Effects of VOCs on Human Health

Vipin Soni, Paramvir Singh, Venu Shree and Varun Goel

Abstract With broad commutability of pollutants, air pollution is a complicated issue that intimidates directly to human health and our environment. Various indoor and outdoor air pollution comprises of regulated and unregulated emissions. Volatile organic compounds (VOCs) are one of them which are carcinogenic and lead to photochemical reactions. Emissions of VOCs are directly associated with large number of industrial processes, emission through transportation, and various indoor and outdoor sources. Due to deleterious effect of different VOCs emitted from transportation, chemical industrial plants and from indoor on the environment make their eviction mandatory or at least degrade them under the limit set by environmental norms. So, it has turned a burning topic to diminish air pollutants and set a norm for volatile emissions. This study focuses on the major sources of carbonyl and aromatic compounds in indoor and outdoor environment. Some remedial processes like photocatalytic oxidation, plasma decomposition, chemisorption, and catalytic oxidation have been described in this study through which decomposition of these contaminants can be achieved. This chapter contains a deep study on health effects from the carbonyl and aromatic compounds.

Keywords Aromatic compounds · Carbonyl compounds · Pollutants
Indoor air · Air pollution

V. Soni · P. Singh (✉) · V. Goel
Department of Mechanical Engineering, National Institute of Technology Hamirpur, Hamirpur 177005, Himachal Pradesh, India
e-mail: param016@gmail.com

V. Shree
Department of Architecture, National Institute of Technology Hamirpur, Hamirpur 177005, Himachal Pradesh, India

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1 Introduction

Mostly, people spend their time in home, office, shopping center, car, etc. The common air pollutants include nitrogen oxides (NO_x), carbon oxides (CO and CO_2), carbonyl compounds, aromatic compounds, and particulate matter (PM). Among these pollutants, carbonyl and aromatic compounds have severe impacts on environment. The possible sources of carbonyl and aromatic compound emissions are transportation, chemical industrial plants, painting, electroplating, etc. [1]. Carbonyl and aromatic compounds, e.g., formaldehyde (HCHO), benzene, toluene, and xylene are emitted in both indoor and outdoor environments through different processes. Longtime exposure to polluted air even containing a few parts per million (ppm) of volatile organic compounds (VOCs) may cause long-term diseases [2]. Carbonyl and aromatic compounds which are generated through naturally and anthropogenic processes are having group of air pollutant in case of indoor as well as outdoor due to long-term health problems in human (WHO 2004). According to the health agencies, VOCs are considered as human carcinogen and longtime exposure of VOCs leads to disease like reduced pulmonary function, asthma [3]. Also, nasopharyngeal cancer can be caused by long exposure to formaldehyde which also comes into the category of carbonyl compounds. In addition, discharge of VOCs in the environment leads to urban smog and ozone, ozone layer depletion in stratosphere, and the greenhouse effect [4]. The increasing research to overcome detrimental effect by VOCs on human health and environment has caused fast recognition of toxic aspect of VOCs during the last two decades [5]. The different VOCs pollutants are categorized as follows: carbonyl compound (aldehydes and ketones), polycyclic aromatic hydrocarbons (PAHs), mono-aromatic hydrocarbons (MAHs), nitro-PAHs, oxy-PAHs, etc. 1,3 butadiene, aldehydes (formaldehyde, acetaldehyde), acrolein, aromatics (benzene, toluene, ethyl benzene, xylene, styrene) n-hexane, naphthalene, etc., are classified as toxic pollutant to environment and human health as per environmental protection agency (EPA) [6]. It is important to convert harmful VOCs into the environment-friendly species. In case of outdoor environmental pollution, the major origin of pollution is the transportation area. The compounds emitted through the incomplete combustion of fuel leads to various air pollutants. The pollutants from engine exhaust sometimes considered as the primary contaminants which affect the quality of air [7]. Though the formation of contaminants from compression-ignited engines is quantity wise low as compared to spark ignited engines, the formation of larger size particulate is the major problem which finally combines with the poisonous VOCs [8]. Urban air pollution and indoor air pollution come in worst pollution category. Air is polluted by various substances like through exhaust gas, liquid droplets, or solid particles. These air pollutants can be further categorized into primary, secondary, and tertiary pollutants [9]. Primary pollutants emit directly from the various sources like volcanic eruption, engine exhaust, and from different factories or industries smoke [10]. The primary pollutants include molecules like emission of carbon monoxide (CO), sulfur dioxide (SO_2), emission of VOCs, and NO_x emission from different industries and motor

vehicles [11]. Apart from the primary pollutants, the pollutants which are not emitted by it are called secondary pollutants. The example of secondary air pollution is formation of ozone at surface level. The possible air pollutants are carbon monoxide (CO), carbon dioxide (CO_2), NOx, sulfur oxides (SO_2), chlorofluorocarbon (CFC), aldehydes (formaldehyde, acetaldehyde, etc.), PAHs, particulates, ammonia, radioactive particles, free radicals, etc. [6]. These pollutants produce many ill effects on both environment and human beings.

2 Sources of VOCs

2.1 Sources of Carbonyl Compounds

The organic molecule containing functional group >C=O is classified as the carbonyl compounds. These carbonyl compounds come in the category of unregulated emission which is toxic in nature, and they have various ill effects on the environment and human health [12]. The common carbonyl group found in the air pollution is grouped as follows: formaldehyde (HCHO), acetaldehyde (CH_3CHO), acetone, acrolein, benaldehyde, butyraldehyde, crotonaldehyde, 2,5-dimethyl benzaldehyde, hexadehyde, methacrolein, propionaldehyde, tolualdehyde, valeraldehyde, etc. [6]. These carbonyl compounds are also established as a part of ozone cycle. The most commonly found carbonyls are HCHO, CH_3CHO, and acetone which are the product of combustion during intermediate stage.

2.1.1 Indoor Sources

Indoor air pollutants caused by use of different paints, various plywoods, cooking, cigarette smoke, etc., which are hazardous to the human health. For this reason currently indoor air contamination has become major problem for the world. Other indoor air pollutant sources are construction work, furniture, textile, clothes, carpeting, and wood processing household appliances, particle board, painting, plywood, etc. [13]. The long-term effects of these indoor air pollutants are death threatening disease. The indoor air pollutants come in dominant position when decorative material used in buildings [14]. As the technology progression takes place, to save energy and for the enhanced thermal efficiency human usually lives in air-constrained buildings. Ultimately, they utilize the thermal insulation for improvement in the thermal efficiency of buildings. This finally results in increment of indoor air pollution. There is a lot of compounds present like cigarette smoke, CO_2, floating dust, VOCs, radon, NOx, PM, HCHO, asbestos [15]. In these pollutants, some are very hazardous to human health. These VOCs have also various sources of emission for indoor air pollution like they emit from thermal insulation, deodorant, cosmetic products, furniture, and some time through the combustion of

something like woods. A new term 'sick building syndrome' has been coined for buildings with contaminations like VOCs [14]. The term SBS has covered those buildings which are recently constructed. SBS generally contains the pollutants emitted from the paints, furniture, building materials, product used for the decoration material, etc. Without any reason if people living in the buildings feel symptoms of illness, medical terminology uses SBS for that building. Features like throat irritation, headache, dizziness, fatigue, etc., are the main noticeable complaints from the people living in these types of buildings. These decorative substances contribute a lot in case of new buildings or apartments. In the recent years, several policies have passed related to diminishment and control the indoor air pollution.

2.1.2 Outdoor Sources

There are several outdoor sources like transportation sector, industrial sector, various combustion processes, and different secondary processes like smog formation. In urban regions as stated by Guo et al., the most dominant sources of carbonyl emission are the exhaust from the tail pipe of vehicles [16]. After the transportation sector, another dominating source of carbonyl emission is petrochemical plants followed by petroleum reservoirs. The primary sources of carbonyl compound include those compounds which cause direct emission, while the secondary sources include the formation of carbonyl in the atmosphere [17]. The primary mode of carbonyl compounds is motor vehicle, industries, plants, combustion process, etc. Apart from vehicle emission, secondary chemical reactions of alkanes and alkenes also produces the aldehyde in the atmosphere [18]. Photochemical process which is secondary process in the ambient is also a source of HCHO and CH_3CHO. Different industrial stages also emit carbonyl compounds. Altshuller had reported that there is substantial production of HCHO and CH_3CHO from the alkanes and alkenes due to the photo-oxidation process [19]. Various biofuels have been tested as the alternate to conventional fuel. There are various alcohols which have been used to improve the efficiency of combustion in vehicles. Since alcohol possesses high heat of vaporization, it substantially reduces the high temperature during combustion process. But different carbonyl emissions from the alcohol-operated engine go significantly high. Stump et al. had studied the emissions through ethanol-convened motor vehicles [20]. They have found that there is a significant decrease in aromatic compound but a substantial increase in HCHO and CH_3CHO due to blending of ethanol. In case of vehicle, there are several modes of emission of carbonyl compound like through tail pipe emission, tires and brakes, catchment area of fuel. The main origin of contamination in air is automobile's emissions as suggested by Faiz [21]. In carbonyl compounds, CH_3CHO and acetone are the main participants for smog promotion due to photochemical process in environment. The use of alcoholic fuels has limitation just because it is a possible source of CH_3CHO emission in environment. Poulopoulos et al. have tested the emission from the ethanol fuels [22]. The result shows that at intermediate load there is enhancement in the

CH_3CHO emission. It is clear that CH_3CHO is known for toxic element. Caplain et al. have investigated the nonregulated pollutants from diesel-fueled cars [7]. They have suggested that for diesel-operated vehicles there is 2–6.4% of carbonyl compound emission. In the possible carbonyl compound, ketone, HCHO, and CH_3CHO are the main molecules which approximately contain 73% of all carbonyl compounds. The high content of carbonyl compound emission is possible due to the cold or warm starting. The current technology advancement toward the use of alternate fuels like biodiesel has attracted researcher's attention for the emission investigation with these fuels. Graboski and McCormic have found that there is inconsistent or increased emission from biodiesel as compared to diesel in terms of ketone emission [23]. Apart from the exhaust emission, the running time period of vehicle/engine also has an effective impact on carbonyl emission. After a longtime period of engine, these can strongly participate in the formation of carbonyl emission and smog formation. The emission of HCHO sometime generated conflict between different results as increased HCHO was observed at higher load condition. Contrary to this result, higher HCHO was observed at lower loads by Takada et al. [24]. Hence, it is clear that for the emission of carbonyl emission through engines, there are several parameters to be considered as dominating factor like oxygenated fuels, engine, cycle and procedure used for running, and the temperature during the combustion process. For the increased oxygen percentage in fuel blending, alcohol and biodiesel have been used. A study has been conducted by Turrio-Baldassarri et al. on biodiesel-blended diesel oil to investigate the carbonyl compound emission [25]. The results show that CH_3CHO, HCHO, propionaldehyde, and acrolein were the common abundant compound during the emission. These are significant compounds which have the 90% of carbonyl emission. It was observed that the use of biodiesel increases the carbonyl emission percentage up to 19% as compared to mineral diesel. Graboski and McCormic have suggested that biodiesel having glycerides enhances the acrolein emission [23]. Peng et al. showed the increase in CH_3CHO emission due to ethanol mixed with biodiesel [26]. Some results show that there is evidence of clean and proper blending of biodiesel. Whether these oxygen-rich fuels provide more oxygen for helping the combustion process and reducing emissions or oxygen in fuels promotes the formation of aldehydes is still unclear. Karavalakis et al. have explained the properties of biodiesel which effects the carbonyl emission [11]. They have found that probably purity level, iodine number, and the fatty acid profile play a key role in carbonyl emission, which is due to disassociation of biodiesel into various other organic compounds. Decarboxylation process enhances the emission of carbonyl compound. This process could dissociate esters which may be processed of generation of intermediates during combustion process. Some air pollutants, namely CO, CO_2, and NO_x, can be regulated by the natural cycle, e.g., carbon cycle and nitrogen cycle but VOCs concentration which is carcinogen has not regulated till now.

2.2 Aromatic Compounds

As carbonyl emissions, aromatic emissions have the similar source like transportation sector, industrial sector, indoor air pollutants and various outdoor combustion processes. After the transportation sector, another dominating source of aromatic emission is petrochemical plants followed by petroleum reservoirs.

2.2.1 Indoor Sources

The organic molecules having ring structure are termed as the aromatic compounds. Due to the formation of isomers, aromatic compounds possess irregular behavior. The human-originated aromatic compounds in indoor have various sources like cooking, smoking, heating, computers, printing machines, electronic equipment, printers, and heating [27]. In general, aromatic compounds are classified in two parts; one is MAHs and other one is PAHs. Usually due to the partial combustion of organic compounds, PAHs are produced [28]. Due to their cancerous and/or ability to change genetics, PAHs are considered as the dominant compounds for the indoor air pollution [29]. These compounds are always existed in the indoors and outdoor environments. Some sources like combustion in indoors are termed as the sources of aromatics compounds in indoor as per WHO. Apart from straightforward sources of emission, other sources like individual sources also contribute to emission sufficiently. Sometimes, personal contribution in emissions may become greater rather than emission from the equipment. Sometimes, the slow emission from the polymeric equipment can affect the indoor air quality and it can produce the sick building syndrome problem. Aromatic compounds include broad range of organic molecules having distinct functional groups. Benzene, ethylbenzene, toluene, isobutyl benzene, styrene, tetramethyl benzene, xylene, naphthalene, and anthracene are the some common aromatic compounds found in the indoor environment. Benzene, toluene, and xylene are the most common indoor air pollutants which are termed as BTX commonly. The organic molecules which have more than two rings are called as the PAHs. These PAHs can be grouped in three different classes of low molecular weight (LMW), medium molecular weight (MMW), and high molecular weight (HMW) having 2–3, 4, and 5–6 rings, respectively [6]. So due to advancement in technology, a major change has been observed in buildings and working conditions. In different buildings and offices, several modifications that have been done for the use of printers, different electronic equipment, fax machines, desktop computer, etc. have strong influence on the indoor air quality. Destaillats et al. has comprehensively investigated the emission from the electronic equipment and observed that cathode ray tube directed computers and monitors of transistor having thin film are also the source of aromatic emission [30]. There are some evidence of aromatic emission from laser printers, fax machine, scanner, color printers, and ink jet printers. Other than it, in buildings, daily use products and decorative material are the important source of aromatic compounds in indoor air.

These are those emissions which are long lasting until the equipment deterioration. Coal tar having used for liquid resistive material in buildings can produce emission like naphthalene, biphenyl, and acenaphthene [31]. Yu and Crump had experimentally investigated on the emission from the building [14]. They suggested that a fresh painted building has the higher emission rate. The observation shows that evaporation is primary form of emission accompanied with diffusion process in indoor air. For the lighting and ornamentation purpose of buildings, candles have exploited as a source from very early times. Candles are also used sometime for the religious means. Due to the incomplete combustion process, inflaming of candles can originate continuous smoke which contributes majorly in the formation of benzene, xylene, toluene, etc [32]. Pagel et al. have described the wax burning as the source of polycyclic aromatic hydrocarbons [33]. Baek et al. have investigated the emission quality in Korea for the domestic buildings, restaurant, and offices [15]. The results show that benzene, ethyl benzene, toluene, m + p-xylene, o-xylene, and styrene were the major pollutants in the air during investigation. The seasonal variation also persists for the aromatic compounds which follow the trend of decreasing to increasing order from summer to winter. The cause of this type of trend is different for other activities used during the winters like different combustion process in winter, use of heat pump, and utilization of room air heaters, so a wide range of aromatic compound always exists in indoor air due to the volatile nature of these molecules. Hence solvents, cleaning product, varnishes, waxes, etc., have also ability to produce aromatic compound emission in indoor environment.

2.2.2 Outdoor Source

Movement toward urbanization and industrialization in twenty-first century broadly changes the current situation for the outdoor air pollution. Outdoor air pollution has increased due to manufacturing facilities and enhancement in motor vehicles. In all the aromatic compounds, the main concern is over PAHs emission. These PAHs are emitted from the partial combustion of organic compounds. The different combustion processes like burning of wood, coal, diesel-operated automobiles, and sometime grilled meats have the sufficient involvement in PAHs emission. The outdoor air pollution is totally hanged on emission from motor vehicle and industries. PAHs are the major component come in the unregulated emission from the engines. Many authors have given their points on the polycyclic emission from the engines [6, 9]. The use of diesel fuel in motor vehicle promotes the organic and inorganic emission for the tail pipe. These unregulated emissions from diesel exhaust are highly volatile and easily become hazardous to the environment and human beings. These emissions contain lots of organic molecules like mono-aromatic hydrocarbons and polycyclic aromatic hydrocarbons. As per the various agencies like International Agency for Research on Cancer (IARC), the exhaust from the burning of diesel fuel is considered as the carcinogen for the human health. The reason for the emission of PAHs from the diesel-fueled vehicles may be the separation of fuel during the combustion. This process leads to the

pyrolysis and pyrosynthesis of aromatic compounds [34]. Lubricating oil which has been used extensively in diesel engine for improving the efficiency also contributes in the formation of PAHs [35]. Other factors which have small impact in generation of PAHs are like kind of engine used, fuel quality, load and speed of engine [36]. There are other unregulated emissions rather than PAHs like nitro- and oxy-PAHs. Singh et al. have given the trend of emission among LMWs, MMWs, and HMWs [6]. The result shows that highest content of PAHs in engine exhaust is those having LMWs along with MMWs and HMWs. Tancell et al. have resulted that about 80% benzo(a) pyrene in tail pipe emission is due to those molecules which exist in fuel [37]. Schauer et al. have studied the emission from the motor vehicle to investigate the compounds in tail pipe exhaust [38]. Result shows that benzene, toluene, and xylene are the main contaminants in air which have many sources of emission within motor vehicles. Caplain et al. have comprehensively analyzed the unregulated emission from the gasoline- and diesel-convened cars [7]. The result shows that the unregulated emission contains 54–75% aromatic compounds for a diesel-convened car. This data shows that diesel-convened engine emits large amount of aromatic compound during combustion. As the demand of diesel fuel increasing, the reservoirs of diesel fuel currently tend to deplete and cost increases simultaneously. This makes the restriction over the rapid use fossil fuels in various industries and transportation sectors. Several researches have done to investigate the optional fuel which has the similarity with diesel fuel. Vegetable oil and its derived form like biodiesel is the current area of focus. Hence due to the resemblance to diesel fuel, biodiesel has been currently used in many countries as an optional source of conventional diesel fuel [39]. There is limited information about the aromatic emission from the biodiesel fuels. Baldassarri et al. have tested the unregulated emission from the biodiesel and diesel mixture [25]. The results show that PAHs, nitro-PAHs, and low molecular weight aromatic hydrocarbons are the major source of unregulated emission through the mixture of diesel/biodiesel. There has been some evidence of low aromatic compound emission from the biodiesel fuels [6]. The cause of less aromatic compound emission from the biodiesel is that it has a sufficient amount of oxygen for the combustion process. But some result is contrary to this assumption like Baldassarri et al. have shown an increase of aromatic compound emission to 18% through blending of biodiesel with diesel [25]. They have found the compounds like xylene, benzene, toluene, benzo[j] fluoranthene, indeno[c,d] pyrene, dibenz[ah] anthracene, benzo[a] anthracene, benzo[a] pyrene, chrysene, 1-nitropyrene, and 2-nitropyrene in the exhaust of tail pipe. As biodiesel was used as the fuel, there was an increase of 16% for B20 as compared to diesel. Karavalakis et al. have used palm-based methyl ester with rapeseed methyl ester for evaluating the emission characteristic of a passenger vehicle [11]. They have found that proportion of benzene in the exhaust is very low. Various alcohols have also used for fulfilling the excess oxygen requirement of combustion process. Cheung et al. have used ethanol as the source of oxygen and dodecanol as the diluent in very low sulfur-contained diesel fuels to investigate the regulated and unregulated components in emission [40]. The result shows that at higher loads benzene molecules tend to decrease. Similar results have also depicted by Takada

et al. that lower benzene contents have shown at higher loads [24]. They have explained the process of being low benzene content at higher temperature. Due to the easy oxidation of benzene at elevated temperature, the content of benzene found low at higher temperature. A similar trend has also found for the emission of xylene and toluene. At low temperature, higher BTX emission has found due to insufficient oxidation. But as compared to the diesel, biodiesel as an optional source of fuel has less aromatic compound emission in tail pipe exhaust because of rich oxygen content. As an outdoor source of emission, combustion of straw, nonroad petroleum combustion and firewood, and aluminum production are also found to be dominant factor.

3 Health Effect of VOCs

Among all the air pollutants, emission of carbonyl and aromatic compounds in air leads to various short-term and long-term diseases based on the concentration level in the air. Some carbonyl and aromatic have long-term health problem also. Some carbonyl and aromatic compounds like HCHO, CH_3CHO, benzene, toluene, and xylene have a tendency to produce cancer in human body. Hence, these compounds are known as the human carcinogen [41]. They also cause irritation in nose, eyes, skin, etc. As stated above, these carbonyl compounds and aromatic compounds play a part in the formation of smog due to photochemical process. Some carbonyl compounds like CH_3CHO, HCHO, and acrolein are considered as hazardous to human health [22]. Several PAHs and aromatic compound in the air as stated above have been taken as the greatest concern for the human beings. Due to long term and high concentration inhalation of VOCs, the lung functions becomes slow because of irritation in nose, throat etc. Hence, the primary motive is to biologically investigate these compounds and their effect on human health. As per the international agency for research on cancer, many of air pollutants have been found as the source of producing cancer to humans [42]. Direct breathing of these carbonyl and aromatic compounds can lead to lung cancer in human beings. The possible disease from these compounds due to direct exposure can proceed to some very fatal health problems like carcinogenicity, teratogenicity, and mutagenicity, so evaluating the effect of these compounds on human health is a worth point for the researchers.

3.1 Short-Term Health Effect

Common health problems reported from newly constructed buildings are headaches, sickness, atopic dermatitis, dizziness, sleepiness, irritation in skin and eyes, sick building syndrome, etc. There are otherproblems related to the buildings is multiple chemical sensitivity and sick house syndrome. These are the short-term

effects of the contaminated indoor air. Other short-term effects of these contaminants include attack on the mucous layer of nose and irritation of eyes. The main problem for person who lives in indoor environment is asthma (a major lung infection) due to the contamination in indoor air [43]. There are a lot of reports of increased sickness and death rate from disease like asthma in the world. Hence, it has been cleared that these problems are arisen due to the contamination of indoor air pollutants in modern era. The sources of asthma type disease in indoor are combustion process in indoors, dust particles, waste collection, etc., which due to highly volatility of some carbonyl and aromatic compounds can easily travel through air. Various health problems have been observed with the fumes of kitchen. These kitchen fumes have aromatic compounds in excessive extent. Singh et al. [44] have tested the air sample from the kitchen. The result showed that the presence of PAHs in the kitchen air has a strong impact on the respiratory system of workers. These organic emissions are extremely lipid soluble, and ultimately it will be easily absorbed into gastrointestinal tract of mammals. These compounds instantaneously affect the tissues and simultaneously have adverse effect on the body fat. Metabolism of PAHs occurs via the cytochrome P450-mediated mixed function oxidase system with oxidation or hydroxylation as the first step. The adverse effect of aromatic and carbonyl compounds on human health is mainly depended on time duration, way of exposure, quantity of compounds exposed to human, the amount of toxic compounds, etc. There are several other factors on which the health factor depends like preexisting health of exposed human and his age [44]. Unwin et al. have listed some short-term effects on the human health due to the high exposure of PAHs which are eye irritation, confusion, nausea, diarrhea, and vomiting [45]. In spite of this, it is not clearly mentioned that which compound is responsible for these symptoms. IPCS (International Programme on Chemical Safety) has dictated effects of the specific PAHs compound like benzo(a) pyrene, anthracene, and naphthalene [46]. These mixtures of PAHs are termed as the inflammatory and irritants. Benzo(a) pyrene, anthracene, and naphthalene are termed as the direct skin irritants. These compounds are known for the skin sensitizers which mean that skin allergic effect on human and animals also.

3.2 Long-Term Health Effect

The long-term health effect of these pollutants may be life-threatening diseases like nasal tumors, leukemia, asthma, nasopharyngeal cancer, and reduced pulmonary function. The emission of dust in buildings and emission of nitrogen dioxide during the cooking process through gas increase the chances of asthma in human beings. In these indoor air contaminants, VOCs have the deep effect on human health. There is clear relation between the air pollutants and disease. The increasing research is required to overcome hazard by VOCs to human health, and environment has caused fast recognition of toxic aspect of VOCs during the last two decades. Cancer of the lung was one of the leading sites of cancer among population living in several

Indian states [44]. Tracheal, bronchus, and lung cancer rank second globally by number of incident cases in both sexes, in 50 most populous countries as per Global burden of cancer report—2013. Singh et al. have termed aromatic compounds and their subsequent as the carcinogenic, toxic, and mutagenic [6]. They have specified that there is tropospheric ozone formation due to benzene, xylene, and toluene emission. This tropospheric ozone creation is based on the concentration of unregulated emission and their structure. Carter had evaluated that some oxygenated compounds like aromatic and carbonyl are important as per the tropospheric chemistry [47]. These compounds have a sufficient contribution in the photochemical oxidants. They have found that ozone and free radicals are the important pioneers of oxygenated compounds. Correa and Arbilla have studied the ambient condition of Rio de Janeiro city and found that pioneer element for the ozone is HCHO [48]. Diesel exhaust emissions have several components which pose severe health problems. All diesel exhaust has taken as the human carcinogen as per the IARC [49]. Emmelin et al. had observed that diesel emission is a major topic in epidemiological studies due to the possibility of lung cancer [50]. Reduced immune system, damaging of kidney and liver such as jaundice, severe respiratory problems, and irregularities in functioning of lung are the long-term or long-standing health effects due to divestment of PAHs. Repeated exposure of carbonyl and aromatic compounds may also possess the intense skin problem like redness and inflammation. Common PAHs like naphthalene have intense impact on our blood system. It involves in the process of breaking of red blood cells if high concentration of this component inhaled. Apart from this, the severe health problem in humans due to the carbonyl and aromatic compounds is based on the route of divestment [51]. Although un-metabolized PAHs can have toxic effects, a major concern is the ability of the reactive metabolites, such as epoxides and dihydrodiols, of some PAHs to bind to cellular proteins and DNA. These carbonyl and aromatic compounds are responsible for the disorganization of biochemical and damaging of cell. Due to this catastrophe in the human beings, mutation, generation of tumors and cancer, and decreased rate of development in body are the grievous impacts [52]. Some other intense disease from the exposure of these compounds are gastrointestinal and bladder cancer.

4 Possible Ways to Control VOCs Emissions

There are several methods which have been used for controlling the carbonyl and aromatic compounds in indoor and outdoor. It is important to convert harmful VOCs into the environment-friendly species. Multiple modes have been introduced till now for abatement of VOCs in indoor like physical adsorption [53, 54], plasma technology [55], plant absorption [56, 57], photocatalysis [58], and catalytic oxidation [59]. Catalytic oxidation for indoor plays a crucial role for the diminishment of VOCs as this mode oxidizes it into CO_2 at room temperature condition [60]. Unlike many other pollutants in indoors which can sufficiently diminish by many

process used, HCHO cannot be properly controlled just because of its higher vapor pressure (3883 mm Hg (2078 in H_2O)) at 25 °C and relatively low boiling point (−19.3 °C (−2.74 °F)) [61]. Since lower temperatures are desired for the abatement of HCHO by catalytic oxidation in indoor, the recent development is based on a catalyst for total diminishment of HCHO at surrounding temperature condition. Probably, main sources of carbonyl and aromatic emissions are building materials, industries, and transportation (mainly diesel engine running vehicles) [6]. Traditional methods like using filters to isolate the pollutants or using sorption materials to absorb different VOCs are the techniques which can only reduce the intensity of the pollutants in environment. These techniques can only change the phase of the pollutants rather than eliminating them completely. For degradation, many techniques have been used including (1) plasma decomposition with or without using catalyst, (2) biological/botanical filtration, (3) chemisorptions, (4) photocatalytic oxidation (PCO), and (5) thermal and nonthermal catalytic oxidations. VOCs can be degraded with plasma decomposition process using air ionizers developed plasma cluster ions. Plasma can be produced with the help of electronic and photo-ionization. Ion density, treatment duration, qualities, and structure of chemicals are the influencing factor for degradation of VOC with plasma techniques [62]. Plasma technology is limited with the low concentration and harmful intermediates generation. VOCs diminishment in present situation has been experimented with botanical filtration also [63]. Some questions which arise with the botanical filtration are: (1) In case of using this method, kinetics related to degradation of VOCs should be known, (2) for the efficient decomposition of VOCs through microbes in plant roots, conversion rate should be high over the time, (3) the capacity of decomposition rate should be variable to degrade varying VOCs concentration level. But many authors have given limitation of this process as technical composition needs more advancement for carrying the more pollutant to biological filter. Some passive technologies have also discussed which are used as the degradation process such as the third method, i.e., chemisorption technique for the diminishment is the adsorption method at sorbent led through chemical reaction. The sorbent used in case of this method is generally some chemical compound treated with impregnation method or other special treated. But this process is incomprehensive due to intromission of forced air. Modified PCO is also a good removal technique. The technique used under PCO is generally using semiconductor catalysts and light energy to degrade VOCs into harmless compounds like water vapor (H_2O) and carbon dioxide (CO_2). PCO process admixes oxygen, VOCs, and water on the activator surface to out-turn CO_2 and H_2O under light radiation. Release of light at TiO_2 surface originates electron and holes in the molecule. The departure of electron from conduction band to valence band originates holes in conduction band after getting the band energy. The origin of holes produces hydroxyl radicals due to the reaction of holes with soaked hydroxide ions. The formation of hydroxyl radical is due to the extreme oxidative nature of holes. Moreover, the PCO process is constrained with UV light until doped with some metals like noble metal and for this process only less than 5% solar radiation is utilized with UV photocatalyst. Visible light source was used for removal in

modified PCO instead of UV light used in conventional PCO. TiO_2 photocatalysts have widely used for the abatement with different concentrations of noble metal (Pt, Au, Ag, etc.) and transition metal oxides. Pt/TiO_2 photocatalyst was investigated for diminishment of HCHO by Zhu and Wu [64]. Pt/TiO_2 photocatalyst showed 98.3% degradation efficiency for HCHO. Some limitation like formation of by-products and deactivation of photocatalyst surface is the problem with PCO. The effective degradation of HCHO is done by thermal (at higher temperature) and/or nonthermal (environmental temperature) processes using catalytic oxidation. For catalytic oxidation, noble metal (Pt, Rh, Pd, Au, Ag, etc.), transition metal, and metal oxides are some normally applied catalysts. For the outdoor emission control, there is no specific technology available which can directly convert these emissions into the harmless products. But there are some specified conditions available which can reduce the formation of emission form the engine exhaust. Many different technologies have been used for the remediation of emissions to control the harmful effect on the environment and human beings. Some authors have given many modification and conditions for the reduction of aromatic and carbonyl emissions in outdoor. Di et al. have given a condition for the reduction of benzene emission [40]. Result shows that at no-load condition the emission is high as compared to higher loads. The basics behind this reduction at higher load are due to the thorough combustion of fuels in the cylinder accompanied with exhaust system. Excess oxygen content in fuel leads to the reduction of PAHs in case of engine exhaust. But this excess oxygen in case of carbonyl emissions increases the HCHO, CH_3CHO, and acetone. For controlling the emission from the transportation, some technologies have also implied like exhaust gas recirculation system, diesel oxidation catalyst, continuous regenerating diesel particulate filter but as the name suggested these methods are not sufficient for decomposition of the carbonyl and aromatic compounds. Agarwal et al. have given a comprehensive view that some aldehyde emission shows higher trend at lower load for all tested fuels [9]. They have investigated biodiesel and methanol-blended fuels and show that at higher load there is a significant reduction of HCHO emission. Similar trend has also depicted by Sharma et al. that emission level of benzene decreased with increasing loads [65]. As from other emission, emission of organic carbon also showed decrement with increment in load. Other aromatic compounds like toluene and xylene possess different trends with the use of biofuels. These compounds have decreased concentration with biodiesel [66]. Poulopoulos et al. have observed that 10% of ethanol blending favors the complete oxidation and thus reduces the emission of acetaldehyde [22]. Increased oxygen content in the fuel during the combustion process leads to lower aldehyde emission [67]. Jo et al. have used PCO process for the vehicle exhaust cleaning [68]. They have used TiO_2 catalyst for the oxidation of VOCs using photo-oxidation technique. Result shows that approximately 100% degradation efficiency has found over the different relative humidity ranges. Bioremediation technique has also used as the promising way for the utilization of PAHs for the outdoors [44].

5 Discussion

Going through all the literature, the term involves special attention regarding carbonyl and aromatic compounds have been illustrated in this point of discussion. The main concern about the indoor and outdoor air qualities is emission of carbonyl and aromatic compounds because there are many compounds which are carcinogenic and mutagenic. These components have various paths of exposure to the human being as well as for the environment also. The severe health concern related to the carbonyl and aromatic compounds have been illustrated in Tables 1 and 2, respectively. As per the authors, the major compound related to the carbonyl and aromatic compounds are HCHO, CH_3CHO, acetone, benzene, toluene, and xylene which have intense effect on human health. The concentration of these compounds depends upon the outdoor condition, indoor condition, different agilities of human, seasonal variation, and chemical reaction. Various agencies have described these compounds into three categories like very volatile, volatile, and semi-volatile based on their boiling point. The associations of carbonyl and aromatic compounds with different severe diseases have also been broadly dictated in Tables 1 and 2. It has been observed that industrial and commercial processing, decoration work in newly made buildings, manufacturing of woods in home, transportation sector, etc., are some concerning point where the emission of carbonyl and aromatic compounds has found more as compared to other places. Common health problems reported from newly constructed buildings are headaches, sickness, atopic dermatitis, dizziness, sleepiness, irritation in skin and eyes, sick building syndrome, etc., which have been illustrated in Tables 1 and 2. Reduced immune system, damaging of kidney and liver such as jaundice, severe respiratory problems, and irregularities in functioning of lung, tumors, cancer are the long-standing health effects due to exposure of carbonyl and aromatic compounds on the human health. Severe disease like cancer, due to the long-term exposure of carbonyl and aromatic compounds, causes multi-disease that not only effects genes but also it has an intense impact on the clonal expansion and escape from apoptosis. Without doubt, there is a lot of improvement, but this should be utilized for the abatement of carbonyl and aromatic compounds. A high-quality investigation should be done for the decrement of these compounds in outdoor environment as well as indoor environment. Air quality in indoors and outdoors is the result of many toxicological and physical factors. More refined research is needed for the abatement of these compounds due to its complex nature and its intense effect on human health as well as environment. In case of indoors, various techniques have been used for the abatement for carbonyl and aromatic compounds such as plasma decomposition, biological/botanical filtration, chemisorptions, PCO, and thermal and nonthermal catalytic oxidations. Yet for the proper control of aromatic and carbonyl compound emissions from the transportation is still a gap for the researchers. Future research must be on full abatement of carbonyl and aromatic compounds from the motor vehicles. There should be a refined technique for the degradation of these compounds from the engine exhaust.

Table 1 Effect and sources of carbonyl compound

Pollutants	Short-term effect	Long-term effect	Source of emission
Formaldehyde [69]	Irritation of the eyes, nose, throat	Human carcinogen Asthma-like respiratory problems Affects reproductive system pregnancy	Power plants, automobile exhausts, and manufacturing facilities Indoor air includes consumer products building materials and tobacco smoke
Acetaldehyde [9]	Irritation of skin, eyes, mucous membrane, throat, respiratory tract Headache vomiting nausea	Carcinogen	Building materials Automobile exhausts Consumer products
Acetone [70]	Nausea, headache, drowsiness, dizziness, and confusion Mild irritation to skin	Unconsciousness adverse effect on the nervous system Red dry cracked skin (dermatitis)	Outdoor: volcanic gases, forest fires, manufacture and use, burning waste materials, exhaust of automobiles, tobacco smoke, landfills Indoor: No
Acrolein [71]	Respiratory and gastrointestinal tracts cytotoxic Histopathological Intense effects in the bronchi and/or trachea (including edema, vascular congestion, inflammation, and hemorrhagic, necrosis, exfoliation)	Effect respiratory tract	Outdoor: fermentation and ripening processes Forest fires due to improper combustion
Benzaldehyde [72]	Irritate the nose, throat coughing and shortness of breath Irritate the skin and eyes Skin rashes	Mutations seizures and passing out	Outdoor: industrial, medical evaluation
Butyraldehyde [73]	Damage to the respiratory tract	Carcinogenic	Outdoor: cigarette smoke Indoor: cigarette smoke
Crotonaldehyde [74]	Irritation of the eyes, skin affects respiratory tract	Carcinogenic	Outdoor: cigarette smoke Indoor: cigarette smoke
Hexaldehyde [75, 76]	Inhalation and skin exasperation of mucous membranes Discomfort in the eyes and discomfort in the nose	No effects on pulmonary function Nasal swelling	Outdoor: industry warehouse, ammonia Indoor: wood pellets, domestic storage room, water-based paints

(continued)

Table 1 (continued)

Pollutants	Short-term effect	Long-term effect	Source of emission
Methacrolein [77]	Exasperation in eye, nasal, and respiratory tract	Gastrointestinal mucosa in the animals Epithelial hyperplasia Ulceration hemorrhage	Outdoor: smoking, second-hand smoke Indoor: exposure to wood and plastic smoke
Propionaldehyde [78]	Exasperation to eyes, pulmonary tract, and skin Headache Consciousness problems Breathing difficulties Sore throat, spasm Edema of the larynx, and exasperation of the nose mucosa	Create problems in the lungs bronchitis to develop with cough Phlegm Shortness of breath	Outdoor: cigarette smoke Indoor: cigarette smoke
Tolualdehyde [79]	Adversely affects mucus membranes of the nasal and oral passages and the upper respiratory tract Exasperation bronchial constriction Choking and coughing exasperation on the skin of the face	–	Outdoor: exhaust from outboard motors, automobiles trucks, and emissions from fireplaces Indoor: perfumes, as a pharmaceutical and dyestuff intermediate
Valeraldehyde [80]	Acute toxicity Exasperation of skin and eyes Skin sensitization	Necrosis	Outdoor: industrial intermediate, in resin chemistry

Challenges and direction related to VOCs emissions

Carbonyl and aromatic compounds emissions have the big challenge for indoor and outdoor air condition. Approximately, all carbonyl and aromatic compounds listed above have the sources in both indoor and outdoor with their severe health effects. Vehicular, industrial, and organic compounds used in indoor are the major source for VOCs emission. As stated in above points that in outdoor, carbonyl emissions are more frequent rather than PAHs emission due to use of oxygenated fuels used for the better combustion. For outdoors, apart from primary sources of emission the formation of secondary and tertiary emission such as smog formation is also a problem to human health and for environment also. The application of new fuels like different alcoholic blends in mineral diesel and use of biodiesel are increasing the emissions of carbonyl and aromatic compounds in outdoors. Some natural process like photo-oxidation process are also becoming the concern in increasing the emission such as photo-oxidation of alkanes and alkenes also

Table 2 Effect and sources of aromatic compound

Pollutants	Short-term effect	Long-term effect	Source of emission
Benzene [81]	Drowsiness Dizziness Rapid or irregular heartbeat Headaches Tremors Confusion	Reason of not producing blood cells through bone marrow, anemia Unconsciousness Death (at very high levels) Reduces the immune system	Outdoor: volcanoes and forest fires, crude oil, gasoline, and cigarette smoke Indoor: detergents, drugs, and pesticides
Toluene [82, 83]	Headaches Dizziness Unconsciousness	Problems while pregnancy: retardation, premature delivery, congenital malformations, and postnatal developmental retardation, cognitive impairment Loss of vision and hearing	Outdoor: biodiesel, diesel fuel Indoor: paint reducer, paint thinner, or paint for their narcotic effects
m-Xylene [84, 85]	Exasperation in eyes, skin, nose, throat Dizziness Excitement Drowsiness Incoordination Staggering gait Corneal vacuolization Anorexia Nausea Vomiting Abdominal pain Dermatitis	Gastrointestinal tract blood problem Liver problem Kidneys problem	Outdoor: automobile exhaust, and during its use as a solvent, hazardous waste disposal sites
o-Xylene [86]	Dizziness Drowsiness Headache Nausea Dry skin Redness Pain Burning sensation Abdominal pain	Nervous system Hearing loss Animal tests exhibit that this component possibly causes toxicity to human reproduction or development	
Ethylbenzene [87, 88]	Exasperation in eyes, skin, mucous membrane Headache Dermatitis	Narcosis, coma	Outdoor: tobacco smoke, gasoline Indoor: household products like cleaning products or paints, pesticides, solvents, carpet glues, varnishes, paints

(continued)

Table 2 (continued)

Pollutants	Short-term effect	Long-term effect	Source of emission
Propyl benzene [89]	Exasperate the skin and eyes Irritate the nose and throat Headache Nausea Vomiting Dizziness Drowsiness and fainting	–	Outdoor: – Indoor: –
Naphthalene [90–92]	Ingestion of mothballs Hemolytic anemia Poisoning in pediatrics patients	Laryngeal or colon cancer	Outdoor: coal tar, synthetic resins, wood smoke, fuel oil and gasoline, fugitive emissions and motor vehicle exhaust, Indoor: paints, solid block deodorizer for toilets, kerosene heaters, and tobacco smoke
Anthracene [93]	Skin-related problems Blood problems Burning, itching and edema, a build-up of fluid in tissues Headaches Nausea Loss of appetite Inflammation or swelling of the stomach and intestines	Kidneys Liver Stomach and intestines	Outdoor: heavy oils, coal tar, roofing tar, or creosote Indoor: –

substantially contributed in formation of aldehyde emission. The other problems related to emission of carbonyl compounds are load conditions for the vehicle emission. As for the outdoors, combustion process in indoors is also a major concern apart from the sick building syndrome problem. These combustion processes happen in every houses, restaurants, buildings, offices, etc. Research agencies on air pollution have clearly mentioned that indoor air pollution is more as compared to outdoor air pollution. Carcinogenic and mutagenic effects of these air pollutants have given in this chapter. Due to high volatility of these compounds, these pollutants easily enter in our body through the respiration process in a continuous manner. To decompose the organic compounds in indoor air, various techniques have described in this chapter. In all these techniques, first three techniques for the removal of pollutants in air use filtration process. This implies that

these compounds will only be separated not degraded. The last two processes described are sufficient for the decomposition of aromatic and carbonyl compounds. These two methods have strong capturing and abatement efficiency. In these two methods, thermal and nonthermal catalytic oxidation techniques are more powerful over the photocatalytic oxidation due to the formation of intermediate products in case of photocatalytic oxidation. In case of outdoors control of carbonyl and aromatic compounds, sufficient abatement method is still a gap.

6 Conclusion

In this article, the effects of carbonyl and aromatic compound emissions on human health have studied from different sources. So the major objective of this chapter is to study the different carbonyl and aromatic compounds and their toxicological assessment on the human health. The major conclusions which can be explored from this study are as listed here:

- Combustion products, construction equipment, paints, varnishes, calks, office materials, cooking, consumer products, etc., may be the source of emission in case of indoor air pollution.
- Emission from the vehicles and industries is the dominant sources of outdoor carbonyl and aromatic compound emissions. There is no available efficient method applied in vehicles which can convert these carbonyl and aromatic compound emissions.
- The use of biodiesel as an alternative to diesel fuels in vehicles generally reduces the aromatic compound emission but supports the aldehyde emission particularly HCHO emission.
- Carbonyl and aromatic compounds are responsible for the secondary and tertiary air pollution. Formic acid, ozone formation, and carbon monoxide are the major by-products of these emissions.
- Tropospheric ozone formations due to benzene, xylene, and toluene emissions have also adverse effect on the environment as well as human health. The secondary pollution contributes in the formation of smog.
- HCHO, CH_3CHO, benzene, toluene, and xylene are the major compound in case of carbonyl and aromatic compound emissions up to a level of 70–90%. These compounds are also responsible for the severe health disease like tumors, cancer, jaundice, decreased lung functioning.
- The technologies explained in the possible ways for the reduction of carbonyl and aromatic compound emissions are sufficient to decompose these compounds into harmless products in indoor context.

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