EFFICIENCY ENHANCEMENT OF RE-HEATING FURNACES BY INTEGRATION OF SUITABLE HEAT RECOVERY SYSTEM

A thesis submitted to the
University of Petroleum and Energy Studies

For the award of
Doctor of Philosophy
In
Power Engineering

By
Yogesh Chandra Gupta

May 2023

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I declare that the thesis entitled "**Efficiency Enhancement of Re-Heating Furnaces by Integration of Suitable Heat Recovery System**" has been prepared by me under the guidance of Dr. Kamal Bansal, Professor & Dean-SoE, University of Petroleum & Energy Studies No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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ABSTRACT

The second-largest population in the world and the seventh position among largest territory in the world has been secured by India. India's manufacturing output was reported to be approximately 7.4 million tonnes in 2009. After China, around the world, India is the second-largest manufacturer including both grey-iron and steel molds. As per the multiple global specifications, the Indian iron & steel manufactures different classes of significant molds. India secures third position among the largest energy user around the globe, and third biggest cause of greenhouse gas (GHG) production, accounting for over 4% of the total global carbon dioxide discharge of 25.2 billion tonnes. India is the world's second-fastest-growing source of GHG emissions, but it has committed to reducing its national economy "emissions frequency" by 33-35 percent by 2030, compared to 2005 levels. Energy conservation and pollution mitigation have always been a worldwide objective and commitment as energy shortages and ecological degradation worsen. “The energy intensity of most manufacturing operations is at least 50% greater than the theoretical optimum defined by the laws of thermodynamics”.

The use of energy-intensive raw resources accounts for increased energy use. Direct and indirect energy losses will thus be suffered because of size reduction and low yields. Coking, sintering/pelletizing, ironmaking, steelmaking, and rolling are all processes that are used in typical metallurgy. Because of the variation of the volume, consistency, and category of waste heat, the complexity of recovery and utilization, as well as the recovery rate, differs. In developed capital iron and steel enterprises, such as Japanese Nippon Steel, the recovery rate of waste heat energy is normally near 90 percent, but most iron and steel firms in India only hit 30 percent to 50 percent. The steel re-rolling mill (SRRM) industry in India portrays a significant role in the country's steel generation. Over 3500 small size and medium-size Steel Re-

Rolling Mills are distributed throughout the world, and they manufacture nearly 70 out of 100 of all long steel goods present in India.

The presented work's objective is to reduce greenhouse gas (GHG) emissions and improve energy efficiency by integrating waste heat recovery devices with steel-rerolling mills in India which will help in adoption of technologies that will be more environment-friendly and energy efficient. Due to uncertainty within conservative, yet comparative business sector and inertia, till date these cleaner and more efficient practices have not been majorly adopted in India. This creates the need to develop a strategy to necessitate the perforation of "low-risk", high-efficiency standardization of technology packages. The collected data confirms the main culprit of low efficiency of a furnace is wasted heat through flue gas. Recovering this heat back and utilizing it by transfer of this heat to the furnace can save a huge amount of fuel and reduce energy consumption. Hence, heat recovery has been obtained by using a thermal battery (Honeycomb, ceramic) at the termination point of the furnace and it absorbs the heat of flue gas. A pair of such burners have been installed facing each other and a saving of 27% is achieved by heat recovery from flue gas. Hence, an optimized process has been designed to recover the losses from flue gases suitable to Indian coal quality. The proposed process uses a regenerative burner along with the partial combustion of coal in the presence the excess oxygen & steam, which leads to the formation of synthesis gas with sufficiently good calorific value. The results model the total increment in the efficiency of a furnace with a suitable design of pre-integrated coal combustion process and application of thermal batteries at the end of furnace flue gas outlet. The study has been performed on various constituents of this gaseous fuel and found that coal gas developed under optimum conditions is best suited and gives calorific value equal to natural gas. Hence, an integrated system of coal gasification along with a scrubber (For cleaning of gas) and pair of the regenerative burner is the optimum option for energy consumption and cost reduction.

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I would first like to thank my Ph.D. advisors, Dr. Kamal Bansal, and Dr. S.N. Sriniwas. Their passion and persistence in science have constantly encouraged me during my Ph.D. Research. Both Dr. Bansal and Dr. Srinivas spent enormous efforts guiding me on research and never lost their patience when my experiment was not going well. They would seek every chance to train my paper writing and presenting skills that help build my confidence and become a qualified researcher. Without their constant support, I would never have been able to accomplish my Ph.D. Thesis. All the knowledge and merit that they passed on to me, has made me today and will continue benefiting my future life.

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Yogesh Chandra Gupta

10-May-2023

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LIST OF ABBREVIATIONS

RHF	–	Re heating Furnace
SRRM	–	Steel Re-rolling Mill
WBF	–	Walking Beam Furnace
WHF	–	Walking Hearth Furnace
PHF	--	Pre-Heating Furnace
WHR	.--.	Waste Heat recovery
PHex	--	Pre-Heating Exchanger
EAF	--	Electric Arc Furnace
PHAST	--	PHAge Search Tool (Software)
IWH	--	Internal Waste Heat
TES	--	Thermal Energy System
NOx	--	Nitrogen Di Oxide
PEBA	-	Polyether block amide
DSC	--	Differential scanning calorimetry
ETEKINA	--	Heat pipe technology for thermal Energy
CtpC	--	A kind of Membrane structure
MBIHE	--	Moving Bed Indirect Heat Exchanger
DML	--	Data Manipulation Language
CKD	--	Cement Kiln Dust
TGR-OBF	--	top gas recycling-oxygen blast furnace
VR	--	Virtual Reality
TPD	--	Tons Per Day
LVFO	--	Light Viscosity Furnace Oil
HSD	--	High Speed Diesel
LPG	--	Liquified Petroleum Gas
LVD	--	Light Viscosity Diesel
EMC	--	Electro Magnetic Compatibility

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CHAPTER 1

INTRODUCTION

1.1 ENERGY ROLE IN INDIA

India is a South Asian nation with a diverse economic and demographic history as well as a diverse culture. It is the holder of second position among the largest population around the globe and seventh-largest territory in the world. Authoritatively, there are 29 states that can be split into six different regions to facilitate a mutual organizational climate among them. However, based on regional energy consumption details from the Power System Operation Corporation Limited (POSOCO), India has been categorized into five main topographical territories Northern, Western, Southern, Eastern, and North-Eastern. POSOCO, an autonomous organization established by the Government, provided energy consumption per day data for the five geographical regions and the entire nation of India [1].

Variable	Mean	Median	Maximum	Minimum	Std. Dev.
All India energy cons	3103.04	3049.50	3775	2592	320.96
WR energy cons	963.94	975.50	1133	761	91.04
NR energy cons	861.60	813.50	1250	566	177.89
SR energy cons	877.94	877.00	983	749	52.81
ER energy cons	347.67	335.50	461	259	50.21
NER energy cons	37.65	37.00	52	28	6.12

Table 1.1 energy consumption data for the five geographical regions

Energy serves a dominant part in the cultural and social sustainability and humanitarian wellbeing of a nation, whether explicitly or implicitly, throughout the complete course of transformation, progress, and the existence of all life on earth. Energy has gained the nickname of a "logistical asset" and any unpredictability including its availability, especially in emerging environments, may hinder the entire economy's ability to work. The majority of such manufacturing facilities are grouped geographically. The steel mill sector is known for its elevated energy demand and production of particulates. Thermal expansion is perhaps the most energy-intensive method in manufacturing plants, and it often releases significant pollutants into the environment. The manufacturing sector is a critical energy consumer and has a significant environmental impact. Energy governance is needed to assess how energy is used, as well as the resource conservation system's performance. Energy sustainability would be based on energy exploration and extraction, capability extensions, renewable energy substitutes, recycling, and energy field policies. In modern times, energy efficiency is becoming a significant concern. Preservation and effective use of sources of energy is critical to bridging the divide between energy production and consumption. Improving energy reliability becomes one of the most appealing short-term solutions for picking up the pace. Energy saving is a cost-effective way to prevent wasting energy. This can also be defined as a modern energy production that, once discovered, could be used immediately even without additional deficit or waiting period. It will be the most cost-effective form of energy. India produces approximately 8%–9% of the global casting cultivation. The world's leading casting manufacturing locations are portrayed. India's manufacturing output was reported to be approximately 7.4 million tonnes in 2009. After China, India is the second-largest producer around the globe including both grey-iron and steel molds. As per the multiple global specifications, the Indian iron & steel manufactures different classes of significant molds [1].

1.2 POLLUTION EMISSION

India holds the position of third-largest energy user and third substantial contributor of greenhouse gas (GHG) production across the globe, accounting for over 4% of the total global carbon dioxide discharge of 25.2 billion tonnes. India is the world's second-fastest-growing source of GHG emissions, but it has committed to reducing its national economy "emissions frequency" by 33-35 percent by 2030, compared to 2005 levels. The manufacturing industry contributes to more than 500 million tons of India's cumulative GHG emissions, which total 1.7 billion tons. The Indian steel industry, which emits 70 million tons of CO2 annually, is also one of the major contributors to this amount. Per capita power utilization and pollution, on the other hand, have steadily declined. The vast proportion is responsible for the decrease in per capita emissions (0.3 tons of carbon per person) [3].

Energy conservation and pollution mitigation have always been a worldwide objective and commitment as energy shortages and ecological degradation worsen [2]. In the meantime, whenever a nation creates finished products energy usage is generated either regionally or overseas. As only finished products are consumed, a finished manufacturing valuation system has been developed in recent decades to link resource utilization to finished manufacturing industries. The distinction between this and usage procurement is the representatives included to distribute energy utilization (final manufacturers or end customers). As a result, the energy usage assigned to an area that primarily serves as a manufacturer of input materials is estimated to be slightly lower than that distributed to a manufacturer of goods produced.

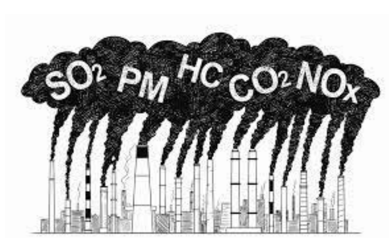


Figure 1.1 Polluting emissions (Source: Google)

Since the 1980s, there has been implementation by the government of variety of policies and structural initiatives with active business involvement, such as the tenth five-year plan, which emphasizes the importance of effective energy resource usage for long-term growth. Multilateral, bilateral, and foreign bodies in addition to national initiatives fund a significant number of projects. These efforts, though, have been restricted to vast and well-arranged industries, such as steel. The interventions by Ministry of Steel interventions is restricted to large integrated steel plants [4].

1.3 STEEL MANUFACTURING SECTOR

Steel is the largest widely used building tool in the nation because of its reliability, process ability, and low cost. Steel processing, on the other hand, uses a lot of electricity and generates a lot of CO2. As Per the World Steel Association, crude steel demand crossed 1691 million tonnes in 2017, resulting in energy consumption of 3.21011 Giga Joules and emission of CO_2 is 3046.80 million tonnes. Energy consumption is widely regarded as the most cost-effective method of lowering energy usage while increasing output. Manufacturing sectors are half as energy-intensive as they should be, according to the International Energy Agency: “The law of thermodynamics suggested that the energy intensity of most manufacturing operations is approx. 50% greater than the theoretical optimum”.

Figure 1.2 Manufacturing Sector

Owing to a shortage of resources, manufacturing interruption, improper technology interfering with manufacturing, a lack of capability in performance evaluation, companies are also reluctant to adopt energy efficiency. India, after China, is the world's second-largest steel manufacturer, manufacturing approximately 110 million tonnes of steel. India's steel production is forecast to hit 200 million tonnes in 2020, according to experts. The recent increase and development of the Indian steel industry has resulted in severe energy shortages and increased stress on the nation's already fragile environmental situation. India has the largest frequency of energy usage among the world’s largest eight main steel-producing countries. In India, one tonne of crude steel produces around 2.5 tonnes of CO_2 emissions [4].

Figure 1.3 Manufacturing steel in high temperature

Electrical energy and High-temperature fuels (natural gas, furnace oil and coal) are used directly in this market. The use of energy-intensive raw resources accounts for increased energy use. Direct and indirect energy losses will thus be suffered because of size reduction and low yields. A SRRM in Haryana has been chosen to perform the experiments to solve the aforementioned issue and achieve the presented work objective. The tests were carried out to pinpoint a possible failure field. Almost all sectors, such as the steel sector, will limit greenhouse gas emissions by boosting their resource utilization.

1.4 HEAT LOSSES

Coking, sintering/pelletizing, ironmaking, steelmaking, and rolling are all processes that are used in typical metallurgy. Because of the variation of the volume, consistency, and category of waste heat, the complexity of recovery and utilization, as well as the recovery rate, differs [5].

Figure 1.4 Excess heat loss

The importance of loss of heat capital is measured not only by their number but also by their efficiency. Performance is divided into three divisions based on temperature rate:

- ❖ **High degree**

The word "high degree" applies to waste heat tools with a temperature greater than 500°C, such as Coke Oven gas, electric furnace gas, converter gas, and heating furnace flue gas, among others. The heat within them, produced by the reactor gases could exceed 1500°C, as well as the heat of the furnace flue gas, also reaches 1000 degC; elevated temp liquids like high-temp iron slag, high-temperature water, steel slag; and high-temperature solids, such as high-temperature coke, high-temperature sintering compounds, and high-temperature steel.

- **Medium degree**

  The medium degree waste heat of temperature 150-500 degC includes exhaust gas recycling of waste heat from the main after sintering, blast furnace gas, flue, and other waste heat.

- **Low degree.**

  Low-degree waste heat is described as heat that has a temperature of fewer than 150 degrees [7].

1.4.1 Major Reasons for Heat Loss

Figure 1.5 Heat Released from a Furnace

In developed capital iron and steel enterprises, for instance Japanese Nippon Steel, the rate of recovery of waste heat energy is normally near 90 percent, but most iron and steel firms in India only hit 30 percent to 50 percent [1]. The following are the reasons:

1. Industrial application is unable to retrieve waste heat in a right manner, while the rate of heat recovery is low along with that the amount recovered is very low.

2. The consumption of all types of heat retrieved is inefficient; coal gas, steam, and hot air that have been collected are ramified due to low temperature, the equilibrium of distribution or the heat source supply by variability.
3. The utilization of all types of heat obtained is inefficient.
4. The primary infrastructure of waste heat recovery and reuse has been neglected; nearly all significant attributes are imported; the heat recovering is either depreciating or unstable, and therefore not able to satisfy the requirements of the users, resulting in a significant number of low-grade heat sources become unavailable.
5. Certain businesses are small, have poor efficiency, and use outdated equipment; at the same time, because importing waste heat recovery equipment is a big expense, the cost often outweighs the benefit, which dampens business interest for waste heat recovery. [5]

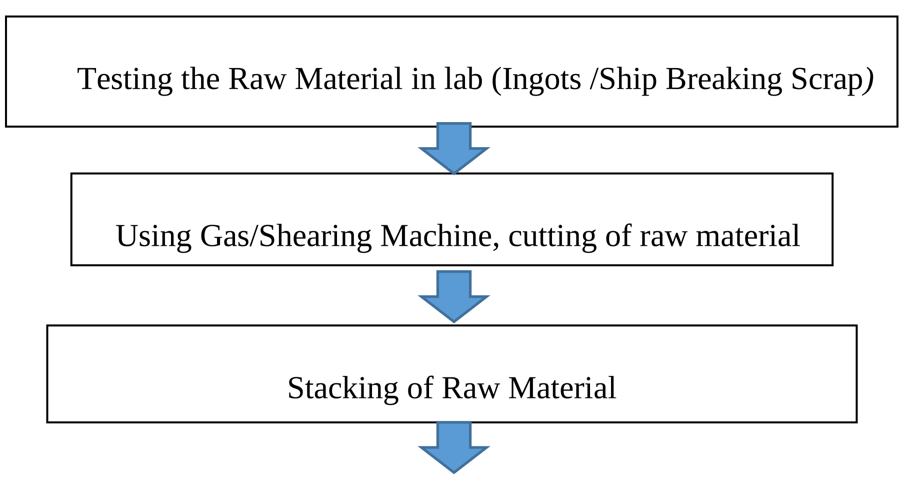
1.5 STEEL RE-ROLLING

Figure 1.6 Steel Re-rolling

The “steel re-rolling mill (SRRM)” industry in India enacts a significant part in the country's steel generation. Over 3500 small sizes as well as medium-size Steel Re-Rolling Mills (SRRM) are distributed throughout the world, and they manufacture nearly 70% of all long steel goods in India [1]. As previously mentioned, small and medium-sized steel rerolling mills (SRRMs) have not been fully funded. However, this industry is an inevitable link in the country's overall steel supply chain. The mills developed haphazardly, relying on out-of-date, low-investment, high-cost technology, and practices that they often funded with their own capital. In accordance with the "Comprehensive Study of Steel Rerolling Market," there are 3500 (working) SRRM units of different sizes in the industry. Any mills are composite (producing ingots for rolling using an electric arc furnace and/or an induction furnace) [1]. As a result, the field has a strong cumulative potential and a comparative advantage across major suppliers due to their output versatility in satisfying lower tonnage specifications in diverse types, forms, and dimensions to satisfy market niches.

Steel re-rolling is a vital segment of the manufacturing sector because it is an inevitable component in the overall iron and steel supply chain. Steel manufacturing consumes many resources. One tonne of steel requires approximately 56-66 liters of furnace oil (or 226-269 kg of coal) and 165-192 kilowatt-hours (KWh) of electricity. Thousands of kilograms of crude steel produced from ore of iron, produces nearly 1.2 tonnes of industrial waste and 2.5 tonnes of carbon dioxide and other contaminants. There are over 3,500 steel re-rolling mills (SRRM) both small and medium sized enterprises (SMEs) present in India, with the bulk (75%) being small-scale units.

1.5.1 PROCESSES USED IN ROLLING MILLS



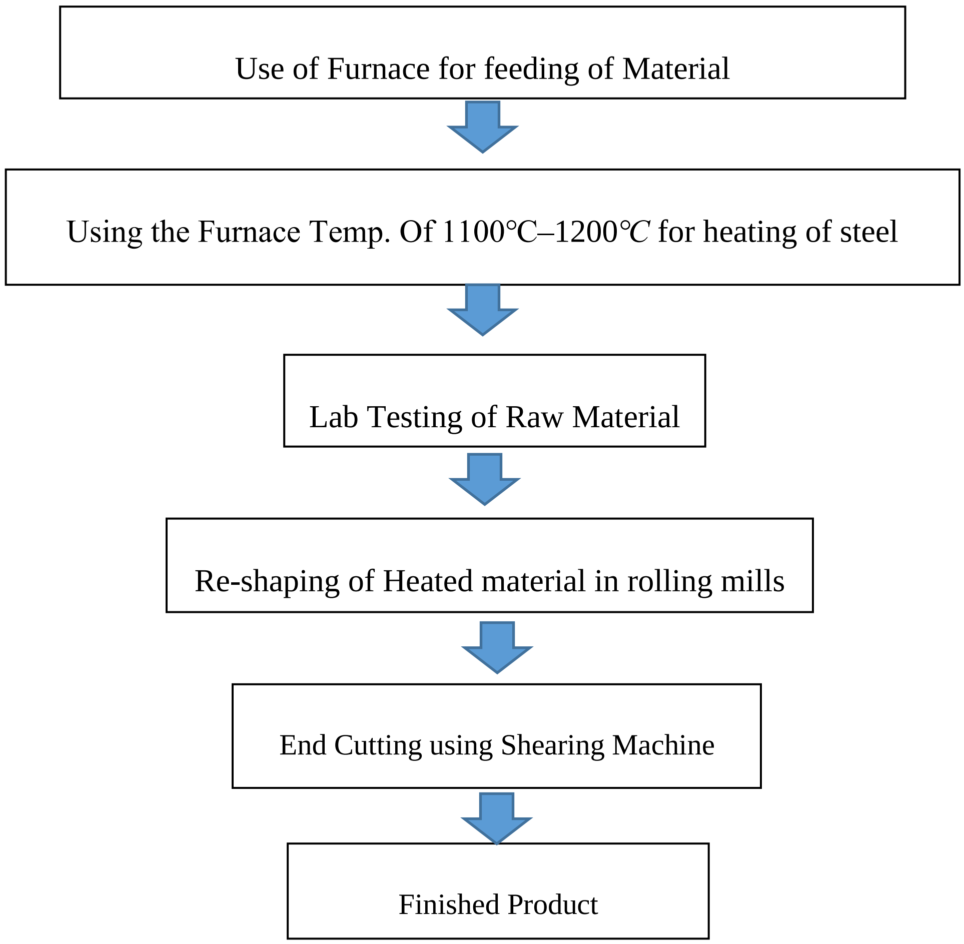


Figure 1.7 Rolling mill process

1.5.2 Furnace

A furnace is a piece of machinery used to cast metal by heat or it heats the products for formation (rolling, welding, etc.) or modification of their characteristics (treatment of heat). A furnace is mostly used to heat the raw product, scrap, or ingots to about 1100℃ to 1200℃ in the case of a steel rerolling mill, such that it turns pliable, yet the blazing heated substance is then lengthen in a chain of rerolling plants in order to produce the component that is desired, such as Sariya/Patra/Angles/Bars. Re-heating of the furnace is the most crucial part of the rolling mill operation. India is home to these re-rolling factories. Patterns can be found in Punjab's Khanna, Ludhiana and Mandi Gobindgarh, Gujarat's Kutch, Bhavnagar, Maharashtra's Nagpur & Nasik, and Rajasthan's Jaipur. There are approximately 300 re-rolling mills in Punjab, with various manufacturing capabilities [4].

Figure 1.8 Steel manufacturing Furnace

Stackle, strip, annealing, finishing, and boogie are the five furnaces that make up the facility. Stackle mill furnace is the most energy-intensive among these five furnaces. As a result, research was conducted on a stackle mill furnace to determine the pattern of losses in the furnace. The radiation losses and flue gas losses were measured in the experiment, and the flue gas losses were found to be 14 times higher than the radiation losses. The flue gas losses are largely determined by the amount of time the product is stored inside the furnace and the temperature of the furnace. According to the results of the experiment, the furnace's average efficiency was 27 percent, with flue gas losses of about 35 percent. Based on the analysis, two additional furnaces were selected for measuring the heat loss due to existing heat wastage in the flue gas. Two furnaces are used to calculate the volume of heat losses in the flue gas: a walking beam and a pre-heating furnace. The heat loss in the form of waste heat was determined to be approximately 141 million Mcal/annum for the walking beam and 598 million Mcal/annum for the furnaces rated at 75 tonnes/hour and 150 tonnes/hour, respectively.

1.5.3 Significant loss in a re-heating mill's furnace

Figure 1.9 steel re-rolling

The following are certain big losses that are present in the re-heating of mill's furnace, as well as potential solutions for achieving improved fuel economy:

1.5.3.1 Process of Charging and Discharging

Reverse charging and side discharging are seen in the furnaces. During these procedures, heat lost is enormous. It can be reduced to a minimum by opening the charging and discharging doors as little as possible.

Figure 1.10 Recharging in a furnace

1.5.3.2 Doorways

Figure 1.11 Door in a Furnace

Aside from the loading and collection doors, the Re-heating furnaces have a range of monitoring doors. By supplying insulation on these doors, the damage from these doors can be reduced.

1.5.3.3 The furnace's hearth

Figure 1.12 Furnace Hearth

The furnace's hearth could be congested or underloaded. The energy present in excess per unit output is utilized in all situations. There should be appropriate charging in the hearth of the furnace and the furnace should always be perfectly built. The flue gases that exit from the furnace's stack have a temperature of 700 to 800 degrees Celsius. Most mills do not have a Recuperator. In certain circumstances, the Recuperator was found to be located underwater with no requirement for wiping the tubing. As an effect, there was an undue pressure reduction in the exhaust system, resulting in overpressure. Since the recuperators in the fireplaces did not have a floating head, the tubes were bent. Due to thermal expansion and compression pressures. The recuperators should be fitted with floating heads, which should be washed regularly. There are electricity savings in mills attributable to inefficient methods such as using needless bye passes in water recirculation and FD fans [6].

1.5.3.4 The draught from the Furnace

Figure 1.13 Furnace Draught

The entry of unregulated air into any furnace must be avoided. To prevent penetration, hold a reasonable amount of extra pressure inside the furnace. Large furnaces, particularly those with stack draught, have pressure-sensing devices that change the limit or the amount of flow of protective gas moving into the furnace using relays and servomotors [4]. If the furnace is under negative pressure, air penetration is likely to happen through holes and cracks, influencing the ratio of air-to-fuel. As a result, the pressure in the furnace should be marginally positive. Maintaining a marginally positive pressure (of 0.01” wg) is a common procedure.

1.5.3.5 Burner

Figure 1.14 Burner

A burner is a device that produces heat. In pulverized coal-fired reheating furnaces, a plain hollow-pipe is used as a burner. It is recommended that a burner with swirl capability be built to ensure improved combustion [14].

1.6 ANALYZING THE PERFORMING SUBSTITUENTS

1.6.1 Material waste analysis

Figure 1.15 Scrap Steel

Steel scraps extracted from residues of different steel factories, shipbreaking factories, or steel ingots extracted from steel foundries are the main raw materials used in steel re-rolling. The latest study is about rerolling steel scraps from Alang's ship recycling yards. It has been estimated that per tonne of raw steel scrap used in the process, approximately 110 kg of material waste is produced at different stages of the re-rolling process. This is equal to about one tenth of a percent of industrial waste. At the same time, it was said that during the entire period of re-rolling from steel ingots, approximately 4% of total waste is produced. The waste created takes several forms, and most of it is not recycled after the re-rolling process. Currently, the waste is either disposed of in local landfills or shipped to other countries. The amount of waste caused and a lack of awareness about reclaiming activities are both issues in re-rolling. Production economics and other sustainability initiatives benefit greatly from waste materials produced. In the re-rolling industry, wastes such as slug, ash, ashes, wastewater, weights, cutting scrap, used furnace oil management, and effluents are common [6].

1.6.2 Energy consumption analysis

Figure 1.16 Heat Energy Loss

Coal or specific thermal potential are used to achieve the overall energy needed for re-rolling. According to the information collected, 1 tonne of steel rerolling from scrap consumes approximately 950 Kw/hr. of total electricity. The two energy-intensive steps in the rerolling process are reheating and rolling.70-80 percent of overall energy consumption is absorbed in the reheating furnace, while 20-25 percent is consumed in the rolling process. Most rolling mills in the re-rolling industry use coal-fired re-heating furnaces, which are inefficient and pose significant environmental and staff health risks due to fine coal dust emissions. It is sufficient to decrease energy consumption by 20 to 30% by improving the furnace exhaust gas demand and auxiliary power specification systems. As Rolling Mills technology advances, it is now possible to reduce the size of the motor and cooling system while maintaining the same productivity and, as a result, lowering energy consumption [8].

The heat energy produced in manufacturing activities that are not brought to any useful usage and are wasted, discarded, or discharged into the atmosphere is referred to as factory waste heat. Multiple waste heat storage systems may be used to recycle waste heat and establish useful energy supplies while lowering total energy demand. In this respect, one of the main sections of analysis to decrease fuel usage, reduce toxic emissions, and increase energy efficiency performance has always been the utilization of collected waste heat recovery systems in several industrial applications. The heat involved in manufacturing operations that might not be applied to any useful application and get discarded or deposited into the atmosphere and will be referred to as manufacturing waste heat. The loss of heat through manufactured products, machinery, and operations through conduction, convection, and radiation, as well as heat generated from combustion products, are the major sources of waste heat [9].

1.6.3 Heat Recovery System

There are several heat recovery systems for storing and recycling waste heat, the most common of those are thermal heat exchangers as a waste heat recovery device like

- Air preheaters,
- Economizers,
- Run-around the coil,
- Plate heat exchangers,
- Regenerative and recuperative burners,
- Regenerators,
- Heat wheels,
- furnace-regenerators,
- Rotary-regenerators,
- Recuperators,
- Heat pipe and
- Heat recovery Steam generator

Are among the most popular waste heat recovery systems. All these units operate on the same concept of capturing, recovering, and exchanging heat with a possible evaporator [5]. Few major and commonly used recovery systems are.

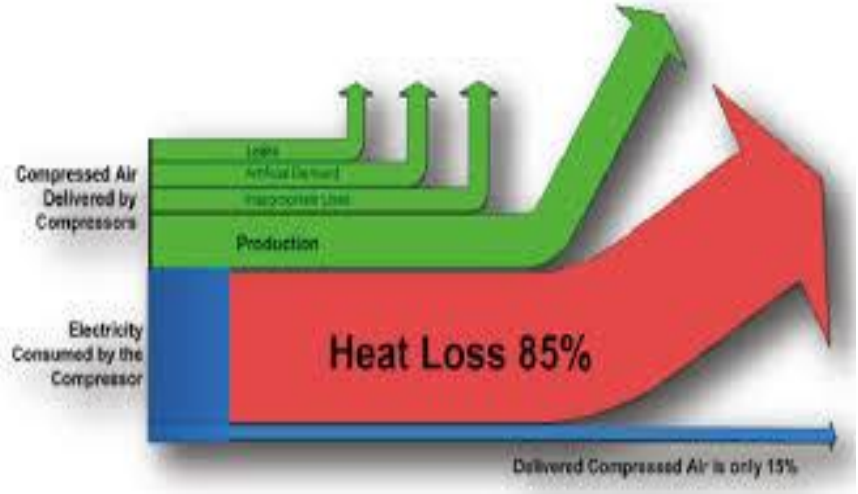


Figure 1.17 Waste Heat

Water granulation dissipates furnace slag, which is basically a waste material of steel and iron manufacturing that is normally disposed of at high temperatures (1200e1600 C) [7], causing severe ecological complications (e.g. hydrogen sulfide and steam, polluted water). As a result, a number of efforts are provided for the energy conservation of heat waste of BF slag. [8]

1.6.3.1. Recuperative and Regenerative Burners

Figure 1.18 Regenerative Burners

Regenerative burners are additional extended surfaces to absorb waste heat from the high-temperature flue gas of thermal utilities, regenerative and recuperative burners improve fuel performance [14]. Regenerative heating systems are attached to the furnace usually composed of two burners with different control valves for heating the air stream. The machine works by pumping hot gas from the furnace into a container filled with refractory content like Al_2O_3 (aluminum oxide) [11]. The exhaust gas increases the heat of the Al_2O_3 component, recovering and holding onto the extra heat from the exhaust. Once the medium is sufficiently heated, the flue gas is diverted; transferring the accumulated heat to the combustion air approaching the burner and hot material of 2nd burner then start igniting. The combustion air from the warmer medium heats the colder medium, and the process is repeated. By employing this technology to heat the air, the regenerative burner may save fuel while increasing combustion potential [11].

1.6.3.2. Finned tube heat exchangers

Figure 1.19 Finned tube heat exchangers

Finned tube heat exchangers, which are also known as Economizers, are generally designed to heat fluids by recycling low to medium excess waste heat. The device comprises tubes coated in metallic fins to optimize heat absorbance surface area and rate of heat transfer [9]. The machine is installed in the outgoing exhaust gas vent and collects waste heat by allowing hot gases to flow through various parts protected by finned tubing. Liquid is filled in the tubes for absorbing the heat generated in tubes. The hot liquid is then returned to the device, significantly enhancing thermal efficiency.

1.6.3.3. Waste Heat Furnaces

Figure 1.20 Waste Heat Furnaces (WHF)

Waste heat furnaces is actually a collection of parallel water tubes that follow the same path as the heat leaving the network. The device recycles heat from exhaust gases of medium to high temperature, while producing steam as a by-product. The low enthalpy steam produced will be either utilized to generate power or recycled back into the system. The flue gas temperature of a thermal power plant is up to 1000 degC. This heat is re-utilized to increase the feed water temperature and enhance the efficiency of heating system-within that case, a WHF is utilized to retrieve and use the heat from the exhaust gas to evaporate the fluid and create steam.

1.6.3.4. Air Preheaters

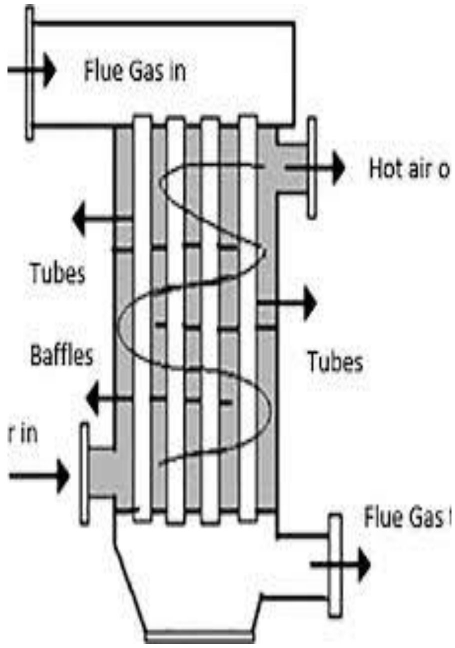


Figure 1.21 Air-Preheaters

Air-preheaters are primarily utilized in low to moderate operating temperatures and for exhaust-to-air thermal restoration. This technique is very useful for minimizing cross toxicity throughout the manufacturing process. Examples of such implementations include heat recovery from furnaces and gas turbine exhaust, and WHR from furnaces and ovens. The surface style and the heat pipe type of air preheating are two distinct designs. The surface form which is perpendicular to the injector of cooler air are made up of parallel plates. The Hot air from the exhaust is blown in between the plates into the pipes, giving rise in temperature of the plates and forming hotter streams into which colder air is blown. Three forms of air preheaters are widely used and known as recuperative regenerators: rotary regenerators and run around the coil. These systems both work on the same concept as air preheaters, but they are configured differently and are designed for various objectives.

1.6.3.5. Plate type Heat-Exchanger (PHEx)

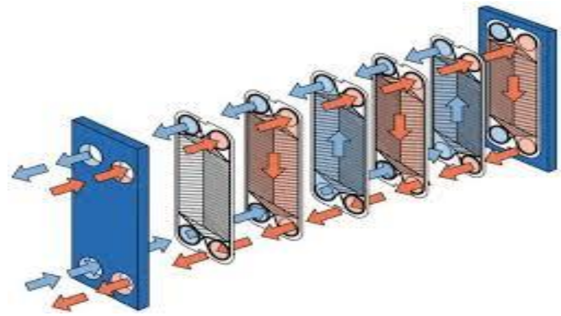


Figure 1.22 Plate type Heat Exchanger

While mutual contact must be prohibited, plate type heat exchangers can be utilized for shifting the heat from one solution to another. A PHEx is composed of several thin metal plates, which can be placed in lined or riveted in series and designed into a vacuous metal casing. Every plate is normally made up of a series of compressed configurations that are surrounded by valves to regulate fluid movement and generate instability for enhanced heat transfer. The valves are structured ensuring that only one kind of fluid can flow from one space while the others are guided via the alternate space. The hot and cold fluids alternately flow into every part of the heat exchanger as well as in plates, sharing the temperature and avoiding contamination. The extended surfaces make it faster heat transfer between hot and cold fluid. These exchangers are like traditional tube and shell heat exchangers.

Steel plants obtain a considerable volume of Blast Furnace gas as a byproduct. Earlier due to its poor calorific value of 700-750 kcal/Nm^3, it could not be utilized as a fuel in re-heating for rolling and Re-heating furnaces. In current scenario, the innovative gas and air dual pre-heating regenerative burner can heat up both gas and air to more than 1000°F, which increases the theoretical combustion temperature of low calorific value gases, such as Blast Furnace gas having a calorific value of approximate 750 kcal/Nm3, that can achieve further 2100°F with the help of dual preheating regenerative burner, which is the reheating temperature requirement in rolling operations [14]. The temperature of the flue gas exhausted from a regenerative burner is just 150 to 180 degrees Fahrenheit and most of the waste heat is recovered, resulting in significant energy savings. The reheating furnace, which uses only Blast Furnace gas or other low calorific value fuels, will spare coke oven gas for other high-value applications [27].

1.7. MOTIVATION AND OBJECTIVE OF THIS RESEARCH

India is a leading steel manufacturing country Besides Integrated steel plants, there are around 3500 Steel Re-Rolling Mills (SRRM). This MSME SRRM play a vital role in the Indian economy. These SRRM converts the big Ingot / Bloom of steel to desired products used by consumers, like Rods, angles, channels, machine tools, Rails, etc. This conversion requires Re-heating of steel ingots; Hence, Re-heating Furnaces are used for heating of ingots to 1200 degC.

These reheating furnaces consume a large amount of heat, furnace efficiency is generally in the tune of less than 25%, and most of the heat goes to waste. Energy is a key consumable in such mills and this SRRM are energy-intensive manufacturing units. The recovery of wasted heat improves the performance of the Re-heating furnace by 25-30%. Hence, Chosen research project of Integration of suitable waste heat recovery device.

1.7.1. The objective of this research

I. Study of furnace exhaust waste heat losses like the quantity of heat loss etc.

II. Study & comparison of various existing solutions to recover the waste heat.

III. Modeling of existing arrangements and their verification / Validation with existing data.

IV. Identifying the various international benchmarks for heat recovery systems in reheating furnaces.

V. Redesigning the heat recovery system to suit the Indian environment.

1.8. ORGANIZATION OF THE THESIS

This research work has been presented in Seven Chapters. A Chapter-wise summary is as follows:

Chapter 1

India is the second largest manufacturer of Steel after China. Being a Developing country, there is a big need for steel products for fast-growing infrastructure development. The plants, which convert ore to steel ingot/bloom, are primary. However. Converting steel ingot/bloom to useful products like angles, rods, channels, bars, etc. is a secondary steel sector. This conversion is done in Steel Re-Rolling mills across the country. Before conversion, steel needs to be heated up to 1200 degC. This heating is done in Re-Heating furnaces. However, there are huge losses of energy in such furnaces. There is various techniques/equipment available for waste heat recovery from such processes. Applying these devices in steel conversion processes reduces energy losses.

Chapter 2

Several research papers on the following topics have been reviewed:

- Furnace losses
- Waste heat recovery in Re-heating furnaces
- Issues with the fuel available
- Integration of WHR device with RHF
- Coal Gasification
- Conversion of coal to clean fuel

Chapter 3

In this chapter, varieties of furnaces have been analyzed for identifying the major losses in steel re-rolling mills. A research study is performed on a running plant of steel located in Haryana. Then analyzing the losses has confirmed that the biggest loss in an RHF is Flue gas loss.

Heat losses by flue gas were 35%, which were the highest of all the losses of re-heating furnace. Hence, identified as the section of major losses. However, radiation losses were only 2.6%

Chapter 4

The analysis of the Stackle mill was performed, and it was observed that the energy efficiency of the Preheating furnace is 48 percent whereas the efficiency of the walking beam furnace is only 15 percent, which is precisely low. The main reason for the low efficiency of the furnace is the high temperature of flue gases and big heat loss through flue gases.

Chapter 5

Before applying the regenerative burners, the flue gas losses were in the range of 45%. However, after modification in this furnace and applying the pairs of regenerative burners, the flue gas losses were reduced to 18%. Hence saving achieved due to flue gas loss reduction, in this case, is 27%.

Another major problem of frequent choking of burners has been observed using economical low-grade coal. The Ash content in Indian coal is 35% - 50%. These burners run well with high-grade coal. However, this technology is to be used with gaseous fuel.

Chapter 6

After integrating regenerative burners in the reheating furnace, a problem of frequent choking is observed. Further investigation leads to the use of gaseous fuel only with the Regenerative burners. Hence, the integration of coal gasifier and Regenerative burner leads to waste heat recovery to the tune of 25-30%. However, parameters of gasification need to be optimized for gaining maximum energy saving through waste heat recovery. In this chapter various gasifiers have been studied and analyzed for the said application and other parameters have been optimized.

Chapter 7

The suggested method employs a regenerative burner and partial coal combustion in the presence of excess steam and oxygen, resulting in the formation of syn gas having high calorific value. The research was undertaken on the different constituents of this gaseous material, and it was discovered that coal gas generated under optimal conditions is ideally suited and has a calorific value comparable to natural gas. As a result, an integrated coal gasification system with a scrubber (for gas cleaning) and a pair of regenerative burners is the ideal choice for lowering energy usage and costs.

Hence, an integrated solution is best workable in such Re-heating furnaces in Steel Re-rolling mills. As of date, approx. 3500 small & medium size steel re-rolling mills are running in India. This may lead to the production of steel at globally competitive prices and may change the GDP of India. Simultaneously reduction of production cost and GHG emission.

The integration of the following is required.

1. Coal gasifier
2. Re-Heating furnace
3. Regenerative burner

1.9. CHAPTER SUMMARY

India is the second largest manufacturer of Steel after China. Being a Developing country, there is a big need for steel products for fast-growing infrastructure development. The plants, which convert ore to steel ingot/bloom, are primary. However. Converting steel ingot/bloom to useful products like angles, rods, channels, bars, etc. is a secondary steel sector. This conversion is done in Steel Re-Rolling mills across the country. Before conversion, steel needs to be heated up to 1200 degC. This heating is done in Re-Heating furnaces. However, there are huge losses of energy in such furnaces. There is various techniques/equipment available for waste heat recovery from such processes. Applying these devices in steel conversion processes reduces energy losses.

CHAPTER 2

LITERATURE REVIEW

2.1 MINIMIZING FLUE GAS LOSSES

Otto et al [2], the utilization of blast furnace gas recirculation, an increased share of EAFs, and specific iron with hydrogen as a reduction agent are all discussed in this paper as potential ways to incorporate renewable energy into the steel production process. It is seen that these processes will lead to less dependency on coal and finally get rid of it. This opens the potential of supplying electricity and heat to the steel industry by combining renewable energy and Hydrogen energy production. In this research paper, it is elaborated through the example of Germany that the introduction of 12000 – 274000 MWh of renewable electrical power into the steel sector will result 47% – 95% of GHG emissions reductions compared to 1990 level and 27% – 95% less primary energy requirement compared to 2008.

According to Quader et al. [3], the electric arc furnace route (EAF) generates roughly 30% of steel by melting recyclable steel waste. The WHR process used in Electric Arc furnaces attempts to trap and accumulate inflammable byproduct gases such as Carbon Mono Oxide to provide sufficient heat energy for the furnace, equivalent to the suppressed combustion technique. One of the several common manufacturing processes of steelmaking from mined waste steel is the electrical melting technique used in EA furnaces. EA furnaces with Graphite electrodes are utilized to melt steel scrap from waste and improve productivity and performance in this process.

According to Zhang et al [4], the crushing methods and dry granulation the solid slag impingement technique, mechanical stirring process, and revolving drum method, is used to retrieve the material. Other atomizer processes, like that of the centrifugal granulated method, air blast method, and the spinning disc and revolving cup atomizer processes, are also possible and have been tested, Chemical processes, but at the other side, also include the methane reforming reaction mechanism and using it directly to create high-value-added materials.

Lu et al [5], the source for this study is a SRRM Re-heating furnace, with 5-6 months of output and energy records. Due to the extreme reheating furnace's electric energy consumption accounting and the rolling line's single calculation, the estimates of the reheating furnace's power consumption can indeed be segregated. As a result, this paper focuses exclusively on the unit product's gas law, steam generation and cooling water. Per total energy, section determines the energy allocation ratio. The energy allocation varies depending on the width of the billet, the output rhythm, and the steel grade, according to a case report. The bigger the steel billet's energy allowance is, the wider it is and the smoother the output rhythm is, and vice versa. Specific steel classes, meanwhile, have varying energy allocations. The findings indicate that the energetic role concept has important effects in the development of the steel billet-loading schedule, output rhythm management, and energy estimation and that it can be often used to achieve energy-efficient operations.

Thompson et al [6], In this paper using the process heating assessment and survey tool, they determined the appropriate size of a pre-heating chamber and the heat dissipation rate through billets in the pre-heating section, and the optimum temperature of billet preheating for efficient operation. They demonstrated that there is a plethora of energy-saving options open. Pre-heating billets to 325°C using waste heat would take 1.48 hours and save about US$215000 in annual electricity costs over a 3 year pay-back period. In the re-heating furnace, preheating can drastically reduce flue gas heat losses, the energy input, and overall energy consumption. The feasibility of preheating billets is shown in this report. Heat must be added directly to the billets, without the use of heat exchangers. This discovery about pre-heating can be utilized to minimize energy and GHG in the steel industry because the re-heating is an important process in steel production that requires a lot of energy. Thus according to PHAST, the reheat furnace's average performance at full output is about 60%. Most energy is lost by flue gas leakage. The energy consumption of the re-heating furnace may be minimized by minimizing flue gas heat losses. It is also possible to upgrade the charging end from either a fixed to an adjustable opener, which will minimize opening losses by 83 percent and save $46 thousand in electricity. Finally, try applying insulation to the walls, cladding, and furnace.

Guang-yu et al [8], The scientific foundation of the thermal-equilibrium study is based on the 1st law of thermodynamics; therefore the approach merely examined the extraction of surplus heat from volume relationships of conserving energy, without taking into account the consistency of the heat and its variations, so the thermal efficiency measure cannot represent the rationale of the use. The second law of thermodynamics is applied as the scientific foundation of exergy research. Since the approach only considers the use of interchangeable, excess energy and ignores the rest of the non-usable waste heat. On the other hand, the exergy performance index investigates the reuse of waste heat from the equilibrium of energy distributed waste heat. In summary, surplus heat, extraction, and reuse should be centered on the two laws of thermodynamics, both to account for heat lost, and to account for the quality reduction process.

Jouhara et al [9], Performed detailed analysis of WHR strategies, and state-of-the-art technology used in manufacturing operations is described in this article. A study of existing processes and procedures is measured by analyzing WHR prospects for energy optimization in the iron, steel, ceramic and food sectors. The study looks at the process and efficiency of common technologies such as regenerators, recuperators, furnace re-generators and rotary re-generators or heat wheels, plate heat exchangers, air pre-heaters, re-generative and recuperative burners, and economizers, and waste heat furnaces and run via coils. Transport Membrane condensation, indirect contact condensation recovery, direct touch condensation recovery, along with the usage of equipment like Organic Rankine cycles, like the Kalina cycle, heat pipe systems, heat recovery steam generators (HRSGs), and heat pumps, are both regarded. With innovative promising technology for transferring power from direct heat to, thermionic, thermos-electric, piezo-electric, and thermo photovoltaic power generation techniques, is also studied & analyzed.

Jouhara et al. [10] showed that using a Flat Heat Pipe in a steel manufacturing facility's wire chilling line would provide up to 15.6 percent heat recovery for a 450°C heat source. In this research, a revolutionary Flat Heat Plate model with dimensions of height 1m x 1m width was designed and validated at the hottest level of the manufacturing line's chilling field. Heated air spread from the system influenced a plain heat pipe grid that was set at an appropriate angle, and the system was loaded with liquid of flow rate of 0.38 kg / s.

2.2 THERMAL ENERGY STORAGE

Miróet al [11], Introduced thermal energy storage, which is a technique that can correct the current discrepancy by retrieving and preserving IWH for further usage Furthermore, the consumption of recycled IWH decreases CO2 production while still saving money and resources. TES systems may be installed on-site or shipped to off-site energy requirements using mobile TES systems, based on the route between the heat demand and IWH source. Around 50 industry research findings are evaluated and presented here, covering both on-site and off-site treatment performance, thus understanding the dynamics of the source of heat, the heat, the TES method, the commercial, the environmental, and energy-saving consequences. In addition, the characteristics and nature of the cases examined are taken into account. The design and engineering field on which investigators have concentrated the most interest is on-site TES systems in simple metallic processing. Furthermore, most factories use fluid (or vapor), erythritol, and zeolite as TES materials, with workspace convenience and power supply is perhaps the most common features.

Luo et al [12], this report illustrates a heat recovery device that uses the heat from BF slag to produce hydrogen-rich gas by endothermic sludge pyrolysis process. The impact of different variables on extraction yield and gas characteristics, such as slag temperature, slag to sludge mass ratio (B/S), feed moisture and particle size, were analyzed individually The temperature of the BF slag had a major impact on the delivery of pyrolysis materials. If the temperature of the heat carrier rises, the variations caused by varying B/S almost vanish. The heat of the BF slag had a major impact on the delivery of pyrolysis materials. If the amount of heat carrier rises, the variations caused by varying B/S almost vanish. By allowing char and tar to engage in gasification reactions, the maximum feed moisture preferred sludge pyrolysis, enhancing gas yield and consistency. By enhancing tar deterioration and biogas processing, BF slag as a catalyst will significantly improve the H2 and CO volume of carbon (CO2 and CH4). Slag particle size reduction helped sludge basic pyrolysis create further light gases, reduced char, but also less condensate, but it had little impact on gas concentrations.

Wang et al [13], in this paper, Cogeneration of cement plants uses the Kalina cycle, organic Rankine cycles (ORC), dual-pressure steam cycles, and single flash steam cycles to recycle waste heat from the pre-heater exhaust and clinker cooler exhaust gases. Each cogeneration system's exergy analysis is analyzed, and parameter optimization for each cogeneration system is accomplished using a genetic algorithm (GA) to achieve optimal exergy performance. Under the same conditions, the optimal efficiency of various cogeneration systems is compared. The findings demonstrate that the condenser, turbine, and heat recovery vapor generator all have significant exergy losses and that lowering these losses may boost the cogeneration system's efficiency. The Kalina loop, as compared to other systems, has the highest efficiency in cement plants.

2.3 REGENERATIVE BURNERS

Rafidi et al [14], Utilized numerous manufacturing regenerative burners and flame specifications, the purpose is to examine the effect of HiTAC flame morphology on heat transfer strength and uniformity within a semi-industrial test furnace. At certain points within the furnace, observations of heat fluxes, local instantaneous and average temperatures, and gas composition were made. The HiTAC flame, which has lower temperature variations, turbulent strength, and combustion intensity, has a greater reaction zone than a conventional flame. Despite its consistent and lower heat, this massive blaze releases more heat energy. Moreover, the convective heat transfer to the surface of an object in the furnace was observed to be consistent and to account for up to 30% of the overall heat transfer. The reduced temperature and temperature variance rate of the HiTAC fires, on the other hand, result in a very high reduction in NOx pollution. Shown above results apply to all burners and setups to a certain degree, though to a lesser extent in the twin-flame counter setup.

Cho et al [15], Presented the temperature distribution and combustion efficiency of natural gas-fired flameless oxidation constraints produced with several semi-industrial regenerative burners. The impacts of different burner locations and firing modes (parallel and staggered) on performance, emissions and temperature similarity are investigated. The process blends twin-burner pairs to produce 200 kW_{th}, resulting in a volumetric heat release that closely matches real manufacturing circumstances (48 MW/m3). The parallel mode process achieves better performance in terms of low CO and NO emissions, as well as constant temp distribution in the furnace. The staged mode process, on the other hand, performed poorly owing to an established asymmetrical flow pattern in the furnace. Owing to the reduced and consistent heat, single digit NO exposure was assessed in parallel mode with minimal CO Particulates. Since the shifting of burners creates cycles of erratic and non-uniform streamlines as well as heat transfer characteristics, CO concentration is heavily influenced by the burner cycle time. The computational modeling of the skeletal response revealed standard flameless oxidation reaction properties, such as a sluggish and uniform reaction development in the furnace.

The ceramic honeycomb re-generative burner heating system demonstrates Fukushima et al [16], the high-preheated air combustion technology. Which results in energy consumption and, as a factor, low NOx production due to the increased heat recovery rate. The framework has piqued the interest of both foreign and domestic companies, especially those who are environmentally conscious. This strategy to improve ultimately low NOx emissions is becoming progressively crucial, both in terms of forest management as a CO2 absorption medium and as a prevention technique to reservoir and meadow erosion. In this respect, the environmental ceramic honeycomb regenerative burner heater method is anticipated to find broader functional purposes as a preventive measure to rising temperatures (due to CO2 emissions) and acid rain in waste disposal, generators, and several other areas.

Shanqing et al [17], has developed several designs for the double preheating regenerative burner, but the most similar architectural element is that they are made up of one air restorative box and one gas restorative box, all of which have been loaded with heat exchangers. After being pumped from the appropriate valve, the air and gas would collide and merge, causing them to ignite in the reactor. This journal also describes the project characteristics of a double pre-heating regenerative burner - reheating furnace, such as burner configuration form, burner configuration, and implementation mode, combustion system protection steps, reversing and combustion power, flue gas exit system, combustion system, special furnace wall structure, and so forth.

Zareba et al [19], the convective and radiative heat transfer of the furnace components were taken into account in the production of a new, detailed mathematical model of continuous annealing furnaces. For the whole annealing furnace, parameters determination is generally performed utilizing a nonlinear least-squares optimization approach, based on calculated standard operational data from a commercial stainless-steel factory, to approximate optimum values of unknown parameters such as emissivity. Owing to the model's sophistication, a sequential method for parameter recognition is suggested and introduced, in which the parameter collection is separated into subsets and parameter estimation is conducted sequentially. The model's output with the predicted specifications is then assessed using a separate test data set. Under both transient and steady state conditions, the objective will forecast temperature transformations along with the furnace in close alliance with simulation results. The model introduced here can be used to design controllers and optimize processes.

To evaluate stress dynamics and temperature in (vertical) continuous annealing lines, the author has used ANSYS software coding [20]. The emissivity and associated heat-transfer coefficient of the strip in a preheating furnace are measured based on an energy model of the strip and roll and the normalization of a least-squares error equation. Points for model parameters are, at best, informed guesses in most situations, but even a small adjustment, especially in the emissivity, can greatly lead to inconsistencies of the strip temperature in the designs.

Akela et al [21], Thermography experiments on hot slabs resulted in improved hot charging of slabs in RHF and a 72 Mcal /ton energy savings. HF operational parameters such as thermal readiness, mechanical readiness, and fuel flow correction actors were also optimized. By designing a roughing mill exit temperature lookup table model, researchers were able to maximize slab dropout temperatures in the Reheating furnace. The RHF dropout slab temperature and the temperatures during roughing mill operation for various steel grades were fine-tuned using the lookup table model. The gas utilization was evaluated both with and without roughing mill output power query processing model, and it was reported that the energy demand was reduced by 20% after the roughing mill query-processing model was implemented.

Gupta et al [22], This paper discusses numerous retrofitted schemes initiated by the Research & Development Centre for Iron & Steel as part of a project funded by the Petroleum Conservation Research Association, New Delhi, to boost the efficiency of small field reheating furnaces. The application of multiple schemes culminated in a 20 percent decrease in fuel economy and a 15 percent increase in furnace efficiency. The multiple energy-efficient techniques found and applied in two small Re-roller reheating furnaces have lowered specific fuel (coal) utilization by about 24% while increasing furnace efficiency by about 15%.

2.4 GASIFIED FUEL

Yao et al [23], to characterize the entire fixed-bed in the flow direction of primary air, a fix-bed model and coupled transient representative particle was created. The model integrates a three-region method, which divides the reactor into three regions based on various fluid velocity profiles, namely forced convection, mixed convection, and natural convection, respectively. The model could make correct predictions based on experimental results with a margin of error of less than 10%. The model can be used to analyze fixed-bed biomass gasification under a variety of operating conditions, like the feedstock moisture content and equivalence ratio, and the direction of the air inlet. The ideal equivalence ratio for optimizing the economic benefits of the gasification process was determined to be 0.25.

Ghadhimi et al [24], the efficiency of tidy and alloyed poly membranes for gas separation is investigated in depth in this report. PEGDA (polyethylene glycol 600 di acrylates) was utilized as an alloying agent in three fractions of weight: 60%, 40%, and 20% depending on the tidy PEBA membrane weight. The primary objective of this project is to eliminate CO_2 from the syngas stream. selectivity, Activation Energy, and Permeability of permeation for gases N_2, CH_4, H_2, and CO_2, were investigated over a broad temperature and pressure range of 25–75 °C and 8–40 bar. Differential scanning calorimetry was used to identify the alloyed PEBA/PEGDA and PEBA membranes that had been packed (DSC), FTIR spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), and complex mechanical thermal analysis are some of the techniques used (DMTA). Alloyed membranes have better separation efficiency than the tidy PEBA membranes, according to the findings of this study.

Mishra et al [25], Outline of the coal-char-gasification process has been presented. Coal gasification promises to be an outstanding green technology that, in addition to satisfying energy needs, would serve to reduce global warming. A variety of variables influence the coal-char-gasification operation. Coal gasification is a means of reducing CO2 emissions and developing clean coal technology. Several operating parameters control the coal gasification operation. This paper compiles a critical analysis of the work of many researchers in the field of coal gasification. The combined impact of many operating procedures

Watanabe et al [26], the multicomponent agent for gasifying partly shares reactive groups on char particles, and the thorough structure of the water–gas-shift response is modeled and applied. These simulations are also used in a three-dimensional RANS-based experiment to study the impacts of CO2 infusion on the way a coal gasifier using entrained flow behaves during gasification. The findings indicate that the current simulation accurately captures gasification efficiency like gaseous temperature distribution, product gas structure, and carbon combustion. The commodity gas inhibits the process, and the multi-component agent for gasifying's partly shared active sites mitigate the reaction. Characteristics gasification on the infusion of CO_2 are also discussed extensively, with contributions from pathways of reaction to efficiency of gasification considered. It is discovered that local management of endothermic heterogeneous reactions and exothermic gaseous processes is required to benefit from the CO2 infusion.

Watanabeet al [27], the latest findings and advances in coal gasification simulation and modeling are listed in this article. Mathematical simulations for multiple chemical processes, including gas-phase reaction, char gasification and devolatilization, are analyzed and explored to increase accuracy. De volatilization frameworks have recently been described and verified on laboratory-scale flames to explain the coal chemical composition with a valid statement. The specification of the active sites shared by the mixture and the creation of physical properties are critical in the modeling of the char gasification reaction as a frequency phase. In the gas phase reaction model, it will be necessary to consider the fundamental transformations. A large-eddy simulation of coal gasification on a lab-scale entrained flow gasifier is carried out to demonstrate the computational technique.

Egilegor et al [28], Waste energy sources were examined as part of the ETEKINA plan at a steel foundry in Slovenia, an aluminum car parts manufacturing facility in Spain, and a ceramic tile manufacturing facility in Italy. Instead of dumping waste heat into the environment, the goal is to utilize more than 40% of the waste heat that has been stored in combustion streams inside of the manufacturing facility. The temperatures and flow rates of the relevant exhaust streams were calculated and analyzed to pick the waste heat recovery procedures, which were then reused in the three industrial plants, to show the profitability of heat recovery. Heat pipe heat exchangers (HPHEs) will be used to demonstrate cost-effective waste heat conservation, and the strategies for constructing the heat recovery applications have indeed been chosen. Leading to volume constraints, pressure reduction limits, and other waste stream problems, HPHEs was chosen as a heat recovery technology owing to their superiority and main attributes over conventional heat exchanger. High temperatures in the heat and waste sink streams, variations in the waste stream temperature and flow rate, and the prevalence of corrosive humidity are all obstacles.

Panayiotou et al [29], By defining and categorizing primary energy use in the key manufacturing industries, as well as their associated waste sources and temperature levels, this study summaries the prospects and potential for industrialized heat recovery in the European Union. For all manufacturing industries, temperature ranges, and EU countries, detailed findings are given based on a comprehensive review that includes Carnot's potential and waste heat calculation. In terms of the projected overall waste heat capacity, the ‘big picture' looks good. Moreover, fossil fuels account for most of the electricity utilized in the manufacturing sector. Any manufacturing activity generates a variety of waste heat sources at various temperatures, the recycling of which will certainly help to improve the production sites' and goods' long-term conservation. Waste heat recovery solutions can save a lot of electricity and reduce greenhouse gas emissions significantly. For the above to become a reality, technical advances and developments aimed at enhancing the energy output of heat recovery appliances while simultaneously decreasing installation costs must be introduced.

Brough et al [30], His study provides the whole aluminum manufacturing process, from ore to final metallic alloy. Furthermore, the paper discusses the most up-to-date technology used throughout the distinct process phase. Casting processes and secondary mining are of special concern, as the amount of recycled aluminum is increasingly growing, and recycling aluminum seems to be more energy-intensive than processing it by primary techniques Future industry technologies, especially inert anode technology, are discussed. The processing of aluminum has a major environmental effect due to gaseous waste and solid residual by-products, which are elaborately analyzed. Aside from the environmental impacts, the sector is very energy consuming and emits a significant amount of energy into the atmosphere as waste heat. Installing technology for waste heat recovery is one way of lowering energy demand and lowering emissions' environmental effects. Applied approaches for reducing energy consumption are studied, with a special emphasis on waste heat recovery technologies' future applications in the industry.

2.5 CHOKING DUE TO ASH PARTICLES

Tong et al [31], to analyze the permeation features of a standard heat exchanger, a mathematical procedure was established. To begin, an integrated model was constructed which included a settling and removal mechanism to simulate fouling properties. The energy balance while particle-surface contact specified the deposition criteria, while the fouling thickness and local wall shear stress calculated the extraction mechanism The discrete phase model was used to monitor the fly ash contaminants throughout the fouling process after the fluid flow patterns were determined. Although the simulation time in the fouling phase is much lower than the real-time one, a fouling time ratio was formulated to improve the simulation time and effects to the real-time scale. The implications of inlet velocity, particle diameter, and fouling resistance on particle diameter on fouling resistance, the effects of inlet velocity, real-time fouling characteristics, flow characteristics were studied. Finally, the findings were compared to those of the studies. The findings show that various vortex mechanisms can effectively regulate particle motion. Fouling occurs mostly in the flow stagnation and recirculation areas.

Li et al [32], the layout of several models and observational tests for fouling, degradation, and heat-exchanger's corrosion etc. was briefed in this article. To start, the underlying processes of corrosion, erosion, and fouling were addressed, as well as prediction methods and techniques simulations using these mechanisms, and related experiments. Furthermore, the prediction procedures for fouling, degradation, and corrosion rate were added using the authors' findings as examples. After that, it could perhaps be acknowledged whether there are indeed several crucial experiments to be performed in the fields of corrosion, erosion, and fouling to properly demonstrate the corrosion, erosion, and fouling processes, as well as to suggest innovative heat-exchangers for anti-corrosion, anti-erosion, and anti-fouling. Future heat exchanger prototypes should be able to solve these concerns, and hence facilitate the production of technology that can effectively recover flue gas heat to increase overall energy consumption performance.

Xiaoya et al [33], a Research paper proposes an optimized prototype of CTPC structures recovered heat from a diesel truck engine, which was built in GT-SUITE software then measured across observational results and discusses the likely fuel consumption changes as well as potential possibilities for development. Over a heavy-heavy duty driving cycle, the transient output of four separate CTPC structures is estimated using a control structure that includes a mode switch module and two PID controllers to achieve reliable, secure, and efficient improvement.

The three operating stages are startup mode, power mode, and stop mode. The results show that CTPC technologies are stable and secure to operate even with highly transient heating systems, indicating that this technique has a bright future in such applications. And although pump and turbine efficiency gains were low to 50%, a design that incorporates both a Recuperator and a pre-heater tends to be the most promising, enabling a 2.3 percentage increases in brake thermal efficiency over the course of the entire drive cycle by utilizing 72.8 percent of coolant and 48.9% of exhaust capacity.

Mahmoud Zadeh et al [34], the installation of a waste heat treatment mechanism on an electric hybrid vehicle is the subject of this research. The chosen waste heat processing system is based on organic Rankine cycle concepts and aims to reduce the total fuel consumption of a hybrid powertrain's internal combustion engine. This research investigates how hybrid electric cars work, with internal combustion engines working alongside an electric powertrain as a key component of the powertrain design. The whole study provides a crucial examination of the integrated powertrain's results across three separate drive cycle simulations, allowing for a straightforward assessment of how this advanced powertrain design will benefit in a variety of different, but appropriate, driving circumstances. The driving cycles showed places where the driver could completely use the hybrid powertrain's operating modes to minimize waste heat ever further.

Gomma et al [49], this research reveals how the Organic Rankine Cycle (ORC) could be used to generate electricity. This is due to the tendency to use heat sources with both low and high temperatures. This research used a hybrid system that integrated waste heat recovery with a solar field to convert energy in the ORC via a thermal oil loop and generate electricity during the design and testing period. The WHR was produced from flue gases from a rotary kiln used in cement production operations, but it also has the benefit of being temperature independent. The temperatures ranged from 250 to 380 degrees Celsius. Including the operating fluid R245fa, the solar domain contained a Parabolic-Trough Solar Collector (PTSC). After that, the efficiency of each part was evaluated and improved. The report's findings show that an ORC can provide substantial industrial and ecological benefits to production by manufacturing 323 to 360 kW of electricity needed to fuel a cement factory, with a recompense duration of 3.75 years and a marginal profit of $280,000 on average annual.

Jiang et al [36], the researchers created a new MBIHE with an embedded agitator that can cause granule mobility. The migrating granule functions as a heat carrier, transferring heat directly to the heat transfer surface improving heat performance. Horizontal granule migrations are identified after replicating the inciting mechanism using the Discrete Element Method. Migrativity (0 1) is a term used to explain the horizontal mixing rate of granules, which describes the capacity of granule migration to improve heat transfer. As Nr > 60, it reaches 1 and rises with the agitator's rotational number Nr. Bad interaction amongst granules and the lower part of the heat transfer tube in a stagnant bed is treated because of granule migration, and the heat transfer region is raised by 20%. To perform heat recovery tests, a pilot-scale MBIHE with granule capability of 60–120 kg/his being installed.

Saha et al [37], the focus of this article is on waste heat recovery as a means of implementing organic Rankine cycle engineering in India's industrial sector. Various factories use a vast amount of energy, which pollutes the atmosphere in a variety of ways. For a few years, researchers have been looking at using organic Rankine cycle technologies to re-use this low-grade waste energy. A detailed analysis has been carried out in this study to assess the considerable potential for recycling low-grade waste oil, especially in the glass, steel, iron, cement industries. There have even been several study analyses focused on data obtained from the related fields. The diverse technical and legal implications of using recovering energy via power grid systems were addressed in the following point. The study outlines the ability of low-grade waste energy to help India's industrial sector and domestic energy industry meet their high-energy demands.

Stein et al [38], The approach is part of a workflow in which the derived parameters and control bands are checked by a specific domain and an analysis report is created remotely the method enables one to blend the strength of appropriate statistical analysis with system knowledge while drastically mitigating the duration required for feature selection. We see this application as a building stone for gaining consumer trust before introducing more autonomous analytics techniques. They introduce the mathematical foundations of iGATE and show its efficacy using Tata Steel blast furnace data as a research study. The iGATE key feature is now publicly accessible in the R programming language's gate kit.

Liu et al [39], presents the DML FSdek approach, which is a function selection system based on a mixture of expert experience and the results of many machine-learning techniques. Each function in DML FSdek is awarded a score depending on how relevant it is to the challenge under investigation as decided by numerous experts and the performance of several machine-learning methods. If a feature's score crosses a certain threshold, it is retained in the final model. While we recognize the value of this strategy, for iGATE, we have chosen to concentrate on the case in which having specialists analyze not all the possible functionality is feasible. In production settings such as traditional warehouses, sensors record hundreds or even thousands of operation specifications automatically, making it impossible for a technical analyst to analyze them all for feasibility for a data technology task.

Abdel et al [40], “A technological and commercial research proposal for developing a model for a factory for cement products integrating CKD in the vicinity of any assemblage of cement plants in Egypt,” was the activity offered by this same project. The proposed facility would produce concrete blocks with a concrete composition of 210–250 kg/m3 with CKD substituting 20% of the cement, according to the feasibility assessment. Based on the required degree of strength, the factory may alternatively produce interlocking construction bricks with a cement composition of 540 kg/ m^3 or 450 kg/ m^3, substituting CKD for 20 percent of the cement. The current investigation substitutes air-cooled blast furnace steel slag (ACS) for organic dolomite aggregate as fine and coarse aggregates in interlocking paving units as opposed to employing CKD as a cement replacement. The use of air-cooled slag was encouraged by the studies that revealed its advantages.

Song et al [41], two static methods for TGR-OBF and COREX were created to acquire specifications on the flow of material of these systems. His study examines the product flow, metallurgical gas production and usage, comprehensive energy employ, electricity usage and production, and carbon dioxide emission of 3 integrated steel plants (ISPs) installed with the COREX, TGR-OBF, and BF, correspondingly, using operational data from the Jingtang steel plant and proven static process models. The findings showed that an ISP with the TGR-OBF used 16 percent and 16.5 percent less energy than a traditional ISP and an ISP with the COREX, respectively.

Hooey et al [42], used method and economic simulations to compare the techno-economic of an ISP with the OBF and CO2 trap They discovered that the OBF with CO2 capture has a substantial ability to minimize total CO2 emissions from an ISP, producing 47 percent CO2 elimination at $56/t CO2 for the results in the accumulation.

Jin et al [43] investigated an ISP's energy usage and greenhouse pollution using the TGR-OBF approach. When compared to a traditional ISP, the energy intake of an ISP utilizing the TGR-OBF route was lowered to 14.4 GJ/tonne of crude steel, and direct Emissions of CO_2 were lowered by 26.2 percent per tonne, using an existing thermal conductivity and mechanism thermodynamic properties mathematical model for the TGR-OBF ironmaking process.

Arasto et al [44], looked at the technological aspects of applying OBF with CCS to an ISP. The use of an oxygen blast furnace and carbon capture and storage (CCS) could greatly reduce CO2 emissions from an ISP, according to the report.

Okuson et al [45], this study assesses the Core for Development by Visualization and Simulation (CIVS) at Purdue University Northwest (PNWnew)'s state-of-the-art strategies for simulation and visualization of the blast furnace, as well as an overview of other innovative techniques in the area. Heat transfer, mass transfer, chemical reactions, and multiphase flow are all phenomena that must be properly understood in the blast furnace for further progress. To that end, blast furnace phenomena are gradually being studied using computer modeling and visualization in many ways. Present analytical methods range from simplistic tools for fast turnaround times to sophisticated solvers for capturing individual particle movement inside the furnace.

Valverde et al [46], The Calcium Looping (CaL) method has been suggested as a viable technology for Thermochemical Energy Storage (TCES) in Concentrated Solar Power (CSP) plants, based on the carbonation/calcination of CaO. Because of its low expense, non-toxicity, availability, and broad geographical range, limestone is commonly used as a CaO precursor in the CaL phase. Pore plugging, on the other hand, will seriously restrict the multicycle operation of limestone derived CaO under relevant CaL conditions for TCES in CSP plants. The alternative use of calcium-rich steel and blast furnace slags after acetic acid treatment is explored in this report. As referred to limestone, the calcination temperature needed to regenerate the CaO is considerably lower.

Rondon et al [47], in this analysis, an analytical program was developed to test the consequence of replacing the coarse fraction of a natural aggregate (type limestone; LS) with a BFS on the tolerance of an HMA. The overall gross substitution was also considered. Marshall Stability, indirect tensile strength (ITS), Cantabria abrasion, robust modulus, permanent deformation, and fatigue resistance were all used to determine the mechanical characteristics of the ratio of the indirect tensile strength (TSR) in wet and dry conditions was used to determine water sensitivity or moisture injury. On LS and BFS particles, X-ray diffractometric (XRD), X-ray fluorescence (XRF) experiments, and imaging analysis in a scanning electron microscope (SEM) were performed. When the coarse fraction of the LS was replaced in volume by BFS, the properties of the HMA mixture were significantly improved. When such a substitute was rendered in vast numbers, the asphalt-aggregate system's adhesive properties degraded. The mechanical activity of the LS was unsatisfactory after it was completely replaced.

Vieira et al [48], in the category of a generic green ironmaking industrial device, namely a traditional charcoal mini-blast furnace (CMBF) plant in Brazil, a virtual reality (VR) model has been created. The CMBF plant's VR prototype was designed by integrating data from numerous software and hardware systems, including comprehensive engineering design of various auxiliary units and main equipment with practical project parameters. Via virtual reality technologies, users will have a one-of-a-kind experience touring all areas of the CMBF facility, promoting technological conversations on engineering and process management with users, and improving information handling, coordination, protection, and maintenance procedures.

Wuenninget al [49], there are several ways to improve energy efficiency. In most furnaces, increasing performance by preheating the combustion air is the most efficient way to do so. To face the demands of rising energy prices and environmental legislation, end consumers, furnace builders, and burner manufacturers must work together to have the strongest quality design in terms of functionality, energy quality, reduced emissions, maintenance-free, and of course, production costs that are not higher than required.

The summary of various literature and research papers studied during research is tabulated below:

Author	Significance	Advantages
Otto et al [2]	The utilization of recirculation of exhaust gas from blast furnace, carbon capture furnaces, more electric arc furnace	Reduced CO2 emissions and primary energy demand up to 95 percent.
Quader et al. [3]	Melting of steel scrap and cut-offs using carbon electrodes enabled electric arc furnace.	Proposed the trapping of byproduct flammable gases like CO using waste heat recovery method.
Zhang et al [4]	Used mechanical crushing e.g. solid slag impingement for dry granulation.	The methane reforming reaction mechanism and using it directly to create high-value-added materials.
Lu et al [5]	Product's gas law, cooling water, and steam generation. Per total energy, section determines the energy allocation ratio	Effects in the development of the steel billet-loading schedule, output rhythm management, and energy estimation, and that it can be often used to achieve energy-efficient operations.
Thompson et al [6]	Calculation of heat transfer rate using billets and preheating box size.	Minimization of greenhouse gases and

		energy consumption in steel industry.
Guang-yu et al [8]	Examined the extraction of surplus heat from volume relationships of conserving energy	Reutilization of waste heat and examine the recovery from distributed waste heat.
Jouhara et al [9]	A detailed analysis of strategies for WHR and advanced technology	an innovative promising technology for direct heat to transferring power
Jouhara et al. [10]	Flat Heat Pipe (FHP) in a steel manufacturing facility's wire chilling line	to 15.6 percent heat recovery for a 450°C heat source (kW)
Miró et al [11]	Introduced thermal energy storage (TES), which is a technique that can correct the current discrepancy by retrieving and preserving IWH for further usage	Most factories use fluid (or vapor), erythritol, and zeolite as TES materials, with workspace convenience and power supply perhaps the most common features.
Luo et al [12]	BF slag's heat used by WHR device hydrogen rich gas through pyrolysis process	Slag particle size reduction helped sludge basic pyrolysis create further light gases, reduced char, but also less condensate, but it had little impact on gas concentrations.

Wang et al [13]	Recycle for WHR in cement plant of preheater exhaust using various steam cycles.	The turbine, condenser, and heat recovery vapor generator all have significant exergy losses, and that lowering these losses boosts the cogeneration system's efficiency
Rafidi et al [14]	The industrial furnace examined for heat transfer strength on HiTAC morphology effect.	The reduced temperature and temperature variance rate of the HiTAC fires, also significant reduction in GHG gases.
Cho et al [15]	Combined effect of two burners to produce heat release of 200 kW_{th}	Standard flameless oxidation reaction properties
Fukushimaet al [16]	The high-preheated air combustion technology is demonstrated by the eco-friendly ceramic honeycomb regenerative burner heating system	Energy consumption and, as a factor, low NOx production due to the increased heat recovery rate
Shanqing et al [17]	Restorative boxes of air and gas been coupled with heat exchangers.	Preheating regenerative burner characteristics described.
Zareba et al [19]	continuous annealing furnace’s modelling has been presented in detail.	Approximate optimum values of unknown parameters such as emissivity.

Chen et al. [20]	Continuous annealing line's stress dynamic and temperature have been evaluated using ANSYS finite element code.	Normalization of a least-squares error equation, the emissivity, the strip's coefficient in preheating furnace.
Akela et al [21]	Designing a roughing mill exit temperature lookup table model	HF operational parameters such as thermal readiness, mechanical readiness, and fuel flow correction actors were optimized
Gupta et al [22]	Retrofitted schemes initiated by the Research & Development Centre for Iron & Steel as part of a project funded by the Petroleum Conservation Research Association, New Delhi	A 20 percent decrease in fuel economy and a 15 percent increase in furnace efficiency
Yao et al [23]	Blended fix bed and transient behavioral model has been presented	The ideal equivalence ratio for optimizing the gasification process for economic benefit was find out to be 0.25
Ghadhimi et al [24]	alloying agent PEGDA (polyethylene glycol 600 di acrylates) used in three weight fractions.	The alloyed membranes have better separation efficiency than the tidy PEBA membranes
Mishra et al [25]	Compiles a critical analysis of the work of many researchers in the field of coal gasification	Coal gasification is a means of reducing CO2

		emissions and developing clean coal technology.
Watanabe et al [26]	CO2 injection effects on gasification behavior has been studied in an entrained flow coal gasifier.	local regulation of exothermic gaseous reactions has been achieved along with endothermic heterogeneous reactions.
Watanabe et al [27]	Mathematical simulations for multiple chemical processes, including devolatilization, char gasification, and gas-phase reaction, are analyzed and explored to increase the accuracy	a laboratory-scale entrained flow gasifier based large eddy simulations have been presented for coal gasification.
Egilegor et al [28]	40-50% recycled waste heat from combustion streams for manufacturing plant.	WHR has been achieved using HPHEs due to their edge over conventional heat exchanger.
Panayiotou et al [29]	Recycling of heat will certainly help to improve the production sites' and goods' long-term conservation.	Waste heat recovery solutions can save a lot of electricity and reduce greenhouse gas emissions significantly.
Broughet al [30]	The processing of aluminum has a major environmental effect due to gaseous waste and solid residual by-products, which are elaborately analyzed.	Installing waste heat recovery technology is one way of lowering energy demand and

		lowering emissions' environmental effects.
Tong et al [31]	Coupled fouling model has been developed using deposition and removal mechanism to simulate fouling properties.	Various vortex mechanisms can effectively regulate particle motion, and fouling occurs mostly in the flow stagnation and recirculation areas.
Li et al [32]	The layout of models and observational experiments for degradation, corrosion and fouling of heat exchangers was summarized in this article	WHR from flue gas to improve energy consumption effectively.
Xiaoya et al [33]	GT-SUITE software used to propose for optimizing CTPC heat recovered from a diesel engine.	2.3 percent increase in thermal efficiency of brake for complete drive cycle using, 72.8 % coolant capacity and 48.9% of exhaust.
Mahmoudzadehet al [34]	WHR system using organic Rankine cycle concepts to reduce the total fuel consumption of a hybrid powertrain's internal combustion engine.	The driver could completely use the hybrid powertrain's operating modes to minimize waste heat ever further.
Jiang et al [36]	The migrating granule functions as a heat carrier, directly	The heat transfer region is raised by 20%

	transferring heat to the surface improving heat performance.	
Saha et al [37]	Waste heat recovery as a means of implementing organic Rankine cycle engineering in India's industrial sector.	The ability for low-grade waste energy to help India's industrial sector and domestic energy industry meet their high-energy demands.
Stein et al [38]	Introduce the mathematical foundations of iGATE and show its efficacy using Tata Steel blast furnace	Enables to blend the strength of appropriate statistical analysis with system knowledge while drastically mitigating the duration required for feature selection
Liu et al [39]	Presents the DML FSdek approach, which is a function selection system based on a mixture of expert experience	In production settings such as traditional warehouses, sensors record hundreds or even thousands of operation specifications automatically, making it impossible for a technical analyst to analyze them all for feasibility for a data technology task.
Abdel et al [40]	Interlocking building bricks using blend of cement content (450 kg/m3/540 kg/m3) and	Used air-cooled blast furnace steel slag as fine aggregates in interlock

	CKD to replace 20% of the cement.	paving units instead of natural dolomite aggregate.
Song et al [41]	Two static methods for TGR-OBF and COREX were created to acquire specifications on the flow of material of these systems	The findings showed that an ISP with the TGR-OBF used less energy (16 percent and 16.5 percent) than a traditional ISP and an ISP with the COREX respectively.
Hooey et al [42]	Compare the economic and technical aspect of an ISP with the OBF and CO2 trap.	47 percent CO2 elimination at $56/t CO2 for the results in the accumulation.
Jin et al [43]	Energy consumption of an ISP integrated TGR-OBF path along with carbon emissions.	14.4 GJ reduced energy consumption of ISP integrated TGR-OBF per tonne of crude steel also emissions (CO_2) were reduced by 26.2%.
Arasto et al [44]	Applying OBF with CCS to an ISP	Greatly reduce CO2 emissions from an ISP
Okuson et al [45]	Assesses the Core for Development by Visualization and Simulation (CIVS). Advanced approaches for	Blast furnace phenomena are gradually being studied using computer modeling and

	imagining & simulation of blast furnace.	visualization in several ways
Valverde et al [46]	The Calcium Looping (CaL) method has been suggested as a viable technology for Thermochemical Energy Storage (TCES) in Concentrated Solar Power (CSP) plants, based on the carbonation/calcination of CaO.	Required temperature (calcination) to generate CaO is considerably lower.
Rondon et al [47]	An analytical program was developed to test the consequence of replacing the coarse fraction of a natural aggregate with a BFS on the tolerance of an HMA.	The properties of the HMA mixture were significantly improved
Vieiraet al [48]	A virtual reality (VR) model has been created for a traditional charcoal mini-blast furnace plant.	Improving information handling, coordination, protection, and maintenance procedures
Gomma et al [49]	A hybrid system for WHR with a solar field to convert energy in the ORC.	Electrical power generated (320 - 360 kW), required to fuel a cement factory, with a recompense duration of 3.75 years and a marginal profit of $280,000 on average annual.

2.6 CHAPTER SUMMARY

Several research papers on the following topics have been reviewed:

- Furnace losses
- Waste heat recovery in Re-heating furnaces
- Issues with the fuel available
- Integration of WHR device with RHF
- Coal Gasification
- Conversion of coal to clean fuel

CHAPTER – 3

ASSESSMENT OF LOSSES IN RHF

3.1 **Reheating Furnace**

A reheating furnace is a piece of machinery that heats materials to adjust their form (rolling, welding, etc.) or the properties of material (heat treatment). Furnaces must be planned & maintained to meet the following goals:

- The desired production rates.
- Maximum thermal efficiency
- Satisfactory product consistency
- Emissions (such as NOx) are held to reasonable or lawful standards.

The interior temperature of a SRRM Re-heating furnace is about 1200 degrees Celsius [12], and it is used to heat the blooms or billets of steel for rolling in the mill. Figure 3.1 depicts the reheating furnace's heating method.

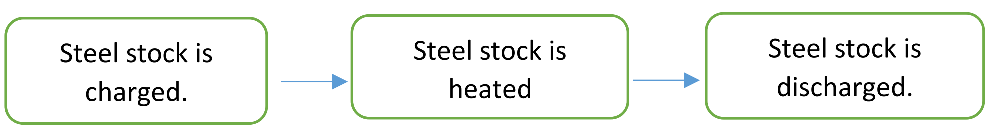


Figure 3.1. The heating process of the reheating furnace

During the heating process, heat transferred is mainly through radiation and convection from the hot burner gases and the furnace walls [15]. The reheating furnace size is generally expressed in terms of capacity, i.e., tons per hour. The capacity signifies the supply of hot steel from cold stock.

The efficiency of the furnace is affected by various design features of the furnace such as total furnace zone, dimensions, various types of the burner, type of insulation used in wall or roof, and many more. Therefore, it is important to make an efficient furnace that uses uniform temperature to heat the steel stock. There are various types of reheating furnaces in steel re-rolling mills depending on the mode of heating, mode of charging and discharging, or mode of waste heat recovery shown in figure 3.2.

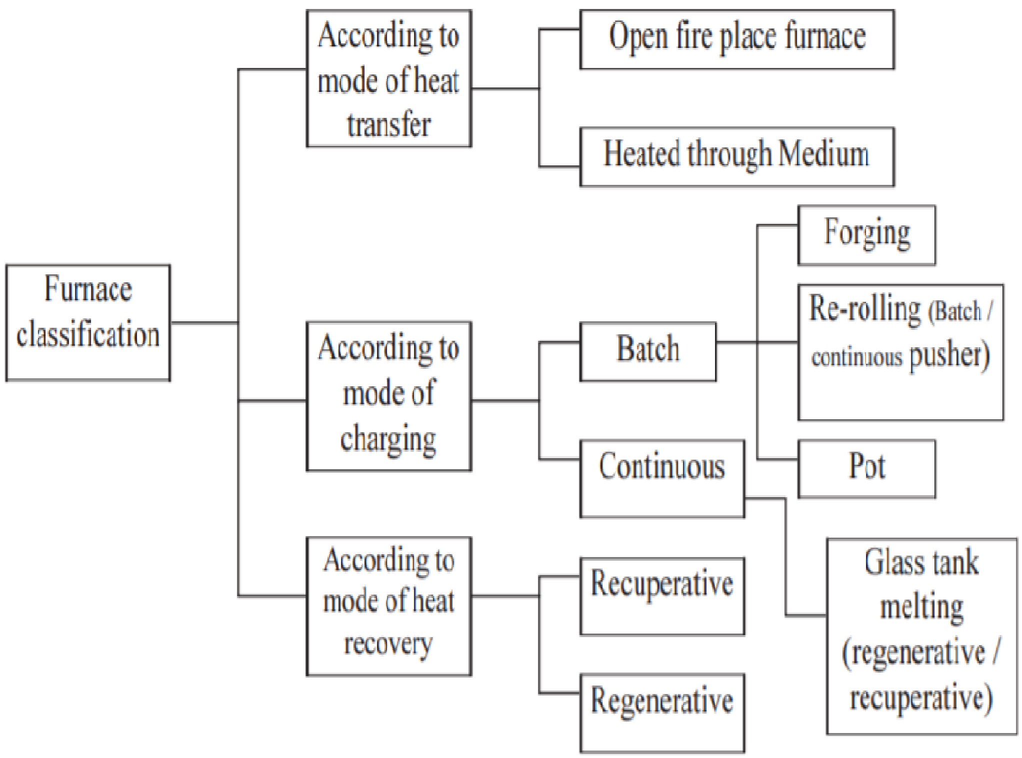


Figure 3.2: Classification of furnace

3.1.1 Types of reheating furnaces in steel Re-rolling mills

3.1.1.1 Combustion type furnace

The Combustion type furnace may be broadly classified as coal-fired, oil, and gas, furnaces.

3.1.1.2 Oil-fired furnaces

The most popular fuel for oil-fired furnaces is furnace oil, which is particularly useful for reheating and heat-treating materials. In furnaces where Sulphur is undesirable, LDO is employed. Full combustion of the fuel with minimal excess air is the secret to successful furnace operation. Furnaces efficiencies are as low as 7%, compared to other combustion devices where efficiencies are as high as 90%. This is due to the high temperatures that the furnaces would run at to satisfy the demand. For starters, a furnace that heats the stock to 1200°C would have flue gases that are approximate 1200°C, resulting in a large heat loss through the rack.

3.1.1.3 Gas-fired furnaces

A forced-air furnace heats your home using the following heating cycle: In the burner, natural gas or propane is fired. The fires heat a metal heat exchanger, which is then exhausted through the flue. Heat is passed from the heat exchanger to the incoming air. The blower in the furnace pushes hot air into the ductwork, where it is distributed around the building. The warmer, denser air is pulled back into the furnace through the return ducts as the warm air fills each chamber, repeating the procedure.

3.1.1.4 Coal-fired furnaces

The burner in a coal-fired forced air furnace is powered by heat extracted from coal. A blower pushes cool air into a heat exchanger and then into the ductwork, which distributes the hot air across the structure. Each room will have a ventilation system exit, which is usually placed on the floor or low on the wall; certain rooms will also have a cold air return duct opening.

3.1.1.5 Electric Arc furnace

It is the most widely used electric arc furnace. The heat is generated by an electric arc and transmitted by specific or longwave radiation of the furnace's internal lining. In the center of two graphite electrodes, an electric arc is formed. One is fixed and the other is movable to monitor the duration of the arc and the amount of heat emitted. Electric-arc furnaces are widely used to melt ferrous metals such as steel and grey cast iron, as well as some non-ferrous metals to a lesser degree.

3.1.1.6 Induction Furnace

An electric-induction coil is built into the furnace's walls to create an induction furnace. Every metallic structure that obstructs the electromagnetic flux produces a current due to an alternating current in the coil. Medium and low frequency current is used in induction furnaces. They have been successfully used in industry to melt solid metal by inducing alternating current. Glass, aluminum alloys, and other ferrous and nonferrous alloys are melted in induction furnaces.

3.1.2 Rerolling Mill Furnace

3.1.2.1 Batch type Furnace

For batch-style rerolling mills, a Chamber-type furnace is used. For re-rolling, the furnace is mainly employed to heat minor ingots, scrap, and billets of 2 - 20 kg. The ‘material' is charged and discharged personally, and the result is in the form of Channels, Angles, strips, rods, and other shapes. The working temperature is about 1200 degrees Celsius. The overall cycle time is divided into two parts: heat-up time and rerolling time. The substance is heated to the desired temperature during the heat-up time and then manually removed for rolling. The average production of these furnaces is 10 to 15 TPD, with specific fuel consumption of 180 to 280 kilograms of coal per tonne of heated product.

3.1.2.2 Continuous pusher type

A continuous pusher furnace has the exact workflow and working cycles as a batch furnace. About 1250 °C is the working temperature. Such furnaces usually run for 8 to 10 hours a day, producing 20 to 25 tonnes per day. When it goes beneath the length of the furnace, the substance recovers some of the heat in flue gases. In contrast to batch type, heat absorbed by the material in the furnace is sluggish and consistent throughout the transaction/area.

3.1.2.3 Continuous Steel Re-heating Furnace

The major purpose of a re-heating furnace is to transfer the heat to steel pieces and increase the temperature in a range of 900° centigrade to 1250° centigrade. For metallurgical and efficiency purposes, the furnace must satisfy standards and goals in terms of stock heating speeds. As the steel stock moves continuously throughout the furnace during continuous reheating, it is heated to the required temperature.

Continuous re-heating furnaces are classified largely based on how a stock is moved through the furnace.

3.1.2.3.1 Pusher Style Furnaces

In the manufacturing sector, pusher-style furnaces are very common. When compared to moving hearth furnaces, it has smaller construction and repair rates. Although the furnace can have a strong hearth, it is, therefore, practicable to drive the inventory through rollers via water-cooled braces that require the product to be heated on both the top and bottom sides.

3.1.2.3.2 Walking Hearth Furnace

The stock may be moved through the furnace in distinct steps using the walking hearth furnace. Simple architecture, ease of installation, capacity to accommodate various stock sizes, insignificant energy losses for water cooling, and limited physical labeling of the stock are just a few of the benefits of such furnaces.

3.1.2.3.3 Rotary Hearth Furnace

Recirculating bogie furnaces have continued to be replaced by rotary hearth furnaces. Since the bogies' heating and cooling effects are eradicated, losses related to heat storage are reduced. The rotary hearth, on the other hand, has a more complicated configuration, with an annular form and a rotating hearth.

3.1.2.3.4 Continuous Re-circulating Bogie type Furnaces

These kinds of moving hearth furnaces are usually intended with compact stock with a range of sizes and shapes. Storage is mounted on a bogie with a refractory hearth in bogie furnaces, which flows through the furnace with others in the shape of a train. Bogies always fill the entire length of the furnace. Bogie furnaces are typically long and short, with issues such as insufficient distance sealing between the bogies and furnace cover, scaling, and firing over a narrow hearth diameter.

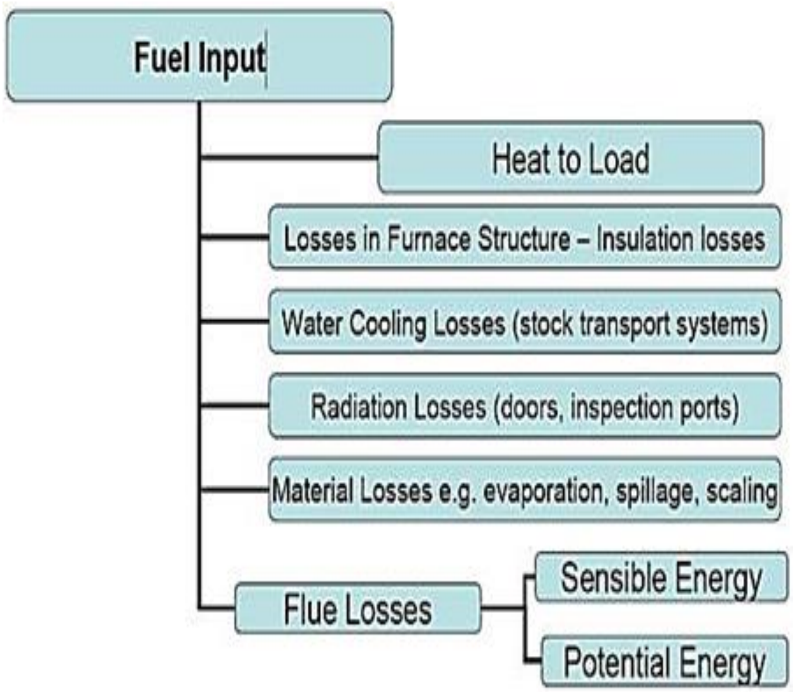
3.2 LOSSES IN FURNACE

The thermal efficiency of heating process equipment is defined as:

$$\frac{\text{heat delivered to material}}{\text{heat supplied to the heating equipment}}$$

like kilns, heaters, ovens, and furnaces is the ratio as shown above.

The main reason for a heating process is to provide required part of thermal energy into a product that leads to rise in temperature of the product at the level where characteristics of the product will change. To carry this process, the product is heated in a furnace up to 1200 ^{o}C. This heating results in energy losses at various parts of the furnace. Moreover, mostly heated equipment supplied their heat as exhaust flue gas resulting in a major portion of waste heat. In most heating systems, a significant portion of the heat output is lost as exhaust flue gases. The various losses in the furnaces are shown in figure 3.3.



Furnaces use a lot of energy from fossil fuels because of their elevated temperatures. Furnaces make the heating of products by way of convection heating. Hence, a huge amount of air is fed into the furnace. The above-Mentioned schematic diagram represents the major losses on a typical steel Re-heating furnace. The primary cause of energy wastage is often flue gases. The current study assesses the costs associated with the reheating of steel in the reheating furnaces at the XYZ steel factory in Haryana.

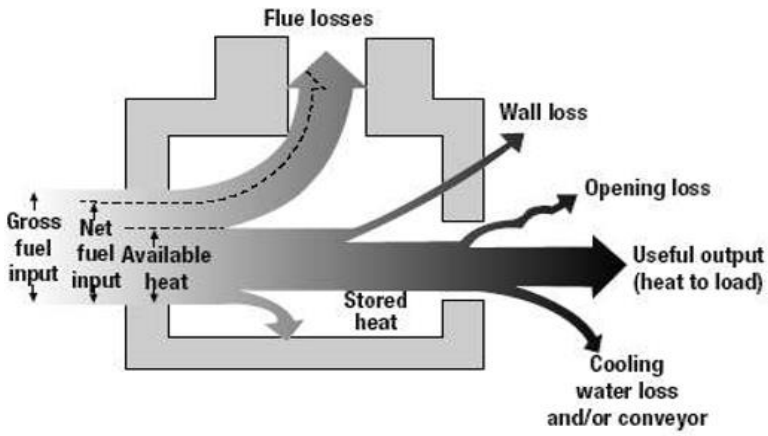


Figure 3.4: - diagram of losses of a furnace

3.2.1 Flue Gas Losses

Due to their high temperature, flue gases are the primary source of energy losses in furnaces [2]. The temperature of flue gas in a steel reheating furnace is approximately the same as the desired temperature of heating of steel. It may be as high as 1200 degC. The following figure for various percentage levels of surplus air can be used to determine reasonable losses as a proportion of net heat input.

3.2.2 Wall losses

Heat is transferred via the heating device's walls, ceiling, and floor, resulting in transmission or wall losses. [13].

3.2.3 Cooling Media Losses

Cooling shields doors, bearing, and rolls in hot furnaces' conditions, but at the expense of energy loss. Extra heat loss from the furnaces is carried by these parts and the cooling media (such as air, water, etc.) [13].

3.2.4 Air infiltration Losses

The combustion air supply does not always include excess air when it enters the furnace. If there is the presence of negative pressure inside the furnace, it may potentially enter from the surrounding room. Negative pressures are typical due to the airflow created by hot furnace stacks, and cold air often manages to get through defective door seals and other furnace openings.

3.2.5 Radiation (opening) losses

Radiation losses play significant role when either furnace or oven operate at above 1000°F temperature. As energy transfer from hotter surface to closely located colder surfaces takes place, resulting increase in rate of energy transfer as $(surface's\ absolute\ temperature)^{4}$ [13].

3.2.6 Roof, Hearth, and Wall losses

The outside area of surface temperature, thermal, thickness and furnace properties of refractory and insulation, etc.

3.2.7 Atmospheric losses

Atmospheric losses are defined as "temperature difference between inside and outside of the furnaces surrounding".

in and out of furnace Atmosphere.

The losses are assessed by performance testing; the subsequent parameters need to be calculated using appropriate calibrated instruments, as appropriate for the computation of furnace performance and efficiency.

a) Analysis of flue gas
   1. Analyze the available CO_2 and O_2 percentage in flue gas.
   2. Analyze the available carbon monoxide percentage in flue gas.
   3. Flue gas temperature (T)

b) Measurements of Flowmeter
   1. Combustion air quantity
   2. Fuel quantity

c) Measurements of Temperature

1. Fuel
2. Combustion air
3. Flue gas

d) Measurements of Pressure

1. Draft
2. Air Combustion, both secondary and primary
3. Fuel

From the assessment, the following sections are opted to improve efficiency.

3.3 IMPROVING EFFICIENCY

a. Waste heat recovery

There is a significant quantity of thermal energy in the flue gases that exit the reheating furnace, and this energy may be recycled.

b. Load Preheating

Heat is needed to initially heat the billets because they are put into the furnace at room temperature. This need for heat can be satisfied by the sensible heat and flue gases leaving the stack.

c. Preheating Combustion Air

Utilizing the heat from the furnace's waste gases, the recuperators may pre-heat the combustion air. This boosts furnace efficiency and enhances flame temperature while lowering fuel usage, which lessens its negative environmental effects.

d. Proper maintenance of the furnace

There is a lack of maintenance in the furnace, as seen at XYZ Plant. The interior wall of the furnace's refractory lining, which is built of fire clay bricks with a 60 % alumina content, has too many fractures and erosions visible during shutdown. The 90 % high alumina castable can be utilized to fill the fractures in the furnace's wall so that heat transmission from the interior to the exterior must be resisted in order to offset losses brought on by lack of maintenance.

e. **Proper utilization of Control system**

In the reheating process, furnace pressure and temperature control have significant effects on energy efficiency improvement. The negative pressure inside a reheat furnace can cause ambient air to enter into the reheat furnace, which needs extra energy to leak the leakage air to flue gas temperature. A furnace pressure controller can keep positive pressure in the furnace chamber to reduce atmosphere losses.

3.4 CASE STUDY:

An experiment is performed to evaluate the losses of reheating operation in a steel reheating furnace. There are eight furnaces installed in an XYZ steel plant. Two of these eight are electric arc furnaces, while the remaining four are fuel-fired. Following are furnaces installed within the plant.

Furnace/Location	**No's**
Boggie furnaces	1
Finishing furnace	1
Annealing furnace	1
Strip mill	1
Stackle Mill	2

Table 3.1: -Furnaces installed in the Plant.

We have limited our investigation to the Stackle mill in order to assess the losses associated with the re-heating operation of steel in the re-heating furnace at XYZ steel plant. Preheating furnaces and walking beam are the two furnaces at Stackle Mill. Depending on the various grades, the furnace uses LVFO, or HSD, LPG as fuel. The requirements for recuperator, raw materials, and fuel are described in detail below.: -

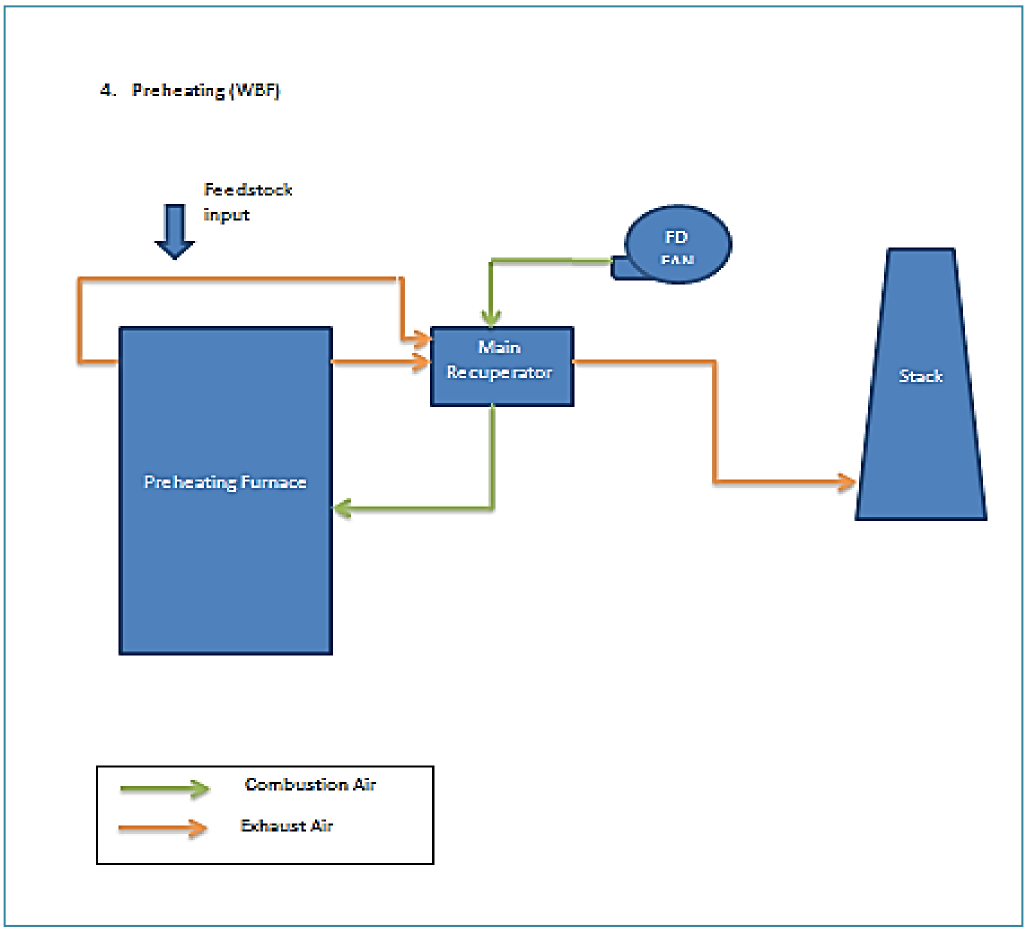


Figure 3.5: - Block diagram of preheating furnace

3.4.1 Furnace Specifications

S. No.	Description (Unit)	JBS	Flat
1	*Fuel Type Utilize in Furnace*	LVFO / HSD	FO
2	*Cycle Time*		
	Coil to Coil Gap (Min)	6	2
	Productivity (MT/Hr.)	12	45
3	*Specification of Raw Material*		
	Bloom Size (T × W × L) (mm)		200×260×5050
	Bloom Weight (MT)		2.00
	Bloom Size (T × W × L) (mm)	200×260×3350	200×200×5050
	Bloom Weight (MT)	1.33	1.53
4	*Recuperator Data*		
	Hot Air (ºC)	330-400	280-350
	Outlet (ºC)	200-220	180-210
	Inlet (ºC)	630-700	550-630

Table 3.2: description of furnaces of Stackle mill

3.4.2 Operating Parameters of Furnace

Furnace Operating parameters						
Grade	Zone Wise Temp (ºC)					Holding (Hours)
	TSZ A	TSZ B	BHZ	THZ A	THZ B	
Flat	1200-1220	1200-1220	1080-1110	1190-1220	1190-1220	3 to 5
JBS	1250-1270	1260-1280	1235-1255	1250-1270	1260-1280	8 to 9:30

Table3.3: furnace-operating parameters of Stackle mill

		WBF		PHF	
		Comb. Blower	**Atomization**	**Comb. Blower**	**Atomization**
	RPM	1480	Comp. air	1470	Comp. Air
	Motor	132 kW		132 kW	
	Pressure (mmWC)	1000		900	
	Flow in NM3/Hrs.	39166		29000	
	Flow in M3/Sec	9.86		7.3	
	Flow (NM3/hr.)	9.86 m3/sec		29000	
	Number of Running Blower at one time	2		1	

	Number of Installed Blower	3		2	

Table 3.4: Blower details of Stackle mill

3.4.3 Calculations for Re-heating Furnace

To calculate the performance of the Re-heating furnace we take into consideration the following [4] [6]

Sr. No	Parameter	Value
1	Capacity (TPH)	150
2	Dimensions: (m)	
	Height	2.5
	Width	11.9
	Length	15.5
3	Flue gas outlet Temperature (ºC)	340
4	Recuperator Inlet Temperature (ºC)	497
5	Hot air Inlet Temperature (ºC)	273
6	Ambient Air Temperature (ºC)	38
7	Feed-out Temperature (ºC)	500
8	Feed-in Temperature (ºC)	70
9	Fuel Used	LDO
10	Steel Grade	JT1250

Table 3.5: Specifications for preheating furnace

3.4.4 Fuel Consumption

Furnace Fuel consumption was 727 kg/Hr**.**

Fuel Reading	
Fuel	Meter Reading
LDO (Kg / hr.)	727

Table3.2: Fuel Consumption

3.4.5 Temperatures of Surface

Thermal Imager and IR had been used to measure temperatures.

Sr. No.	Surface temp	Avg.	Maximum	Minimum
1	Back Wall (ºC)	202	263	152
2	Front wall (ºC)	70	162	53
3	Roof (ºC)	66	70	58
4	Left wall (ºC)	92	113	50
5	Right wall (ºC)	105	146	75

Table 3.7: Measured Surface Temperature

3.4.6 Efficiency of Furnace

The furnace's calculated Efficiency utilizing several methodologies [8] was 27 %.

Parameter	**Value**
Heat input	15412400 kCal
Fuel consumption for cycle	1454 kg
Heat output (Q)	4155112 kCal
Net Weight of Feed stock in furnace	89759 kg
Slab quantity in the furnace	8 Nos.
Cp of Bloom	0.45 kJ/kg.K
Temperature Difference	430 ºK
Final Temperature of Bloom	773 ºK
Initial Temperature of Bloom	343 ºK
C.V. of Fuel (L.D.O.)	10600 kCal/kg
Cycle time of furnace	2 hr.
Actual Fuel Consumption (Measured)	727 kg/hr.
Efficiency	**27%**

Table 3.8: Efficiency of furnace

3.4.7 Radiation Losses calculation

Realizing the amount of heat lost by radiation will allow the radiation loss to be determined [4]

Parameter	Value
Ambient temperature	313 ºK
Back wall	
overall, Losses through the back wall	82806 kCal/hr.
Losses through the back wall	2783 kCal/hr.

Energy input to furnace	7706200 kCal/hr.
Overall heat losses through surface	201247 kCal/hr.
Front wall	
Overall heat losses through the front wall	9216 kCal/hr.
Losses through the front wall	310 kCal/hr./m^2
Ceiling	
overall, Losses through Ceiling	54685 kCal/hr.
Losses through Ceiling	296 kCal/hr.
Left wall	
Overall heat losses through the left wall	23464 kCal/hr.
Losses through left wall	606 kCal/hr./m^2
Right wall	
Overall heat losses through the right wall	31076 kCal/hr.
Losses through right wall	802 kCal/hr./m^2
Average wall temperature	
Back wall	475 °K
Front wall	343 °K
Ceiling	339 °K
Left wall	365 °K
Right wall	378 °K
The emissivity of external wall surface	0.75 E
Total Surface Area of the furnace	
Back wall	29.75 m^2
Front wall	29.75 m^2
Ceiling	184.45 m^2
Left wall	38.75 m^2
Right wall	38.75 m^2
losses through radiation	**2.6%**

Table 3.9: - Radiation losses of Furnace

Thus, the radiation losses of the furnace were calculated as 2.6% only.

.

3.4.8 Flue gas losses

This often accounts for the bulk of furnace losses [12], as can be shown below in this situation.

Parameter	**Value**
Annual waste heat-saving potential	8267364 McCall/Annum
operational Days	320 days
operational hours	24 hr.
Waste Heat Potential	2691199 kCal/hr.
Specific Heat	1.17 kJ/kg.K
flow rate	1526 kg/hr.
Allowable stack Temp	473 ºK
FG Temp	833 ºK
Flue gas Losses	**35 %**

Table 3.10: - Flue gas losses of Furnace

3.5 CHAPTER SUMMARY

In this chapter, varieties of furnaces have been analyzed for identifying the major losses in steel re-rolling mills. A research study is performed on a running plant of steel located in Haryana. Then analyzing the losses has confirmed that the biggest loss in an RHF is Flue gas loss.

Flue gas losses were the greatest of all losses at 35%, indicating that they represent a significant source of losses. However, Radiation losses were only 2.6%

CHAPTER 4

FURNACE ENERGY LOSSES

4.1 STEEL PLANT PROCESSES & ROLE OF FURNACE

Secondary steel mill is the most popular method of producing end user steel products all over the world and there are many steel re-rolling mills in India. Of all these industries, we have selected only one for the part of this analysis to show the considerable amount of saving potential in the steel sector. Almost all the products like Bar, rod, angle, channel etc. made from steel are finished in the re-rolling mills. The secondary steel industry is a feasible and an alternate source to satisfy the country's future steel requirements due to the expanding demand for steel in the nation and the constraints of the primary steel manufacturers to meet this growing demand. Over 3500 steel re-rolling factories may be found throughout India, including in four major clusters. The steel re-rolling mill, which is a part of our analysis, has an annual consumption of 185GWh. The annual production of the plant is 4.29 lakhs MT.

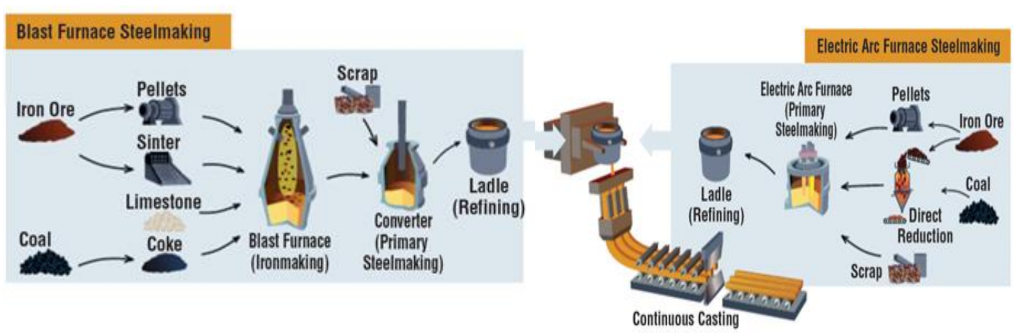


Fig.4.1. Process of the steel industry

The furnace is the equipment used to heat metals for changing their shape. There are many types of furnaces available. In this XYZ facility, there is eight number furnaces installed in the plant. Out of eight, two are electric arc furnaces while the rests are fuel-fired. Furnaces installed in the case study plant are:

Furnaces	**No's**
Boggie furnaces	1
Finishing furnace	1
Annealing furnace	1
Strip mill	1
Stackle Mill	2

Table 4.l Furnace in the case study industry

Stackle Mill has two furnaces viz.

I. walking beam (WBF) &
II. Preheating Furnace (PHF).

Depending on the various grades, LVFO, or HSD, LPG, are utilized as fuel for furnaces [1]. The following is a detailed explanation of the fuel, raw material requirements, and recuperators:

Sr No	Description	JBS	Flat
1	Type of Fuel Used in Furnace	LVFO / HSD	FO
2	Cycle Time		
	Coil to Coil Gap (Min)	6	2
	Productivity (MT/hr.)	12	45
3	Raw Material Specification		
	Bloom Size (T × W × L) (mm)		200×260×5050
	Bloom Weight (MT)		2.00
	Bloom Size (T × W × L) (mm)	200×260×3350	200×200×5050
	Bloom Weight (MT)	1.33	1.53
4	Recuperator Data		
	Hot Air (ºC)	330-400	280-350
	Outlet (ºC)	200-220	180-210
	Inlet (ºC)	630-700	550-630

Table 4.2 Stackle Mill Parameters

4.1.1 Walking Beam Furnace

With a mean working temperature of 1100°C, walking beam furnaces are predominantly used in the steel industry for applications such as annealing, welding, boiling, tension relieving, quenching, and tempering. The material is continuously fed through the furnace with the assistance of water-cooled beams that lift and move the products one little step at a time in the transit direction. Refractory bricks make up the walls. The scale-resistant spring steel and arrester secure the walking beam furnace drive mechanism. The beams have an advanced cooling mechanism to ensure a long service life and limited downtime. The Walking Beam Furnace has a door that steadily opens and shuts as the products move into the furnace. To ensure a high production performance, the furnace can be shipped independently or as part of a fully automated furnace line with conveyors and automatic charging equipment such as handling robots. Both of our commercial furnaces and ovens come with full paperwork and a CE – Certificate that meets the requirements of the LVD, EMC, and Machinery Directives.

Unfinished materials such as bars, wires, re-bars, tubing, and assorted structural shapes are reheated to a uniform temperature in a walking beam furnace before entering the shop area of a manufacturing factory. These use a four-function cycle to direct a commodity through the furnace by executing the rise, traverse, lower, and return functions. Natural gas is used mostly in a walking beam furnace.

4.1.1.1.Process Flow of Walking Beam Furnace

External shell (steel construction), moving parts lubrication system, refractory brickwork, combustion products outlet system, heating system, hydraulic system, and movement system are the key components of a walking beam furnace. A water-cooling system is also a part of the furnace and certain elements within it are cool. Steel charge heating, in which the highest service temperatures may surpass 1300C, is the most typical application for a gas burner-based heating system. The furnaces are also separated into several zones and can be numerous meters long. The charge heating procedure is generally controlled by the heating curve, that establishes specific temperatures for the charge at each location and moment in the furnace. A furnace temperature that is set for each furnace zone is connected to the charge temperature by most furnace control systems. The temperature recorded by furnace thermocouples positioned in the zones serves as the simplest representation of the furnace temperature. The link between the temperature of the charge as it travels through the furnace and the temperatures of the furnace zones is referred to as a heating function. The process flow in the walking beam furnace is shown in the figure below 4.2.

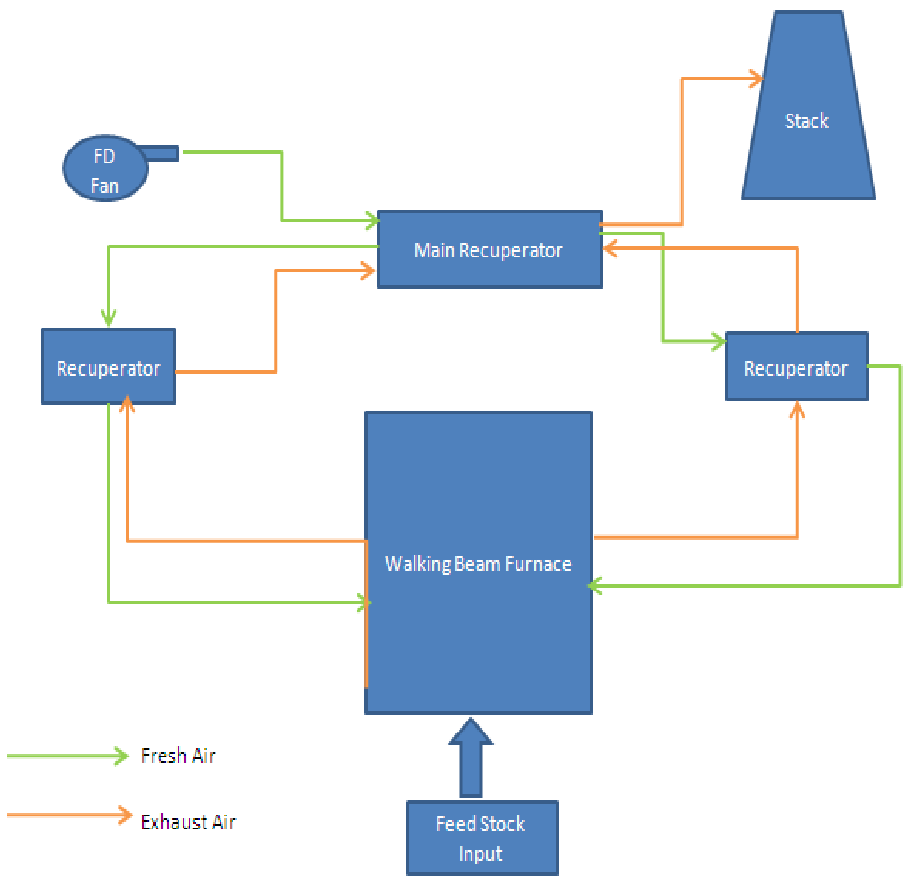


Figure 4.2 Walking Beam Furnace Process

4.1.1.2 Fuel Consumption in Walking Beam Furnace (WBF)

The yearlong data of fuel consumption was analyzed and plotted.

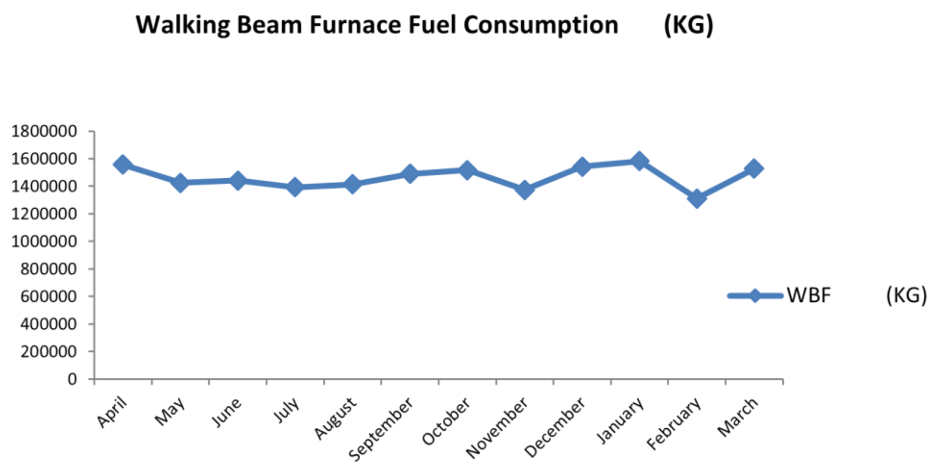


Figure 4.3 Fuel Consumption of WBFA

The details of burners used in the furnace are as follows:

Area		**Burner Model No**	**Location**	**No of Burner Installed**	**Make**
STECKEL MILL	PHF	1201-100	Side Wall	3+3	SGS / Bloom Engg
	WBF	1202-200	Soaking Zone	10+7	
		1201-250	Heat Zone	10+8	

Table 4.3 Burners in WBF

4.1.1.3 Loss Calculation in WBF

In an ideal case, the total heat input to the furnace and the total heat output should be equal. However, in a real scenario, this is not possible as there will be certain losses in the process [2]. The loss calculation for the WBF is shown below:

Fuel Consumption = 1054 Nm^3/hr.

Furnace cycle time = 3.5 hrs.

Fuel C.V. (L.P.G.) = 25775 kCal/Nm^3

Heat input = m*GCV = 1054*25775*3.5 = 95083975 kCal (1)

Cp of Slab = 0.45 kJ/kg K

Slab's Final Temperature = 1270 ºK

Slab's Initial Temperature = 736 ºK

Furnace Slab quantity = 14 Nos

Furnace Net Weight of Feedstock = 248155 kg

Heat output (Q) = m × Cp × ΔT

= 248155 × 0.45 × (1270-736)

= 14265944 kCal

The overall variance in heat output and input is the loss which is quantified as follows:

Heat Loss = Heat Input - Heat Output

= 95083975 kCal -14265944 kCal = **80818031 kCal**

The losses identified are heat loss through radiation and the heat loss in flue gas as the flue gas was emitting at higher temperatures.

The efficiency of the furnace is mentioned below:

Efficiency % = (Heat Output/Heat Input) × 100

= (14265944/95083975) × 100

= **15%.**

The overall efficiency will improve if the heat in the flue gas is also utilized. Generally, it is utilized for preheating combustion air. To reduce the heat losses in flue gas, techniques for recovering waste heat must ‘be applied.

A. Radiation Losses in WBF

Surface Radiation Losses Of WBF	
Parameter	**Value**
Ambient temperature	313 (ºK)
Total Surface Area of the furnace	
Discharging door	12 (m^2)
Charging door	12 (m^2)
Ceiling	165.92 (m^2)
Left wall	77.64 (m^2)
Right wall	77.64 (m^2)
Average wall temperature	
Discharging door	518 (ºK)
Charging door	455 (ºK)

Ceiling	488 (°K)
Left wall	423 (°K)
Right wall	448 (°K)
the emissivity of external wall surface	0.75 (E)
Right wall	
Overall heat losses	165793 (kCal/hr.)
Losses	2135 (kCal/hr./m^2)
Left wall	
Losses	1604 (kCal/hr./m^2)
Overall heat losses	124551 (kCal/hr.)
Ceiling	
Losses	3507 (kCal/hr.)
Overall losses	581814 (kCal/hr.)
Charging door	
Losses	2296 (kCal/hr./m^2)
Overall heat losses	27549 (kCal/hr.)
Dis-Charging door	
Losses	3990 (kCal/hr.)
Overall losses	47884 (kCal/hr.)
Surface Overall heat losses	**947592 (kCal/hr.)**
Energy input to furnace	**27166850 (kCal/hr.)**
% Losses through radiation	**3.50%**

Table 4.**4** Radiation losses in WBF

Flue gas Waste Heat Potential	
Parameter	**Value**
Annual waste heat-saving potential	141945795 Mcal /Annum
operational Days	320.00 days
operational hours	24 hr.
Waste Heat Potential	46206313 kCal/hr.
Specific Heat	1.17 kJ/kg.K
flow rate	35991 kg/hr.
Ambient Temp	473 ºK
FG Temp	734 ºK

Table 4.5 Flue Gas Recovery Analysis

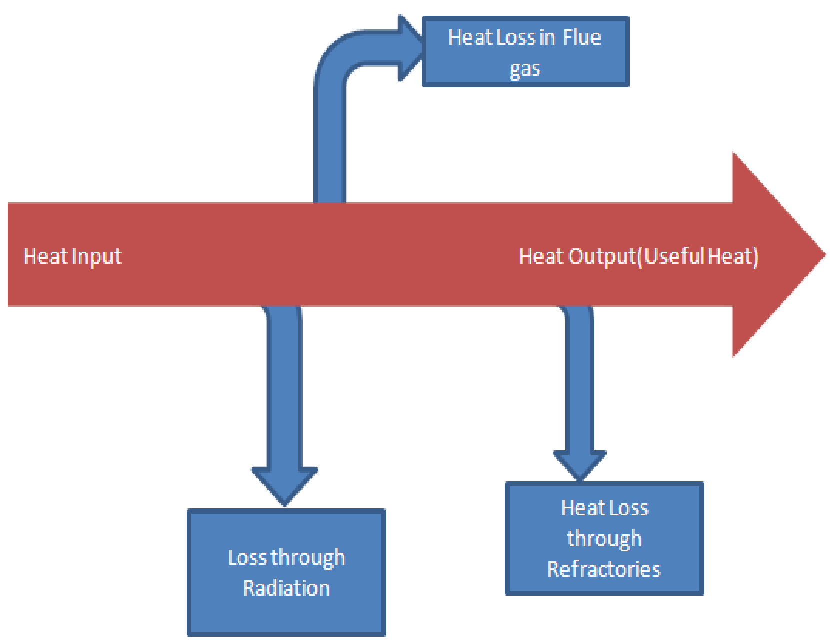


Fig.4.4. Sankey's Chart for Walking Beam Furnace

4.1.2 Pre-heating furnace

The outer layer of the furnace is heated by vigorous recirculation of the furnace environment. Even so, to produce the best heating efficiency, the environment flow pattern must be adjusted to the layout of the forgings and their loading pattern on the conveyor belt. Tiny parts are usually filled from a magazine automatically. Larger pieces are usually fed into the furnace by a robot, which then removes them and transports them to the forging press. Travel manipulators are used for very large forgings. Dual-track plate conveyor systems with mutually independent track control can be used to reduce system length.

The furnace specification of the Preheating furnace is given below.

S. No.	Parameter	Value
1	Flue gas outlet Temperature	340 ºC
2	Recuperator Inlet Temperature	497 ºC
3	Hot air Inlet Temperature	273 ºC
4	Ambient Air Temperature	38 ºC
5	Feed-out Temperature	500 ºC
6	Feed-in Temperature	70 ºC
7	Fuel Used	LDO
8	Steel Grade	JT1250
2	Dimensions:	
	Height	2.5 m
	Width	11.9 m

	Length	15.5 m
10	Capacity	150 TPH

Table 4.**6** Specification of PHF

4.1.2.1 **Process Flow of Furnace Pre-Heating**

The process flow of the Furnace Pre-Heating is

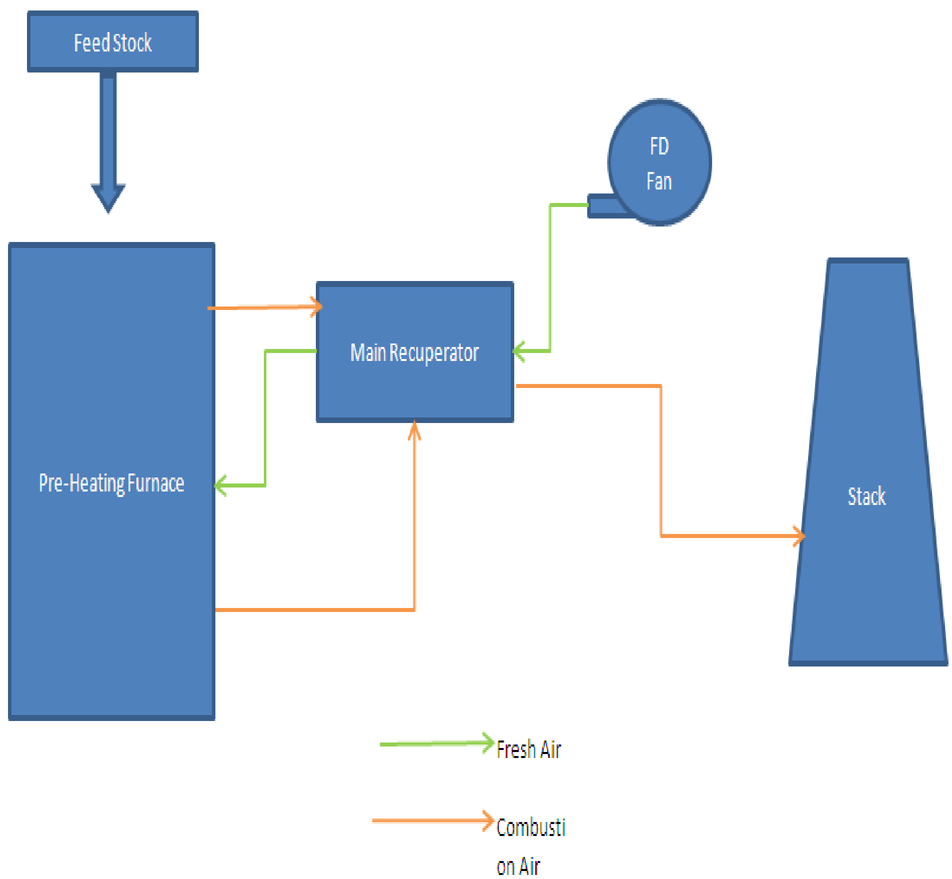


Figure 4.5 PHF Process Flow

4.1.2.2 **Month-wise Fuel Consumption of PHF**

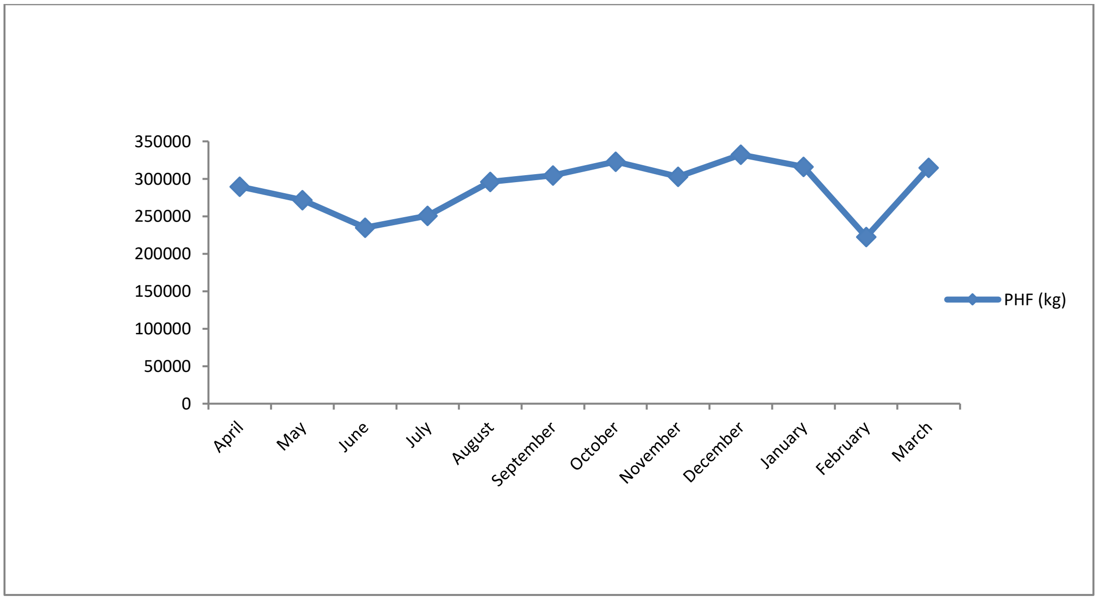


Figure 4.6 Fuel Consumed by PHF

4.1.2.3 Losses Calculation in PHF

Actual Fuel Consumption = 727 kg/hr.

Furnace Cycle time = 2 hrs.

Fuel C.V. (L.D.O.) = 10600 kCal/ kg

Heat Input = m × GCV × Cycle time (1)

= 2 × 727 × 10600

= 15412400 kCal

Bloom's Initial Temperature = 343 ºK

Bloom's Final Temperature = 773 ºK

Furnace Slab quantity in = 8 No.s

Slab Cp = 0.45 kJ/kg K

Feedstock Net Weight in furnace= 160210 kg

Heat output (Q) $= m^* \; Cp^*\Delta T$

= 160210*0.45*(773-343)

= 7416420 kCal

The overall variance in heat output and input is the loss which is quantified as follows:

Heat Loss = Heat Input - Heat Output

=15412400 kCal - 7416420 kCal = **7995980 kCal**

Efficiency % = (Heat Output/Heat Input) × 100

= (7416420 / 15412400) × 100

= **48%.**

Flue gas loss saving Potential of the Furnace

Flue gas Waste Heat Potential	
Parameter	**Value**
Annual waste heat-saving potential	59838858 M Cal/Annum
operational Days	320 days
operational hours	24 hr.
Waste Heat Potential	19478795 kCal/hr
Specific Heat	1.17 kJ/kg K
flow rate	11000 kg/hr.
Allowable stack Temp	473 ºK
FG Temp	833 ºK

Table 4.**7** Flue gas Saving Potential

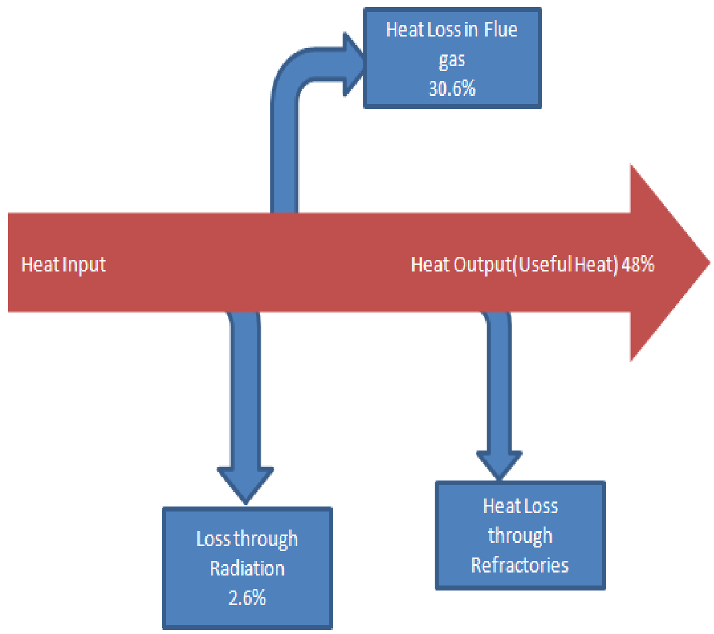


Figure 4.7 Sankey's Loss Flow Analysis

4.2 CHAPTER SUMMARY

The analysis of the Stackle mill was performed, and it was observed that 48% was the efficiency of Pre-heating furnace while the efficiency of the walking beam furnace is only 15%. Which is very low. The main reason for the lower efficacy of the furnace is the higher temperature of flue gases.

CHAPTER 5

WASTE HEAT RECOVERY OPTION

5.1 RECOVERY DEVICES

These flue gas losses may be recovered by adapting a suitable waste heat recovery device. Some of those devices are:

5.1.1 Efficient recuperators

The Re-heating furnace temperature in a Steel Re-rolling mill is maintained above 1100 degC, as the temperature required for easy re-shaping of steel is 1050 degC.

Issue: Recuperators do not perform well at this high temperature and face a frequent breakdown.

5.1.2 Heat recovery steam generators

This removes the heat from flue gases and transfers them to waste; which are converted to steam & hot water. Heat recovery steam generators are not suitable for steel mills as there is no application of steam / hot water in steel plants.

Issue: Steam or hot water produced cannot be utilized in steel plants. Hence, recovery in steam form is of no use

5.1.3 Regenerative burners

Regenerative burners maximise the heat input by first storing the heat from flue gases before using it to pre-heat the combustion gases and air flowing to the burners. Regeneration alternately heats the combustion air or stores and recovers heat from the furnace exhaust gas in a cycle using a dual burner.

Extremely high thermal efficiency is possible at air pre-heat temperatures of up to 1000 °C. Therefore, the temperature of released flue gas is almost equal to ambient, leading to negligible losses. Hence, the Most Suitable solution is Regenerative Burners.

5.2 FURNACE WITH REGENERATIVE BURNER

A furnace heating system that allows for highly high-efficient recovery of exhaust heat is known as a regenerative burner. Due to its significant impact on fuel economy, this system is best utilized in relatively high-temperature furnaces, such as heat treatment furnaces, forging furnaces, rolling furnaces, etc., in order to save energy, money, and CO_2.

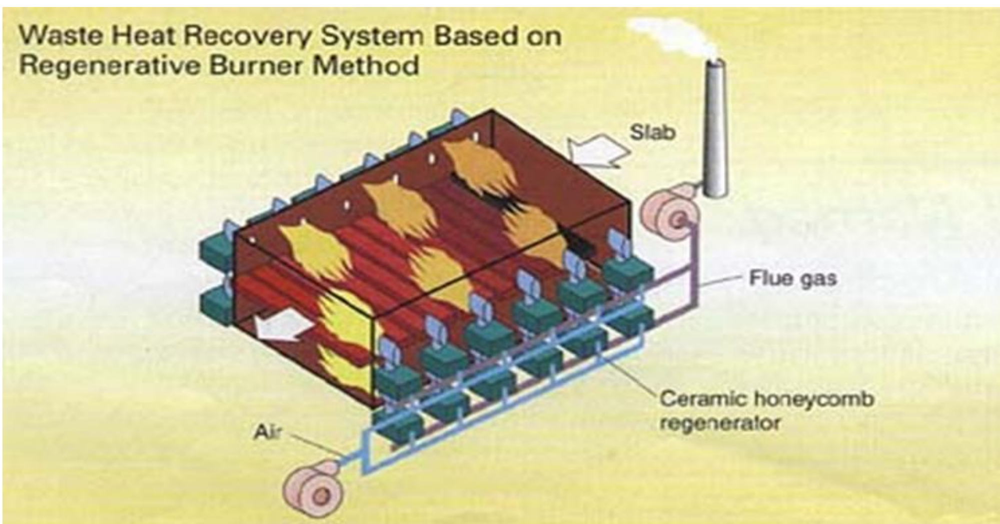


Figure 5.1 WHR system using Re-generative Burner.

A pair of burners that are integrated with the heat reservoirs are typically ignited alternately at intervals of several tens of seconds using a regenerative burner system. The burning of one burner helps in the recovering of energy of exhaust gas by heating the heat chamber of the next burner. When the second burner is burning, the air for combustion flows through the heated heat reservoir again to collect the energy from the exhaust gas that would have otherwise been lost and offer highly efficient combustion.

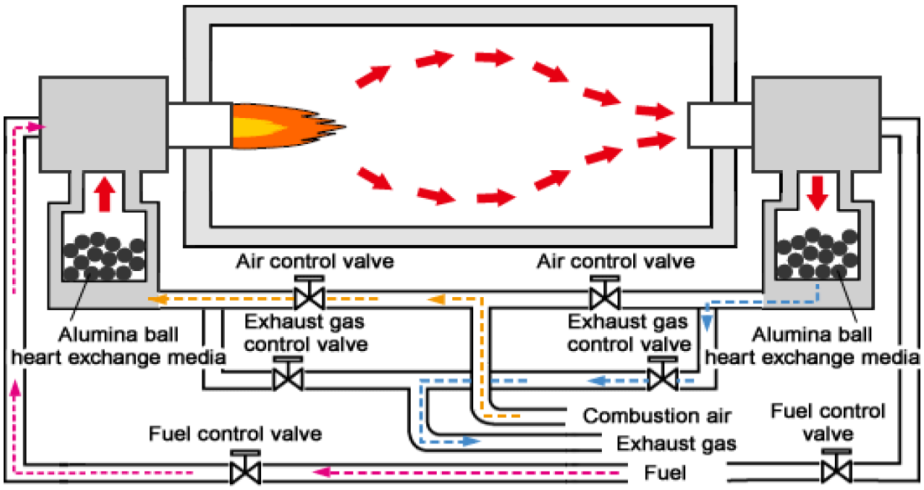


Figure 5.2 working of Regenerative burner.

The regenerative burners are configured to recycle heat from the gas of exhaust and transfer it to inlet air that will be used in the combustion process. The regenerative burner consists of two burners, a regenerator, and a reserving mechanism that collects heat using alumina balls. If the first regenerative burner is heating the furnace, the other is exhausting the gases. The heat is passed to the alumina balls by moving the exhaust gas through the regenerative burner body. As a result, heat would be passed to inlet air from exhaust gas.

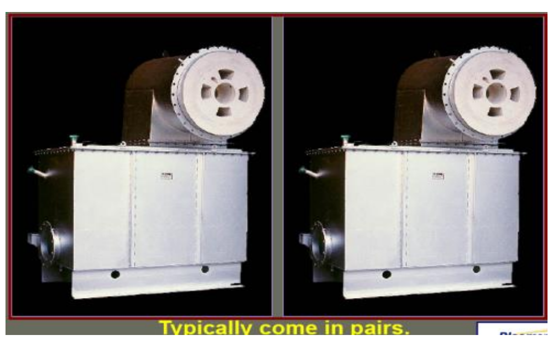


Figure 5.3 pair of Regenerative burners

In steel re-rolling mills, re-heating furnaces are used to raise the steel stock's temperature to rolling temperature of about 1200 ^{o}C, that are adequate for plastic distortion of steels and, therefore, for rolling in the mill. The steel stock is “charged at the furnace entry”, “heated in the furnace”, and “discharged at the furnace exit” during the continuous process of heating in re-heating furnace. During its passage through the furnace, the steel stock (Fig. 1) is heated primarily by radiation and convection from the gases of burner and the walls of furnace. Up to 45% of energy may be saved by using exhaust gas, which produces at least 1,000^{o}C of warmed air at a temperature of 12,000^{o}C (Compared to without exhaust gas recovery).

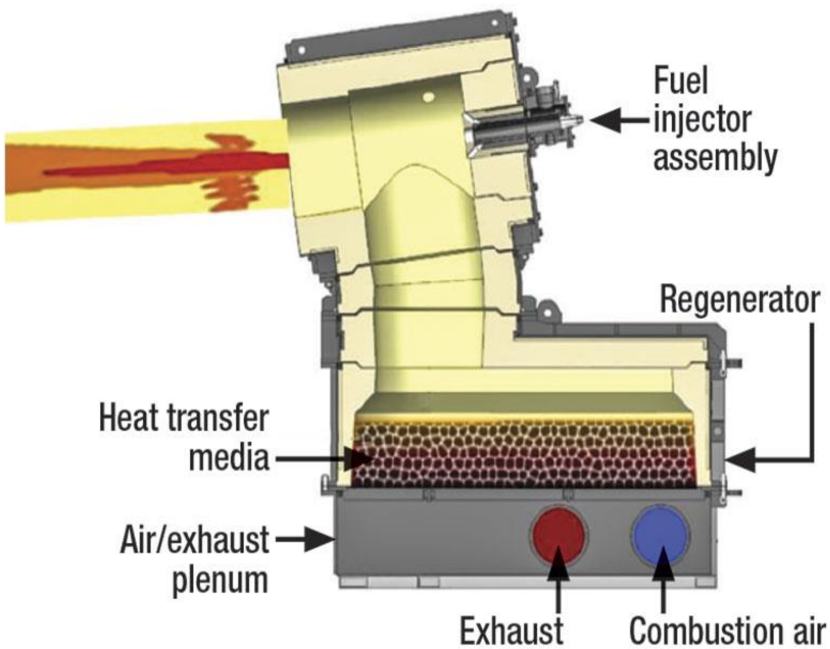


Figure 5.4 Design of regenerative burner

Regenerative burners run in pairs and use ceramic heat regenerators to store heat for a limited period. They extract between 85 and 90% of the furnace waste gases' heat, allowing the received burning air to be pre-heated to extremely higher temperatures of up to 10° -150 °C while the furnace is off. Temperatures in the applications vary from 800 to 1500 degrees Celsius. It is possible to reduce fuel consumption by up to 60%.

Incorporation of regenerative burner can help in the preservation of energy up to 25%-45%, though it also depends on the patterns of Operation, Air ratio, and Temperature of furnace.

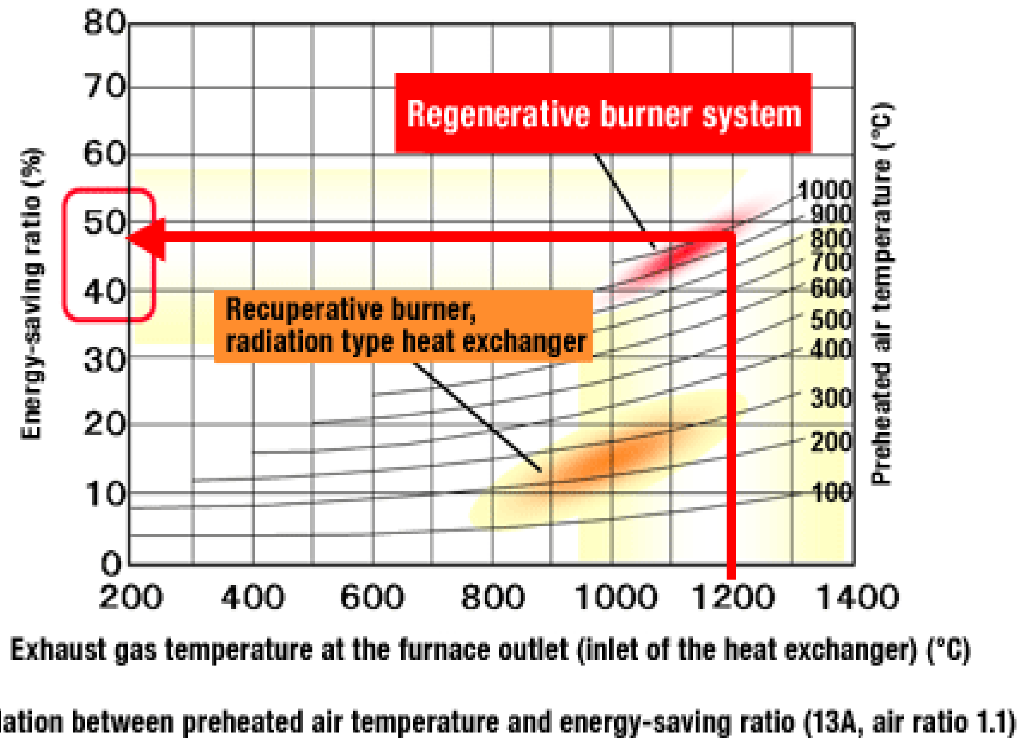


Figure 5.5 Energy saving ratio Vs flue gas temperature at the furnace outlet.

Regenerative burners are having the following advantages:

- Outstanding Fuel Savings.
- Carbon Footprint Is Negligible.
- Heat Transfer is fast.
- Excellent Temperature Consistency.
- Installation is simple.
- Cost-effective.

These are the additional benefits of a regenerative burner system. Hence, we can obtain a highly efficient system.

5.3 CASE STUDY

A pair of regenerating burners are installed at a Re-heating furnace in a small steel re-rolling mill with a production capacity of 45 Tons/hr. along with an air blower of capacity 17000 Nm3 / hr. The flow control of gas, as well as air, has been provided zone-wise. The ratio of Air to fuel was efficiently sustained up to 0.72. The furnace had three zones with six burners in each zone.

Figure 5.6 Burner with flame

Various data collected during the experiment are as shown below:

5.3.1 Reheating furnace Specifications:

Three-zone regenerative type furnace

Furnace Dimensions:

External Length	- 26.68 meter
Internal Width	- 4.6 meter
Internal Height	- 3.25 meter

Blower:

No. - 2 (One standby)

Pressure - 10300 Pa

Flow rate - 17000 m^3/hr.

Burner's details:

S No.	Location		BFG burner quantity	Air burner quantity	Bfg burner capacity M^3/hr
1.	Preheating zone	Top	6	6	1263
		Bottom	6	6	1540
2.	heating zone	Top	6	6	1263
		Bottom	6	6	1540
3.	Soaking zone	Top	6	6	1180
		Bottom	4	4	1514

Table 5.1 Burners

Temperature profiles:

a) Furnace Temperature:

Soaking Zone - 1220 - 1250 ^{0}C

Heating zone - 1150- 1200 ^{0}C

Preheating zone - 700 - 850 ^{0}C

b) Furnace wall skin temperatures:

Soaking zone - 225 ^{0}C average

Heating zone - 200 ^{0}C average

Preheating - 160 ^{0}C average

Roof - 165 ^{0}C average

c) Material temperature:

Roughing temperature -	1180 ^{0}Caverage
Finishing temperature -	900 ^{0}Caverage

5.3.2 Flue gas Analysis:

Excess air	-	149 - 354 %
Oxygen	-	12.57 – 16.38 %
CO_2	-	7.2 -11.12%
CO	-	up to 15000 ppm

5.3.3 OBSERVATIONS

- The furnace had a high positive pressure.
- Furnace average skin temperatures were found as
    - Soaking Zone – 225 ^{0}C,
    - Heating zone- 200 ^{0}C and
    - Pre-heating zone- 160 ^{0}C
- The flow control of gas, as well as air, has been provided zone-wise.
- 0.72 was maintained as the Air fuel.
- Higher CO levels were in furnace.
- 0.9 % as an average scale loss in furnace.
- All zones were incorporated with temperature indicators.

5.3.4 Heat Balance

1.	Heat taken by stock	41%
2.	**Flue gas heat losses**	**18%**
3.	furnace structure Heat losses	11%
4.	Loss of Heat due to hydrogen in fuel	2%
5.	Loss of Heat due to furnace rails cooling	8%
6.	radiation Heat losses via openings	1%

7. Loss of Heat due to partial combustion 10%
8. Un-accounted losses 9%

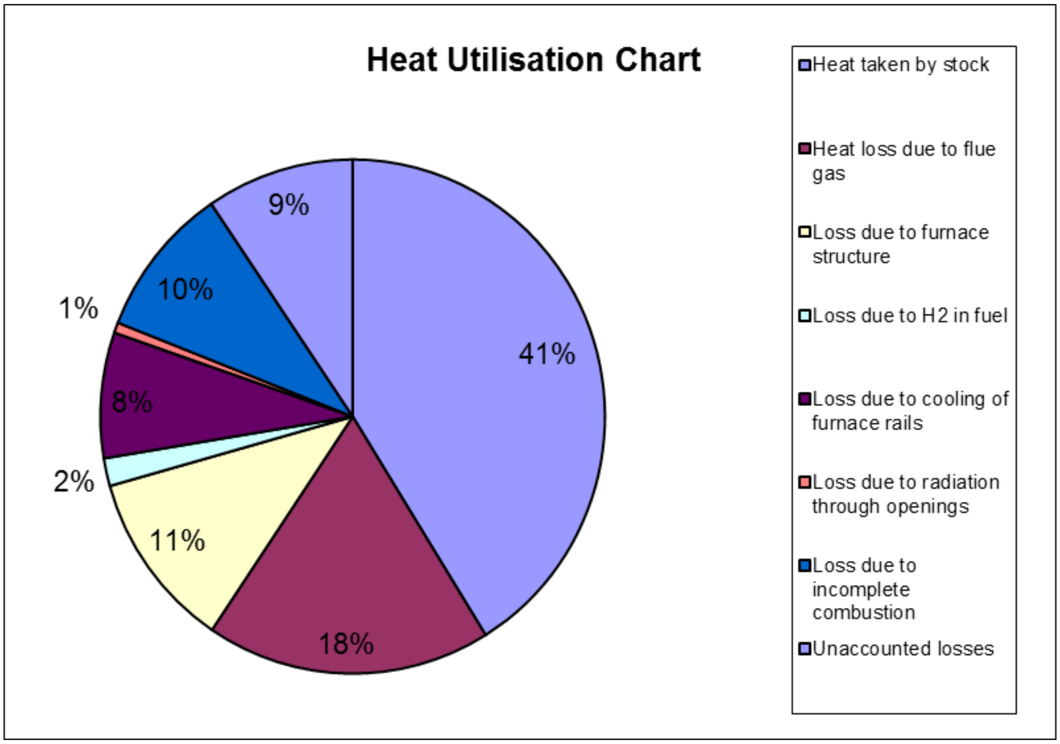


Figure 5.7 Heat utilization chart

5.4 CHAPTER SUMMARY

Before applying the regenerative burners, the flue gas losses were in the range of 45%. However, after modification in this furnace and applying the pairs of regenerative burners, the flue gas losses were reduced to 18%. Hence the saving achieved due to flue gas loss reduction, in this case, is 27%.

Another major problem of frequent choking of burners has been observed using economical low-grade coal. The Ash content in Indian coal is 35% - 50%. These burners run well with high-grade coal. However, this technology is to be used with gaseous fuel.

CHAPTER 6

INTEGRATION WITH GASEOUS FUELS

The data from the last chapter experiment confirms that using of Regenerative burner has reduced the flue gas loss of heat up to 18%, though the previous experiment has confirmed that the flue gas level was 45%. Hence, the use of regenerative burners has reduced the flue gas heat losses by 17% in general. It may go as high as 30%.

6.1 PROBLEM OF FREQUENT CHOKING

Using Indian coal in regenerative burners causes a problem of frequent choking; Generally, the Ash content in Indian coal is 35% - 50%. The solution to this problem is:

6.1.1 Installing a removable mesh filter before honeycomb thermal storage:

This observes frequent choking because of a high level of big particles in ash. Hence, this is not a practical solution; rather it is a barrier towards the use of Regenerative burner by MSME SRRM.

6.1.2 Using only gaseous fuel:

Natural gas or other gases may be used in the re-heating furnace as fuel. The calorific value of natural gas is generally 1300 kCal/kg. However, the cheapest and most used fuel in India is coal. Hence, a coal gasifier is the best solution.

The properties of gas generated by gasifier are dependent on the parameters of gasifier like CV, size, coal quantity, water quantity, quantity of steam, Temperature steam enthalpy, Pressure, etc.

Fuel economy works out for burning coal as fuel. Hence, coal needs to be gasified for combustion. It is one of the cleanest fuels also. A coal gasifier is an easy solution for use of coal in these furnaces. Coal is modified to Syn gas by the process of pyrolysis. The calorific value of Syn gas may reach as high as natural gas i.e., 1300 kCal/kg.

Integration of Coal gasifier with regenerative burner is expected to save approx. 30% energy. Balance Flue gas also may be fed back to the gasifier. Gasification is conversion of solid fuels like coal / biomass into gaseous fuels. After conversion of solid fuel to gas, it becomes compatible and flows like a fluid. This may substitute liquid fuels by solid fuels in furnaces.

Gasification technology may be used to efficiently and environmentally re-heat rolling mill furnaces, which use furnace oil. Most of these modern gasifier designs use an oxygen blower. Winkler (fluidized bed), Chevron Texaco, Shell (entrained flow), MBEL (fluidized bed), and Destec (entrained flow) are a few of the famous technologies (entrained flow). The oil equivalent capacity of the gasifiers running in rolling mills ranges from 125 to 500 liter/hr. The temperatures needed in the reheating furnace may be produced using the gas produced by an air-blown gasifier, that have a calorific value of around 1100–1300 kcal/N m^3, coupled with warmed combustion air (1150-1200 ^oC). Consequently, it is theoretically conceivable to totally replace the furnace oil with producing gas.

The amount of solid fuel (coal or biomass) needed to replace furnace oil will depend on the solid fuel's calorific value. It is feasible to use the gas in hot raw circumstances for heating steel ingots or bills. Most of the tars in the gas are kept in vapors form at the burner intake, where the temperature is maintained so that they continue to provide energy to the furnace. Fuels containing carbon are gasified, or partially oxidized, to create a gaseous fuel. CO, H2, and a few hydrocarbons make up most of the gas created by gasification's combustible components. N_2 and CO_2 are the non-combustible components (if the air is used as the gasifying medium). The kind of gasifying medium, gasification conditions, and gasifier design, all affect how much of each of these components is present.

Typically, steam and oxygen or air are used as the gasifying medium. Nitrogen travels through the gasification reactor unreacted and appears as inert in the product gas when air is utilized, since only oxygen in the air participates in the gasification processes. The temperature is regulated using steam. The gas that is generated must be conditioned, which may include cleaning, chilling, and desulphurization. The level of conditioning is determined by the intended use of the gas. Most direct heating applications don't need much conditioning, such heating steel in a reheating furnace.

6.2 GASIFICATION PROCESS

A warmed mixture of steam, air, oxygen, or a combination of these is injected into the system when coal is placed within a chamber. A coal particle goes through four processes, in this sequence, to get gasified.

- Gasification
- Combustion
- Pyrolysis, and
- Drying.

When coal is introduced into the gasification chamber, drying takes place. As the coal descends, the temperature is increased by the gas created farther down in the chamber, causing it to dry at the same time. At the same time, the syngas that is created lower in the system is cooled. The ongoing temperature increase causes pyrolysis to start as time goes on. The weaker chemical bonds are now disrupted as de-volatilization has started. The weight percentage of the char rises when volatile gases are emitted.

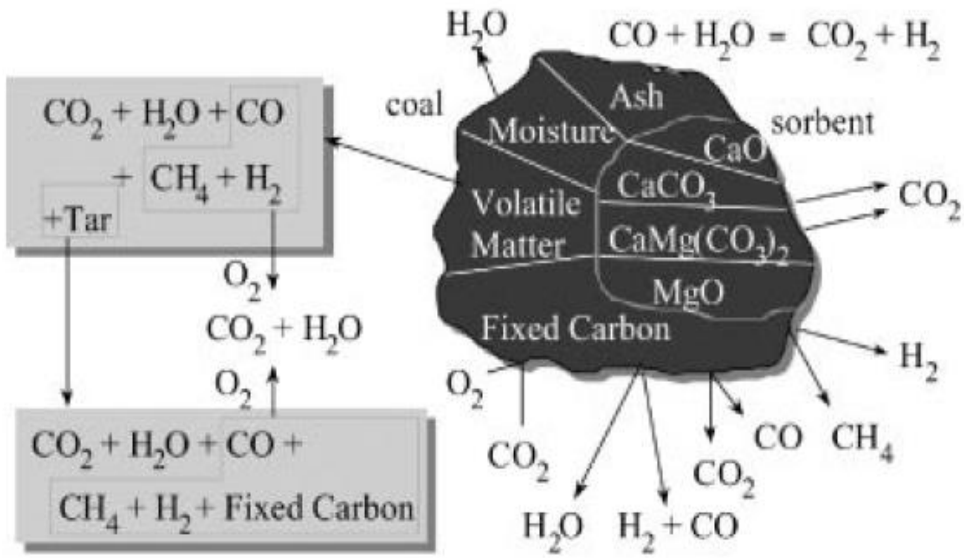


Figure 6.1 Gasification Reaction

Volatile gases and part of char combine with the O_2 during burning to produce CO_2 and CO. These exothermic reactions provide the heat required for the consequent reactions. The residual char combines with steam during the gasification process to create H_2 and CO.

The feedstock is hydrogenated during a gasification process. In order to generate a produce with a greater H_2-to-C ratio as compared to the feed stock, either directly or indirectly, hydrogen must be introduced to the feedstock or the system must be pyrolyzed to eliminate C. These procedures may be carried out either sequentially or concurrently. The total efficiency of the synthetic gas manufacturing process decreases as more hydrogen is supplied or as more carbon is removed. Steam is employed as a hydrogen supply and the gasification reactor produces hydrogen in an indirect hydrogenation process.

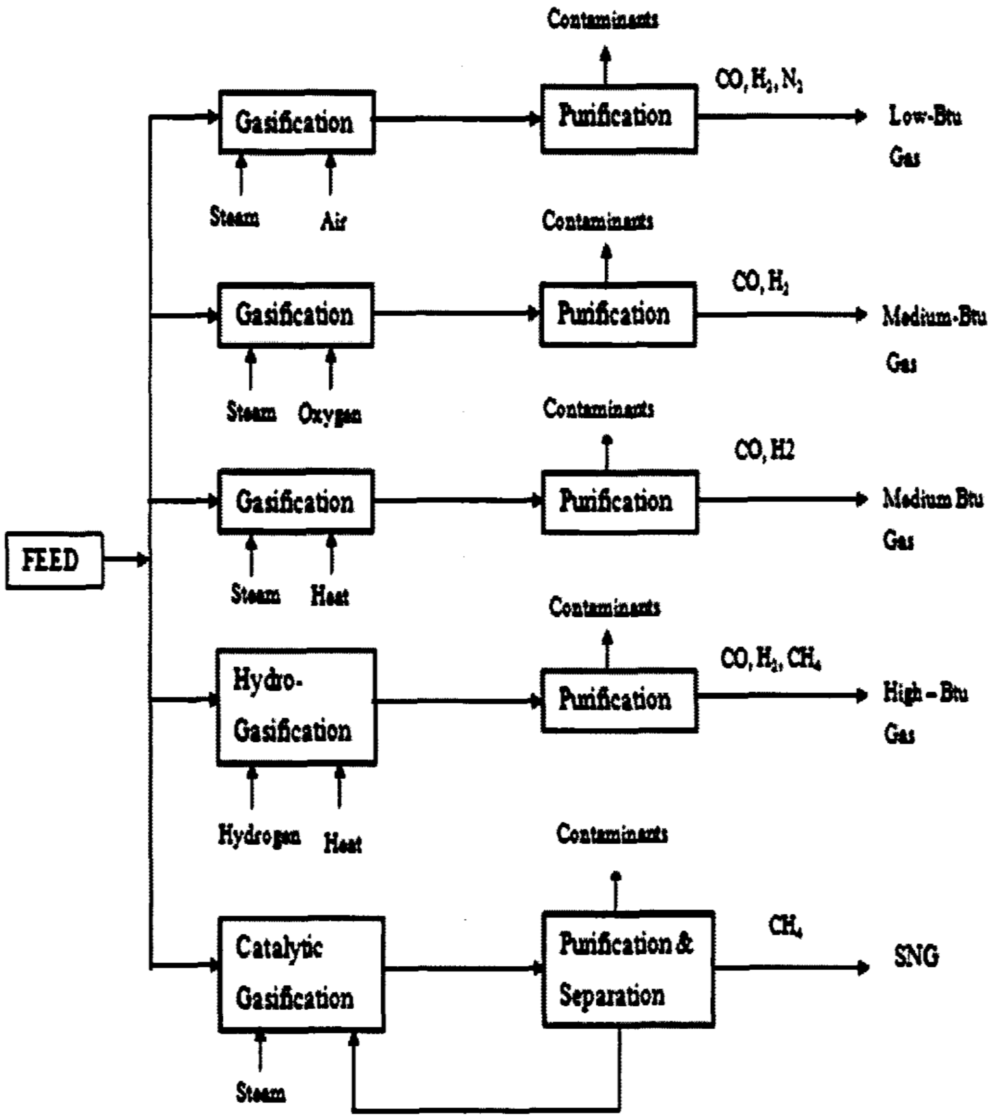


Figure 6.2 various Gasification Methods

6.2.1 Reactions in a gasifier

Following are the reactions that occurs in the gasifier, dependent on the process of gasification:

(1) $$CO_2 \leftrightarrow C + O_2$$

(2) $$CO \leftrightarrow C + \frac{1}{2}O_2$$

(3) $$H_2O \leftrightarrow H_2 + \frac{1}{2}O_2$$

(4) $$CO + H_2 \leftrightarrow C + H_2O$$

(5) $$CO_2 + 2H_2 \leftrightarrow C + 2H_2O$$

(6) $$2CO \leftrightarrow C + CO_2$$

(7) $$CH_4 \leftrightarrow C + 2H_2$$

(8) $$H_2 + CO_2 \leftrightarrow CO + H_2O$$

(9) $$CH_4 + H_2O \leftrightarrow CO + 3H_2$$

(10) $$\frac{1}{2}CH_4 + \frac{1}{2}CO_2 \leftrightarrow C + H_2O$$

Most of the oxygen pumped into gasifier, whether it be as air or pure oxygen, is spent in reaction (1) via (3) to generate the heat required to dry the solid fuel, dissolve chemical bonds, and increase temperature of reactor to diversification processes (4) via (6). (9). The main gasification processes are reaction (4) and (5), sometimes referred to as water-gas reaction, which are endothermic, prefer lower pressures and higher temperatures. At similar temps. and in absence of catalyst, reactions (6), the endothermic Boudourd reaction, proceeds significantly more slowly than reaction (1), the combustion process. Except at high pressures, reaction (7), hydrogasification, proceeds extremely slowly. If producing H_2 is a goal, reactions (8), the water-gas shift reactions, may be significant. Maximum yield is attained with the catalyst at low temperature (up to 500°F), and growing hydrogen production is unaffected by pressure. In catalyst absence, reaction (9), the methanation process, progresses extremely slowly at lower temperatures. Methane production is sluggish compared to reactions (4) and (5) unless accelerated, however reaction (10) is generally thermally neutral, indicating that gasification might continue with minimal heat input. In contrast to the agent for gasifying (steam, air, or O_2) and the gasifier operating pressure and temperature, other factors also affect the end-user applications, heating values, and chemical composition of the gasifier produced gas. The product gas's quality is influenced by the following variables:

- Residence time
- Reactor heating rate
- Feedstock particle size and preparation
- Feedstock composition

Plant configuration

• Syngas clean-up system

• Heat transfer and generation method — indirect or direct

• Mineral removal system - slag or dry ash

•Feedstock-reactant flow geometry

•Feed system - dry or slurry

6.2.2 Synthetic gas

Four different forms of synthetic gas may be created, dependent on the gasifier, system setup, circumstances of operation, and gasification agent:

• Low heating-value gas (100 to 270Btu/ft3 or 3.5-10 MJ/ m3)

• Medium heating-value gas (270 - 540 Btu/ft3 or 10-20 MJ/ m3)

• High heating-value gas (540 to 940Btu/ft3 or 20-35 MJ/ m3)

• Syn Gas (over 940 Btu/ft3 or 35 MJ/ m3)

Inert flue gases and hydrocarbons are mixed together to form the gas stream. This syngas, or producing gas, does have a calorific value (CV). Due to the utilization of air, the gas stream often includes a significant amount of nitrogen, up to 60%. Certain operations use oxygen or steam to supply the required oxygen. A gas stream with a substantially greater CV is created by these processes. Nevertheless, this raises extra expenses as well as security concerns.

6.3 GASIFICATION REACTORS

Several diverse reactor types, such as the following, may be used for gasification:

6.3.1 Moving Bed / Fixed Bed

In moving-bed gasifiers, also known as “fixed-bed gasifiers”, oxidant and steam are added at the bottom and flow vertically upward, while feedstock is introduced at the end. Up flowing hot syngas heats the feedstock. The upper portion of the gasifier reactor vessel is where volatile components are powered off from the feedstock and partly gasified. The remaining char settles at the bottom of the gasifier, where it is burned in the reactor's bottom zone. The middle region of the gasifier's endothermic gasification processes is heated by the heat from the combustion zone. A moving-bed gasifier's average outlet gas temperature is between 425 and 650 °C. Strong hydrocarbon molecules, such as tars and oils, will not break at this temperature. As a result, heavy hydrocarbon compounds are usually removed using a downstream condenser, resulting in a process condensate supply that needs treatment. Furthermore, because of the low syngas outlet temperature, a significant amount of methane is released. Dry ash gasifiers have a lower combustion zone temperature (around 1000 °C) than slagging gasifiers (around 2000 °C). As a result, dry ash gasifiers are more suited to reactive feedstock like lignite than bituminous matter. Because of the effective heat transfer from counter-current flow and the comparatively low operating temperature, moving-bed gasifiers use less oxygen than other forms of gasifiers. Big particles can be handled by this kind of gasifier. Fine particles are entrained in the outgoing syngas and can obstruct the flow direction of the syngas.

6.3.2 Fluidized Bed - Bubbling

Due to its appropriateness for medium-scale operations, the BFB gasifier is among the foremost popular biomass gasifier models (up to 25 MWth). It is composed of a vessel wherein the agent for gasifying is supplied vertically at a speed (2.8 – 3.6 Km/hr.) high enough to stir the bed materials at the gasifier's bottom and maintain the required temperatures. The hotbed receives biomass from the side, where it is devolatilized. Char volatiles and particles (tar precursors) gasify and shatter when in interaction with heated fluidized bed. Another agent for gasifying may be introduced above the beds in the 2^{nd} zone for the conversion of entrained un-converted char volatiles and particles into fuel gas. A flue gas with a less to moderate tar concentration is the product. Syngas is relieved from ash in gas-solid separator facilities farther down-stream. The agent for gasifying may be delivered to 2 zones. A fluidized bed has the 1^{st} zone inside for the maintenance of the proper temperatures. Char particles and unconverted volatiles are transformed to fuel gas in the second field, which is located above the bed. The bubbling fluidized bed gasifiers has two primary drawbacks: high solids conversion isn’t attained owing to back oxidation spots, and mixing problems occur due to insufficient O_2 transport.

6.3.3 Circulating Fluidized Bed Reactors (CFBs)

CFBs are a kind of FBR that function similarly to fluidized bed reactors. Fluid bed reactors employ several heated reactors with cyclones to separate the char, while CFBs only use one heated reactor. Combustion of the suggested char can be used to produce the heat energy or there are many other ways of using it. For the pyrolysis process, CFBs utilizes a “first fluidized bed unit”; however, they provide the in-organic carrier of heat with the char they produce into a “second fluidized bed unit”. In this “second fluidized bed unit”, the inorganic heat carrier's char is burnt to produce heat, which will largely be used by the initial unit, to which the heated in-organic carrier of heat will be transported for the completion of the pyrolysis procedure. CFBs are sometimes mentioned to as “transport bed reactors” even though the heat transporter is transferred to the second “fluidized bed unit” and then returned to the “first pyrolysis fluidized bed unit”.

6.3.4 Entrained Flow Bed

“Fine coal feed, oxidant (air or oxygen), and/or steam” are all supplied to the gasifier at the same time in entrained-flow gasifiers. When the coal particles flow into the gasifier in a thick fog, the oxidant and steam cover and entrain them. Fast feed conversion and high throughput are produced by entrained-flow gasifiers, which operate at high pressures and temperatures with a highly turbulent flow. Gasification reactions take place at a rapid rate (typical residence period is a few seconds), “with high carbon transfer efficiencies (98-99.5 percent).”

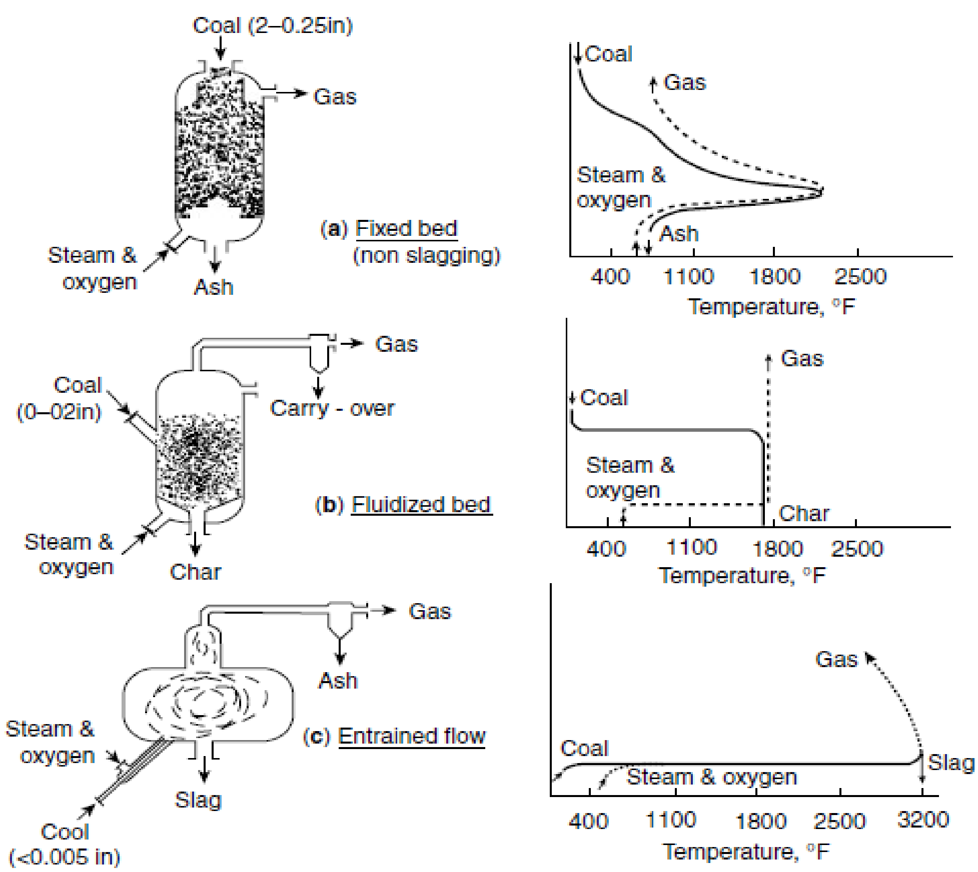


Figure 6.3 Fluidized bed gasifier

Out of the above mentioned, the fluidized bed gasifier is most popular for the medium heating range. As the temperature, range is 800-1000 degC and Cold gas efficiency is highest (up to 89%).

6.4 ADVANTAGES OF FLUIDIZED-BED GASIFICATION

- There can be change in air: fuel ratio that also assists to controlling the bed temperatures.
- As compared to other kinds of gasifiers, the fluidized bed gasifiers can handle variations in the feed stock better.
- "They maintain unvaried radial temperature profiles and avoid slagging problems."
- "Higher throughput of fuel as compared to other gasifiers."
- Enhanced heat and mass transmission from fuel.
- "High heating value."
- Concentrated char.

6.5 ENERGY AND MATERIAL BALANCE

To evolve the model, the feed stocks' chemical formula is explained as **CHxOyNz**.

"The global gasification reaction can be written as follows:"

$$\begin{aligned} &\mathbf{CHxOyNz + wH2O + m\ (O2 + 3.76N2)} \\ &\quad \mathbf{= n_{H2}H2 + ncoCO + n_{co2}C02 + n_{H2o}H20 + n_{cH4}CH4 + (z/2 + 3.76m)\ N2} \end{aligned} \qquad (1)$$

where "w" is the "amount of moisture per kmol of feedstock" and "m" is the "amount of oxygen per kmol of feedstock", and "x", "y", and "z" is the "number of hydrogen, oxygen, and nitrogen atoms per number of carbons in the feedstock", respectively. Equation (1)'s left-hand side inputs are all specified at 25 °C. The "ni", “number of the mole of the species”; “i” on the right-hand side, is similarly unknown.

Five equations were required in order to identify the 5 unidentified species of the producing gas. Those equations were produced utilizing equilibrium constant and mass balance relationship. “Considering the global gasification reaction in equation (1),” Every chemical element was balanced as indicated in equations to create the first three equations (2-4).

C balance: “$f1 = 0 = n_{co} + n_{co2} + n_{cH4} - 1$” (2)

H_2 balance: “$f2 = 0 = 2n_{H2} + 2n_{H20} + 4n_{cH4} - x - 2w$” (3)

O_2 balance: “$f3 = 0 = n_{co} + 2n_{co2} + n_{H20} - w - 2m - y$” (4)

Chemical equilibrium is generally elucidated either by the “minimization of Gibbs free energy or by using an equilibrium constant.” Constrained optimization techniques are often used to reduce the Gibbs free energy, which requires an understanding of challenging math concepts. Due to this, the equilibrium constant rather than the Gibbs free energy served as the foundation for the evolution of the present thermodynamic equilibrium model. The equilibrium constants of the processes taking place in the gasification zone were used to generate the last two equations, as shown below:

Boudouard reaction: $2C0 = C + CO2$ (5)

Water-gas reaction: $CO + H2 = C + H2O$ (6)

Methane reaction: $CH4 = C + 2H2$ (7)

Equations (5) and (6) can be merged to provide the water-gas shift reaction by subtracting equation (5) from (6).

Water gas shift reaction:

$$CO2 + H2 = CO2 + H2O \quad (8)$$

All chemical processes taking place in gasification zone were expected to be in thermodynamic equilibrium for the sake of the study's concept. It was assumed that all gases are perfect and that all reactions begin at "pressure 1 atm."

It was determined in this research utilizing the energy balancing approach. Analyses were done using coal's ($C_1H_{0.872}O_{0.285}$) molecular structure, and the findings are as follows:

Analysis of Thermodynamic

P = 20 Bar T= 700 degK H_f" = 3917kJ/kg H_f" = 217.6111111 kJ/kmol

With the help of Gibb's Free energy and Energy & mass Balance

HHV (kJ/kg) = 33823*C+144249*(H-(0/8)) + 9418*S= 25758.51925

LHV (kJ/kg) = HHV-22604H-2581M = 24628.31925

Hf° coai= (LHV/MW of COAL) + I (HfoC02+HfoH20) = -497511.9776 kJ/kg

To ascertain the equilibrium constant, the temperatures of the gasification region must be assessed. The gasification procedure, that was often considered to be adiabatic, was balanced either on the enthalpy or energy basis for the reason.

"Specific heat at constant pressure in kJ/kmol K" and is a "function of temperature". It can be elucidated by the following empirical equation:

$$a + bT + cT^2 + dT^3 = Cp\,(T)$$

Where "T" is the "temperature in Kelvin" and

$$\int_{298}^{T} \bar{C}_p(T)dT = aT + bT^2 + cT^3 + dT^4$$

Where "k" is a "constant derived from the integration" and "a, b, c, and d" are the "particular gas species coefficients", that are indicated in the table.

Gas Species	a	b	c	d	Temp. range, K
Hydrogen	28.6105	0.0010194	-1.476E-07	7.69E-10	298-1500
CO	29.0277	-0.0028165	1.16437E-05	-4.7063E-09	298-1500
CO_2	21.3655	0.0642841	-4.10506E-05	9.7999E-09	298-1500
Water Vapour	32240	1.923	0.01055	-0.000003595	298-1500
CH_4	19.2494	0.0521135	0.000011973	-1.13173E-08	298-1500
N_2	29.5909	-0.005141	1.31829E-05	-4.968E-09	298-1500

Table 6.1 Coefficients for specific heat calculation

De Souza-Santos recommended the relationship "for finding the enthalpy of formation for solid fuel in reactant" that is:

$$\bar{h}^0_{f,fuel} = \overline{LHV} + \sum_{k=prod} \left[n_k \left(\bar{h}^0_f \right)_k \right]$$

Where IHY is the "solid fuel's lower heating value" in kJ/kmol and (hof) is the energy of "creation of product 'k' under absolute combustion of the solid fuel." The "Newton-Raphson technique" may now be used to calculate the temperature in the gasification zone from the equation once the enthalpies of formation in the equation have been solved. By knowing the quantity of air, this connection helps "predict the reaction temperature." Because of this, the model may be used to show how the reaction temperature changes when the mole of air changes. The tables below show how compounds' Gibbs energy fluctuates.

Comp-ound	a'T*lnT	b'T*T	0.5*c'*t^3	0.33*d'*T^4	(0.5*e')/T	g'*T	Δg
CO	61.639478	-26.775	10.7713	-3.08397375	-0.163033	-91.965	-244311.4501
CO_2	-213.802	70.25625	-41.31	11.60416125	-0.163033	-181.05	-396191.4466
H_2O	-98.179984	-8.262	8.7901	-2.46918375	0	-25.83	-164641.0201
CH_4	-506.80617	25.425	22.258	-11.10464438	-0.163033	-335.1	74274.65887

Table 6.2 Gibbs free energy overall calculations

The two reactions that follow are subjected to independent computations.

CO + H2O = CO2 + H2

C + 2H2 = CH4

The 2 reactions mentioned above were chosen because they contribute to raising H2/CO, that raises the caliber of the synthesis gas generated.

We created a MATLAB function in Math Works' MATLAB ® to find the ideal H2/CO ratio that may be formed given the thermodynamic information.

By utilizing the code, researchers can create the ideal ratio and make Synthesis Gas of a considerably higher caliber than is currently attainable with conventional fluidized bed gasifiers. The generated code and outcomes are shown below:

6.6 CODING USING MATH WORKS' MATLAB®:

MATLAB CODE

```
Function y = pop(y)
Pop1 = y (1);
Pop2 = y (2);
Pop3= y (3);
Pop4 = y (4);
Pop5 = y (5);
j = 1;
for i =1:10
flyl =1;
f1y2 = 1;
f1y3 = 1;
f1y4 = 0;
f1y5 = 0;

f2y1 = 0;
f2y2 = 0;
f2y3 = 4;
f2y4 = 2;
f2y5 = 2;
f3yl =1;
f3y2 = 2;
f3y3 = 0;
f3y4 = 0;
f3y5 = 1;
f4y1 = .359423*Pop5;
f4y2 = - Pop4;
f4y3 = 0;

f4y4 = - Pop2;
```

```
f4y5 = .359423*3;
f5y1 = 0;
f5y2 = 0;
f5y3 = - 1;
f5y4 = (2*.00259*Pop4);
f5y5 = 0;
A = [f1y1 f1y2 f1y3 f1y4 f1y5; f2y1 f2y2 f2y3 f2y4 f2y5;
f3y1 f3y2 f3y3 f3y4 f3y5; f4y1 f4y2 f4y3 f4y4 f4y5; f5y1 f5y2 f5y3 f5y4 f5y5];
fun1 = Pop1+Pop2+Pop3-1;
fun2 = 2*Pop4+2*Pop5+4*Pop3-4.872;
fun3 = Pop1 + (2*Pop2) + Pop5-2.885;
fun4 = .359423*(Pop1*Pop5) - (Pop2*Pop4);
fun5 = .00259*(Pop4'^2) – Pop3;
F = [fun1; fun2; fun3; fun4; fun5]
Ynew = Y - (inv (A)*F);
Eps = Y - ynew;
Y = ynew
Pop1 = y (1);
Pop2 = y (2);
Pop3 = y (3);
Pop4 = y (4);
Pop5 = y (5);
j = j+1;
End
```

The outcomes from ultimate and proximate analyses of Indian coal utilized in this paper are described. The higher calorific value of the coal is determined “by using Dulong and Petit equation, given as,”

$$\text{HHV of coal} = 33823 \times C + 144249\left(H - \frac{O}{8}\right) + 9418 \times S \text{ kJ/kg},$$

Where "C, H, O, and S", are "mass percentages of carbon, hydrogen, oxygen, and Sulphur, respectively," and are gained from ultimate analysis

With the use of the method described by Engel Brecht et al., fixed, and total carbon transformations have been assessed. The formulas for calculating the fixed and total carbon conversions are supplied by

$$\text{Fixed carbon conversion} = \frac{\{(a \times b) - [(d \times e) + (f \times g)]\}}{(a \times b)},$$

$$\text{Total carbon conversion} = \frac{\{(a \times c) - [(d \times e) + (f \times g)]\}}{(a \times c)},$$

where "a" is "coal feed rate in kg/h", "b" is "the percentage of fixed carbon content in coal," "c" is "percentage of carbon content in coal", "d" is "flow rate of bed ash in kg/h", "e" is "percentage of carbon content in bed ash", "f" is "flow rate of filter ash in kg/h" and "g" is "percentage of carbon content in filter ash".

6.7 CHAPTER SUMMARY

After integrating regenerative burners in the reheating furnace, a problem of frequent choking is observed. Further investigation leads to the use of gaseous fuel only with the Regenerative burners. Hence, the integration of coal gasifier and Regenerative burner leads to waste heat recovery to the tune of 25-30%. However, parameters of gasification need to be optimized for gaining maximum energy saving through waste heat recovery. In this chapter various gasifiers have been studied and analyzed for the said application and other parameters have been optimized.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 CONCLUSION

The waste heat in furnace flue gas may be recovered by using a regenerative burner along with a ceramic thermal storage system. However, this system works well with gaseous fuel. Hence, cheap fuel like the one coal/biomass may be converted to Syngas, and energy saving to the tune of 25%-30% may be achieved.

A “bubbling fluidized bed gasification reactor” has been studied using Indian low-grade coal containing high ash content. The equivalency ratio has been modified between 0.25 and 0.35. It is the ratio of the “actual mass flow rate of air supplied” to the “stoichiometric air mass flow rate required for absolute combustion”. Coal and steam have different mass flow rates, ranging from 0.15 to 0.25. In-depth research has been done on how steam and air flow rates affect the "calorific value of product gas, carbon conversion, and cold gas efficiency."

As the “air to coal feed rate ratio” increases, the synthetic gas calorific value decreases. Though, it increases as soon as the "steam to coal feed ratio" rises, maintaining a constant equivalency ratio. The synthetic gas calorific value "increased from 3.6 MJ/m3 to 4.8 MJ/m3" in this investigation when the “steam to coal ratio” was “raised from 0.15 to 0.25”.

Additional residence time is accessible for ash-bound coal particles to react when the "air to coal ratio" is reduced. When a result, as the ratio of air: coal declines, so does the overall carbon transformation. The total carbon conversion rises by around 10% as the "air to coal ratio" decreases from two to about 1.5. The total carbon conversion is unaffected by the steam: coal. Overall carbon conversion is shown to remain practically around a value of 83.4 percent when the "steam to coal ratio" is raised from "0.15 to 0.25", as there is only a little change in the "value of unburnt carbon in the fly ash and the bed ash".

Compound	No. of moles by using MATLAB
n-CO	0.6259
n-CO_2	0.3719
n-CH_4	0.0022
n-H_2	0.9164
n-H_2O	1.5152
n-N_2	1.128

Table 7.1: MATLAB Solution

Whereas many fluidized bed gasifiers provide H2/CO ratios between 0.6 and 1.2, our current estimates indicate that 1.46 or around 1.5 will be achieved as the ultimate ratio. This is a result of the current research.

7.1.1 Cold gas efficiency

The efficiency of Cold gas is evaluated utilizing the formulae provided below:

$$\text{Cold gas efficiency} = \frac{\text{Syn gas flow rate in m}^3/\text{s} \times \text{Gas HHV in MJ/m}^3}{\text{Coal feed rate in kg/s} \times \text{Coal HHV in MJ/kg}} \text{X100}$$

7.1.2 Gas higher heating value

“Gas higher heating value (HHV)” depend on “product volume percentages (Vi)” of “CO, H2, and CH4 and their calorific values (CVi).” It is quantified as

$$\text{Gas HHV} = \frac{V_{CO} \times CV_{CO} + V_{H_2} \times CV_{H_2} + V_{CH_4} \times CV_{CH_4}}{100}$$

One important factor that influences how a gasification unit operates is the reaction temperature. The steps in gasification must be combined in a way that the endothermic processes, that primarily consume gases like H2O and CO2, get heat from the exothermic reactions, that release heat and need oxygen.

The cold gas productivity rises with the decline in “air to coal ratio.” Cold gas effectiveness rises with the increment in “steam to coal ratio.”

According to this research, there is a perfect functioning device for a certain sort of coal in a particular reactor. The gasification performance is significantly improved by careful modulation of the air, coal, and steam flow rates as well as proper particle size selection in the feed coal. The degenerating effects of coal with a high ash content may be avoided by providing sufficient bubbling (by appropriately setting up the regime) and sufficient residence time.

The above evidence shows that the key cause of a furnace's poor performance is heat loss through the flue gas. Recovering this heat and transferring it to the furnace will conserve a significant amount of fuel and reduce energy consumption. As a result, heat recovery was accomplished by inserting a thermal battery (Honeycomb, ceramic) at the furnace's end, which extracts warmth from the flue gas. Heat recovery from “flue gas” has been used to save 27 percent by installing two of these burners facing each other. However, due to the high ash content in Indian coal, this thermal battery is prone to repeat choking. As a result, it has been discovered that these types of heat recovery devices can be used for renewable fuels such as gases.

Approximate 25% energy consumption of Re-Heating furnace may be reduced using Re-Generative burner along with blended gaseous fuels. The economically viable eco-friendly fuel will be producer gas made from low-grade coal and it may change the GDP of India. Based on the findings, two additional furnaces were selected for testing to measure the heat loss due to waste heat “in the flue gas.” The volume of waste heat within the flue gas was calculated using two furnaces: a walking beam and a pre-heating furnace. The heat loss in the form of waste heat was found to be approximately 141 million Mcal/annum for the walking beam and 598 million Mcal/annum for the furnaces rated at 75 tonnes/hour and 150 tonnes/hour, respectively.

As a result, an efficient method for recovering losses from flue gases that is suitable for Indian coal quality has been developed. The suggested method employs a regenerative burner and partial coal combustion in the existence of excess “oxygen and steam,” resulting in the formation of synthesis gas with a high calorific worth. The research was undertaken on the different constituents of this gaseous material, and it was discovered that coal gas generated under optimal conditions is ideally suited and has a calorific value comparable to natural gas. As a result, an integrated coal gasification system with a scrubber (for gas cleaning) and a pair of regenerative burners is the ideal choice for lowering energy usage and costs.

Hence, an integrated solution is best workable in such Re-heating furnaces in Steel Re-rolling mills. As of date, approx. 3500 small & medium size steel re-rolling mills are running in India. This may lead to the production of steel at globally competitive prices and may change the GDP of India. Simultaneously reduction of production cost and GHG emission.

The integration of the following is required.

4. Coal gasifier
5. Re-Heating furnace
6. Regenerative burner

7.2 FUTURE SCOPE OF WORK

In the future, some more biomass may be mixed along with coal and study may be made for getting the most productive fuel for the furnaces with regenerative burners. In addition, a new design of burners may facilitate avoiding choking in the regenerative burner. This new design may have the feature of avoiding choking or frequent online cleaning of burners. This way it will further save the energy used for the conversion of coal to gas.

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LIST OF PUBLICATIONS

1. **Publication 1: Scopus Indexed**
   Research Article:
   https://www.sciencepubco.com/index.php/ijet/article/view/10076
   10.14419/ijet.v7i2.6.1007
   Article: **Secondary Steel Mill furnace performance**
   Journal: International Journal of Engineering & Technology, 7 (2.6) (2018) 102-106. Authors:
   1. Mr. Yogesh Chandra Gupta, UPES
   2. Dr. Kamal Bansal, UPES
   3. Dr. S.N.Sriniwas, UNDP

2. **Publication 2: Scopus Indexed**
   Research Article: http://www.ripublication.com/ijaer17/ijaerv12n23_48.pdf

   Article: **Assessment of Losses of Reheating Furnace in a Steel Re-Rolling Mill** Journal: International Journal of Applied Engineering Research

   ISSN 0973-4562, Volume 12, Number 23 (2017) pp. 13359-13364. Authors:

   1. Mr. Yogesh Chandra Gupta, UPES
   2. Dr. Kamal Bansal, UPES
   3. Dr. S.N.Sriniwas, UNDP

3. **Publication 3: IEEE Conference Paper,** ID: 5169043
   Effects of furnace efficiency in Steel Re-Rolling Mills - Highlighting the

   Conservation opportunities IEEE Explore. Authors:

   1. Mr. Yogesh Chandra Gupta, UPES
   2. Dr. Kamal Bansal, UPES
   3. Dr. S.N.Sriniwas, UNDP

4. **Publication 4: Scopus Indexed**
   http://www.testmagzine.biz/index.php/testmagzine/article/view/10028

   Efficiency Enhancement of Furnace and Waste Heat Recovery by Regenerative Burner System

   Journal: TEST Engineering & Management , May – June 2020 ISSN: 0193-4120, Volume 83, Page No. 16392 – 16395 . Authors:

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