, the fuel mixture was used as the reactive fuel to create a vent in the designed geometry to represent the burning pool fire. Monitoring devices were placed at different distances from the burning pool to measure the radiation heat flux.

### *3.3 Probit Modelling*

The probit model for the fire scenario is a function of the thermal radiation dose. The thermal radiation dose was obtained from the radiation heat flux calculated from the pool fire model and an estimated escape time of the recipient (Assael and Kakosimos 2010). For the explosion scenario, the scaled distance based on the recipient's position was determined from the explosion energy. The explosion impulse was also calculated as an input parameter for the probit model in explosion effect modelling. The coefficients c1 and c2 used in the calculation of the probit models for each of the seven human effects, caused by the fire and explosion, are adopted from (TNO 1992).

## 4 Results and Discussion

Table 3 presents the parameters calculated for the explosion overpressure through the ME method.

Figure 4 demonstrates the explosion overpressure at different distances from the centre of the explosion calculated with ME method. One may observe that the maximum value of overpressure is at the distance 20 m from the point of explosion while it drops moving further from the centre of the explosion. The minimum threshold of the explosion overpressure for 100% fatality is 0.7 bar (Shardlow et al. 2009) which is obtained after 60 m from the explosion point. The overpressure affects most of the vessel area due to its magnitude, considering that the worst-case scenario for the explosion was employed in this model (explosion severity of 10).

Figure 5 illustrates the explosion risk profile. It is observed that up to a radius of around 40 m, the explosion risk value is over 10 which is high. After 50 m, the

**Table 3** Parameters used for ME method explosion modelling

| Parameters | Value | Units |
|---|---|---|
| Mass of LNG leaked | 759.03 | kg |
| Volume of natural gas | 1084.33 | $m^3$ |
| Volume of cloud | 10,843.3 | $m^3$ |
| Cloud diameter | 17.3 | m |
| Energy of the explosion | 38,103.0 | MJ |

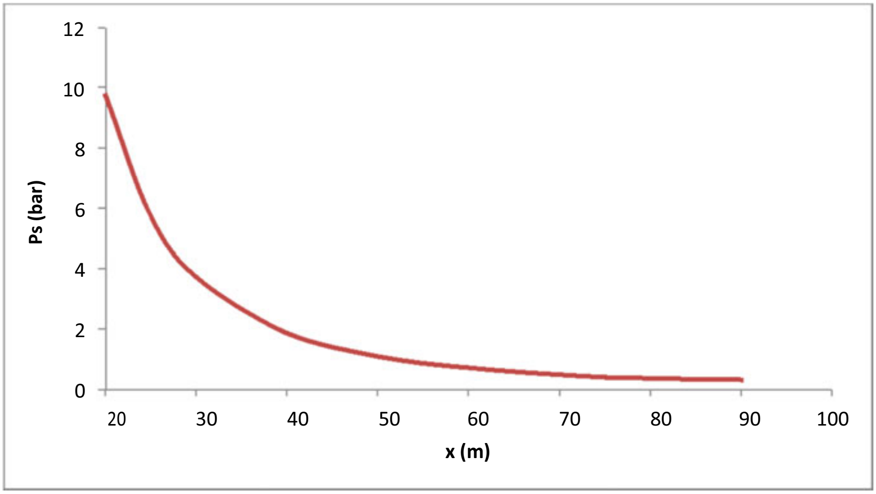


**Fig. 4** Explosion overpressure, obtained by ME method, at different distances from the explosion point

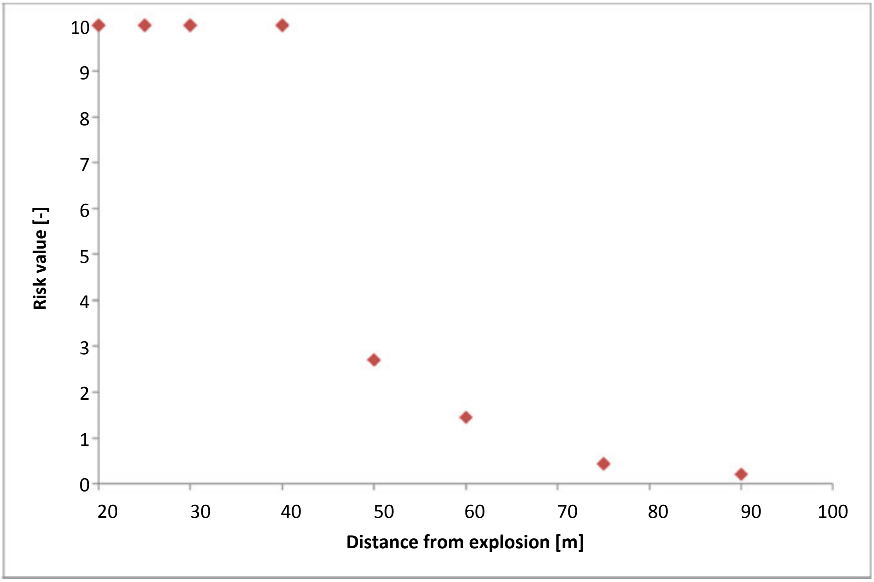


**Fig. 5** Explosion risk profile over the high speed vessel

explosion risk is less than 3 and it continues to drop by moving further from the centre of the explosion.

The calculated details to estimate the radiation heat flux of the pool fire through solid-flame model are presented in Table 4.

As demonstrated in Fig. 6, the radiation heat flux estimated from the solid-flame model ranges from 0.11 to 26.64 kW/m$^2$. The minimum threshold that causes pain to a human after 1 min of exposure is 2 kW/m$^2$ (OGP 2010). Based on Fig. 6, to be a safe distance from the surface of the flame, one must be at a distance further than 20 m from the flame surface. The external factors such as the wind conditions also influence the estimated radiation heat flux of the pool fire, with an increase in wind

**Table 4** Parameters used for solid-flame fire modelling

| Parameters | Value | Units |
|---|---|---|
| Mass flow rate of LNG | 12.65 | kg/s |
| Volume of released LNG | 1.145 | m$^3$ |
| Pool diameter | 5.4 | m |
| Burning rate | 0.078 | kg/m$^2$s |
| Flame length | 13.55 | m |
| SEPact | 33.69 | kW/m$^2$ |

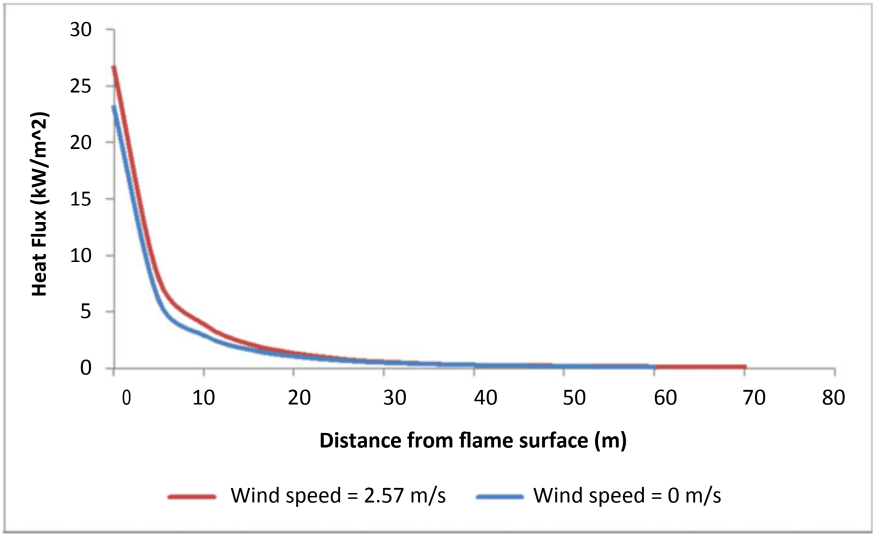


**Fig. 6** Heat radiation, obtained by solid-flame model, at different distances for the surface of the fire

speed resulting in a larger tilt angle of the flame and subsequently a higher radiation heat flux being emitted to the receptor.

Figure 7 demonstrates the fire risk profile based on the distance from the surface of the fire. One may observe that less than 5 m from the surface of the flame, the fire risk drops to less than 2 which is safe (minimum risk is due to first degree burn with the value of 2).

## *4.1 Integration of Effects*

Figure 8 demonstrates the total risk contours for the LNG tank fuel position. Rhinoceros 5.0 with the grid sizes 10 m was used to present the risk profile on the vessel. Each contour represents the border for the zone with a range of risk value, e.g. the contour with the red colour represents the boundary for the risk zone 8–10. The tank which is represented in Fig. 8 is tank position 4. One may also observe the individual risk contours within the range of 0--10.

While the highest risk value due to the fire was obtained in the vicinity of 2 m from the release location, the total risk values are significantly higher and cover much larger areas on the vessel.

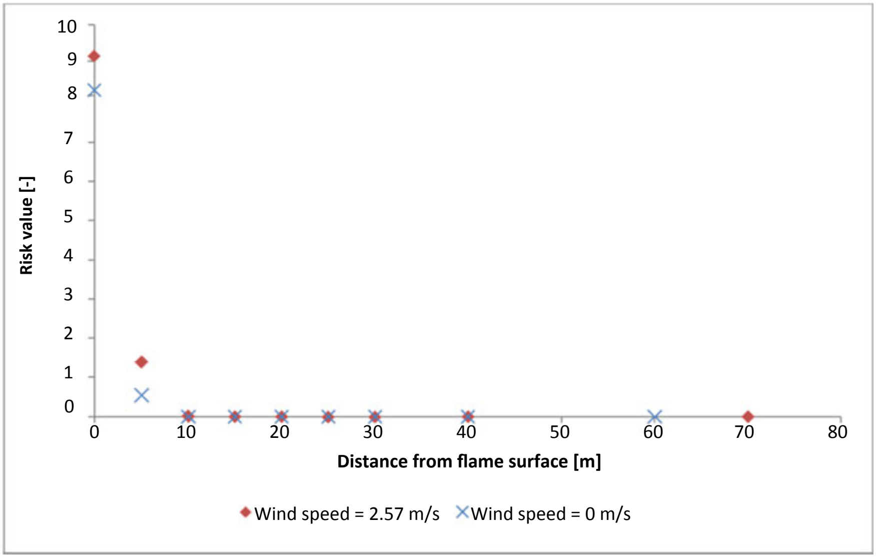


**Fig. 7** Fire risk profile over the high speed vessel

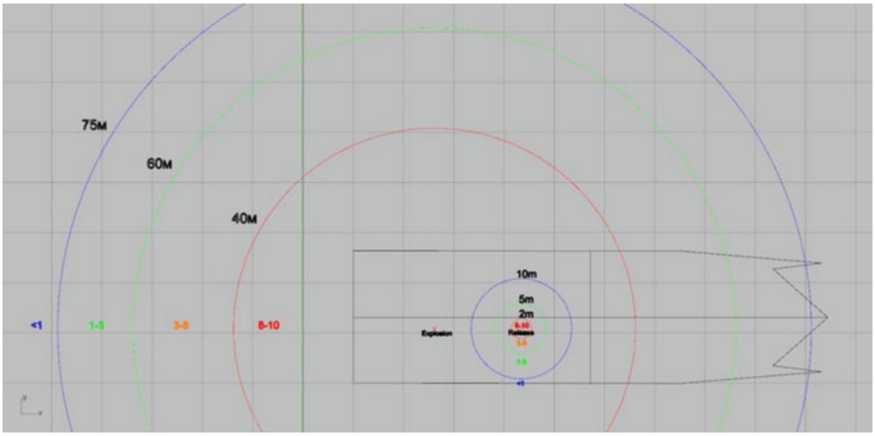


**Fig. 8** Integrated risk profile over the speed vessel

## *4.2 Comparison of CFD Results*

The average radiation heat flux with respect to the centre of the flame measured for the different tank positions in FDS is used to compare with the solid-flame model (no-wind condition) as demonstrated in Fig. 9.

Considering the assumption of the pool fire burning in the open for the solid-flame model, tank position 4 that was located on the roof of the vessel possessed

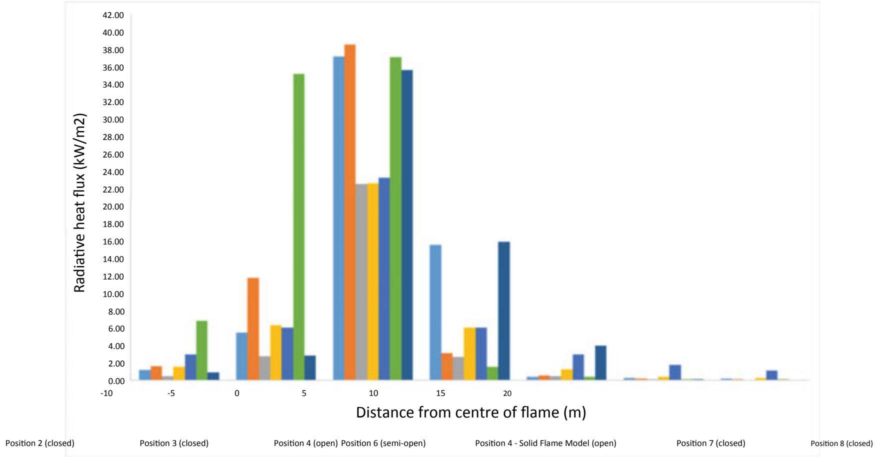


**Fig. 9** Comparison of radiation heat flux for different tank positions

similar characteristics as a comparison model. It was observed that FDS slightly under-predicted the radiation heat flux emitted. It was concluded in (Benucci and Uguccioni 2010) that this under-prediction may be due to the heat absorption from the surrounding wall and material characteristics which the solid-flame model is not able to consider. It was also observed in this study that fire occurrence in a closed location measured significantly higher values of radiation heat flux at the centre of the flame 5 m away as compared to the open-air scenario, resulting in a significant increase in the fire risk index at the location. This is the result of what is known as a ceiling jet, caused by the turbulent diffusion flame above the burning fuel. When the flame impinges on the ceiling of the vessel deck, the unburned gases spread out radially and entrain air for combustion. A circular flame is then established under the ceiling, resulting in downward thermal radiation; hence, a significantly higher value of radiation heat flux was observed for the scenarios in a closed location. The simulation results showed that tank position 4 recorded the lowest radiation heat flux with respect to the distance from the flame. Furthermore, a device placed to measure the radiation heat flux 20 m from the flame, which is approximately the location of the wheelhouse, recorded an average value of 0.01 kW/m$^2$, suggesting that it is safe for the personnel operating in the wheelhouse. Hence, tank position 4 is the most suitable location.

The integrated risk assessment methodology, proposed in the current study, confirms that to evaluate the effects of fire and explosion accidents on a speeding LNG powered vessel, the interactions between both phenomena must be considered. The proposed risk-based approach also considers the integrated adverse effects because of both fire and explosion which is an aid in safer design of such facilities and in more effective emergency plans preparedness.

## 5 Conclusion

The consequences of the release of LNG on a high speed ferry due to collision were investigated and modelled using the solid-flame model and CFD code FDS for the fire, and the ME method for the explosion. The interactions between both associated consequences (fire and explosion) were considered rather than individual consequences. This approach was used to model the VCE and subsequent pool fire scenario on the vessel. It provided an estimation of the overpressure and radiation heat flux from the escalating scenario. An integrated risk-based approach (Dadashzadeh et al. 2013) was introduced and implemented in the case study to optimize the location of LNG tanks on the vessel, considering the safety issue.

The cumulative impact on personnel was predicted using the integrated risk profile to determine the total risk over the affected areas. In applying the methodology to an identical scenario for six proposed tank positions, the explosion risk was found to be more significant over the areas on the vessel due to the high risk value (10) which consequently affected surrounding areas of 40 m distance from the tank. The solid-flame model showed that areas of high fire risk were only 2 m from the flame centre. However, when the geometry of the vessel was taken into account for the CFD model, positions 2, 3, 7 and 8 which were in a closed location were observed to have higher radiation heat flux and risk values. The results also demonstrate the advantages and importance of interaction between the two scenarios as it can be observed that the fire risk was significantly lower for distance more than 5 m from the flame centre, but the integrated risk resulted in a high value due to effects of the explosion.

This study concludes that tank position 4 has the least cumulative effects, and thus, it was chosen as the most appropriate installation location for the LNG tank. Finally, considering the interactions between the consequences of the explosion and pool fire scenario, safety measures such as emergency exits and muster points can be designed on the vessel for the overall safety of the passengers and personnel.

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# Design of Fire and Gas Detection System for a Process Plant: A Review

**A. Prashanth Kumar Reddy, E. Sathwik Reddy, T. N. S. S. Bhaskar, Bikarama Prasad Yadav, and Akshi K. Singh**

## 1 Introduction

A process industry contains toxic, flammable gases, and liquids, which creates hazardous atmosphere, and to prevent plant from any accident that occurs from that hazardous atmosphere, we require an early detection system to detect toxic gas and flammable fluid leaks. In process plant, the early detection of toxic and flammable release done with the help of fire and gas detection system, which is installed and maintained in order to reduce or eliminate the catastrophic accidents and their severity. Various design considerations are needed to consider while designing a fire and gas detection system for a process plant based on plant operation, equipment used, raw material, wind direction, and many other factors.

Fire and gas detectors are the major components in fire and gas detection system along with logic solver, alarm system, fire suppressors, etc. Fire and gas detectors detect the early sign of fire and release of toxic gases and it signals the logic solver which is a control system for the whole fire and gas detection system and actuates the alarm mechanism and other mitigating measures that are to be done (Ali et al. 2016). Fire detectors are may be heat, smoke, and flame detectors and gas detectors are flammable, toxic and acoustic leakage detectors.

In addition, fire and gas detection system is connected to other building service systems to improve effectiveness of building evacuation, to prevent false alarm, and to assist firefighting (Ewer et al. 2009). Any process plant in operating condition needs to comply with the standards of National Fire Protection Association (NFPA) to reduce or to eliminate the loss of life or property by fire and it is a legal requirement

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for any process plant to survive. To install the fire and gas detectors, we follow NFPA 72, API 45 standards.

Selection of fire and gas detectors is also an important point to consider when designing a FDS system depending on the process plant type and its operations and surrounding conditions. Though some fire and gas detectors can perform well in certain process conditions but may unsuitable for the different conditions (Skippon and Short 1993). Suitability of different types of fire and gas detectors with process plants, offshore applications is studied and is used based on specific design considerations (Legg 2012).

## 2 Literature Review

In order to find out the best suitable fire and gas detection layout, a large number of factors must be considered. This is a highly complex process due to high number of variables and FGS requirement changes from one process installation to other. Because of this complexity, there is no detailed approach available for fire and gas detection design in process industry. Even the standards are providing the considerations, which are general in nature. UK Health and Safety Executive (HSE) in 1999 published a report indicating that successful detection of hydrocarbon gas leaks is only 60%.

Standards such as NFPA 72 (National fire alarm and signaling code) and EN 54(Fire detection and fire alarm systems) specified the type of equipment, installation, design, maintenance, and use of detectors and fire alarms. They provided very comprehensive set of information in for designing and installing equipment. These standards are very effective for the fire detection and alarms in general occupancy such as office buildings, commercial buildings, schools, and hospitals. However, they do not provide detection in open process areas where toxic and flammability hazards are inherent in nature.

Continuous Monitoring for Hazardous Material Release by CCPS (2009) had given a general guidance on fire and gas detection in process areas. It illustrated various detector placement approaches and their applicability. It provided a general overview on the factors to be considered for selecting a detector. It also emphasized various detector technologies available with each of their advantages and shortcomings. Still this standard has its own strength and weakness. It mentioned dispersion modelling is needed for the placement of detectors. However, did not provide performance targets and detailed standard procedure for placement of detectors.

The ISA technical report TR 84.00.07 (2010) provided guidelines for fire and gas detection systems and illustrated the application of risk assessment in FGS. It laid down performance-based FGS life cycle process with risk concepts. It provided for procedure for coverage areas assessment.

## 3 Fire and Gas Detection

The fire detection system consists of the fire detector, control unit, and control devices, which activates from the signal of control unit. When the fire breaks out, two things comes into pictur'; one is saving life and the other one is safeguarding assets. The main objective of the fire detection system is to monitor for the potential leakage of flammable or toxic gas and triggers the personnel by alarms thereby allow for further control measures. In majority of the cases, these are all part of a fully automatic system, which alerts protective devices such as steam curtains, or releases firefighting agents to tackle the situation. In other cases, however, the function of the detection system is limited to just providing an alarm signal to the personnel, who has to interpret and implement control measures such as emergency shutdown, ventilation, ignition source control, and fire–fighting system. There are several reasons for not making the system fully automatic always. First thing is that detection systems are liable for false alarms; second is that it is not always easy to predict and define in advance precisely, what is required.

FGS design consist of various types of detectors, tuned to different set points and alarm logics, thus many factors has to be considered before installing FGS like type of detector, number of detectors, location, set points, and alarm logic. When leakage of gas occurs, it can be either form a stable cloud or be dissipated depending on factors like the leak rate, wind, density of the gas, and environment present around the leak. All the factors are to be considered for designing of FGS for a process plant layout. Generally, industrial detection is needed for loss of containment (leaks) and fire. Three types of gas detectors can serve for detecting the loss of containment; they are flammable gas detector, hydrogen gas detector, and toxic gas detector. In case of detection of fires, three detectors can serve the purpose; they are flame detector, heat detector, and smoke detector.

## 4 Criteria for Detector Selection

Detectors are of two types, fixed or portable. Fixed detectors are permanently installed in a given location for continuous monitoring of process plant. Fixed detectors are useful in enclosed spaces and are less reliable in open spaces. Portable gas detectors are small handheld device, which are used for testing gas at confined space and emergency response. When employing fixed detection system, one can choose between two detection principles which are point detection and open-path detection.

Point detectors measure the concentration of interested vapor/gas at sampling point. They cover limited area and are often used near to single equipment. Gas concentrations are measured in % lower flammability limit and toxic gas in ppm or ppb (Bafjord 2011). For detection coverage over large areas, multiple-point detectors are needed. Many industrial detector types like infrared, catalytic, acoustic, semiconductor, and electrochemical detectors are based on this principle.

Open-path detector contains infrared source and separate receiver. The target gas when passes through the infrared beam is detected through receiver. The advantage of path detector over point detector is that a single-point detector can monitor large area instead of several point detectors. Gas/vapor concentration is measured in path length multiplied by % LFL or ppm. The problem with path detector is that it is difficult to distinguish between a small part of gas with high concentration and a large one with less concentration. Since the open-path detector covers large area of detection, it is difficult to find precise location of gas. Weather conditions and dust can have serious effect on functioning of the open-path detectors.

Selection of detector type depends on type of target gas/vapor. Before deciding the detector, one should have sound knowledge on type of gases to be detected on process plant and applications of various detectors, for example, catalytic bead sensors are suitable for detection of combustible gases, whereas electrochemical sensors are useful for detection of toxic chemicals. Moreover, the designer should aware of gases that cannot be detected, for example, infrared sensors cannot detect hydrogen. Some types of detectors are susceptible to particular type of gases. All such required data should be reviewed before choosing particular type of detector.

Expected concentration of gas is a determining factor for choosing a detector. Both catalytic bead detector and ionization detector can monitor flammable gases, but their range of detection varies significantly. Catalytic bead sensor cannot measure below LFL of flammable gases; however, ionization detector can measure as low as 1 ppm (CCPS 2009).

## 5 Factors Affecting the Design of Fire and Gas Detector Systems

There are many environmental and operational factors, which can impair the performance of the FGS, so the designer should evaluate all the responsible factors before designing the FGS to a process plant.

### *5.1 Density*

The density of the measuring gas is one of the prime factor of importance, gases with higher density than air locate more toward ground, whereas the gas with lower density than that of air disperses fast and rises upwards. Before installing, the designer has to check for the type of the gas to be leaked and its density for deciding the position of the detector, i.e., near to ground or at certain height at ceiling.

## 5.2 Wind Speed

The speed of the wind can affect the dispersion of the released gas. In case of calm weather, the leaked gas behave according to density but at higher wind speeds, the gas movements are abnormal. Take an example of placing detector near to ventilation may not give desired output, even in case of leaked gas behaves like the air because of quick mixing with local air. These factors are to be considered especially in case of offshore installations.

## 5.3 Temperature

Selection of detector is based on the ranges of operation of temperature; generally, it varies from manufacture to manufacture and on type of technology. Operating FGS at upper and lower limits allowable temperatures may lead to drift in reading of 5--10% than the actual lower flammability limit concentration (API 1991).

## 5.4 Obstructions

There are many chances of obstruction in process plant especially in case of open-path detectors ranging from personnel, piping, equipment, dust, and particulate matter which deteriorate the detection capability and lag in response time. In order to prevent this, constant inspection is needed for FGS during both installation and operation.

## 5.5 Vibration

Even though vibrations of higher frequency do not have significant effect on sensor, low frequency and high vibrations create a problem in FGS. Vibration results in breaking the electrical circuit thereby fails the detection mechanism. Care should be taken to avoid the mounting of detector on vibrating structures such as rotating equipment.

## 5.6 Miscellaneous

The sensitivity of the detectors generally decreases with time due to aging. Proper installation and maintenance make the sensors to work for a period of 3--5 years. Check for calibration of detector regularly. The frequency of calibration is based on experience. Higher levels of humidity (>95%) is the factor which can affect the sensitivity and response time. Manufacturer has to be consulted.

## 6 Detector Placement Methods

Detector placement plays an important role for achieving the objective of FGS to give quick and reliable detection for early mitigation of major hazards. There is no guarantee of cent percent safety for detector positioning always a better way exists for detector placement. Heuristic placement for detector layout is simple and completely depends on experience in similar applications. Any sort of numerical modelling is not used in this approach for determining detector coverage. Most of the times, heuristic method falls short for achieving safety goals because it puts more emphasis on source of gas leaks rather than gas accumulation. On the other hand, prescriptive placement is used for placing detector, which is strictly based on predefined standards. In this method, design engineers locate detectors solely based on rules of thumb or prescribed standards.

Semi-quantitative method for detector mapping is one of the most common methods to determine coverage (DET-TRONICS 2011). It considers factors like type of hazardous chemical, equipment used, process parameters, and level of occupancy. After evaluation of these factors, risk value is estimated and based on the level of risk (NORSOK 2008), the place is classified into zones. After zonal classification, each zone's plot is loaded into the mapping application to determine the detector coverage, which is based on the rules of thumb. Before loading, each application must be carefully considered based on toxic or flammable gas detection. Mapping application gives the percentage of detected and undetected coverage. Finally, decision has to be made by design engineer to whether to accept the level of coverage.

Full quantitative mapping or a risk-based approach, which is developed in recent years. Initially, a set of all possible release scenarios are defined and all the required input data such as release rate, grid set, and environmental factors are considered. In second step dispersion, modelling is done to identify the maximum distance of exposure (Defriend 2008). In third step, the risk of every possible scenario is calculated similar to semi-quantitative method. Then, risk-based objective function is developed which is to be solved by using any iterative approach to get the optimum detector layout.

## 7 Set Point and Voting of Detector

As mentioned in the previous sections, the objective of the FGS is to monitor the hazardous gas and alert the personnel, most of the cases after detection the alerting mechanism is alarm system. After measuring the gas concentration, the set point should be present for sending signal to alarm. For toxic gases, the set point is OSHA permissible exposure levels and for flammable gases, maximum of 50% of lower explosion limits for a minimum of 30 days. Review the frequency of alarms and average concentration of gas leaks to adjust the set point downwards until minimal set point is reached to avoid nuisance alarms. According to NORSOK standard, the set point for low alarm and high alarms is 20% LEL and 30% LEL for point-type detectors (Health and Safety Executive 2003).

To avoid situations like emergency shutdowns because of alarm signal obtained from one detector due to small gas leakage at that particular detector, voting logic is employed in industries. Voting logic is deciding of the number of gas detectors that has to monitor the gas out of N detectors. Suppose if voting logic is two out of 5(2oo5), then two detectors should detect the gas for the alarm to give signal. Voting of detector results in change of effective coverage and time of response because a gas cloud must grow to come in contact with multiple detectors. Many mapping applications do consider voting logic on gas detection coverage.

## 8 Methodology for FGS Design

The overall design procedure for FGS is shown in Fig. 1. Process industry poses a wide range of hazards because of its inherent nature of dealing with flammable and toxic chemicals. FGS system should not be used for good facility system and maintenance. Whenever potential leak of flammable or toxic gas cannot be eliminated, there arises the need for fire and gas detectors. One should always remember that installing FGS does not fits the purpose until proper control actions are installed along with FGS.

Verify that release of concern can actually be detected with a relatively high probability of success especially in case of open areas.

Detection philosophy shall cover the design requirements of FGS systems and to what extent the coverage is needed. There is no straight forward answer to the some interpretion of the risk in FGS with arbitrary calculations of SIL which may lead to some over engineered systems. Design philosophy varies with companies as well as type of plants. It is based on previous experience and knowledge in their domain. It is also based on the amount of funds allocated to FGS and to what level of safety systems are needed for the specific plant.

Once the design philosophy of FGS is developed, one shall collect all the required input data, which is required for design of FGS. Equipment plot layout of the unit, all the equipment list, process flow diagram, process data sheet, heat and material balance sheets and site topographical data and wind velocities (Miyata 2011).

Once the preliminary collection of data is completed, start collecting properties of all chemical components involved in the process. The properties like flash point auto-ignition temperature and density of the pure components. Then start analyzing every stream of the process and identify the components in each stream, which are greater than 5% volume in composition. Based on the design philosophy, identify which type of detector is needed for specific equipment.

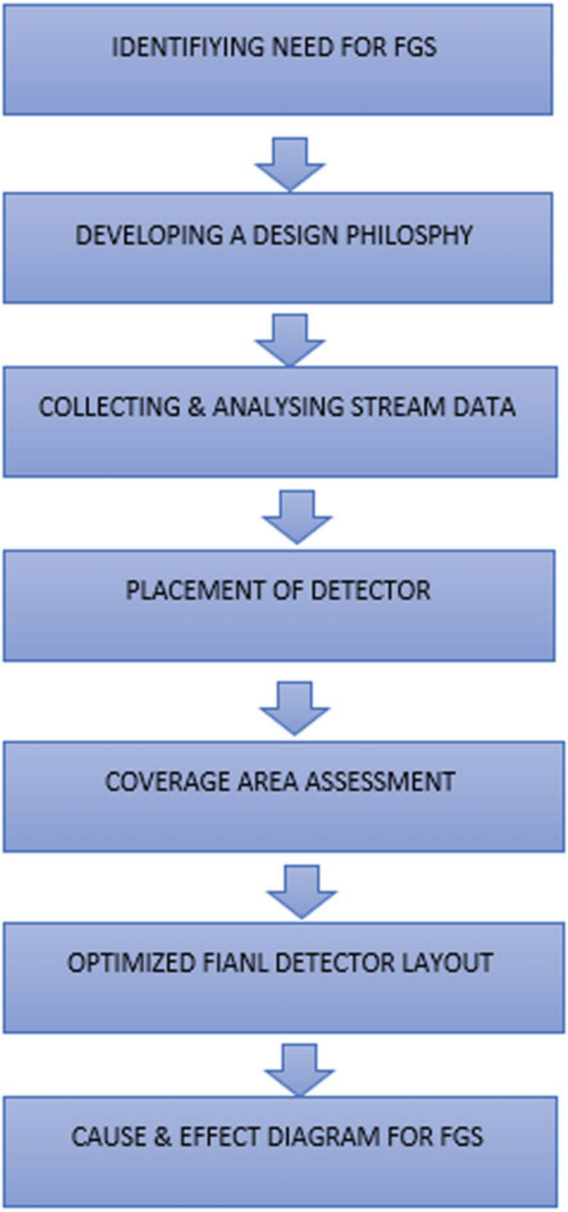


**Fig. 1** Methodology to carryout FGS

Segregate the plot plan into zones based on the similar type of equipment in one zone. Start placing the detector in equipment plot plan from the previously identified. Place the detector by considering the wind directions. Coverage area assessment is needed to validate the detector layout and optimize it. It can be of two types: geographical assessment and scenario assessment. For flame detectors based on the vendor specifications, check for area coverage in three-dimensional plot. For scenario assessment, carry out dispersion modelling using available mathematical CFD tools and there by optimize the layout of the detector for cost-effective detection (Vazquez Roman 2016). As mentioned in previous sections, the signal from the detector is properly linked with control equipment like alarm signalling, emergency shutdown, activating firewater pump, etc., for the mitigation of risk.

## 9 Redundancy and Cost

Based on experience review of past case studies, it is aware that there are one or more detectors, which do not have any extra value of safety. These redundant detectors can be removed from mapping layouts; however, there should be no compromise on effective ness of safety. A balance should be maintained between cost of the detection and safety offered by the FGS. All risk mitigation measures should be employed unless there is a negative effect on gross disproportionation to the benefits (Vinnem 2007).

## 10 Traditional 2d Versus 3d Detector Mapping

Traditional 2D mapping is drawn on a paper or using plant layout computer software, which considers two-dimensional view. There are many problems involved in using 2D mapping; one of the main problem is field of view of detectors can have obstructions like piping's and equipment's. After completion of detector, mapping a walk throughout the plant is necessary to identify for any deviations. Walkthrough needs sound knowledge and experience in detector mapping. Consider the factors like ease of maintenance, cleaning, and calibration during the walkthroughs. After the detector mapping is completed, review it multiple times for any deviations.

## 11 Conclusion

The ultimate aim of any safety system installed in the process plant is to protect the life of personnel and prevent damage to the asset and environment. Proper detector selection and various performance factors are to be considered for improved placement of detectors. By carrying out dispersion analysis and coverage area assessment, one can validate the detector layout. Quantitative detector mapping is advantageous over heuristic approach for enhanced effectiveness of safety. Optimization of detector layout yields the better safety performance and reliability at low costs.

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# Identification of Elements Responsible for Poor Construction Safety Culture and Their Mitigation Measures

**Kalpesh Chaudhari, Akash Sonawane, Bikarama Prasad Yadav, and Nihal Anwar Siddiqui**

## 1 Introduction

The construction industry is characterized by broad operations in complex and hazardous environments that cause numerous injuries and deaths. This paper aims to assess and minimize the aspects used to develop a competent leadership security framework in construction industry. There is an increasing need for improvisation of safety on construction sites due to rising costs due to workers' compensation and OSHA fines. For the structure industry, the accident proportion is higher compared to other trades. The employee compensation rate has increased dramatically in the past 50 years. The OSHA has increased its fines over the years. To reduce fines and reduce potential accidents, construction companies are recruiting security officers and security coordinators, implementing safety programs, and raising the awareness and education of injured workers through the introduction of return-to-work programs. The construction industry also funds several research projects to improve site safety.

To improve the safety of site, it is vital to recognize the factors responsible for safety. The correct evaluation of these factors is important for the safety success. In this paper, safety leadership, safety, and safety management are discussed. Various pressures on the construction site, namely production pressure and personal factors, also affect safety in construction business.

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## 2 Literature Review

Construction is one of the most accident-prone industries because of its uniqueness. Light accidents can hamper production, and a serious accident can lead to a variety of problems that affect delivery, schedule, quality, cost, and even social responsibility. The combination of social responsibility and economic pressure has triggered the need to reduce work-related accidents and improve construction site safety. The first step is to identify the critical causes for the problem of poor site safety. Elements of poor construction safety management typically include poor top management safety consciousness, absence of training, poor project manager safety mindfulness, unwillingness to input incomes for security, and irresponsible actions.

No general servicer intends to hurt anybody or shape an inferior project. Though, if the construction administration is bad, that will be the result as well. Poor management can jeopardize the accomplishment and achievement of a project as well as employee care.

This can lead to a lost status and loads of vanished rupees. Upcoming effort depends on the insight of present and previous work. It is important to learn to recognize unproductive design organization practices initially, before they are paid for by the nose. Uncertainty and variability of goals increase the danger. The consequence is a growth in safety and substantial events, damages, and losses.

There are many signs of poor management. These are just a few examples that can inform someone about existing matters and forthcoming issues:

- Staffs are ill-supervised.
- Orders are executed late.
- Modification requests are not properly managed.
- Constant risk of lawsuit.
- Amplified order accumulation.
- Not any administrative funds.
- Command lacking all the required info.

## 3 Reasons of Accident in Construction Business

Today, numbers on accidents in the building business give confidence to investigators to invent innovative ways to improve the safety performance in the structure business. In addition, together straight and unintended accident costs increase the cost of construction projects due to inadequate local safety. Maximum of these fates, almost 99% are due to insecure acts, risky conditions, or both. In order to advance the well-being routine in the industry, we must determine the sources of construction accidents.

The equipment and machinery, the condition of the site, the nature of the industry, the attitude and type of management and human fundamentals can unswervingly affect the well-being routine in the construction business. Working at heights, acceptable safety precautions, deprived administration, obstruction on the job site, carelessness on the part of workers, and the hiring of untrained workers are commonplace in the structure business, increasing the risk of accidents and causing damage and injury.

Conferring to Pipitsupaphol and Watanabe (2000), the apparatus and machinery, the state of site, the nature of industry, the attitude and type of management and anthropological fundamentals can affect the safety performance directly in the construction industry. Working at heights, adequate safety precautions, poor management, obstruction on the job site, negligence on the part of workers, and the hiring of unskilled workers are commonplace in the construction industry, increasing the risk of accidents and causing damage and injury.

Kartam and Bouz (2000) pointed out that the reasons of accidents are member of staff revenue and inability to perform, inadequate safety, unsuitable or impure material, no maintenance tools, and insufficient surveillance and review work.

On the other side of coin, we can classify the roots of accidents into humanoid and corporal factors. Human issues relate to individual duties and responsibilities, such as neglecting the use of shielding apparatus, use of unapproved machinery and equipment, hectic operating and working conditions, personal factors, removal service and powered equipment, removal of safety devices, selection of unsafe position at work. Use of inappropriate devices and other insecure performances. Though corporeal features are directed to the wrongdoing of additional individual, regardless of the cause of the accident, special procedures, clothing danger, environmental threat, fire danger, incorrect technique or procedure, misallocation of employees, absence of field wardens and additional hazardous state (Abdelhamid and Everett 2000).

Lubega et al. (2000) stated that, if the site accident is unswervingly linked to scarce well-being regulations, the cause is not the application of local regulations, no safety considerations by the local staff, no encouragement of workers to face mechanical problems on site construction machinery and equipment as well as chemical or physical disturbances.

## 4 Outcomes

Glitches can be produced by procedures, individuals, or a bit of together. Eventually, complications are the product of an incompetent organization and indecisive administration.

1. **Organization Complications**

**System difficulties ascend from deprived management of the three Ps: processes, procedures, and practices** (Whirlwind Steel 2015). These are the directives every firm trails to discourse the effort people do. Maximum of the time, the three Ps become challenging when there is deficiency of preparation or after the Ps are unnoticed.

a. **Impractical Assumptions**

Lacking a watchful study of the terms of the contract, conventions are completed about arrangement, maneuvers, and quality potentials that may prove to be illusions.

For instance, an underprivileged scrutiny can direct toward the creation or approval of an excessively violent agenda. Shortcomings in progressions, actions, or practices will quickly emerge as workforces try to work outside their dimensions to cut short, pile craft, or work overtime. If there is not plenty period to work, there is not sufficient time to evaluate the danger of these deeds.

Impractical opportunities can root fluctuations to the unique strategy, habitually too rapidly, to regulate the jeopardy to the plan. As the association attempts to recuperate from these unexpected variations, the likelihood of antagonistic proceedings upsurges.

b. **Unsuccessful or Imperfect Risk Assessments**

For rapid targets or high-performance requirements, the risk assessment may be neglected. This affects the response to both typical project risks and specific situations. An inadequate or unproductive risk evaluation, while not causing much of a problem, will cause hitches. And then, these glitches create more complications.

c. **Ineffective (or Lack of) Planning**

Planning does not just mean preparation. It means taking care of logistics, anticipating possible deviations in advance, and knowing the limitations of the development. Retrieval tactics and workarounds must be established prior a problematic situation arises to reduce the effect.

d. **Poor Sub-selection**

The performance of subcontractors is attributed to the contractor and ultimately to the owner, irrespective of whether it is not really an "employer." Without an existing process for identifying quality submarines or replacing substandard subsystems, the company will take the heat. Their abilities should be assessed early and replaced by competent workers as soon as possible.

2. **Poor Pre-construction Practices**

It is effortless for customers to become annoyed when nonentity becomes noticeable. That cannot happen. The pre-construction preparatory work covers maximum of the arrangement required for a smooth project.

- Reasonable budget is set.
- The risk calculation of the project is carried out.
- Employees and subcontractors are designated.
- The original development calendar and the operating plot are established.
- Metrics that benefit and detect snags prematurely and resolve them are identified.

With appropriate scheduling, the squad has period for innovation and management, and a business can lessen the swelling hazard.

3. **System Misalignment**

Changes take place in the organization. Guidelines and actions are modernized over period, or firm progress requires specialty of subdivisions. Deprived of good leadership by the organization, progressions will advance that are no longer adapted to the needs of the company. In accumulation, an alteration in one course can affect another in another part of the business, causing misperception and disorganization.

This misalignment also outspreads to communication problems. Faster choices and solutions will no longer arise. Employees have to choose for themselves which procedure to tail and how to make things happen inside.

Plan administration and security apprehensions tumble by the pavement and increase the risk for both the owner and the customer.

4. **Insufficient Company Oversight**

Construction developments and worldwide contractors have many affecting portions. Deprived of observant supervision, any association can plunge into disorder or lose of money in certain works.

Just as a misalignment of processes can lead to inefficient work, the profits and unity of companies can decrease if there are several profit centers within the organization. After all, they can compete with each other, take higher risks, and compromise security.

5. **People Problems**

Although everything is due to a population problem, these questions are extra private and less organizational in nature. They are not the result of processes, but of management.

6. **No Motivation**

To be honest, exercise, examinations, inducements, and castigation cannot encourage anyone. In construction, this can lead to poor work routine and protection anxieties. If the employer wants his employees to do the best possible job, he should know that interactive involvements have their restrictions.

## *4.1 Lack of Capability*

The employer wants his employees to grow in their jobs, but if someone has gotten a job that goes beyond his or her abilities, the catastrophe is probable to happen. Choosing the right settings, getting people into the accurate characters, and providing training and provision ensure victory. If you leave the entrance exposed for unanticipated or unsuitable activities, the owner and employee will be overthrown.

Under rated bid has significant impact on the quality of structure and entire life cycle of project. Competency of manpower along with on time execution has also one of the drawbacks taken into consideration for those reasons. Thus, project cost estimation and entire bidding process has proven a milestone towards lack of capability of executing construction projects. Once this process has initiated and work executed, faulty process, incorrect means and methods becomes messy. Thereby employee competency or competent employment are one of the major problems identified due to inappropriate cost estimation and planning.

At least the owner will expense superiority effort and profits. In the poorest case, security is bargained.

## 5 Mitigation Measures

**Raising Awareness** This notion is related to the necessity for accident stoppage through safety education (Institute of Mechanical Engineers 2001; Paul 2001). Safety awareness is highly related to personal attitudes (Pirani and Reynolds 1976). Built on earlier lessons, this component can direct toward an increase in efficiency that increases profits (Duignan 2002; Raad 1999). At the construction sites, the provision of a safety leaflet was found to be one of the elements affecting safety performance. Induction and other specific training related to the work has also a concept of achieving outcomes of safety first at workplace (Sawacha et al. 1999).

**Accident Investigation** Accident investigation is generally known as a practice that presupposes the causes of accident events and the implementation of preventive measures (Lundberg et al. 2009). Therefore, this practice includes conducting a regular safety audit and implementing its recommendation, reporting accidents by publishing magazines, articles in journals, newsletters, etc., and systematically monitoring safety (Adebiyi and Charles-Owaba 2009).

**Decision-Making** Decision-making refers to the capability of administrators to effectively address safety matters in many ways (Fruhen et al. 2013). The aim is also to gain a profounder understanding through the use of numerous foundations of information in decision-making, which has a positive impact on safety. Managers' proven commitment to safety is assessed by the personnel on the basis of the choices made.

**Safety Training** It has been appealed that several business leaders have responded completely to the growing figure and content of health and safety training programs (Wilkins 2011). This may be because training improves safety at work (Sawacha et al. 1999; Spellman 1998). The goal line of employee training and development is to give employees the skills and abilities they need to properly perform their tasks (Fernández-Muñiz et al. 2007). This concept enables employees to be aware of the risks in the workplace and, through their direct involvement, to take practical countermeasures in safety management (Bottani et al. 2009).

**Enthusiasm of Labors and Security Staffs** The motivation of workforces and safety people can be prejudiced by the commitment of management to safety. The motivation of the employees can be reflected in numerous activities (Adebiyi and Charles-Owaba 2009). Similarly, safety incentives and penalties were used to motivate site operators, and the results showed a lower number of accidents and better safety performance compared to the project, with no incentives or penalties (Hasan and Jha 2013).

**Resource Allocation** The allocation of budgets indicates the acceptance and conviction of the management (Schein 2004). In the context of resource allocation, efficient financial security requires sufficient financial support to ensure the safety of a construction site (Ismail et al. 2012).

**Show Leading Headship** Many industry troupes, controllers, researchers, and mass media professionals settled with leadership as a crucial factor of a company's well-being (Lekka and Healey 2012). Leadership is defined as "the process of social influence exercised by individuals in formal positions of power or leadership in an organization such as managers and supervisors" (Kelloway and Barling 2010). A study shows that the presence of health and safety executives can be measured by monitoring how administrators or superintendents become character representations and how their presence in the workplace is felt (Ismail et al. 2012). They make available all the support the assistants need, helping the subordinates set goals and decisions, setting workgroups, setting clear responsibilities between subordinates and colleagues, and managing OSH activities.

**Visibility** There is nothing additional conspicuous to workforces than a plant boss who brands himself noticeable on a regular basis by going through the process and accidentally informing and speaking to staffs about safe working practices, and involving top administration in the safety measures by construction worker (Lack 2002; Zeng et al. 2008).

**Personal Protective Equipment (PPE)** Providing PPE to workers can affect the safety performance of a business (Sawacha et al. 1999). It is the responsibility of the employer to make available the labor force with the essential individual defensive apparatus (Bottani et al. 2009). Therefore, a sufficient number of safety equipment, especially PPE, such as safety shoes and hard hats, should be constantly ensured and in good condition (Hasan and Jha 2013).

**Communication** Safety communication can be described as a mechanism for written, verbal, or graphical knowledge in many forms, including policies and procedures, training, performance statistics, risk and event reporting, job creation, and risk assessment (Vecchio-Sadus 2007). The management, which communicates regularly with its employees, could achieve better safety results (Sawacha et al. 1999). In addition, decent communication and advice are the right security philosophies amongst administration and employees to increase the safety and morale and productivity of a business (Hudson 2003).

**Safety Programs** Occupational safety and health is a term that defines how people (corporate landlords, executives, and personnel) tackle grievances and infections in the factory (OR-OSHA 2002). Many researchers have stated that the safety program can be an effective control tool to significantly reduce accidents as a construct for more secure operations and to create a safe work atmosphere that helps workers.

**A Positive Attitude to Safety** A optimistic boldness to safety is demonstrated by the skill of organization to consistently promote safety at all levels of the organization and to address various challenges even in times of economic decline.

**Conduct Toolbox Conversations** A toolbox conversation is an official conversation about the work that normally takes place in an assembly amongst the workforce and the direct superintendent at their workstation (Quemard 2004). At the construction site, toolbox discussions were considered as one of the most effective ways to promote and facilitate site security (Choudhry and Fang 2008).

**Continuous Monitoring and Improvement** A commitment to safety continuously improves safety plans and practices by monitoring employee performance and via dependable response as an instrument to improve the factory (Abudayyeh et al. 2006). Adding on to, the commitment of upper organization is one of the fundamentals obligatory to implement a safety management scheme improvement system to dodge replication of struggle and lessen resource consumption although increasing design safety (Zeng et al. 2008).

**The Presence of a Safety Culture** The expense of defining safety was complex even for specialists in the interior of the organization (Biggs et al. 2013). The safety culture is "part of the overall culture of the organization and is considered to be influential to the attitudes and beliefs of its members in terms of health and safety performance" (Cooper 2000). In developing a corporate culture of safety, it is important to recognize the importance of senior management as an influential factor, emphasizing shared belief and assurance to the safety officer and site supervisor (Ismail et al. 2012). In a project, the safety culture becomes visible as soon as all workers, from the workers to the upper management levels, are safe (Abudayyeh et al. 2006).

## 6 Conclusions

Once we talk about construction project, construction safety is very crucial and difficult to manage at workplace. The risk exposure level for employees, workers, or visitors must be the top priority for the owner if he/she wants to regain the confidence and trust and wishes to observe a proactive safety culture. To continue the same, comprehensive safety programs are most effective tool under the assurance of competent team or by deploying any third party. Contractor's behavior or their set of actions toward their employees and work execution are one, which prevents accidents and maintaining proactive safety culture at workplace. Employer-biased decision and profit-making attitude or ill-mannered approach to safety has laden enough stress on the employee leading to accidents, and therefore, competency and shortcuts are to be avoided. Apart from it, employers' monopoly, influenced background, socioeconomic condition, and partial legal enforcements are a few reasons which provokes employers/owners to take blunt decision in their favor and against employee safety.

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# A Comparative Study of Fire Resistance of Concrete Incorporating Ultrafine Slag

**Saurav, Anjani Kumar Shukla, and Pratyush Malaviya**

## 1 Introduction

The inherent fire resistant personality of concrete is advantageous over many other constructional materials; but safety against fire must also be incorporated in the very design of concrete structures. In addition, ensuing stresses owing to the expansion of the structural components because of exposure to fully grown fires and resulting strains should also be resisted. For a safe and sound structure, fire contemplations must be elemental in the conceptualization along with the design-related junctures. This ascent of temperature forces the free water of concrete to convert itself from liquid stage into gaseous stage. Such alterations change the transmission rate of heat from the core concrete section (interior) heading for the periphery (exterior) and vice versa. This amplification in temperature creates a potency drop in context to the elasticity modulus of both concrete and steel. However, the cadence of descent in strength depends upon the stroke of temperature amplification of fire along with the natural insulation traits of concrete. The modification in concrete characteristics because of the elevation in temperature depends upon the sort of aggregates incorporated. Hence, we can say that study of the residual properties of concrete are imperative while assessing the load carrying competence of concrete along with inspecting the supplementary use of the damaged structures in an event of a fire. Prior investigations stand witness to the fact that the type of concrete, its ingredients, the duration and temperature of maximum exposure, mineral admixtures usage, their nature and magnitude of their involvement in concrete chemistry develop the fire endurance

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properties of concrete, exposed to high temperatures. As elevated temperatures are administered within concrete, the incongruities of thermal deformations within the rudiments of concrete instigate cracking. The microstructure change, owing to dehydration and steam pressure, builds-up and accumulates inside the pores. This shift in volume will conclude itself in building up of great internal stresses which shall ultimately lead toward release of accumulated energy via micro-cracks. Elevated temperature additionally spawns numerous chemical and micro-structural changes like the moisture exodus, thermal inaptness of interface between cement paste and aggregate. All such processes will pose a demeanor outcome on the strength and stiffness of concrete.

## 2 Literature Review

Concrete has been known to be the best fire resistant and economical building material as evaluated with other available building material (Kodur and Raut (2010)). The admirable fire resistance of concrete is owing to its constituents, which upon chemical combination, give birth to a material which is essentially of inert nature and possesses low thermal conductivity with an admirable heat proficiency and slower strength deterioration with rising of temperature. Slow rate of transfer of heat accompanied by delayed loss in strength enables concrete to perform as an efficient fire-shield not only between neighboring spaces but also in providing resistance to fire damage. The behavioral response of a fire-exposed structural member made up of concrete is reliant, upon thermo-mechanical and deformation characteristics of the composition of materials, participating as concrete. With respect to temperature variation, such properties are divergent in nature along with the accountability falling on the composition and characteristics of the individual constituents. A structural member subjected to a pre-determined and definite time interval of fire exposure, shall result in a predictable distribution of temperature within the member. Change in behavioral characteristics along with deformations has always been noticed in the constitutive materials of the structural members when subjected to fires. The modulus of elasticity of concrete is also an important parameter influencing the fire resistance of concrete which falls with elevation in temperature. At elevated temperatures, disintegration of products of cement hydration and bond rupture at the microstructure realm of cement paste diminishes the elastic modulus. The loss of moisture, temperature and the sort of aggregate used, can be held responsible for such a diminution.

### 2.1 *Transient Strain*

The strain occurring at high temperatures within concrete, when concrete structural members exposed to fire has been found to add to deformations; moreover, strains being generated in the initial phases of heating of concrete is known as transient strain and are not time wise-reliant. Such strains are caused by thermal incompatibilities among aggregate and the cement paste. Transient strain of concrete, is a complex phenomenon analogous to high temperature creep, and is inclined toward the parameters such as loading under elevated temperatures, potency under the mix proportions, hydrations, etc. (Kodur 2014). Transient strains and creep fall under the category of time-oriented deformations of concrete and have been identified to be highly enhanced at elevated temperatures under compressive stresses (Bazant and Kaplan 1996). Increased creep in concrete registered under elevated temperatures has been articulated to be due to the exodus of moisture from the concrete matrix. Such phenomenon was additionally amplified by thinning out of moisture and bond rupture within the cement gel (C–S–H). We can infer that the liability of creep origin and its progressiveness is significantly due to two processes—“Dispersion of moisture and concrete dehydration due to high temperatures”; and; “Accelerated process of bond breakage.” To summarize, we can establish that aspects like the modification of the concrete’s chemical composition along with the misalignment of thermal expansion, originate internal stresses along with micro-cracking in the concrete components (aggregate and cement paste); this was found to be due to complex transformation of moisture along with chemical disparity in the composition of the cement paste and the thermal spreading out among the cement paste in addition to the non compliance of aggregates with each other resulting in transient strain in the concrete (Schneider 1988). Transient strain occurs during the first time heating of concrete, but it does not occur upon repeated heating (Khoury et al. 1985).

## *2.2 Fire-Induced Cracks*

Fire efficiency of structural members is evaluated in terms of the duration of exhibiting stability with respect to structural integrity; the changes in state of concrete due to fire result in chemical variations in the concrete structure which end up adversely influencing its mechanical strength. Under administered fire, temperature generally exceeds 1000 °C (Buchanan 2002; Purkiss 2007). But several authors agree that concrete reaching up to a temperature of 500–600 °C should be treated as damaged (Kowalski 2010). Concrete, at elevated temperatures, undergoes significant physico-chemical changes. These cause thermal, mechanical, and deformation characteristics of concrete properties to behave abnormally at high temperatures and has been believed to be responsible for more complexities, such as crack genesis and maturing into spalling. Studied have shown that in normal concrete, under-fire spalling was observed to be initiated by cracks origination at an temperature of 250 °C. At about 300 °C, concrete began to loose strength and at 400 °C, significant spalling was visibly evident. Within 550–600 °C, the load bearing capacity was lost and finally, at 600 °C and above, concrete was seen to loose its ability to function as a structural member. The surface with close proximity to fire suffered maximum damage[1] (Baley 2002). A case study emphasizing upon the penetration of fire-induced cracks in concrete inferred that depth of ingress of cracks was in accordance to the fire temperature and generally, penetration depth was evidently very profound, reaching to a depth of 300 mm and more inside the concrete. The heat-cool cycle due to dousing out of fire and resulting effect on the expansion-contraction of the concrete's constituents was held responsible by the authors for such a deep crack penetration (Georali and Tsakirdis 2005).

## 2.3 Fire-Induced Spalling

A trace of the prior cases presented a variance in opinion upon the spalling caused by fire and it questions the exact mechanism of spalling in concrete. Some investigators inferred spalling in a concrete structural member's subjected fire was explosive in nature while other studies presented little or insignificant spalling. A possible explanation for such contradicting phenomenon is all the factors involving spalling and their interdependencies; major causes were chalked out were concrete not being watertight and migration of moisture in concrete reported at elevated temperatures. Following are two theories of significance via which the explanation of phenomenon of spalling can be explained (Kodur 2000).

1. *Accumulation of pressure*: The hypothesis of spalling is supposed to originate by of pore pressure accumulation under-fire exposure (Diederichs et al. 1995; Hertz 2003). The enormously soaring water vapor pressure generated in event of a fire is incapable to exit the matrix owing to the highly densified and compact (low permeability) nature of concrete. When the tensile resistance of concrete gives-into the effective pore pressure (which is measured as porosity times pore pressure), chunks of concrete wear away from the structural member. This pore pressure is supposed to cause progressive failure which has lead to the belief that lower is the permeability of concrete, greater shall be fire-induced spalling. This degeneration of concrete may or may not be likely to explode on the surface depending on fire and concrete characteristics. (Harmathy 1993; Anderberg 1997).
2. *Thermally induced dilatation of restrained nature*: This philosophy considers that spalling is a result of restrained thermal dilatation in proximity of the heated surface, resulting in the occurrence of compressive stresses parallel to the heated surface. The compressive stresses generated fracture in the concrete which was brittle in nature (spalling). Pore pressure enacts a significant role on the inception of instability of the concrete matrix which is visible as the thermal spalling of explosive proportions (Bažant 1997). This massive vapor pressure, originated from a rapid augmentation of temperature, cannot escape owing to high density (low permeability) of concrete matrix, and this pressure accumulation often reaches the levels of saturation vapor pressure. Authors have reported that the pore pressure can reach up to 8 MPa at around 300 °C; such internal pressures are

[1] Alliance for concrete codes and standards, balanced code provisions for residential structures.

often too high to be resisted by the tensile strength of concrete. The drained conditions in the vicinity of the burnt concrete surface along with the low permeability of concrete leads to enormous pressure gradients close to the surface and are known as moisture clogging (ASTM 2011; ISO/DIS 2008). When the pressure generated by the vapor overcame the tensile resistance of concrete, pieces were seen to fall-off from the structure under evaluation; in such a study, the significant parameters which gained attention were strength, porosity, density, load, fire intensity, aggregate type, relative humidity, amount, and type of admixtures used (Kodur and Phan 2007; Kodur et al. 2003; Phan 2007). All above enumerated parameters were found to be very much dependable upon each other and this made forecasting of spalling became quite a complex task. Spalling was found to be associated with the cumulative epoch of concrete and its ambiguity is amplified during the entire serviceable life of concrete. In order to provide the necessary remedies, engineers recommended that the capability of aged (existing) concrete structures in resisting duress induced by fire and the structural loads needs to be assessed with regards to the risk of spalling resulting from fire (Wang et al. 2013). Most authors have concurred to the fact that aggregate expands and cement paste shrinks when subjected to heating (Khoury et al. 1985, 2002). The thermal incompatibility among the aggregate and cement paste, during initial phases of heating, had been considered damageable to concrete, and the expansion due to heat was considered as the superficial and a significant cause of spalling but owing to the dawn of new age modern methods of testing, certain authors contradicted such a reasoning. During the virgin heating, concrete's components move reciprocally, i.e., attenuation in cement paste accommodates the expanding aggregate and consequently, concrete under compression and subjected to high temperature, adjusts to the combined duress of fire and external load; this ends up eventually into unstable spalling when a certain limit is reached where-in the mutual adjustment cannot sustain itself anymore. Hence, shortening was also seen to appear against elongation in loaded structural elements (Chudzik et al. 2017).

An extensive review about the genesis and control of spalling can be summarized as follows. Concrete witnesses thermal distresses in terms of stresses and strains, upon fire exposure. The earlier approach to a fire proof design was targeted at the maximum temperature of the duress which was quite unsafe and an immature approach to the engineering aspect. It was later summarized that the rate of elevation of the temperature is also a very contributing factor, along with the maximum fire temperature. The maximum temperature determines the resulting temperature within the concrete and the rate of its ascent decides the episode of spalling. Serious structural damage has been visibly evident due to rapid heating inducing explosive spalling in structures. Concrete is advantageous as fire proof due to its non-combustibility and little thermal diffusivity but it experiences explosive spalling and deterioration of properties under heating which need to be addressed at the materials realm to produce a cost-effective concrete. The declines of properties such as compressive strength depend upon the constituents, their compatibilities, and molecular changes under fire.

Investigations of the loss of properties of concrete under fire keeping in mind the occurrence of explosive spalling should be the prime intentions of experiments carried out at the materials level. In such cases, the prologue of a thermal barricade at the correct locations needs to be considered along with a secure structural design to guarantee that the structure does not collapse in event of a fire and that the safety is made certain. Properties worth inspecting are the compressive strength and the strain behavior at the materials level. Rapid heating during fire induces explosive spalling with serious consequences to structure and people (Khoury 2008).

# 3 Experimental Investigations

Fresh Portland cement incorporating 12% alccofine-1203 by weight was assorted with fine and coarse aggregate. The relative amount of cement and aggregates was 1:1.35:2.19 and 12% cement (by weight) was replaced by the inclusion of alccofine. Optimum water cement ratio obtained which was 0.43 and used for the preparation of the specimen. Optimum dosage of alccofine has been established as 12% from previous investigations for maximum strength gain.

## *3.1 Alccofine*

Alccofine 1203 exhibits superior approach than all other mineral admixtures used in concrete within our country. Because of its fundamental CaO content, ALCCOFINE 1203 triggers dual reactions during hydration phenomenon.

1. Primary reaction of cement hydration.
2. Pozzolanic reaction.

ALCCOFINE like pozzolans forms additional C–S–H gel by consuming the calcium hydroxide which happens to be a by-product obtained as a result of the hydration of cement. This has a domino effect in formation of a denser pore structure and evidently higher strength gain. ALCCOFINE 1203 is a particularly processed product based on slag of soaring glass content with high reactivity obtained via controlled granulation process. Its unprocessed materials are made up primarily of low calcium silicates. Processing along with other chosen ingredients results in desired particle size distribution (PSD). The computed blain value as per PSD is around 12000 $cm^2/g$ and is beyond doubt ultrafine. Owed to its exceptional chemistry and ultrafine particle size, ALCCOFINE 1203 provides reduced water demand for a given workability, even up to 70% replacement level as per requirement. Authors have reported enhanced hardened characteristics of concrete with incorporation of Alccofine 1203 and the compressive strength of concrete using alccofine, in general upon investigation was found to be improved (Saurav AG 2014).

The outcome of analytical evaluation shows that the chemical components in ALCCOFINE 1203 are important features in controlling the theology of the concrete. The mechanism by which ALCCOFINE 1203 disperse cement particles is of proactive in nature with a dual nature of generating a negative charge on cement particles and causing dispersion via "electrostatic repulsion" and in the advance stages of the chemical reaction among the Alccofine 1203 and cement particles, dispersion is found to be steric-hindrance administered mechanism. The cement particles have a penchant for flocc formation when in contact with water. During such a process, they entrap water between them, resulting in lesser water available for hydration of cement which ultimately influences adversely upon the cement paste consistency. The consistency can be improved by higher water content but it brings a fall in the strength. ALCCOFINE 1203 remedies this issue owing to its surface-active agents which have charged periphery. When mixed with the cement particles, there occurs modification among the surface charges causing dispersion and releasing of any entrapped water. Hence, the consistency and flowability are improved and that too at low water cement ratio. These chemical enhanced assets are active only for limited period of time, and as soon as the desired intent is achieved, the cement paste starts stiffening. ALCCOFINE 1203 commences its enchantment in the green state instantly after mixing.

### *3.2 Casting and Curing of Specimens*

Concrete under investigation was compacted via the compaction table and de-molded after a passing of 24 h from the initiation of casting and water-submerged for 7, 14, and 28 days awaiting the time of testing (Fig. 1).

### *3.3 Fire Resistance Test*

The 100 mm × 100 mm × 100 mm size cubes were casted and mold was reserved in a wet place for 24 h, submerged under water for 28 days at room temperature after demoulding. Cubes were heated in the electric muffle furnace afterwards which is provided with a thermostat to preserve constant temperatures of different ranges. At a time, 24 cubes, i.e., eight sets of three cubes each, were prepared among which half were submerged for 14 days and other half for 28 days. These sets were heated for 1, 2, and 3 h at four different temperatures (27, 500, 650, 800 °C). After that, these sets were left at room temperature for 24 h for cooling. Compressive strength has been calculated as per BIS 516-1959. Each of the samples selected for testing should be exposed to the desired duration of constant temperature once it has reached the desired temperature. After fire resistance test, compressive strength of the samples was determined to detect effect of fire on strength properties of concrete cubes (Figs. 2 and 3).

**Fig. 1** Cubes being casted and on vibrating table


**Fig. 2** Cubes incorporating alccofine at varying temperatures placed in muffle furnace

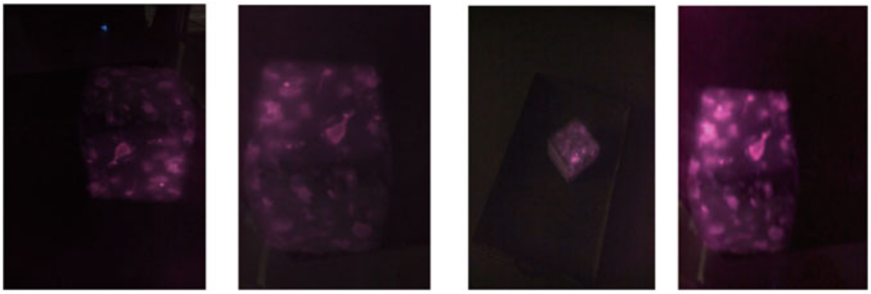

**Fig. 3** Cubes taken out from furnace after desired exposure duration

**Fig. 4** Superficial cracks on cubes due to varying thermal gradient

## 3.4 *Development of Cracks at Elevated Exposure Temperature*

Concrete on heating expands and contracts on cooling. Restraint to contraction causes the development of tensile stresses. The temperature-related contraction stress can cause cracking. Cracks may also be caused by differential temperatures in thick members. When the surface layer cools and contracts, movement is restrained by the core of the member which is still at a higher temperature, and hence cracks may form in the surface (Fig. 4).

## 3.5 *Testing of the Specimens*

Subsequent to heating in the oven, the concrete specimens were tested using a compression testing machine having a capacity of 400 tons and the evaluation of compressive strengths at 07, 14 days, and 28 days are as shown in Tables 1, 2 and 3 (Figs. 5, 6, 7 and 8).

**Table 1** Compressive and % residual compressive strengths of cubes after exposing to elevated temperature cured for 7 days

| Temperature (°C) | Compressive strength (N/mm$^2$) | | | % residual compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|---|---|
| | 1 h | 2 h | 3 h | 1 h | 2 h | 3 h |
| 27 | 42 | 42 | 42 | 100 | 100 | 100 |
| 500 | 48 | 40 | 29.09 | 114.28 | 95.238 | 69.26 |
| 650 | 45 | 38 | 20.65 | 107.142 | 90.476 | 49.166 |
| 800 | 19.7 | 21.11 | 17.75 | 46.904 | 50.261 | 42.0261 |

**Table 2** Compressive and % residual compressive strengths of cubes after exposing to elevated temperature cured for 14 days

| Temperature | Compressive strength (N/mm$^2$) | | | % residual compressive strength (N/mm$^2$) | | |
|---|---|---|---|---|---|---|
| | 1 h | 2 h | 3 h | 1 h | 2 h | 3 h |
| 27 | 48 | 48 | 48 | 100 | 100 | 100 |
| 500 | 54 | 46 | 35.09 | 112.50 | 95.833 | 83.54 |
| 650 | 45 | 40 | 26.65 | 93.75 | 83.33 | 55.520 |
| 800 | 25.5 | 27.11 | 23.75 | 53.125 | 56.479 | 49.479 |

**Table 3** Compressive and % residual compressive strengths of cubes after exposing to elevated temperature cured for 28 days

| Temperature | Compressive strength (N/mm$^2$) | | | % residual compressive strength | | |
|---|---|---|---|---|---|---|
| | 1 h | 2 h | 3 h | 1 h | 2 h | 3 h |
| 27 | 58.2 | 58.2 | 58.2 | 100 | 100 | 100 |
| 500 | 67.51 | 57.42 | 41.31 | 116.006 | 98.65 | 70.97 |
| 650 | 63.17 | 55.65 | 30.61 | 108.53 | 95.61 | 52.59 |
| 800 | 26.29 | 27.252 | 28.60 | 45.17 | 46.82 | 49.14 |


**Fig. 5** Random specimens before and after testing

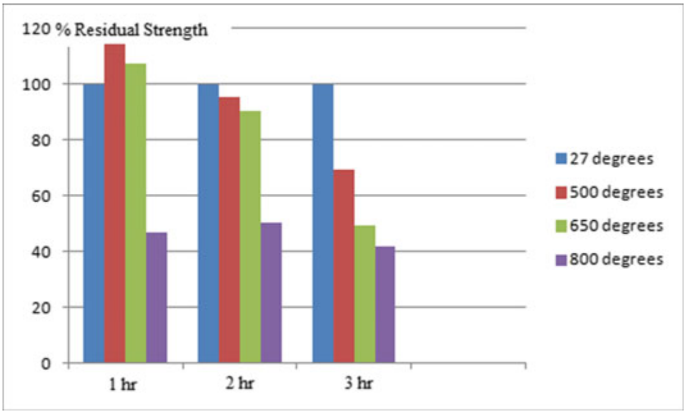


**Fig. 6** Variation of % residual compressive strength with varying temperature at 7 days of curing

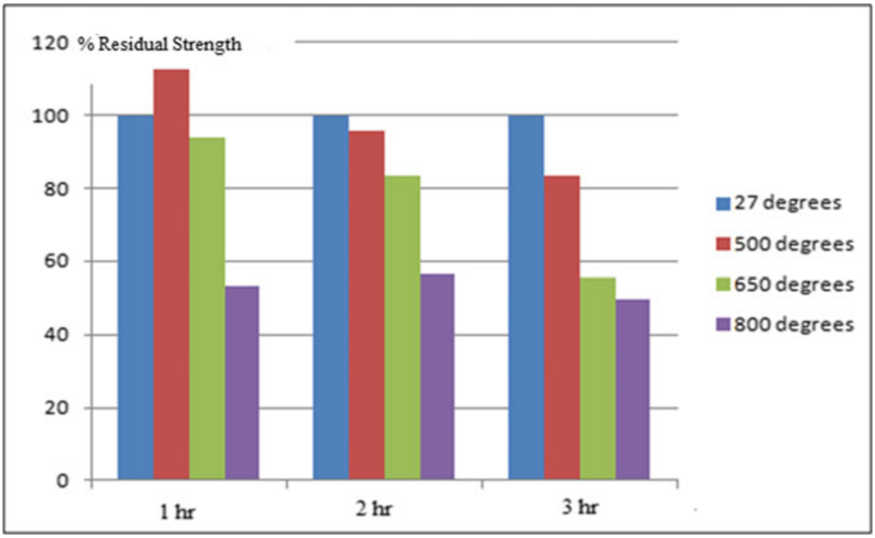


**Fig. 7** Variation of % residual compressive strength with temperature at 14 days of curing

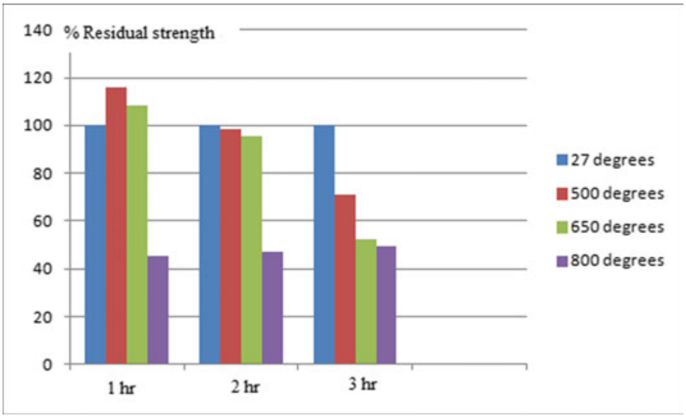


**Fig. 8** Variation of % residual compressive strength with temperature at 28 days of curing

# 4 Results and Discussions

## *4.1 Inferences Based upon Appearance*

At 500 °C, concrete experienced minor cracks along with dehydration of the cementitious paste with absolute loss of liberated moisture and a diminution in paste volume.

At 650 °C, prominent cracking of both the cementitious paste and aggregates due to expansion. Color of concrete turned some-what pinkish.

At 800 °C, cComplete dehydration of the cementitious paste accompanied with substantial shrinkage cracking was observed. Concrete became crispy and easily broken down upon contact. Color of concrete tainted to gray.

# 5 Conclusion

The disparity of compressive strength with the augmentation in temperature is studied in terms of the percentage residual compressive strength for different durations of 1, 2, and 3 h. Initially, the strength improved with temperature 27–500 °C for different durations and ahead of that, it was reduced. Utmost compressive strength was perceived when the cube was heated at 500 °C for 1 h duration. The compressive strengths are increased up to 27–500 °C and beyond that, it was rapidly reduced with increasing temperature. The compressive strength was lost to a large extent when they are heated to temperatures greater than 500 °C. Addition of Alccofine 1203 provided a revolutionary advent to the fire resistance of concrete and evidently restricted spalling up to a stage, owing to its presence in the concrete matrix.

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# Industrial Hygiene in the Pharmaceutical Industry

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## 1 Introduction

Industrial hygiene is nothing but science and art dedicated to anticipating, recognizing, assessing and controlling those environmental variables or stresses that arise in or out of the workplace that can cause illness, impairment of health and well-being, important discomfort among employees or among community people. The magnitude of exposure of workers and engineering use, job practice checks and other methods to manage future health risks are identified through environmental monitoring technologies and analytical methods by the industrial hygienists (Melcher 1983; Dahlstrom et al. 2014).

In the middle ages, the sick workers and their families were assisted by the guilds. In 1556, the German scholar, Agricola, described miner's illnesses in his book De Re Metallica, assigned preventive measures and sophisticated industrial hygiene science. The book described aspects about mine ventilation, worker protection and mining accidents and also about the disease named silicosis. In 1700, the concept of industrial hygiene became more respectable when the book "De Morbis Artificum

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Diatriba" was published, which was written by Bernardo Ramazzini, "father of industrial hygiene." The book explained about various occupational diseases which were usually common among the workers of that time. Dr. Alice directed campaigns to promote industrial hygiene in the early twentieth century at Hamilton, USA. She noted firsthand industrial circumstances and shocked factory managers, mine owners and state officials with proof that there was a connection among the workers, disease and toxin exposure. The first state industrial hygiene programs were established in 1913 by the New York Department of Labor and the Ohio Department of Health. By 1948, all countries implemented such laws. In most countries, employees contracting occupational diseases have some compensation coverage. Today, almost every employer is needed to enforce the components of an industrial hygiene and safety, risk communication or occupational health program and respond to the Occupational Safety and Health Administration (OSHA) and its laws (Otterson 1972; Plog and Quinlan 2002).

Industrial hygiene and OSHA under the OSHA Act 1970, essential safety and health regulations are developed and established. To assess employment and future health risks, OSHA depends on industrial hygienists. Industrial hygienists should be empowered to forecast, acknowledge, assess and suggest physical and environmental hazard controls that can contribute to the health and well-being of employees and the individuals around them (Safety and Hygiene 2005). OSHA industrial hygienist's two tasks are to identify these circumstances and assist, eliminate or regulate them by suitable measures (Harper 2014).

The American Conference of Governmental Industrial Hygienists (ACGIH) is an organization of charitable science that promotes occupational and environmental health (Dahlstrom and Bloomhuff 2014). ACGIH's primary goal is to promote the safety of workers by offering timely, objective, science data to experts in occupational, industrial and environmental health.

The American Industrial Hygiene Association (AIHA) is one of the biggest international associations serving the requirements of industrial hygiene practitioners in sector like government, labor, academia and autonomous organizations. AIHA is dedicated to attaining and preserving the highest professional norms for our employees and providing occupational health and safety experts with the opportunity to retain qualifications in their respective areas (Hicks 2014).

The National Institute for Occupational Safety and Health (NIOSH) plays a significant role in developing and implementing fresh expertise in the areas of occupational safety and health. NIOSH performs scientific research, develops advice and suggestions, disseminates data and responds to workplace health risk assessment requests (Kiersma 2014).

## 2 Hazards in Workplace

Industrial hygienists must be acquainted with the features of the risks in order to be efficient in acknowledging and assessing on-the-job risks and endorsing controls.

Potential hazards can include chemical, biological, physical and ergonomic hazards (Fthenakis 2003).

Chemical hazards are hazardous chemical compounds that exert toxic impacts through inhalation (breathing), absorption (through direct contact with the skin) or ingestion (eating or drinking) in the form of solids, liquids, gases, mists, dust, fumes and vapors (Carson and Mumford 2013). Airborne chemical risks occur as mist, gas, fumes, vapor or solid levels. Few are poisonous through inhalation, and when it comes to touch, it irritates the skin; some may be poisonous through skin absorption or ingestion, and some may be corrosive to living tissue. The magnitude of employee risk associated with exposure to any specified constituent relies on the environment and influence of the toxic impacts and the extent and length of exposure. Information on the threat to employees from chemical hazards can be acquired from the material safety data sheet (MSDS), which consists of OSHA's Hazard Communication Standards of all hazardous materials that has to be provided to the buyer by the supplier or importer. The MSDS is a record of significant health, safety and toxicological data about the ingredients of the chemical or mixture (Sanders 2005). Other regulations of the hazard communication standard require appropriate warning and identification labels for all containers of hazardous substances in the workplace (National Institute for Occupational Safety and Health 2015).

Acute and chronic diseases could be triggered by the biological threats such as viruses, bacteria, fungi and other living organisms either directly entering the body or breaking through the skin. Workers dealing with crops or livestock or their products or food and food processing may be exposed to biological hazards for employees. Biological hazards may also be subjected to laboratory and medical personnel (Rim and Lim 2014). Any occupations resulting in contact with body fluids present a biological hazard danger to employees. Biological hazards are addressed in occupations involving animals through the prevention and control of illnesses in the animal population as well as the proper care and handling of infected animals. Effective personal hygiene, especially care for minor cuts and scratches, especially on the hands and forearms, also helps to minimize employee hazards. Workers should exercise adequate personal hygiene in professions where there is impending acquaintance to biological hazards, especially hand washing. Physical hazards typically involve excessive concentrations of electromagnetic radiation, vibration, noise, temperature, lighting, ionizing and non-ionizing. In occupations where ionizing radiation is exposed, time, distance and protection are significant instruments to ensure the safety of the employee. Radiation hazard increases with the time that individual is exposed to it; therefore, the shorter the exposure time, the less the radiation hazard. Distance is correspondingly a useful instrument for monitoring ionizing as well as non-ionizing radiation exposure. It is possible to estimate radiation concentrations from some sources by relating the distance squares between the employee and source. In addition to the higher radioactive source-worker, the protective mask reduces exposure to radiation. However, in some cases it is not efficient to limit exposure to certain types of non-ionizing radiation, such as lasers, or to increase distance. An efficient technique of control can be to shield employees from this source. Noise can be regulated by multiple interventions, another important physical hazard. A number of ways of reducing noise could be achieved. Few are by installing equipment and systems that have been engineered, designed and constructed to function silently; by ensuring that equipment is in excellent repair and correctly maintained with all replaced worn or unbalanced components; by encompassing or shielding noisy equipment; by mounting noisy equipment on unique vibration-reducing mounts; and by installing silencers, mufflers or baffles. Another important way to decrease noise is to replace quiet working techniques for loud ones. Also, acoustic material can be used to treat floors, ceilings and walls to decrease reflected or reverberant noise. Furthermore, erecting sound obstacles around noisy activities at neighboring workstations will decrease employee exposure to noise produced at neighboring workstations. In addition, it is feasible to decrease noise exposure by reducing the distance among the source and receiver, segregating employees in acoustic booths, restricting the exposure time of employees to noise and offering security for hearing. OSHA needs regular testing of employees in loud environments as a precaution against loss of hearing. Another physical hazard can be regulated by installing reflective shields and offering protective clothing, such as radiant heat exposure in factories such as steel mills. Ergonomic hazard studies evaluate a wide range of functions, including lifting, carrying, pushing, walking, reaching, etc. Many ergonomic issues result from technological modifications such as enhanced assembly line speeds, addition of specific duties and enhanced repetition; some issues lead from badly constructed tasks. Ergonomic risks including excessive vibration and noise, eye strain, repetitive movement and heavy lifting problems may trigger either of these conditions (Niu 2010). Ergonomic risks can also be associated with improperly constructed instruments or job regions. Repetitive movements or repeated shocks often can trigger irritation and inflammation of the tendon sheath of the arms and hands, a condition known as carpal tunnel syndrome, over long periods of time as in employment concerning sorting, assembly and data entry. Ergonomic risks are mainly prevented through the efficient design of a job or job site and through better designed instruments or equipment that satisfy the requirements of employees in terms of physical setting and job duties. Through comprehensive worksite analyses, companies can set up processes to correct or control ergonomic risks using suitable engineering controls (e.g., designing or redesigning job stations, lighting, instruments and equipment); teaching right job practices (e.g., proper lifting techniques); using appropriate administrative controls (e.g., moving employees across multiple duties, decreasing demand for manufacturing and growing breaks); and supplying and mandating personal protective equipment where required. Assessing working circumstances from an ergonomic point of view includes considering the worker's complete physiological and psychological requirements. Overall, industrial hygienists point out that the advantages of a well-designed, ergonomic working setting may include enhanced effectiveness, fewer accidents, reduced operating expenses and more efficient staff use. In summary, industrial hygiene includes a wide range of work setting (Clarke and Cooper 2003).

## 2.1 Hierarchy of Controls Over Hazards

A hierarchy of control has been followed while implementing solutions, of which elimination and substitution are the primary means of reducing employee exposure to occupational hazards followed by other processes such as engineering controls, administrative controls and personal protective equipment (Makin and Winder 2009). Elimination refers to the physical removal of hazard causing conditions from the industrial workplace. For example, identifying a potential hazardous object such as solvent storage containers, gas cylinders and sharp items and removing it from the workbench qualify as elimination. Replacing dangerous materials or machinery with safer and less hazardous ones refers to substitution. Replacing a product that is present in dry powder form by a pellet perhaps reduces airborne dust and eventually minimizes the inhalation risk (NIOSH 2015).

Engineering controls eliminate or reduce the exposure to risks by implementing changes of design or modification to plants, systems, processes and equipment. Additionally, engineering controls include enclosing work processes or restricting work operations, and the installation of general and local ventilation systems (Bowes 2008). Administrative controls include controlling employees' exposure by either scheduling production or tasks, or both, to curb the levels of exposure. For instance, the employer can plan operations with the highest exposure potential when fewer employees are present. Appropriate personal protective equipment must be used when effective engineering controls are not achievable or while such controls are being introduced/use of individually selected properly fitting gloves, safety goggles, helmets, safety shoes, protective clothing and respirators is examples of personal protective equipment. However, to be effective, personal protective equipment must be worn properly, maintained regularly and replaced, if necessary (Sargent and Gallo 2003).

If an employee exposes a potent compound, the probability for the compound to elicit the designed response is high. Occupational health professionals and industrial hygiene professionals respond to this hazard recognition by executing strategies for risk evaluation and control of the potent active pharmaceutical ingredient, also known as a "potent compound."

Inhalation, ingestion, absorption and injection are the modes of entry for several chemicals being used in the industries. The toxicity of the compound causes either a local or systemic effect, or both. A localized effect occurs as a result of contact between the toxic substance and a specific part of the body, whereas when the internal organs are affected it is referred to as causing a systemic effect. Examples of systemic effects include hepatotoxins, nephrotoxins, neurotoxins, hematotoxins and anesthetics.

The interaction of a compound with another results in several effects, namely additive, synergistic, potentiation and antagonistic effects (Tallarida 2006). When the overall biological effect of two chemicals acting together is the sum of the effects of the chemicals acting independently, it is referred to as an additive effect. Synergistic effect is when the combined effect of two chemicals is much greater than the sum of the effects of each alone. Potentiation effect is when the resulting toxic or pharmacologic effect of two substances is greater than that of the individual substance. Antagonistic effect is observed when the combination of two or more compounds inflicts a milder response than that of the individual compounds.

The exposure limit is the extent to which a person might be exposed safely to a hazardous substance (typically a gas or a solvent vapor) without endangering his/her health. The legal limit of exposure for an employee to a chemical substance or physical agent is termed as permissible exposure limit (PEL). Permissible exposure limits are established by the Occupational Safety and Health Administration (OSHA) after adoption of the Occupational Safety and Health (OSH) Act in 1970. A short-term exposure limit (STEL) is the permissible concentration to which workers can be exposed over a short period. Ceiling value is the highest concentration of a toxic substance to which an unprotected worker should ever be exposed. Entering an area where the toxic substance concentration exceeds the ceiling threshold level should be barred. A time-weighted average is the sum of each time period multiplied by the levels of the substance during the time period divided by the hours in the workday (Rappaport 1993).

Threshold limit value is the maximum level up to which a person can be exposed to any chemical or agent during wok. Biological monitoring is the process of analyzing the human biological sample, viz., blood, urine, saliva, earwax, feces, tears, sputum, sweat, expired air, nails, hair, skin in response to the reaction occurring due to the chemical exposure. Enzyme and antibody production can be identified as the marker in response to the biochemical reaction (Ziem and Castleman 1989).

Biosafety level 1 (BSL1) is the least hazardous biosafety cabinet, wherein it can be installed in a normal laboratory working conditions that does not pose any microbial infection to healthy humans (U.S. Department of Health and Human Services 2009).

At biosafety level 2 (BSL2), all precautions used at biosafety level 1 are followed but additional precautions are also taken. The difference between the BSL1 and BSL2 is:

BSL2 should be handled by well-trained personnel. General entry to the laboratory should be restricted. Extreme care should be taken to dispose the sharp items after usage. All protocols involving infectious aerosols or splashes must be carried out within the cabinet. General entry to the laboratory should be restricted.

Biosafety level 3 is used in the case of microbes with the capacity to cause lethal diseases in the workplace area.

Under these conditions, the laboratory personal should be medically immunized. They should wear protective clothing (PPE) that should not be worn outside the laboratory and must be discarded or decontaminated after every use. Laboratory safety manual must be clearly drafted, and the laboratory personnel should strictly comply with the instructions.

Biosafety level 4 (BSL4) is the highest level of biosafety precautions, and it is appropriate for dealing with agents that could easily be transmitted as an aerosol within the laboratory or the workplace and causes severe fatal diseases in humans for which there are no available treatments and vaccines.

## 2.2 Process Safety Management

Process safety management can be defined as the analytical tool intended to prevent the release of a substance considered as "highly hazardous chemical" by the EPA or OSHA (Hariramani 2008). It is a set of interrelated approaches used for managing hazards associated with the process in manufacturing industries. Additionally, it is anticipated to reduce the frequency and severity of incidents which results from releases of chemicals and other energy sources. These standards comprise organizational and operational procedures, design guidance, audit programs and other methods.

Workplace monitoring is the process where the conditions in the industrial, manufacturing, production and commercial regions in terms of the physical factors are monitored and analyzed. Monitoring the system would allow an optimum and standardized condition of the working locations and as a consequence yield better output. Parameters such as temperature, humidity, light intensity, noise levels, volatile organic compounds, carbon dioxide, carbon monoxide and particulate matter are analyzed during a workplace monitoring program once or twice a year.

An EVM meter is used for monitoring the temperature, humidity, carbon dioxide, volatile organic compounds and particulate materials in the surroundings of the workplace area. The lux meter is used to measure the light intensity of a region. The preferable light intensity in the office/laboratory workplace ranges between 150 and 200 lx. The noise meter, used to monitor the noises in the workplace surroundings, should be placed approximately 100 m away from the industrial machineries. The level of noise should be less than 85 db; if the level of noise exceeds the threshold, the issues in the machine that creates noiseshould be repaired or replaced. To test electrical insulation for any problems or issues, Megger testing is a good option. However, the testing device detects low and hence some punctures in insulation go undetected. Megger testing provides information about the leakage current and the amount of moisture, deterioration and winding faults.

When the concentration of potent compounds in a product is high, the potential risk of airborne exposure is also high. The product's physical form influences the risk of airborne exposure. The product forms are arranged according to the highest to lowest risk order (powder > uncoated tablets > coated tablets > liquids > semi-solids > capsules).

# 3 Occupational Exposure Banding

Occupational exposure banding also known as hazard banding is a process to quickly and accurately assign chemicals into specific bands. Each band corresponds to a range of exposure concentrations designed to protect the worker's health at workplace (Hashimoto 2007). The bands are classified as A, B, C, D and E (Brouwer 2012; Terwoert et al. 2016).

The procedure for banding requires the following stepwise management:

- Collecting the data to facilitate evaluation of individual health effect endpoints.
- Comparing the hazard data for each endpoint.
- Identifying the endpoints that appear to generate the highest level of hazard leading to selection of an overall hazard band.
- Assigning the band and associated air concentration range.
- The band-specific technical criteria apply to nine potential toxicological or human health outcomes: carcinogenicity, reproductive toxicity, specific target organ toxicity, genotoxicity, respiratory sensitization, skin sensitization, acute toxicity, skin corrosion and irritation, and eye damage/irritation.

The chemicals are classified as per the toxic and hazardous level based on the concentration ($\mu g/m^3$). The levels are non-hazardous (1000–5000 $\mu g/m^3$)—Band 1/A, almost non-hazardous (100–1000 $\mu g/m^3$)—Band 2/B, mildly hazardous (10–100 $\mu g/m^3$)—Band 3/C, hazardous (1–10 $\mu g/m^3$)—Band 4/D, highly hazardous <1 $\mu g/m^3$)—Band 5/E. Each band is assigned with specific methods of containment/controls based on the hazard classification. These include:

- Band 1/A—Open systems with local extraction.
- Band 2/B—Down-flow booths, cone valve drum containment, local extraction.
- Band 3/C—Split valves, down-flow booths, cone valve drum containment, continuous liners.
- Band 4/D—Isolators, split valves, cone valve drum containment, continuous liners.
- Band 5/E—Isolators, split valves with dedicated extraction/washing, cone valve drum containment and continuous liners.

## 4 Industrial Hygiene Control Program Elements in Pharmaceutical Operations

Engineering controls are the primary element to control workplace exposures. To predict the potential exposure present in industries, all processes should be evaluated, analyzed and characterized through complete and documented industrial hygiene monitoring surveys on a periodic basis. A detailed program of reviewing the toxicology and potency of new compounds to be manufactured should be documented. Additionally, an effective hazard communication and training program should be organized for all employees to understand the nature of the risks and take necessary precautions. The importance should be directed on closed material transfer systems and process containment systems with no open handling of potent compound powders. Negative/positive air pressure relationships and necessary buffer zones should be established (i.e., anteroom/gowning room/airlock) and monitored on a regular basis either manually or automatically. As per the requirements, area access should be restricted. Local exhaust ventilation systems should be tested and maintained on a regular basis. In order to prevent unwarranted removal of exposure, a change control system should be in place. Personal protective equipment should to be worn always when subjected to industrial and laboratory working exposures. Powered air purifying respirators (PAPRs) with HEPA cartridges or supplied-air respirators should be used as a secondary means of exposure control where potent compound exposure potential is possible. Effective cleaning and decontamination protocols should be established for equipment and operating suites. A hearing conservation program to monitor, analyze and document high noise areas should be established (Ader et al. 2009).

Industrial hygiene provides health and safety to all individuals in the industrial workplace. The industrial hygiene maturity ladder comprises six steps. The first step deals with the commitment and planning of the basic awareness and knowledge. It includes the basic industrial hygiene trainings, assigning and training dedicated persons for industrial training, and maintaining the basic hygiene and regulatory practices. The second step includes the easy fixes, quick wins and also the must-do activities that indicate prevention and compliance. The third step assesses the risks involved in the industrial workplace. It includes the inventory of different types of chemicals and gathering information which would help in risk assessments. The risk evaluation includes classification of airborne exposures by severity ranking, detailed risk assessments for known carcinogens followed by the implementation of changes. The fourth step deals with development, reviewing and approving of the action plans. The auditing, sharing and implementation of best practices are the fifth step on the ladder, and the sixth is to integrate and maintain the continuous improvement. It includes the fully integrated industrial hygiene in every business decisions, periodical updates of safety data sheets, trainings, inspections, reviews and improvement of chemical hazard communication, PPE and RPE. The pharmaceutical supply chain initiative (PSCI) ensures the supplier's activities and performance, and promotes responsible practices in the areas of ethics, labor, health, safety, environmental protection and management systems (Henschel et al. 1997).

The proposed NIOSH occupational exposure banding process utilizes a three-tiered approach (Zalk and Nelson 2008).

- Tier 1 (**qualitative OEB assignment based on GHS**) involves assigning the OEB based on criteria aligned with specific GHS hazard codes and categories and is intended for individuals with basic toxicology knowledge. Chemicals are categorized according to its possible effect on human health. Substances capable of inflicting irreversible health effects even at relatively low doses are assigned to band D or band E. Chemicals or substances that are likely to cause reversible health effects are branded in band C. Since the data requirements are relatively low for Tier 1, there insufficient information to suggest exposure ranges for chemical bands A and B in Tier 1. Hence, bands A and B are not assigned in Tier 1. In general, Tier 1 can be used as a quick screening method, but NIOSH recommends Tier 2 if the user expertise and data are available.

- Tier 2 (**semiquantitative**) involves assigning the OEB on the basis of key findings from prescribed literature sources, including use of data from specific types of studies. Tier 2 being more quantitative in nature than Tier 1 is intended for individuals with intermediate toxicology knowledge. In order to categorize chemicals into bands A, B, C, D or E, individuals performing Tier 2 assessments will need to determine a point of departure by using the instructions provided for endpoints.
- Tier 3 (**expert judgment**) involves the use of expert judgment to assign the OEB based on in-depth review of health effect studies. It should only be carried out by individuals with advanced toxicology knowledge. Tier 3 involves a more quantitative comprehensive evaluation of the scientific evidence and requires integration of all available data to determine the 2 band assignment.

On understanding the potential hazards of the compound and calculating the preliminary occupational exposure limit, the occupational toxicologist or an industrial hygienist should perform a detailed assessment of the risk. Assessing the situation and the possible risks are important components of a potent compound safety program that will define the probability of exposure. Factors such as handling of the pharmaceutical ingredient, the physical form, the quantity, the frequency, duration of exposure and several more are carefully documented and evaluated (Bress 2009).

## 5 Conclusion

Work is an essential component of life, development and personal fulfillment. Unfortunately, every industry involves processes, operations and materials that causes risks, accidents, unsafe conditions and hazards to the workers' health, to those nearby and to the environment.

Adequate hazard and risk control interventions can prevent the generation and release of harmful chemicals, reagents or by-products in the working environment. This not only protects the health of the industrial workers but can also limit the environmental pollution amidst industrialization. When toxic or hazardous chemicals are eliminated from the work process, both the workers and the environment are protected.

The science, techniques or profession that aims specifically at the prevention and control of hazards arising from work processes can be defined as occupational hygiene. The goals of occupational hygiene include the protection and promotion of workers' health, safe-guarding the environment and contributing toward a safe, judicious and sustainable development.

The need for occupational or industrial hygiene for protecting workers' health cannot be overstated. An unhealthy work environment degrades health. The control of health hazards has the ability to break the vicious circle.

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# Process Safety Culture and Its Relevance to Research Laboratories

**R. V. Anant Shashank Bharadwaz, Giridhar Vadicharla, and Vara Prasad Chinta**

## 1 Introduction

It is a common misconception even after many industrial incidents that if nothing bad happens, there are no hazards and so one need not take preventive measures. Process safety generally deals with low frequency but high severity risks of accidents. The risk of process safety accidents can be avoided by preventing explosions, fire and unexpected toxic chemical releases. Process safety incorporates a systematic approach to management systems with a universal goal of preventing accidents and minimizing risk to all facets of chemical manufacturing.

Process safety management (PSM) is regulated through the PSM standard, 29 CFR 1910.119, titled process safety management of highly hazardous chemicals. These regulations set up an all-inclusive safety program that includes and integrates management practices, procedures and technologies.

## 2 Process Safety Management (PSM)

PSM constitutes 14 elements which manage facilities, technology and personnel. These include process safety information (PSI), employee participation (EP), operating procedures (OP), process hazard analysis (PHA), contractor (CONT), training (TNG), mechanical integrity (MI), pre-startup safety review (PSSR), management of change (MOC), hot work permit (HWP), emergency planning and response (EPR), incident investigation (II), trade secrets (TS) and compliance audit (CA).

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The implementation of PSM resulted in better impacts on process industrial safety viz. near miss, injury and fatality was decreased, damage to property was reduced, technical data (HAZOP, operating procedures etc.) were well reorganized, productivity and quality were improved and the problem of reinsurance was solved.

Identifying the hazards and associated risks forms the core of PSM. PSM, though, is initially designed for process industries; it is suitable for research and development (R&D) laboratories also. Though R&D laboratories have identified the need for a robust learning and development program to diminish these risks, most of them has dearth of well-defined methods for knowledge transfer and developing skills.

R&D facility consists of laboratories and pilot plants that are well-designed and built to conduct experiments which investigate the critical aspects of a process, which can be scaled up for commercial production. There is a general opinion that R&D facilities are less hazardous and much safer than a commercial plant and that they do not need the same safety management systems as commercial plants (Olewski and Snakard 2017). However, with the advances in technology, R&D facilities are turning out to be complex systems because of introduction of number of unknown chemicals with less information available about the material and processes, frequent modifications to the experimental setup and experiments, limited automatic safety interlocks and lack of waste characterization. These complexities lead to substantial hazard potential resulting in property damages, environment excursions, injuries and sometimes fatalities. Hence, developing a standardized and comprehensive process safety program, which cover all potential scenarios leading to process safety incidents, is a very challenging task for R&D organizations.

PSM wheel for laboratory/R&D is as provided below in Fig. 1 (DuPont Process Safety Management 2014), which integrates three broad dimensions viz. facilities—to manufacture and handle hazardous materials, personnel—who operate, maintain and support the process and technology—of the process.

## 3 Case Studies

The implementation of PSM would have avoided three major mishaps happened in the last decade. Each of these is presented here as case studies and how the mishaps could have been avoided has been reported.

### *3.1 Case Study 1. Fatality in a flash fire at the University of California, Los Angeles (UCLA)*

Research assistant of UCLA was working on an organic chemistry experiment in UCLA's molecular sciences buildings during a holiday. Only three months into her


**Fig. 1** PSM wheel

job in the laboratory, she used a plastic syringe to extract a small amount of t-butyl lithium, a chemical that ignites instantly when exposed to air, from a sealed container. As she withdrew the liquid, the syringe spewed the flaming chemical and flash fire set her clothing afire and she suffered second- and third-degree burns over her body, which ultimately resulted in her death, eighteen days later (Kemsley 2009). Root cause analysis for the incident is given in Table 1.

### *3.2 Case Study 2. Explosion at Texas Tech University (TTU)*

Two TTU graduate students were synthesizing an energetic material, nickel hydrazine perchlorate (NHP). Though it was advised not to synthesize more than 100 mg of NHP, the students synthesized 10 g. One of them, named Brown, took half of the sample to run characterization test while the other took the remaining for solubility studies. As the material was lumpy, Brown placed his sample into a mortar. As he believed that the material was safe when wet, he added some hexane and tried to break the chunks of the material very gently using a pestle, wearing safety goggles but working in the middle of the laboratory with no blast shield. When he thought he was done, he took off his goggles after setting down the mortar and decided to stir the compound one last time and the mortar exploded in his hands. He lost three fingers of his left hand, severely injured his right hand, scratched his right eye, perforated his left eye and had cuts to various parts of his body that were exposed while the

**Table 1** Root cause analysis for case study 1

| S. No | Cause | Best practice | Missing PSM element |
|---|---|---|---|
| 1. | Person was not wearing proper PPE | PPE suitable for handling pyrophoric material is not used | Operating procedure and safe practices |
| 2. | An open flask of hexane, which was not required for the experiment, was present in the fume hood | Best fume hood handling and maintenance practices | Operating procedure and safe practices |
| 3. | Post-incident, safety shower was not used | Emergency response procedure (ERP) not in practice | Training and performance and ERP training |
| 4. | Usage of plastic syringe in place of glass ware | As per Aldrich technical bulletin, glass ware syringe to be used | Operating procedure and safe practices |
| 5. | Usage of 1.5 inch syringe | As per Aldrich technical bulletin, syringe of 1–2 foot long to be used | Operating procedure |
| 6. | No laboratory records of undergoing any such training | Proper training with documentation to be carried out before carrying out job | Training and performance |

**Table 2** Root cause analysis for case study 2

| Sl. No | Cause | Best practice | Missing PSM element |
|---|---|---|---|
| 1. | Person was not wearing proper PPE | PPE suitable for handling pyrophoric material is not used | Operating procedure and safe practices |
| 2. | Despite being told by their adviser, to make no more than 100 mg of the material, the students synthesized 10 g. | Hazard analysis to be carried out before major change in the operating philosophy | Management of change |
| 3. | No laboratory records of undergoing any such training | Proper training with documentation to be carried out before carrying out job | Training and performance |

other student was not injured (Texas Tech University Laboratory Explosion 2016). Root cause analysis for the incident is given in Table 2.

## 4 Case Study 3. Explosion at University of Hawaii (UH)

One of the experiments at UH used a mixture of hydrogen, oxygen, and carbon dioxide, which is a flammable mixture. All the compounds were stored separately

**Table 3** Root cause analysis for the case study 3

| Sl. No | Cause | Best practice | Missing PSM element |
|---|---|---|---|
| 1. | No Hazard assessment and management of change | To carry out the pre-startup safety review | PSSR review |

and are mixed at the point of use. The experiment was reconfigured by a post-doc researcher, which now uses premixed gas supplied from a 50 L pressure tank. As per the report, the mixture contains 55% $H_2$, 38% $O_2$ and 7% $CO_2$ at 120 psig. While the post-doc was running the experiment, flammable mixture got ignited by a static discharge, causing an explosion that resulted in damage to the laboratory and mutilated the post-doc who lost an arm. Due to high pressure and presence of oxygen, the flammability of $H_2$ in air and the intensity of the energy released is increased.

The post-doc and the principal investigator have consistently expressed interest in laboratory safety. However, there was no hazard assessment before the experiment was reconfigured and there was no management of change. The experiment was reconfigured to address an operational problem, but the first time the modified process was used it had catastrophic results (Kemsley 2016). Root cause analysis for the incident is given in Table 3.

## 5 Conclusions

Based on the above case studies, the following conclusions can be drawn.

1. The physical hazards of the energetic materials research work were not effectively assessed and controlled.
2. Comprehensive hazard evaluation guidance for research laboratories does not exist.
3. Previous laboratory incidents with preventive lessons were not always documented, tracked and formally communicated.
4. Insufficient safety accountability.
5. No safety provision by research granting agencies.

These incidents show that process safety management (PSM) is definitely relevant for a safe-working environment across laboratories. R&D laboratories across India (Universities as well as Industries) must take a leading role in preventing accidents with big industries/universities in particular investing resources to build academia wide awareness and capability for the implementation of elements of process safety management.

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# Design and Development of Industrial Internet of Things-Based Polling Booth for Voting

**Anita Gehlot, Rajesh Singh, Kushagra Rastogi, and Jai Gupta**

## 1 Introduction

This research paper provider knowledge about Aadhar QR code which contains voters name and his fingerprint detail in their database that can be decrypted by using binarization and Reed–Soloman error correction. In Aadhar card-voting system, it accepts person fingerprint and if the authentication is successful, then it allows person to cast vote otherwise does not allow person to cast vote. Researchers uses three document file with password which can be known by only special officer, and this will help to solve the fake voting and provide transparency in voting system. First document contains voter name and voting time. Second document contains voter information and address. Last document contains party votes and total number of votes. These all files are handled by special officer (Srinivasu and Rao 2018). This paper provides information about fingerprint, and the fingerprint verification technique is better than current voting system to cast the vote. If we use an Aadhar card ID with password, voting will become more time consuming and you have to remember password also but biometric verification takes less time in verification. Another good part of this method is that voter will ensure that his vote has gone to correct party (Karthikeyan and Nithya 2017). The main purpose of paper is to have a secure electronic voting machine using fingerprint sensor and that is connected with Aadhar card database. Electronic ballot reset can be done by finger vein sensing that allows voter to cast vote. There should also send data to main officer of the booth using WI-FI. The thumb impression is the key for a person for voting; this is cross-checked by the available record in the database (Rajendiran et al. 2017). This paper proposes a good efficient battery saving technique for IoT devices. In IoT, as the there are many devices and

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the battery consumption is in large amount, paper researcher provides technique to resolve this problem. Power management is under heterogeneous settings. In this, they provide a virtual polling interval that we can easily evaluate variance and mean of the delay and power consumption by applying querying formulae (Feng et al. 2017). There are many new technologies involved for voting machine that improved the counting of votes, accessibility, alteration in the result, etc., but there can be error in the EVM machine that the input provided by the voter can observe an error in output. We can perform verification of e-voting system, called Pro-Vote. Pro-Vote is a conclusion to end e-voting framework with a voter verified paper audit trial, created inside the system of a bigger activity whose objective is surveying the attainability of presenting e-voting in the Autonomous Province of Trento (Villafiorita et al. 2009). Whole system needs IoT devices, a server, computing device, and applications of IoT. Server communicate through network. The computing device has IoT application and interface with RPC interface. The IoT interface communicates through IoT-enabled application using RPC interface. The IoT interface communicates via IoT protocols to IoT server (Choi et al. 2018). Internet of things (IoT) is extremely advantageous for availability to gather and exchange real-time information that is useful for new rising innovations. IoT gives the approach of software-defined networking (SDN) that helps arrange administrators and clients to control and access the system gadgets remotely. There is a wide range of SDN-based advances which are helpful for the necessities of IOT and there are different networking aspects such as core, access, edge, and data center networking (Bera et al. 2017). All wireless devices and actuators are connected with IOT are the design of cyber-physical systems. Their paper first summarizes about wireless communication principles for the connectivity needs of IOT and CPS. The paper reviews about the relevant wireless communication standard. It also emphasizes about more in-depth security in protocols layers, which comprises both physical layer and logical layer security (Modi and Jagdish 2017).

## 2 New Approaches of Our Project

Internet of things (IoT) implies system of physical devices embedded with some sort of microcontrollers, microprocessors, software, sensors, actuators, and network connectivity which enables these objects to connect and exchange information. In our model, fingerprint sensor will be embedded with Node MCU ESP8266 and Node MCU ESP8266 will be connected to the cloud through Internet for checking the data of Aadhar card and Voter ID card. Nowadays, when user go for voting on polling booth, user has to show his Voter ID whenever he or she goes to the booth to poll his or her vote. This is often a time-consuming method because the user needs to check the Voter ID card with the list officer has, and make sure it is an authorized card and then gives the entry to the user to poll his or her vote. Thus, to avoid this kind of problem, we have designed a device that is enabled with fingerprint sensor where the user does not require to carry the Voter ID and Aadhar card.

Today, our Aadhar card contains fingerprints of user. We have all the fingerprint data in database as our fingerprint is linked with Aadhar card. Our fingerprint sensor will read the fingerprint of user and pass to the Node MCU ESP8266 for further processing. Node MCU ESP8266 will read the fingerprint and compare the fingerprint with existing fingerprint. If the fingerprint matches with the already stored fingerprint, the user is allowed to poll his or her vote. If not, a message is displayed on LCD and therefore the user is not allowed to poll his or her vote.

After entering in the poll booth, user will give the vote on Node MCU ESP8266 by choosing the right person and can see the display of his or her vote on Voter-verified paper audit trail (VVPAT). After giving the vote, Node MCU ESP8266 will send the data for further processing to the cloud.

# 3 Methods of Voting

## *3.1 Traditional Voting Process*

This procedure is isolated into four classes.

### 3.1.1 Verification

In Verification process, each voter accompanies with his/her Voter ID in the booth. The directing officer checks the id of the voter by coordinating it with the voter list containing the subtle elements of the voter; after approval, the officer gives a poll paper to the voter and engravings his/her finger with an indelible marker.

### 3.1.2 Vote

In the wake of giving the ballot paper, the voter goes into the secured booth which is put in a side of the room, checks the symbol of the applicant of interest on the poll, folds it, and drops it the ballot box.

### 3.1.3 Vote Counting

At the point, when the voting time frame closes, the directing officer gathers all the ballot boxes of the center and begins counting. While counting, it is imperative to confirm the best possible votes. Just the directing officer and Election Commission designated, approved individuals are qualified for this procedure.

#### 3.1.4 Result

Subsequent to checking of votes, the directing officer reports the outcome and announces the winner of that center.

The traditional voting framework requires a drawn-out stretch of time and parcel of material. It is additionally defenceless against illicit vote casting. It is a manual framework and there is dependably risk of manual errors during the counting.

### *3.2 Existing E-Voting System*

#### 3.2.1 Introduction

Electronic voting framework has acquired progressive change than the traditional manual voting framework. It can without much of a stretch make that voting procedure basic and cheerful. Principle motivation behind a voting machine is to record vote and give result quick.

#### 3.2.2 Electronic Voting

Electronic voting alludes to any framework where a voter casts his or her ballot utilizing an electronic framework, instead of a paper. Once the vote is casted, an electronic vote is secured deliberately and exchanged from each electronic voting machine to counting system.

#### 3.2.3 Electronic Vote Counting

Electronic vote counting alludes to the system that calculates the votes that are casted through the electronic voting machine. Votes are counted through a computer software.

Computer software tells about the number of votes.

## 4 System Description

Figure 1 shows the block diagram of the system, which contains three parts (a) Verification node, (b) Vote punching node, and (c) Cloud server.

### *4.1 Fingerprint Sensor*

There we utilize optical unique finger impression sensor which makes finger impression identification and confirmation simple. In sensor, there is powerful DSP chip that images rendering, estimation, highlight finding, and looking. At that point associated with the microcontroller that with universally asynchronous receiver/transmitter (UARTs) that can be utilized to get and transmit information serially.

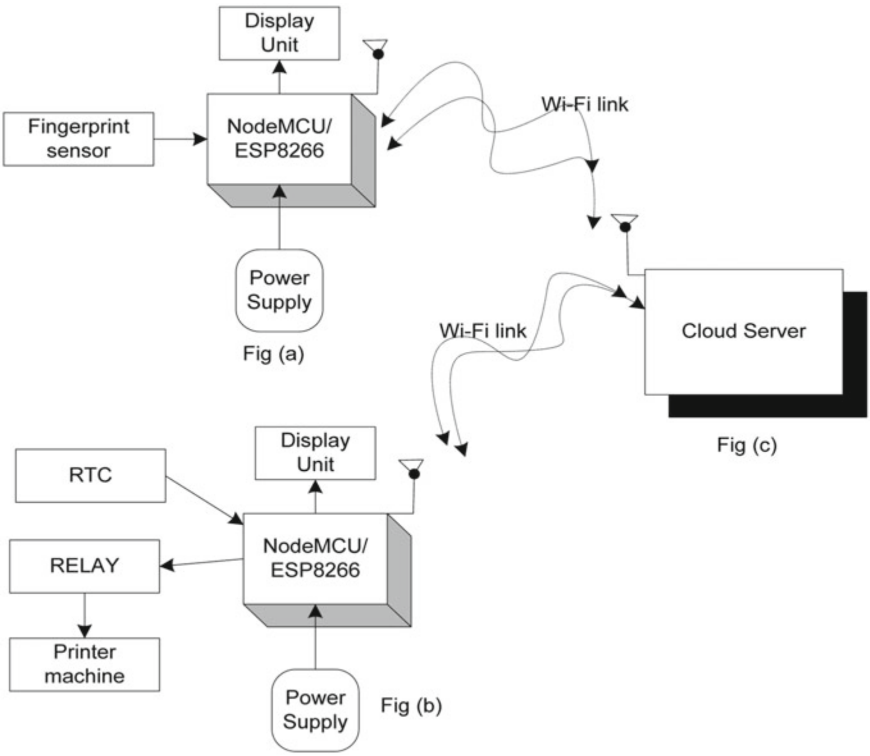


**Fig. 1** Block diagram of proposed system

### *4.2 Node MCU ESP8266*

It is an open-source IoT-based platform. This is microcontroller and uses LUA-based programming language. It is arduino like simple, smart, and WI-FI enabled. It is small in size and cheap. On board, it has 10 GPIOs(D0-D10), pulse-width modulation (PWM) functionallity, one analog signal (A0), 3.3 V power supply voltage, etc.

### *4.3 Arduino Integrated Development Environment (IDE)*

This is an open-source Arduino software which is easy to use code. This supports C and C++.This runs on MAC OS, Windows, and Linux. Using it, we perform program that is compatible with microcontroller board. Mainly, this software translates the program instruction into a complex code for board's specific chip.

### *4.4 Real-Time Clock (RTC)*

It is a computer clock which keeps track of current time. It also has an alternate of source of power; if primary battery gets off, it will keep track on current time. It will give accurate time of vote by the voter.

### *4.5 Voter-Verified Paper Audit Trail (VPAT)*

This is a method that providing feedback to voters that vote cast by voter is correct by the machine. This will help to remove machine error and election fraud. The machine is placed in a glass case that voter can see it (Figs. 2 and 3).

Figures 4 and 5 circuit schematics of verification node and circuit schematics of vote punching node, respectively. The NodeMCU is Wi-Fi modem capable to compute the calculation related to voting machine or polling booth.

## 5 Flowchart

Figure 6 shows the working of the fingerprint sensor. This is a flowchart of working with fingerprint sensor outside the polling booth. In this, the person will come to the booth and put his fingerprint on the sensor as shown in Fig. 2. If the person has an Aadhar card and Voter ID card, fingerprint sensor will check and verifies that the person has a valid Aadhar card and Voter ID card. After verification, person can

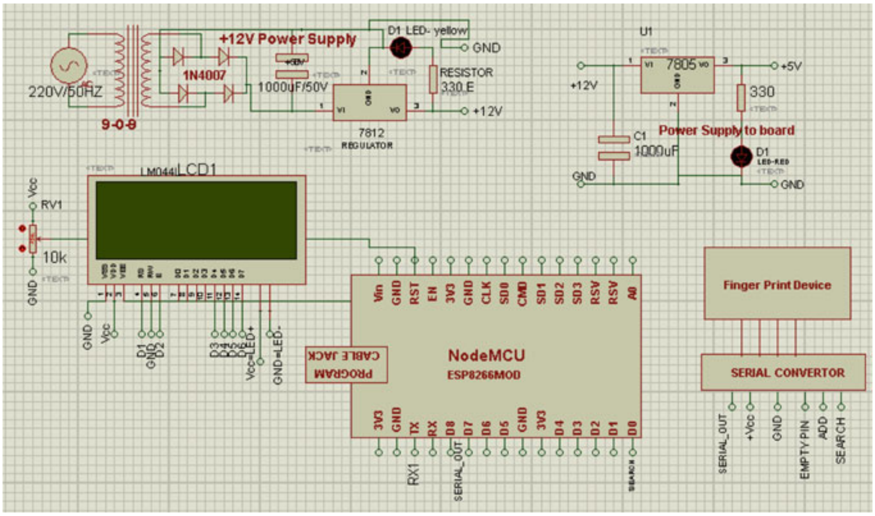


**Fig. 2** Circuit schematics of verification node

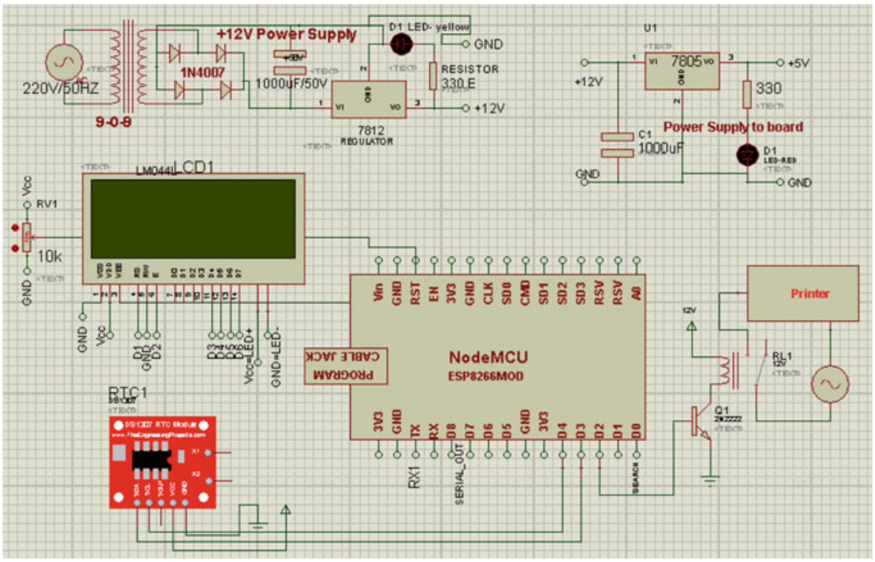


**Fig. 3** Circuit schematics of vote punching node

go to the booth and give his/her vote to whom he/she wants to give the vote. If the person has not an Aadhar card and Voter ID card, he/she will not get the entry in the polling booth. Fingerprint sensor will do our work easy and reduce the man labor and manual error.

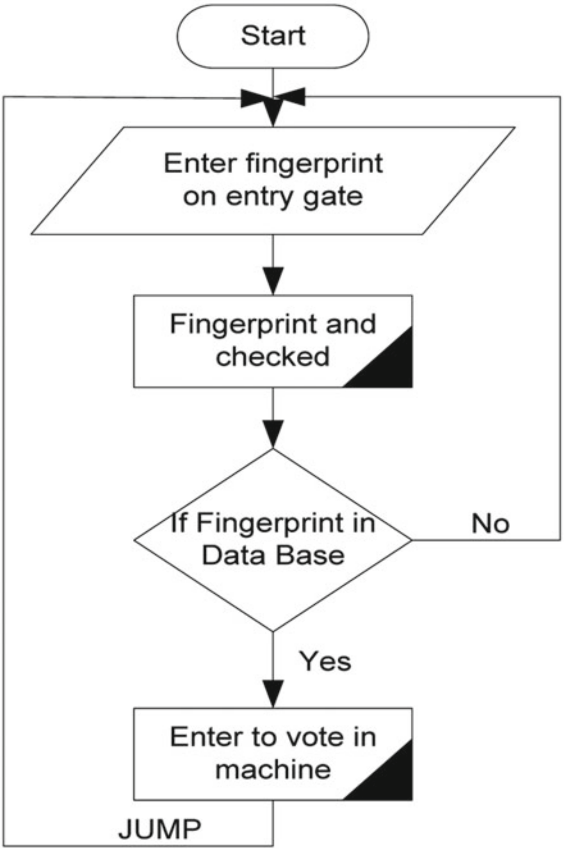


**Fig. 4** Flow chart of proposed system

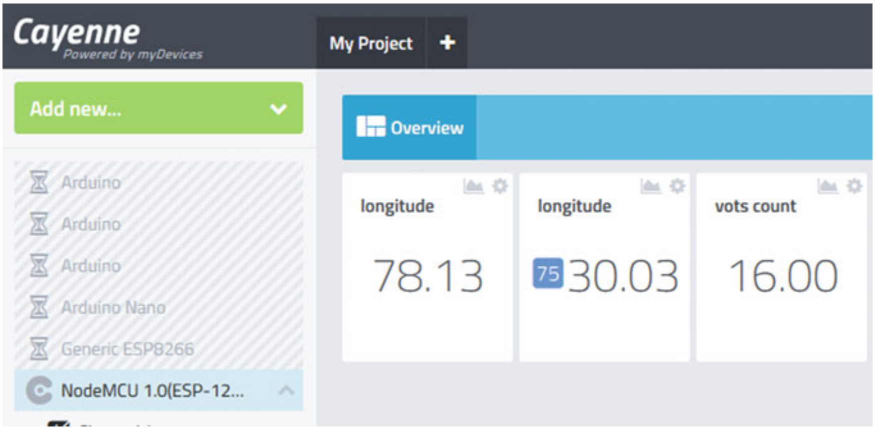


**Fig. 5** View 1 of data of votes are in Cayenne APP

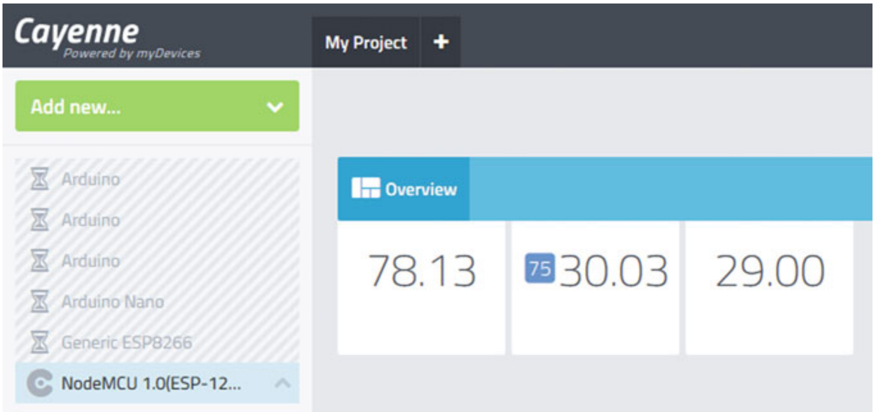


**Fig. 6** View 2 of data of votes are in Cayenne APP

## 6 Result Analysis and Future Scope

In this paper a structure for electronic voting system in light of unique finger impression sensor is executed with the objective of wiping out counterfeit voting and vote redundancy. Electronic voting systems have numerous ideal conditions over the traditional technique for voting.

Figures 5 and 6 show the data of location and votes are available on cloud server using cayenne application. Some of these purposes of intrigue are lesser cost, speedier classification of results, improved transparency, more conspicuous accuracy, and lower risk of human and mechanical mistakes. It is greatly difficult to layout culminate e-voting structure which can allow security and insurance on the unusual state with no exchange off. Future redesigns centered to plan a framework which can be anything but difficult to utilize and will give security and protection of votes on a satisfactory level by concentrating the confirmation and taking care of the area. In the future, the acknowledgment should be possible by eye retina for better precision.

## 7 Conclusion

The paper "IoT enabled Polling Booth" has been successfully designed and tested. As normal EVM is the burning issue in recent days, this Electronic Voting Machine system will be a solution for all those problems in the following ways-

The voter's right is preserved.

1. It is secured by fingerprint.
2. User precious time is saved.

The democracy of the nation is protected by using this safe and secured system.

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