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A Review on: Analysis and Investigation of Hardening Furnace for Minimization of Heat Losses and Efficient Fuel Utilization

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***Abstract*--In an iron and steel industry heat treatment of the semi-finished product from blooming billets or stabbing mills and continuous shop such as slabs, blooms and billet is done to achieve certain mechanical properties such as strength, flexibility, hardness and reduction of residual stresses. During heat treatment semi-finished productare heated to a temperature ranging from 900ºC to 1200ºC depending upon the type of heat treatment required. . Many heat treating processes require the precise control of temperature over the heating cycle. For heat treatment the products are heated in a furnace and the energy for heating is supplied by burning liquid or gases fuel.This energy supplied accounts for about 2% to 15% of the total production cost. Heat supplied by the fuel is partly absorbed by the semi-finished product and rest of the energy is lost in the form of heat losses. This lost heat energy increase the fuel consumption and hence the production cost. A work is carried out in SUNFLAG IRON AND STEEL INDUSTRY, BHANDARA to investigate a hardening furnace for analyzing the modes of heat losses. The aim of the paper is to find out different areas and forms of the heat losses and to analyze the different possibilities for energy efficiency improvements. Among different modes of heat losses major amount of heat is lost through flue gases and the heat from the flue gases can be utilized by heat recovery system to heat the incoming air or to preheat the semi-finished products. This preheating of the incoming air helps in reducing the amount of fuel used for heat treatment process. The paper also deals with the utilization of excess air whichalso an important factor is leading to heat losses.**

Keywords--Hardening furnace, heat treatment, heat losses, excess air, heat recovery, LDO oil.

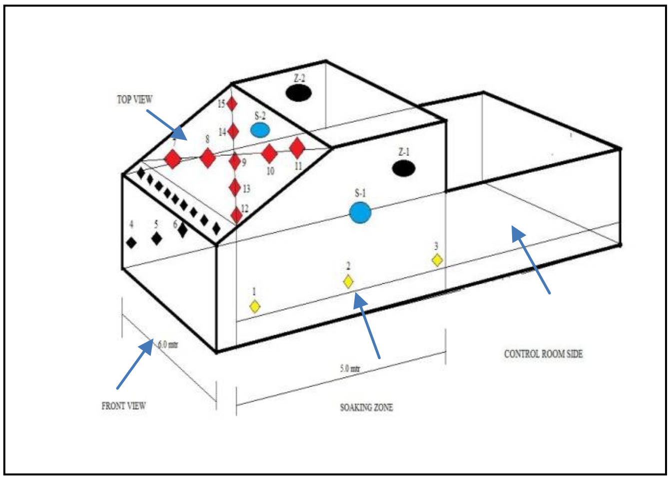
I. INTRODUCTION

Heat treating is the controlled heating and cooling of a material to achieve certain mechanical properties, such as hardness, strength, flexibility, and the reduction of residual stresses. Heat Treatment may be defined as heating and cooling operations applied to metals and alloys in solid state so as to obtain the desired properties. Heat treatment is often associated with increasing the strength of material, but it can also be used to refine the grain size, relieve internal stress, to improve machinability and formability and to restore ductility after a cold working process. Some of the objectives of heat treatment are summarized as follows:

• Improvement in ductility
• Relieving internal stresses
• Refinement of grain size
• Increasing hardness or tensile strength
• Improvement in machinability
• Alteration in magnetic properties
• Improvement in toughness

For heat treatment the metal are heated in a furnace. A furnace is an equipment used to melt metals for casting or to heat materials to change their shape (e.g. rolling, forging) or properties (heat treatment). A furnace is essentially a thermal enclosure and is employed to process raw materials at high temperatures both in solid state and liquid state.Furnace is by definition a device for heating materials and therefore a user of energy. Several industries like iron and steel making, nonferrous metals production, glass making, manufacturing, ceramic processing, calcination in cement production etc. employ furnace. Furnace ideally should heat as much of material as possible to a uniform temperature with the least possible fuel and labor. The main requirement of the furnaces in the heat treatment process is to provide the necessary heat input for the load/work piece. The furnace also requires a control system to control the temperature in the furnace accurately.

The project work done on the furnace is of continuous type indirect heated LDO OR LPG [Duel fuel]fired per-cast refractory walking beam type hardening furnace suitable for heating various size of steel bars ranging from 6 mm- 80 mm in diameter and 4 m – 6.5 m in length. The furnace is principally designed for a production of 1000 kg/hr. production for the reference size of 22mm x 6m rod. The materials are loaded manually on an inclined table with un-scrambler arrangement which will transfer a batch of bars into the grooves of the fixed beam outside the furnace. The walking beam mechanism then moves the materials by one station during each walking beam cycle. For the walking beam cycle time is adjusted by the timer of PLC. The furnace is fired with LDO oil. The burners are located on either sidewall in staggered manner along the length of the furnace. There are 6 burners located on the wall of the furnace.There are total 15 k- type thermocouples mounted at different locations on the furnace for measurement of uniformity of temperature. The schematic diagram of the furnace and location of this thermocouple is shown in figure. 1.



3 Nos Thermocouples on control room side	'TUS' THERMOCOUPLES
3 Nos Thermocouples on opposite side control room	'TUS' THERMOCOUPLES
9 Nos Thermocouple on top side	'TUS' THERMOCOUPLES
9 Nos Optional Thermocouple	'TUS' THERMOCOUPLES
Z-1Furnace Control room side	CONTROLLING THERMOCOUPLES
Z-2Bright Bar side	CONTROLLING THERMOCOUPLES
S-1Furnace Control room side	'SAT' THERMOCOUPLES
S-2Bright Bar side	'SAT' THERMOCOUPLES

Figure. 1 Diagrammatic View of Furnace

II. LITERATURE REVIEW

Anton Jaklic a, Tomaz Kolenko b, Borut Zupancic[1], this paper presents a study of the influence of the space between billets on the productivity of a continuous walking-beam furnace.The space between the billets has a significant effect on furnace productivity. Whenthere is no space between the billets long reheating time is needed.When the space between the billets becomes longer the productivity increases until the optimum space between billets is reached and it is taken as 80mm for 180mm billets, where the maximum productivity is achieved.When the space between the billets exceeds the optimum, the productivity is observed to decrease.

Dr. R.K. Jain [2], this paper deals with the importance of an LDO fired furnace for ferrous foundries. A number of castings have producedusing a furnace andthe effect of air preheating and excess air has been studied.At 10 % excess air a flametemperature of 2000^{o}C is obtained. Reducing excess air reduces the combustion volume which ultimately increases the flame temperature. This increased flame temperature not only reduced the fuel consumption and emission levels but also significantly increased the melting rate and quality of castings produced.

J. Kang, R. Purushothaman, Y. Rong[3],The objective of this work is to develop a comprehensive furnace model by improving the current Computerized Heat Treatment Planning System (CHT) based furnace model to accurately simulate the thermal profile of load inside the furnace. The study include involvement of various constant and their effects are studied. A new model was developed using the Knowledge Data Discovery technique. The recommended future work for the project is the incorporation of a load optimization routine. Another idea is using FEA as a knowledge input to model the process variations once the thermal profile of the load is calculated.

Steinboeck,a, D. Wildb, T. Kieferb, A. Kugia[4], A mathematical model of the reheating process of steel slabs in industrial fuel-fired furnaces is developed. Temperature field inside the slabs is computed by means of the Galerkin method. Radiative heat transfer inside the furnace constitutes boundary conditions that couple the dynamic subsystems of the slabs. The model allows the computation of a 1-dimensional approximation of the transient temperature field. The dynamic subsystems of the slabs are coupled by radiation boundary conditions.

Yongxiang Yang, Reinier A. de Jong and Markus A. Reuter [5], In this paper, a mobile heat treatment furnace was simulated by using CFD to investigate thermal performance of the furnace and the heating process of the metal pieces. Since the temperature evolution inside the metal piece cannot be tracked in practice, CFD simulation provides a useful tool to predict the temperature evolution within the metal pieces during the heat treatment. The current CFD model consists of turbulent combustion, thermal radiation, and conjugate heat transfer. Temperature measurement was carried out to provide thermal boundary conditions and calibrate model parameters.

Shri P.K.Thakur, Shri K. Prakash,Shri K.G.Muralidharan, V.Bahl, Shri S.Das [6], In this paper work is carried to analyze the possibilities for energy efficiency improvements through utilization of measurement and automatic control; this includes both direct fuel savings and indirect savings due to product quality improvements.DCS/PLC systems along with smart instrumentation systems and digital drives are used for efficient operation of walking beam reheating furnace and this helps in reducing scale losses and achieving energy optimization. Fuel saving is achieved using waste heat recovery system.

Dipesh D. Shukla, Niraj C. Mehta, Ravi K. Popat [7], in this paper analysis is done to study effect of wall thickness on heat losses. Heat flow decreases with increase of wall thickness and after some value of thickness it againincrease. Heat lossesare calculated at various wall thickness of furnace and it found that heat losses are minimum for higher thickness and lower for thin walls.

III. PROBLEM IDENTIFICATION

Thermal efficiency of process heating equipment, such as furnaces, ovens, heaters, and kilns is the ratio of heat delivered to a material and heat supplied to the heating equipment. The purpose of a heating process is to introduce a certain amount of thermal energy into a product, raising it to a certain temperature to prepare it for additional processing or change its properties. To carry this out, the product is heated in a furnace. This result in energy losses in different areas and forms.Ideally, all heat added to the furnaces should be used to heat the load or stock. In practice, however, a lot of heat is lost in several ways as shown in Figure 2.

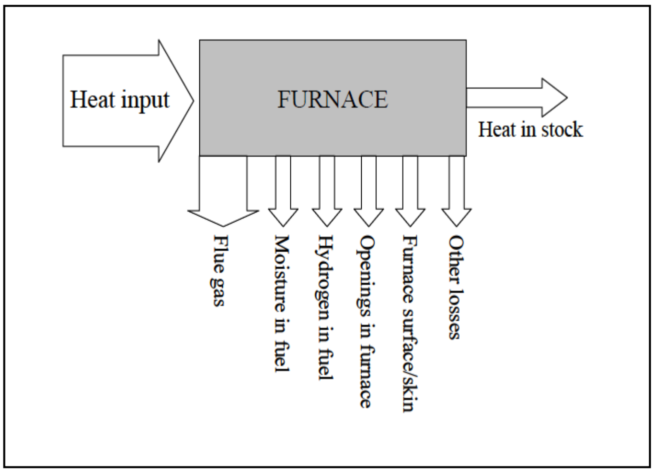


Figure. 2 Heat Losses in a Furnace

Losses occurring in the furnace include:

- Heat storage in the furnace structure
- Losses from the furnace outside walls or structure
- Heat transported out of the furnace by the load conveyors, fixtures, trays, etc.
- Radiation losses from openings, hot exposed parts, etc.
- Heat carried by the cold air infiltration into the furnace

1) Stored Heat Loss: First, the metal structure and insulation of the furnace must be heated so their interior surfaces are about the same temperature as the product they contain. This stored heat is held in the structure until the furnace shuts down, then itleaks out intothe surrounding area. Fuel is consumed with no useful output.

2) Wall losses: Additional heat losses take place while the furnace is in production. Wall or transmission losses are caused by the conduction of heat through the walls, roof, and floor of the heating device.

3) Material Handling Losses: Many furnaces use equipment to convey the work into and out of the heating chamber, and this can also lead to heat losses. Conveyor belts or product hangers that enterthe heating chamber cold and leave it at higher temperatures drain energy from the combustion gases.

4) Cooling Media Losses: Water or air cooling protects rolls, bearings, and doors in hot furnace environments, but at the cost of lost energy. These components and their cooling media (water, air, etc.) become the conduit for additional heat losses from the furnace. Maintaining an adequate flow of cooling media is essential, but it might be possible to insulate the furnace and load from some of these losses.

5) Radiation (Opening) Losses: Furnaces and ovens operating at temperatures above 540°C might have significant radiation Losses. Hot surfaces radiate energy to nearby colder surfaces, and the rate of heat transfer increases with the fourth power of the surface's absolute temperature. Anywhere or anytime there is an opening in the furnace enclosure, heat is lost by radiation, often at a rapid rate.

6) Waste-gas Losses: Waste-gas loss, also known as flue gas or stack loss is made up of the heat that cannot be removed from the combustion gases inside the furnace. The reason is heat flows from the higher temperature source to the lower temperature heat receiver.

7) Air Infiltration: Excess air does not necessarily enter the furnace as part of the combustion air supply. It can also infiltrate from the surrounding room if there is a negative pressure in the furnace.Every time the door is opened, considerable amount of heat is lost. Economy in fuel can be achieved if the total heat that can be passed on to the stock is as large as possible.

IV. GENERAL FUEL ECONOMY MEASURES IN FURNACES

There are about 92% heat losses occurred in a hardening furnace while heat treatment of steel material. Hence the amount of fuel required for this treatment is more i.e. 90 liters per hour which increases the cost material production. So there is need of minimizing these heat losses so that fuelconsumption can be minimized. Typical energyefficiency measures for an industry with furnace are suggested below:

1) Complete combustion with minimum excess air
2) Correct heat distribution
3) Operating at the desired temperature
4) Reducing heat losses from furnace openings
5) Maintaining correct amount of furnace draught
6) Optimum capacity utilization
7) Waste heat recovery from the flue gases
8) Minimum refractory losses
9) Use of Ceramic Coatings

In this project work concentration is focused on controlling the amount of excess air and to recover energy from exhaust flue gases by mean of heat recovery system.

Complete Combustion with Minimum Excess Air

The amount of heat lost in the flue gases (stack losses) depends upon amount of excess air.Air ratio is the value that is given by dividing the actual air amount by the theoretical combustion air amount and it represents the extent of excess of air.To obtain complete combustion of fuel with the minimum amount of air, it is necessary to control air infiltration, maintain pressure of combustion air, and fuel quality and excess air monitoring.Higher excess air will reduce flame temperature, furnace temperature and heating rate. On the other hand, if the excess air is less, then unburnt components in flue gases will increase and would be carried away in the flue gases through stack.The optimization of combustion air is the most attractive and economical measure for energy conservation.

B. Waste Heat Recovery from Furnace Flue Gases

The exhaust flue gases leaving the furnace carry major amount heat energy with them while leaving the furnace. Hence to recover this lost energy from flue gases is important for energy efficiency of the furnace. The flue gases leaving the furnace carry 35 to 55 percent of heat input to the furnace.Waste heat recovery should be considered after all other energy conservation measures have been taken. Minimizing the generation of waste heat should be the primary objective. The sensible heat in flue gases can be generally recovered by the following methods:

• Charge (stock) preheating,
• Preheating of combustion air,
• Utilizing waste heat for other process

1) Charge Pre-heating: When raw materials are preheated by exhaust gases before being placed in a heating furnace, the amount of fuel necessary to heat them in the furnace is reduced. Since raw materials are usually at roomtemperature, they can be heated sufficiently using high-temperature gas to reduce fuel consumption rate.

2) Preheating of Combustion Air: Preheating of the incoming air into the furnace is another method of waste heat recovery. This method was not earlier used in most of the industry. A variety of equipment can be used to preheat the combustion air. External recuperators are most commonly used for this purpose. The hardening furnace uses the shell and tube type recuperator and by using it incoming air to the furnace can be heated up to280ºC to 300ºC. So about 30% of heat is recovered using the recuperator. External recuperator is shown in figure 3.

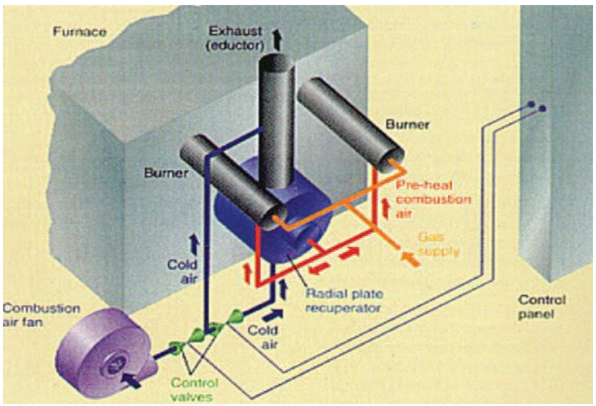


Figure. 3 Preheating the Air by a Recuperator

V. CONCLUSION

Working and construction detailing of the hardening furnace is studied and modes of heat losses are found out. Amount of heat loss is largely depends on excess air used during combustion. Too high excess air increases heat losses while too low excess air results in incomplete combustion. Hence amount of excess air should be optimized. Also large portion of heat energy is lost along with flue gases leaving the furnace. This lost heat energy can be recovered by using it for heating of the material or by preheating incoming air to the furnace and it helps in reducing fuel consumption rate.Mathematical modelling of the furnace is also done for efficient operation and for fuel economy. The utilization of space between the billets is also important consideration for heat economy of the furnace. Lesser space between the billets results in low heating of the billets and hence increases the fuel consumption rate. Hence there should be the optimum space maintained between the billets so that proper heat is distributed to the billets and hence less fuel consumption is achieved.

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