A REVIEW ON: EFFICIENT ENERGY OPTIMIZATION IN REHEATING FURNACES

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Abstract- In Iron and Steel Industry Semi-finished products from blooming-billet/slabbing mills and continuous casting shop such as slabs, blooms & billets are reheated in reheating furnace to a temperature of 1260°C to 1280°C using mixed gas(Coke Oven gas & Blast Furnace gas/BOF gas) having calorific value around 2400 kcal/m³ along with hot combustion air for plastic deformation in rolling. During the process reheating of the semi-finished products, scale formation (metal loss) takes place and it depends on the variation of the time-temperature cycle with rolling rate and mill delays, presence of CO₂, SO₂, moisture and unburnt oxygen etc in the flue gas. The aim of this paper is 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. Focus is on energy use in steel reheating furnaces for rolling mills. The demands on the reheating process and the operational conditions that are essential for its control are described. There is another area for reducing energy consumption is by waste heat recovery from flue gases and the reduction in specific fuel consumption/ton of finished products, scale losses during reheating and rolling process and the advantages of walking beam furnace over pusher type reheating furnaces. The paper also deals the control of surface oxidation by improving the combustion efficiency, controlling temperature for minimizing fuel consumption and better utilization of energy in terms of specific fuel consumption/ton of finished steel.

Keywords- Energy Optimization, Semi-Finished Products, Reheating Furnace, Scale Formation (Metal Loss), Specific Fuel Consumption, Waste Heat Recovery, Walking Beam and Pusher Type Reheating Furnaces, Better Utilization of Energy

I. INTRODUCTION:

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 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 results in energy losses in different areas and forms as shown in snaky diagram figure1.1. For most heating equipment, a large amount of the heat supplied is wasted in the form of exhaust gases.

In the reheating furnaces, the thermal efficiency and uniform heating play an important role in reduction of energy cost and minimization of metal defects. The purpose of a reheating furnace is to provide uniformly heated slabs/blooms/billets at the discharge end of the furnace before they are rolled. It is essential to improve the efficiency of furnace by saving energy and to get higher yields, less unwanted grain coarsening and more homogeneity in the products and to obtain better thermo-mechanical properties of the steel. It is essential to adopt the modern heating trends/parameters/control system/technology for the better management of energy in the present scenario for faster industrialization and less resources of energy as well as eco balance.

Reheating furnaces constitute an important element of the rolling mills, in which the semi-finished steel products are heated to a desired temperature for achieving the plastic properties in the products for rolling.

The basic purposes of heating the semi-finished metal products for rolling:
- Is to soften the metal suitable for rolling.
- Providing a sufficiently high initial temperature so that rolling process is completed in fully austenitic temperature region.

In order to have smooth operation of rolling mills, design features and operation of reheating furnaces plays an important role. The design features and operating parameters determines the quality of rolled
product, yield, energy consumption, pollution and the economics of the product. In modern walking beam reheating furnaces, semi-finished products such as slabs/blooms/billets are uniformly heated to a desired temperature and have minimized skid marks. The operations of walking beam reheating furnaces are computerized control (using PLC/DCS systems along with level 2 systems) to achieve higher energy efficiencies and to have plan view rolling.

The basic operation requirements of reheating furnaces are:

- To achieve the desired minimum temperature consistently and to get desired metallurgical properties at the finishing stands of the mill.
- Minimizing temperature difference between surface and core and along the length to a desired level as low as 15°C to 25°C.
- Minimizing cold spots (skid marks).
- Avoiding overheating and burning of metal.
- Minimizing scale formation, decarburization.
- Avoiding thermal stresses and cracks.
- Elimination of scratches on the bottom surface of slab/blooms/billets.
- Low Energy consumption and minimal heat losses.
- Advance and easiest control functional systems.

The Heating operation in the reheating furnaces is associated with combustion of fuel as mixed gas and preheated air, the generated heat exchanged from the combustion products to the walls of furnace and finally from the combustion products & the walls of furnace to the stock by conduction/convection/radiation processes. Combustion process and the process of heat transfer from the combustion products to the stock have some limitations and may create some quality problems in the final products. The oxidation of the steel during reheating cycles as function of entire furnace atmosphere like oxidizing or reducing, steel residence time in the furnace and steel temperature that causes scale formation and wastage of energy in terms of metal loss.

II. CHARACTERISTICS OF AN EFFICIENT FURNACE:

Furnace should be designed so that in a given time, as much of material as possible can be heated to an uniform temperature as possible with the least possible fuel and labour. To achieve this end, the following parameters can be considered.

- Determination of the quantity of heat to be imparted to the material or charge.
- Liberation of sufficient heat within the furnace to heat the stock and overcome all heat losses.
- Transfer of available part of that heat from the furnace gases to the surface of heating stock.
- Equalization of the temperature within the stock.
- Reduction of heat losses from the furnace to the minimum possible extent.

III. OXIDATION AND BURNING OF METAL:

Understanding the oxidation kinetics in Reheating Furnaces is important because the scale formation in Reheating Furnace represents a yield loss of steel. The yield loss in Reheating operation varies from 1.50% to 2.50% by weight as well as energy losses.

The Oxidation levels in Reheating Furnaces depend on the following factors.

- Composition of metal.
- Oxygen content in the furnace atmosphere.
- Temperature of metal.
- Steel residence time.

The product of combustion is always highly oxidizing and rate of scaling will increase as the surface temperature and the partial enrichment of oxygen, carbon dioxide in the fuel. The rate will decrease as the partial pressure of carbon monoxide increase in the steel. The oxygen percentage in product of combustion is maintained at 1% to 2% to minimize the scale loss. A 35% of saving of steel lost due to scale can be achieved by reducing the excess air in the combustion, which is the total loss of energy during reheating of semi-finished inside the furnaces. Shown in figure no.1.2.

Factors determine the oxidation levels in steel are:

- Factors, which influence oxidation, are Temperature of metal, Residential time of metal and Oxygen level in the atmosphere.
- Temperature factor which influences oxidation of metal - At low temperatures
(900°C and below) oxygen content has no influence on oxidation of steel. At high temperatures (1200°C and above) increase of oxygen content in the furnace atmosphere from 0.3% to 3% increases the oxidation rate by 50%. Further increase of oxygen level above 3% will have little bearing on oxidation.

The scale formation is strongly dependent on surface temperature of metal and residence time in furnace. It also depends on percentage of oxygen present in combustion product. Temperature is the most important factor which, influences oxidation of metal.

E. M. Kotliarevsky used he empirical equations for calculating the scale thickness as follows:

\[ S = \sum \left\{ e^{-\beta/T_{avg.}} \times \delta \tau \right\} \]  

(1)

\[ \mu = \sqrt{(K \cdot S)} \]  

(2)

\[ L_s = \mu / \rho_s \]  

(3)

Where, 
\[ \beta = 18,000 K \text{ for steel} \]
\[ K = 6,130,000 \text{ Kg/m}^4.\text{hr} \text{ for steel} \]
\[ L_s = \text{Thickness of scale, m} \]
\[ \rho_s = \text{Density of scale} = 4500 \text{ Kg/m}^3 \]
\[ \delta \tau = \text{Time duration, hour} \]
\[ T_{avg.} = \text{Average surface temperature of steel, K} \]

Oxidation also causes burning and melting of the grain boundaries in the metal. This defect cannot be rectified. During burning the bond between the metal grains gets loosened and the metal cracks during rolling. To prevent melting, overheating and burning, heating regime of the metal should be observed carefully especially during delays in the mill.

The secondary scale, the scale formed on a hot slab/bloom/billet after water jet is de-scaling or any waiting during rolling, does not crack or spill off easily. The waiting time after de-scaling should be avoided for better quality of products.

IV. DECARBURIZATION (METAL – GAS REACTION):

At reheating temperatures, i.e., 1100°C to 1250°C carbon is oxidized more rapidly than iron. Thus, oxidation in reheating furnaces removes carbon from the surface layer of the steel resulting in deterioration of mechanical properties in the products.

Decarburization is controlled by diffusion of carbon from core to the surface and can be minimized by keeping the residence time at high temperature as short as possible. The furnace atmosphere also influences the depth of decarburization by determining how much decarburized metal is called off.

V. IMPROPER HEATING OF STOCK:

The rate at which heat is absorbed by mild steel must be controlled to avoid “sweating” or partial melting of the surface. The higher rate is maintained during the early stages of the reheating cycle and much lower rate at the end of the cycle. In reheating of metal for hot rolling, it is desirable that their temperatures should be as uniform as possible throughout their sections. Non-uniform heating, overheating and under-heating are the possible deviations in heating of metal. All the problems with respect to heating occur due to the limitations in the design of the furnaces and due to improper operation practices.

VI. FACTORS THAT CONTRIBUTE TO LOSS OF FUEL:

- Furnace capacity un-matched with rolling capacity.
- Improper selection of combustion equipment.
- Inefficient recuperators or absent recuperators.
- Absent / by-passed automatic air / fuel ratio control system.
- Absent automatic temperature control system.
- Absent automatic furnace pressure control system.
- Improper maintenance and operation of furnace and combustion system.
- 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.
- Heat carried by the excess air used in the burners.

Efficiency Problems:

- Fuel-fired furnaces suffer from the perennial problem of low efficiency.
- The largest source of heat loss is through the exit flue gases.
- The higher the furnace temperature, the greater the flue loss.

VII. ADVANTAGES OF WALKING BEAM REHEATING FURNACE:

Walking beam reheating furnace has been developed to achieve low specific fuel consumption of 0.3Gcal/t
and scale losses limited to 0.6%. The walking beam reheating furnace consists of two independent beams mechanism that permit charging and or discharging slabs/billets/blooms without interference the typical residence time for a slab is approximately 2.5 hours, with average velocity (pushing rate of 24 m/hr and average dropout temperature of 1230°C. Skids in soaking zone are not parallel with the axis of furnace to minimize skid marks. There are 10-12 independent controlled heating zones and unfired preheating zone for better fuel efficiency.

Walking-beam furnaces provide better quality slabs/billets/blooms to the mills. Skid marks, or cold spots is a common problem in the rolling mill. Walking-beam units keep slabs/billets/blooms separated. To minimize skid marks, pegs and strands are welded on the top of skid pipes and the spaces between them are filled by heat insulating material. In addition, walking beams which are in direct contact with the metal are usually arranged at an angle to the furnace axis, so that the point of contact between beams and metal changes as the latter moves through the furnace.

Steel product quality is better in walking beams. In a walking beam, slabs/billets/blooms are lifted, moved forward, and put down so that there will not be any mechanical mark (scratches at bottom). The extractors are used to take out slabs/billets/blooms and keep on roll runner table.

The walking-beam furnaces heat more efficiently than pusher furnaces. The new furnaces also reduce decarburization in the slabs/billets/blooms. Steel begins to lose carbon if it stays in a reheat furnace too long because of a delay at the rolling mill. But in the new furnaces, more modern controls allow operators to cut back heat faster than with the older pusher furnace as shown in figure no.1.3.

Some of the following important facilities are available in walking beam reheating furnace

- Optimization of combustion regimes.
- Optimization of thermal regimes.
- Optimization of pressure regimes.

The operation of walking beam reheating furnace control is DCS/PLC system based to achieve the optimal reheating and better quality of products to achieve the following objectives:

- Maintaining Uniform discharge temperature
- Minimum surface scale loss.
- Ability to charge hot slab/bloom/billet without surface damage
- Flexibility to heat hot & cold slab/bloom/billet simultaneously
- Optimum fuel consumption.
- Minimum downtime and ease of maintenance.

The DCS/PLC control system functions are:

- Furnace material tracking
- Online mathematical model
- Control of desired temperature regimes and air-fuel ratio are possible.
- Control of furnace pressure will reduce air ingress and in turn control on oxygen inside furnace.
- Operation interaction for control of temperature is lesser.
- The set values of zonal temperatures - automatically controlled.
- The combustion air flow and gas flow measured.
- Cascade control i.e. ratio of fuel / air flow is controlled by a signal received from temperature controller through flow control valves and oxygen trimming using zirconium based oxygen Analyzers.
- Furnaces pressure control maintains positive furnace pressure.

Figure 1.3. Walking Beam Type Furnace

The operational advantages in waking beam reheating furnace are:

- Removal of scale in soaking zone is done very easily and no solid hearth builds up since there is no solid hearth.
- No pilling up of blooms/billets/slabs.
- Fast and easy removal of slabs/billets/blooms from the furnace to take up repair work.
- Movement of slabs/billets/blooms in the furnaces can be varied as per requirement.
- Differential temperatures in soaking zones can be maintained to have a temperature difference between front and tail ends of long blooms/billets.
- DCS/PLC controlled operations enables in maintaining optimal thermal regimes.
- Forced draft combustion for achieving optimal level of O₂ in flue gas.
- Metallic combustion air and fuel gas preheating system for optimum heat utilization.
• Interlocking and sequential control with respect to charging and discharging.
• Safety for abnormal conditions.
• Records of various inputs and maintaining the database.

VIII. COMBUSTION CONTROL MODEL:

Combustion control models optimize the sensible heat that slabs/blooms/billets absorb and can be applied along the full length of a furnace to achieve the desired drop out temperature with minimal fuel use. When firing zones are not fully isolated and, therefore, not subject to individual control, this leads to inefficient fuel use due to uncontrolled flow of waste gas within the furnace atmosphere. The models can integrate the information of fuel CV, excess air in furnace atmosphere and firing zone temperatures, slab/bloom/billet entry temperature, maximum hearth coverage and mill status etc.

The advantage of process control system is their ability to optimize the ramping of furnace set point temperatures over time during unscheduled delays on mill. It also has potential to decrease furnace set point temperatures during periods of low production and the observed reduction in scale build up, resulting in increased yield and the models can reduce the energy consumption by 3% to 6%.

Discharge Temperature:

The fuel consumption in a reheating furnace depends not only on the mean discharge temperature, which itself dependant on the size of the slabs/ blooms as well as the quality of the steel but also on production time, the schedule downtime and the delay time. Thus, higher discharge temperature will increase fuel consumption, scale formation and reduce furnace efficiency. Adherence of optimum thermal regimes and delay strategy will ensure optimal discharge temperature resulting in reduction in fuel consumption and scale formation.

Good Operational Practices:

Walking beam reheating furnaces have capabilities for better operation, which influences the scale formation, fuel consumption and quality of heating. The factors that contribute are:

• Furnace Productivity
• Hearth Coverage
• Discharge temperature of stock
• Quality of heating
• Excess air in flue gas
• Furnace Pressure
• Waste heat recovery
• Hot charging of stocks

Operational improvements are the most vital factors. With the advent of DCS/PLC system based smart control & Instrumentation systems, digital drives will reduce dependence of human interference to a great extent in operation of furnace.

Waste Heat Recovery from Furnace Flue Gases:

In any industrial furnace the products of combustion leave the furnace at a temperature higher than the stock temperature. Sensible heat losses in the flue gases, while leaving the chimney, carry 35 to 55per cent of the heat input to the furnace. The higher the quantum of excess air and flue gas temperature, the higher would be the waste heat availability. 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. (Figure1.5)

• Charge (stock) preheating,
• Preheating of combustion air,
• Utilizing waste heat for other process (to generate steam or hot water by a waste heat boiler)
**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 room temperature, they can be heated sufficiently using high-temperature gas to reduce fuel consumption rate.

**Preheating of Combustion Air:**

For a long time, the preheating of combustion air using heat from exhaust gas was not used except for large boilers, metal-heating furnaces and high-temperature kilns. This method is now being employed in compact boilers and compact industrial furnaces as well. (Refer Figure 1.6) The energy contained in the exhaust gases can be recycled by using it to pre-heat the combustion air. A variety of equipment is available; external remunerator are common, but other techniques are now available such as self-recuperative burners. For example, with a furnace exhaust gas temperature of 1,000°C, a modern remunerator can preheat the combustion air to over 500°C, giving energy savings compared with cold air of up to 30%, shown in figure no. 1.4.

**Figure 1.6. Fuel saving by preheating of Combustion Air**

**Hot charging of material:**

Hot charging of the material is one of the most efficient fuel saving measures. However this requires suitable facilities in the shop and good synchronization of rolling with the feeding mill. In hot charging, the available sensible heat of the stock can reduce the heat requirement in the furnace considerably, thus improving fuel saving. The walking beams furnace has facilities to choose the charging temperature of slabs/billets/blooms and computer accordingly chose the heating curves and set zones temperatures for optimum heating.

It is important to note that the benefits of hot charging are tangible only when the thermal regimes are adjusted suitably; otherwise only overheating/melting of stock takes place. The regimes can be adjusted only when a considerable number of hot booms/slabs are charged continuously. It is practically impossible to work out regimes for hot charging where it is intermittent and temperature of input stock is widely varying. In some plants to supply consistently uniform temperature of stock, hot boxes are used. Figure 1.7. shows the potential for fuel saving by hot charging.
CONCLUSIONS:

The use of DCS/PLC systems along with smart instrumentation systems and digital drives for efficient operation of walking beam reheating furnace not only reduces the scale loses, but also helps in achieving the energy optimization, achieving product quality in rolling. The walking beam reheating furnace has been developed based low specific fuel consumption of about 0.3Gcal/t and scale losses limited to 0.6% and being achieved by bringing operational improvement in the furnaces. Optimum utilization of furnace can be planned at design stage. Correct furnace for the jobs should be selected considering whether continuous type furnace, the overall efficiency will increase with heat recuperation from the waste gas stream.

The energy optimization in rolling has become essential to reduce the cost of product and to be price competitive and reduction of specific energy consumption is the most important and least cost approach for energy saving.

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