

Chapter 2

The Role of Lower Thermal Conductive Refractory Material in Energy Management Application of Heat Treatment Furnace



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2.1 Introduction

In a modern scenario of translation of technology causes more production of versatile products which needs to go from the heat treatment process to increase its working effectiveness. In this translation of the production sector where demand had sustainably increased, the use of energy to run this heat treatment furnace is also increased. The extensive use of power to fulfil the functional requirement of the furnace is a typical result of an increasing number of reactive chemicals such as CO and HC, which cause growing greenhouse gases in the atmosphere (Lisienko et al. 2016). The cause of global warming by industrial applications is an intensive problem, on which several national-level government bodies are working to curb the level of emissions under control despite the strict policy no significant growth for emission reduction is observed if companies on primary ground start to work on energy management solution this problem can be effectively solved in upcoming years (Källén 2012). The heat treatment of any product is an intensive process that consumes a large amount of fuel to fulfil temperature requirement in the furnace, the typical working temperature in heat treatment range from 900 C to 1200 °C depending on the application and intensity of work the requirements of temperature corresponding to the fuel is burned which causes an emission of harmful gases (Stål och värmebehandling – En handbok 2010). Most of these greenhouse gases expelled from the furnace contribute towards pollution and lowers efficiency. Methane, the other GHG, is secondary resource energy (SER) and is used in metallurgical units

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for burning carbon dioxide. Hyl-3 processes are used in iron and steel manufacturing processes, such as Corex, Romelt, and Midrex. Iron or sponge iron is loaded into steel arc furnaces (EAF) with added scrap iron (Cvinolobov and Brovkin 2004; Yusfin and Pashkov 2007; Romenets, et al. 2005; Voskoboynikov et al. 1998). In metallurgical furnaces, the main source of heat is natural gas combustion. Energy costs are an integral part of manufacturing, covering costs, and energy savings in high-temperature processes are extremely important. The chamber furnaces are part of a group of regular furnaces commonly used to forge and warm heavy components. For chamber furnaces, the time change in the chamber temperature should be held in line with technical requirements. Therefore, it is very important to save energy by reducing the heat transfer rate by isolating the furnace walls (Rusinowski and Szega 2001). The energy loss in the furnace can be calculated by correlation with energy balance for the burning in which the furnace's thermal condition varies over time, and the performance of energy consumption depends heavily on the length of the specific process step. The energy input must equate with energy production to ensure the oven's continuous function and a relatively straightforward calculation of heat loss from the walls (Chen et al. 2005). In periodic chamber furnaces, the measure of heat loss is further complicated by the deposition of energy in the furnace walls. The loss of energy is primarily dependent upon the temperature of the insulation, thickness of isolation, the temperature of the furnace chamber, and the mode of operation of a furnace (Han et al. 2011). In the event of transient heat piping, calculating the heat loss from the furnace wall entails the time change in furnace walls. Heat loss occurs during discharge or refreshment in the furnace as thermal treatment is carried out from the interior wall surface. Obtaining exact heat loss value in fined tuned accurate CFD simulation which was proposed by Yang et al. (2007) where they performed time variation transient CFD simulation of product to predict the thermal performance, in which the model consists of turbulent flow with intensive calibration of the system. From the various literatures (Dubey and Srinivasan 2014; Kim et al. 2000; Kim and Huh 2000; Mayr et al. 2017, 2015; Jaklič et al. 2007; Quested et al. 2009), it is observed that there is a scant amount of research performed on energy conservation system of furnace influence by lining material, so the current study is an attempt to perform practical validation of furnace influence by lower thermal conductive in lining refractories material. The achieved data are correlated by using advanced neural network technique to find a correlation between input data with conventional refractories and the target set of pyro block refractories.

2.1.1 Heat Treatment in Furnaces

The heating is carried out in the different furnaces using different heating mediums. A large amount of energy is required to heat the components. In the total manufacturing cost of forgings, a major share is consumed by the energy cost. Typically, the heating furnace is used to carry out a thermophysical operation such as.

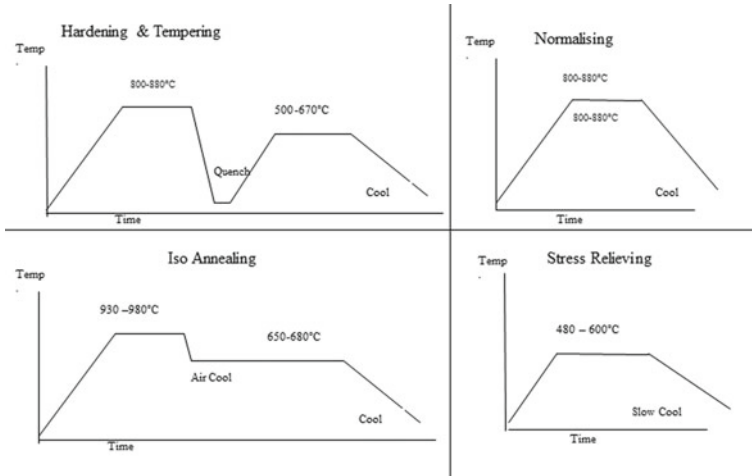


Fig. 2.1 Heat treatment operations

1. Hardening tempering
2. Normalizing
3. Iso annealing
4. Stress revealing.

Maximum consumption of heat is required in the operation of hardening and tempering, normalizing, and iso annealing. The typical heat contribution is achieved by burning fuel. The below chart shows the temperature range for the operation (Fig. 2.1).

The furnace efficiency is determined by the ratio of thermal input from the furnace to the material. All the heat applied to the furnace can be used for heating the material or components of industrial heating furnaces. The part is heated by continuously incorporating specific quantities of thermal energy into the product placed in the chamber. Figure 2.2 shows a schematic of various energy losses in furnaces.

2.1.2 Refractory Material

Refractory isolation is used to decrease the heat loss rate across furnace walls. This is due to a high level of porosity and the desired pore configuration of tiny, uniform pores that are spaced uniformly throughout the entire refractory brick to reduce thermal conductivity. Refractory material selection is conducted based on its application where the need for material to be chemically and physically stable in the high-temperature application. In the present investigation, typical refractory material as fire brick used in bogie hearth furnace will be replaced with lower thermal conductive pyro block material on which a detailed comparative energy conservation analysis

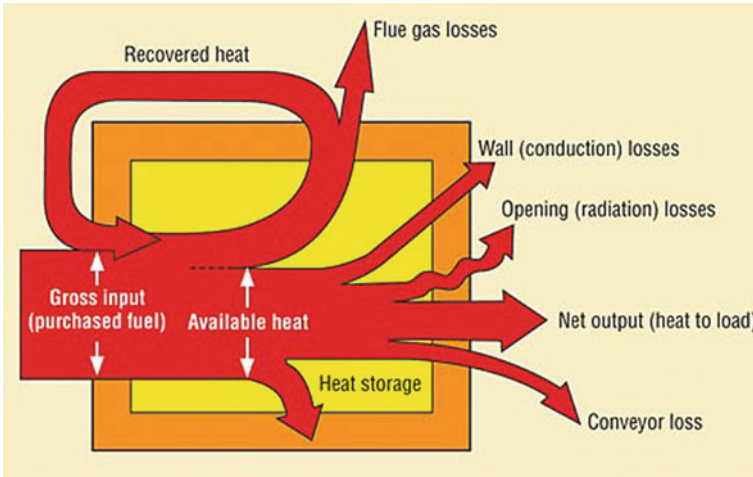


Fig. 2.2 Furnace energy losses

is presented. The output data are verified and validated using the advanced data analytics ANN technique based on the generic optimization process.

2.2 Methodology

The present investigation is performed to study the importance of refractory material and its impact on the energy conservation system of heat treatment furnaces. The practical validation is proposed in the study based on a comparative analysis based on refractories with wall brick material, further replaced with the ceramic fibre wall material. The flowing outline shows the performed detail of the investigation (Fig. 2.3).

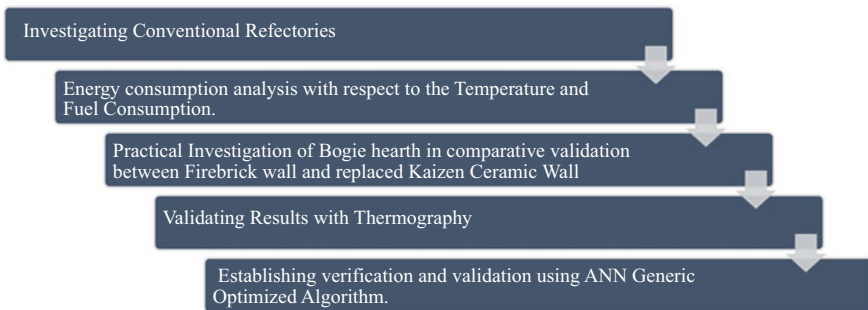
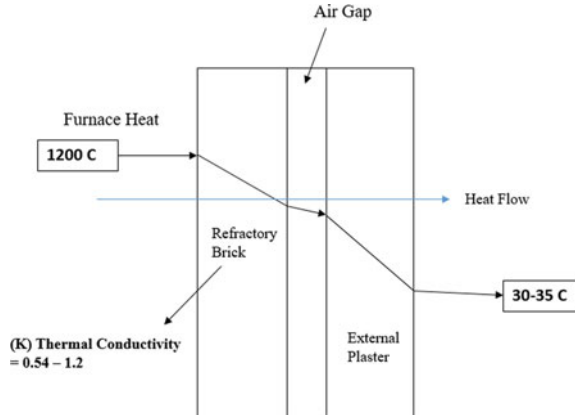


Fig. 2.3 Methodology flow chart

Fig. 2.4 Conventional fire brick



2.2.1 Investigating Conventional Refractories

In Bogie Hearth furnaces, the conventional material used for the lining is made up of firebricks, whose temperature rating of about 1649 C in preliminary life condition. This material requires to make thermal insulation for the heat treatment furnace by isolating generated heat inside the furnace. The typical advantage of thermal fire brick offers effective working across wide temperature use; it has a lower level of impurities and a lower level of shrinkage value. The disadvantage of this material offer is that it has too many pores in structure, making it weaker with an increment of the application life cycle. It does not provide soundproof coating; it is having lower thermal resistance to the thermal properties. In the present investigation, the Boogie Hearth furnace was initially loaded with conventional refractory brick, further replaced with lower conductive ceramic brick classified as a pyro block. The below table shows the comparative properties between conventional fire brick and replaced pyro block. The mathematical modelling of thermally insulated refractories is shown in Figs. 2.4 and 2.5.

Table 2.1 represents the properties of both fire brick and ceramic fibre (pyro block)

2.2.2 Development Scope for Existing Boogie Furnace

In the designing operation of furnaces, it is particularly beneficial to utilize the heating value of fuel as economically as practicable in the design and operation of furnaces. Inevitably, though, some of this heat is lost to the environment because of

1. Incomplete combustion of fuel
2. Flue gas sensible heat
3. Convection and radiation from the furnace wall.

Below is the key furnace classified resulting in heat loss.

Fig. 2.5 Ceramic fibre (pyro block)

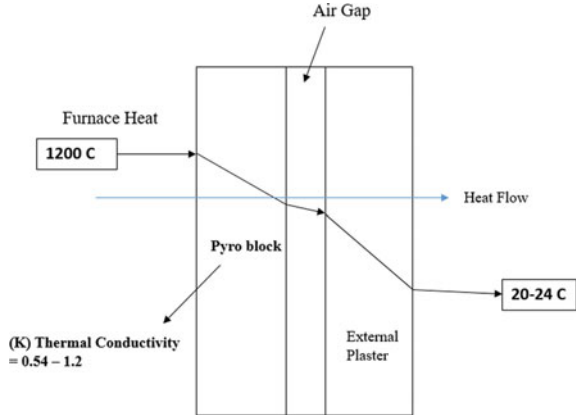


Table 2.1 Refractory properties

Parameter	Firebrick	Pyro block
Density	< 2300	160–240
Chemical composition	Up to 1648 °C	1260 °C
Al ₂ O ₃	<44%	44–50%
SiO ₂	<78%	50–56%
Thermal conductivity	1.2	< 0.340

2.2.2.1 Burner

The burner should burn its fuel efficiency by maintaining an adequate fuel-air ratio in circulation mode. If this condition is not getting satisfied, there is a creation of instability in the burner’s flame. Multiple burners are used to sustain flame and achieve heat inside the furnace to keep the stability of flame creation.

2.2.2.2 Furnace

In several applications, firebricks have been phased out and replaced by cast plastic refractories. Utilize the optimal insulation width. Reduce air and flue gas leakage by improved furnace design. Increase the vertical depth of the furnace to allow for increased heat transfer by radiation. Consider the likelihood of creating a temperature profile by separating the furnace into zones to reduce the amount of fuel required, the option of using a serial device, which often results in a reduction of energy requirements.

The present investigation aims to increase the thermal stability of the furnace by increasing production efficiency in lower proportionate consumption of fuel. The replacement of conventional firebricks is done with the lower thermal conductive pyro block material, which works as thermal insulation to store generated heat within

the furnace only. The validation of the presented study was generated by using thermographic plots near the furnace's outer door compared to the furnace wall insulated with fire bricks vs the furnace wall insulated with lower thermal conductive pyro block material. The following achieved results multi-objective study presented using advanced data predictive artificial neural network study.

The artificial neural network (ANN) is the most recently developed and commonly used technique for predicting parameters for various input and output values. In the current analysis, the association data points are used as feedback to the ANN. In ANN, the Levenberg Med algorithm is used to consider feed-forward backpropagation. 70% of the data were used for preparation, 15% for research, and 15% for validation. The number of neurons between the input and output layers varies, as is the degree of neuron independence. The network with the lowest MSE error value and the highest regression coefficient is considered. In the present study, the regressive multi-optimization study generated between the input fuel value required to achieve the desired output as a production quantity in a furnace in correlation with the exact amount of energy needed.

Table 2.2 illustrates the possible areas where improvisation needs to be done along with its priority (Table 2.3).

2.3 Implementation of Proposed Ceramic Fibre

The present investigation is carried over Boogie Hearth furnace investigated over two types of refractory material: furnace with fire brick thermal refractory and pyro block refractory. The practical validation is generated using thermographic plots placed on the furnace's door to account for the variable of heat lost in the environment between both materials. In this investigation, replacing conventional material with pyro block, a detailed energy account is implemented with the audit of kaizen implementation as part of quality check and continuous improvement policy of energy conservation approach. The below section shows the account for the implementation of kaizen technology on the furnace refractories. Pyro block modules are ceramic fibre lining devices explicitly developed for use in high-temperature furnaces. The module is made from a high-purity mix of raw materials used to make standard and zirconia type ceramic fibres. The monolithic fibre is easily sliced to match through holes and modified in the field. Additionally, these modules are compact, have a low-heat storage capacity, and have a long-lasting operation (Fig. 2.6).

The heat loss calculation is shown in Table 2.4. The prosed improvement of pyro block offers versatile amounts of benefits to the working of the furnace by keeping generated latent heat inside the furnace only, ensuring sustainability for the production of the products. Due to the phenomenon of a pyro block, which offers lower thermal conductivity on working furnace temperature, suggest that the storage required in batches of output for the case of existing bricks lining gives around 2,448,236 kcal. In comparison, when the pyro block is implemented, the total heat needed for a storage unit for batch-wise production is about 1,221,506 kcal. The

Table 2.2 Improvement kaizen SPN chart

Principles	Questions to be asked for the process	Process No.	Solution	Effective	The benefit to cost ratio	Adaptability	SPN
Modification	Can we modify the furnace design for energy conservation	Heating	Furnace lining bricks replaced by ceramic fibre	5	3	3	45
		Combustion	Used biofuel instead of SKO-2	3	5	5	75
Automation	Can we automate the process partially or fully with or without a close loop system?	Combustion	Oxygen sensor for to control the excess air	3	3	3	27
Utilities	Can we identify the individual elements of energy consumption by looking at the tree structure of utility						
Ideal running	Can we record the cycle in terms of energy parameters and reduce the idle running time?	Utility	Provision of VFD motor for combustion blower	3	3	3	27
Benchmarking	Can we do a benchmark against the most efficient process within	Heating	To improve furnace efficiency up to 20 from 13%	2	2	2	8

Table 2.3 Solution priority criteria chart index

	Effective	Cost benefit	Adaptability
<i>Solution priority number (SPN) criteria</i>			
Low	1	1	1
Medium	3	3	3
High	5	5	5

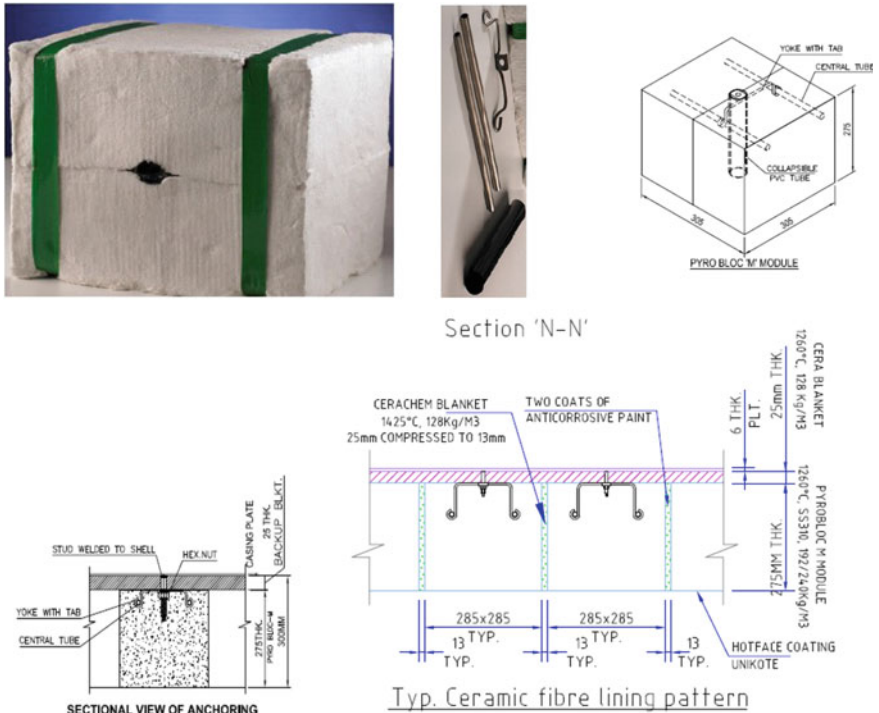


Fig. 2.6 Pyro block annealing to the wall section pre-processing

gross difference in value is about 52% which suggests the correct implementation of the kaizen strategy (Fig. 2.7 and 2.8).

2.4 Validation of Results

The validation of results is generated by using thermographs to plot the thermal visuals around the furnace door. The thermographic plot suggests how the furnace's thermal loss was encountered before implementing kaizen strategic pyro block where

Table 2.4 Furnace datasheet

Description	Unit	Existing	Proposed	Remarks
Furnace length	M	5.40	5.40	
Furnace width	M	3.77	3.77	
Furnace height	M	2.55	2.30	
Wall thickness	M	0.45	0.4	
Top thickness	M	0.55	0.50	
Bottom thickness	M	0.75	0.55	
Material		Fire bricks	Ceramic bricks	
Furnace working temp.	°C	880	880	
Ambient temp.	°C	28	28	
Furnace heat losses	kCal/Hr	34,231	17,831	16,400
	Kwh/Hr	40	21	19
Furnace heat storages	Kcal	4,950,000	1,530,000	3,420,000
	Kwh	5776	1785	3991
Considering bricks 50% heat transfer	Kwh/batch	2888	1785	1103



Fig. 2.7 Furnace before kaizen



Fig. 2.8 Furnace after installation of pyro block

inner refractories lines are equipped with fire bricks vs inner refractories lined with pyro block (Tables 2.5 and 2.6).

2.4.1 Thermographs

From the above validation for comparative cases, it can be validated that when Boogie Hearth furnace was implemented on conventional lining wall brick material, it fails to store the maximum amount of generated heat inside the system thus, local hot spot creation can be observed over the thermographs of furnace door in case 1, comparatively when the kaizen implementation allocated in strategic product development to save the cost of burning fuel and increase the sustainability, thermograph visual shows at the same furnace door, there is less creation of local hot spot; thus, the generated heat tends to be stored inside the furnace only. Furnace effectiveness concerning the energy consumption to the product can be seen in Figs. 2.9 and 2.10

In heat treatment of any product, the primary intention is to generate heat and store it inside the confined space so maximum heat can be used to treat the product. Heat can produce by burning fuel inside the burner, so it is essential to monitor fuel spend to achieve heat versus heat spend. In the present study, the initial furnace was loaded with conventional fire brick refractories. The burning fuel LPG was net around 10,059 M³, compared to when the furnace loaded with strategic Kaizen implemented pyro block specific reduction fuel consumption has achieved for around same production rate. The total energy conservation saving achieved around 50%. The saving of fuel

Table 2.5 Result validation



Energy conservation			
Heat losses are reduced by insulation, energy saving by using high-velocity burners and furnace	Implementation (target)	Investment cost: 2.40 RML	
Before Kaizen	After Kaizen		
			
Consumption (basic calculation): (A)	Consumption (basic calculation): (B)		
Before implementation, energy consumption	After implementation, tempering furnace LPG consumption is 7.30 M ³ /MT		
F or hardening furnace LPG consumption was 13.34 M ³ /MT			
Reduction: (A)–(B) LPG 6.0 M ³ /MT, i.e. 35% energy saving and ROI is 12% PM	CO ₂ reduction: 190. MT/ Year/F C		
Heat treatment team		LPG M ³ /MT	Remarks
	Before	13,34	Energy saving
	After	6.94	45%
	Saving	6.40	
F or CO ₂ calculation: 1 kg LPG–2.83 kgs CO ₂ emits			

Table 2.6 Energy consumption report

	LPG consumption in M ³	Production in MT	M ³ /MT
Before	3.023	271	11.15
	3.494	215	16.25
	3.542	268	13.22
	10.059	754	13.34
	After	1.031	146
	1.204	169	7.14
	1.299	198	6.56
	1.593	251	6.35
	5.127	763	6.72
Energy saving	M ³ /MT		6.62
	Percentage		50%

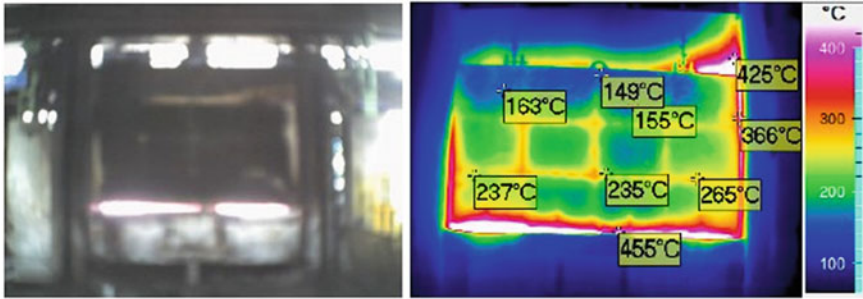


Fig. 2.9 Before Kaizen

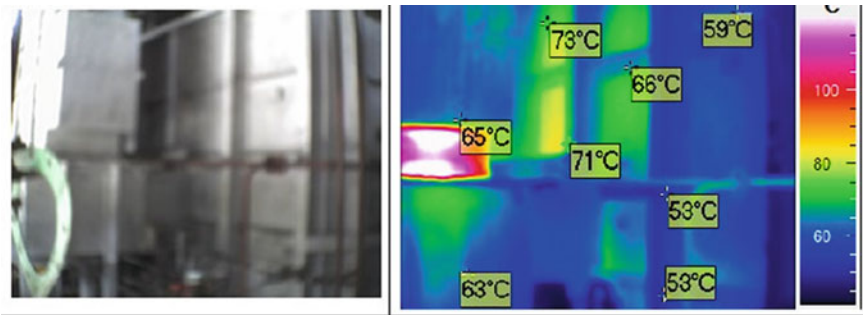


Fig. 2.10 After Kaizen

leads to saving working costs and amount of CO₂ emission in the environment. The increased sustainability of the furnace is presented in Table 2.7. The expected CO₂ emission for a standard 1 kg LPG tends to be a 1.5 kg/kg production value. In this, 1 M³/MT = 1000 kg of production (https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm).

Table 2.7 Effective utilization of comparative fire brick wall vs pyro block

S. No.	Fire brick wall	Pyro block
LPG	13.34 M ³ /MT	6.72 M ³ /MT
CO ₂ estimation	13,340 kg LPG × 1.5 kg/Kg CO ₂	6720 kg LPG × 1.5 kg/Kg CO ₂
Total CO ₂ (tonne/MT)	20.01 tonne/MT	10.01 tonne/MT
Effectiveness	By pyro block = 45% less CO ₂ emission	

2.5 Artificial Neural Network

The artificial neural network (ANN) is the most recently developed and commonly used technique for predicting parameters for a range of input and output values. In the current analysis, the association data points are used as feedback to the ANN. In ANN, the Levenberg Marquadt algorithm is used to consider feed-forward backpropagation. 80% of the data were used for preparation, 10% for a test, and 10% for validation (Talele et al. 2021; Talele et al. 2021; Talele et al. 2021). The number of neurons between the input and output layers is varied. Analysis of neuron independence is also conducted, with the network with the lowest MSE error value and the highest regression coefficient being regarded. The present study uses a network of ten layers, and it is found that the contribution of the ANN is specific and reliable in predicting the working effectiveness of the furnace. The topmost close fitting of a curve can be observed value near the one shown in Fig. 2.11.

This is the form of multi-objective analysis where the predictive correlation is built between both cases to determine a correlative difference in the working effectiveness of the furnace. The data visualization is performed by Python code where the object is set to be the production value against which fuel must burn in the specific case. The mathematical array developed in both the comparative cases, as shown in Fig. 2.12.

Figure 2.12 represents formulated data visualization with an available mathematical array. A comparative plot can be seen as in Fig. 2.12, where the burning value of instantaneous fuel is compared with the total effectiveness of the system. A furnace equipped with a conventional lining of fire bricks consumes more fuel, with the strategic kaizen implementation to change material of furnace wall with pyro block lining results conversion of energy within system and consume less amount of burning fuel.

2.6 Conclusion

Furnaces are one of the essential tools in the steel, forging, and metallurgy industries. As evolution occurs and the world moves towards net-zero emission, it is essential to maximize energy utilization. Replacing existing refractories, using clean fuel, and ensuring complete burning are the primary stages. The study performed illustrates that ceramics play a prominent role and often are efficient solutions for energy storage-related problems. We can conclude that ceramic fibres (pyro block) can be used as efficient furnace linings to fulfil both cost-saving and energy saving aspects during this performed experiment. As a result of low-thermal conductivity, the amount of heat that was dissipated through the furnace walls was drastically reduced. This helped keep the internal combustion chamber heated for a longer time and equal temperature distributions.

As discussed, the thermal conductivity of conventional refractories is 1.2 W/Mk, and that of ceramic is as low as 0.34. This lower thermal conductivity has reduced

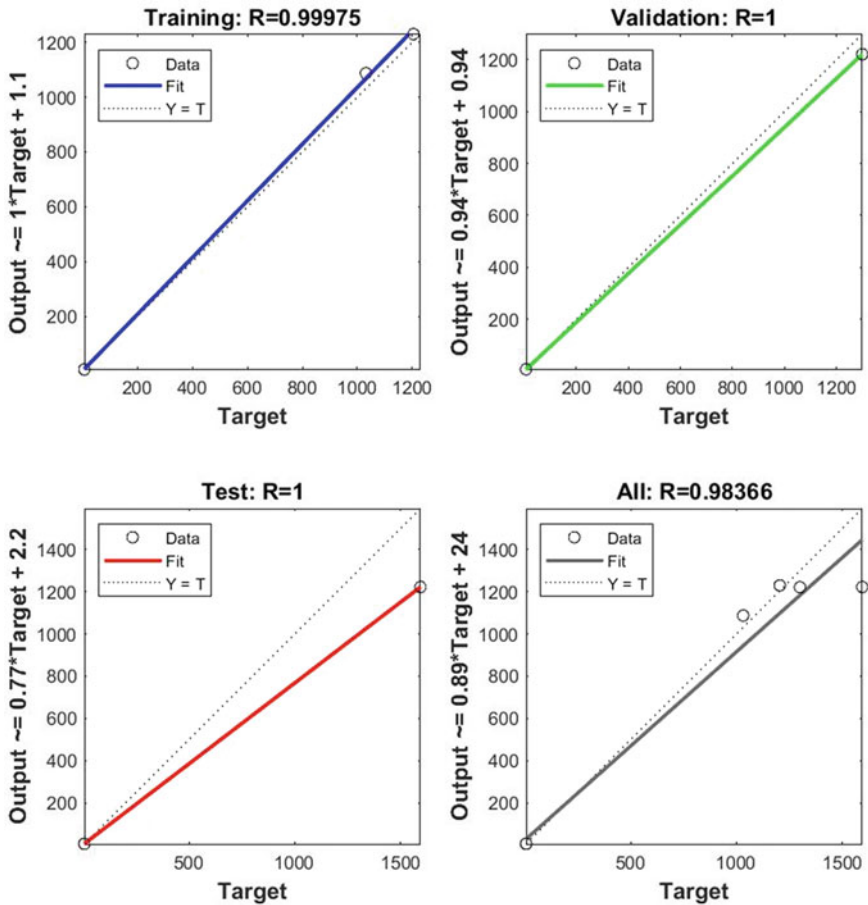


Fig. 2.11 Coefficient of regression obtained from ANN

the conduction through walls. This results in maximum heat acquisition and reduced burner operating time. The development of smart burner technology makes it possible to control heating and concentration on areas with low temperatures. This has drastically reduced the fuel consumption required per batch. Alongside all these industrial benefits, these low-thermal conductivity ceramic fibres contribute significantly to the environment. These new furnace linings have reduced fuel consumption gives clean burning without leaving any residues. It has also reduced CO₂ emissions. Furnaces are also equipped with oxygen sensor which prohibits fresh/non-polluted air to escape through chimneys. This air is reheated using recuperators and reused for better combustion. A multi-objective analysis is conducted based on neurons study for practically validated data of the furnace. It can be seen that the plot of the neurons is near to the value of 1 for the 3 cases, which predict the quality of results.

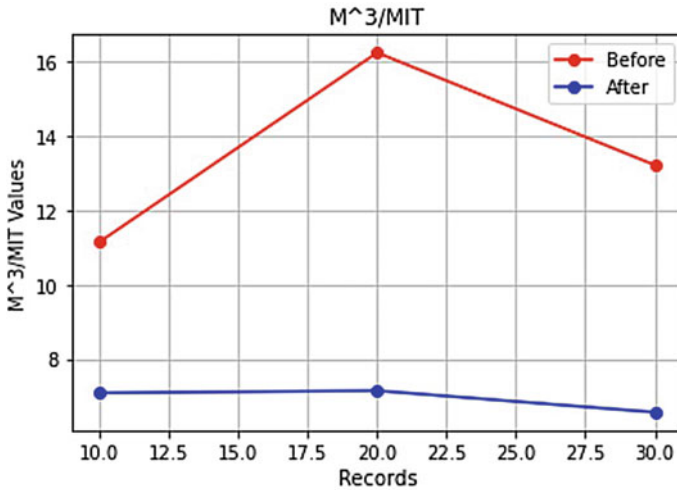


Fig. 2.12 Before and after case for burned fuel versus effective ratio

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