Energy Conservation Measures in Pusher-Type Reheating Furnace through Modifications and Modernization

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Abstract: ***Energy conservation measures taken by Bhilai Steel Plant to improve specific energy consumption are discussed in this paper. Modifications in pusher type reheating furnace are examined to reduce various heat losses through skin losses, excess scale formation, exhaust gas, air inhalation for achieving high thermal efficiency of pusher type furnace. Key energy implications from modernization of pusher type furnace to walking beam type furnace are also discussed as specific energy consumption of reheating furnaces has been brought down by 50% to 260 Mcal/input.***

Keywords: Walking Beam Type and Pusher Type Reheating Furnace, Scale Formation (Metal Loss), Specific Energy Consumption, Semi Finished Products.

1. Introduction

In Bhilai Steel Plant, Semi-finished products from blooming-billet mills such as blooms & billets are reheated in reheating furnace to a temperature of 1150°C to 1250°C using mixed gas(Coke Oven gas & Blast Furnace gas/BOF gas), having calorific value in the range of 1900-2050 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 CO_2, SO_2, moisture, unburnt oxygen in the flue gas and skin losses[1] etc.

Reheating furnaces consume approx. 70-80% of total energy consumption of rolling mill therefore it is paramount to monitor various furnace heat losses (shown in Fig. 1.1) and execute necessary modifications to reduce them.

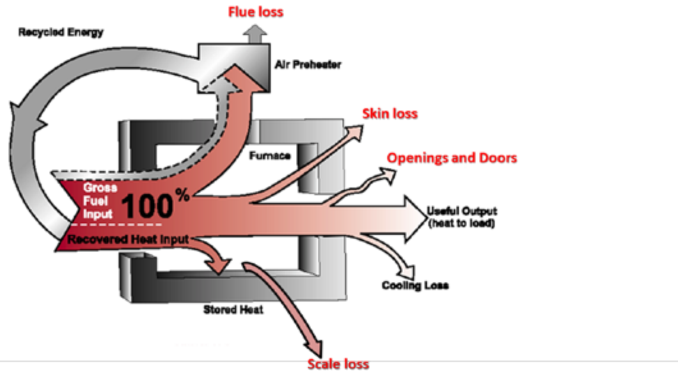

Figure 1.1 (---- Major Loss)

A survey for comparative analysis of various heat losses in reheating furnaces was conducted by BSP and it was found that major heat losses are through flue gas (as hot dry gas and unburnt oxygen), furnace openings and doors(especially during billet discharging) and excess scale formation. Fig 1.2 shows the survey results of these losses.

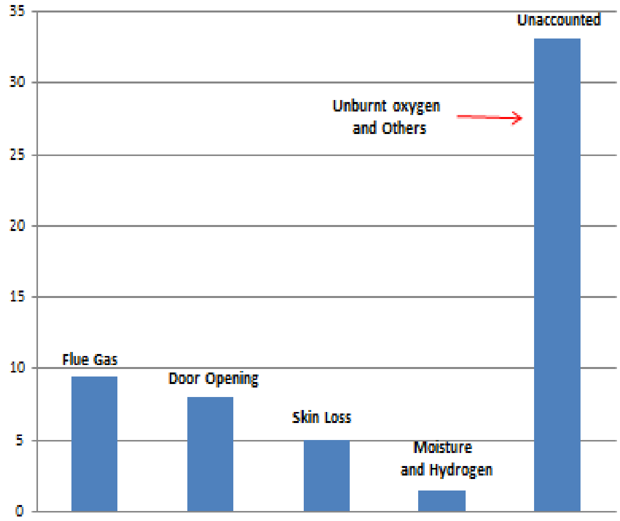

Figure 1.2

Thermal efficiency of these rolling mills is in the range 20 to 30 % [2] and lot of heat is lost in the flue gasses, convective and radiative losses, heating the cooling water, leakages from the furnace etc.

2. Modifications Taken to Reduce Heat Losses

2.1 Installation of Online Oxygen Analyzer

Heating process in reheating furnace is conducted through controlled combustion of mixed gas (Coke Oven gas & Blast

Furnace gas/BOF gas) and air thereby producing high amounts of carbon dioxide in the hot rolling process. Here oxygen concentration in furnace plays a vital role as excess of it will result in unnecessary fuel consumption and iron oxide(scale) formation on metal surface. As air is used for combustion, excess oxygen also leads to formation of NOx emissions which causes nothing but the removal of heat through flue gases (shown in Fig 2.1).

Aim of this modification is to provide the precise amount of oxygen in order to just complete the combustion and simultaneously achieve minimum level of residual oxygen [3]. This results into lower levels of oxygen and NOx emission in flue gas. Hence control of oxygen concentration in furnace is paramount to save majority of heat and metal loss. In the reheating furnace the fuel consumption per ton of steel is about 500-530 Mcal and the oxide scale causes a slab weight loss of about 0.5-0.8%.

<u>There are majorly two sources of oxygen as following</u>

1. **Combustion Air:** This air is supplied to burner through natural draft for causing the combustion of mixed gas

2. **Air Ingress:** Although this is not the major source of air but still sometimes negative pressure is created in furnace due to abnormal cooling which leads to air ingress into the furnace atmosphere.

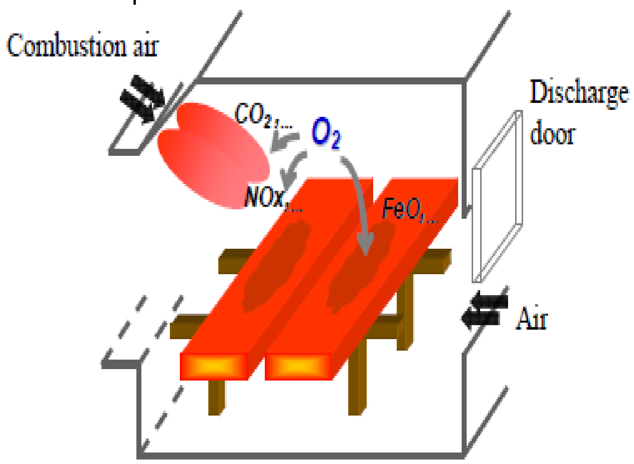

Figure 2.1

Besides the air infiltration, the fluctuation of fuel composition also disturbs the oxygen concentration. The unit volume of air required for complete combustion of fuel is called the theoretical air consumption coefficient and is based on the fuel composition for example, the coefficient for mixed gas. This is usually used as the source of the heating fuel in the reheating furnace. The furnace temperature is controlled by adjusting the fuel flow supplied to the burners and the air flow needed for complete combustion according to the coefficient through automated butterfly valves as shown in Figure 2.2. However, it is difficult to control the composition of mixed gas precisely. Figure 2.3 shows that the calorific value of mixed gas changes in the range of 1900-2000 kcal/m3. If the fuel heating value changes, the amount of air needed for combustion of fuel may be excessive or inadequate, resulting in a variation of the oxygen concentration in the exhaust gas.

Figure 2.2: Operating and Displaying Interface for controlling fuel flow

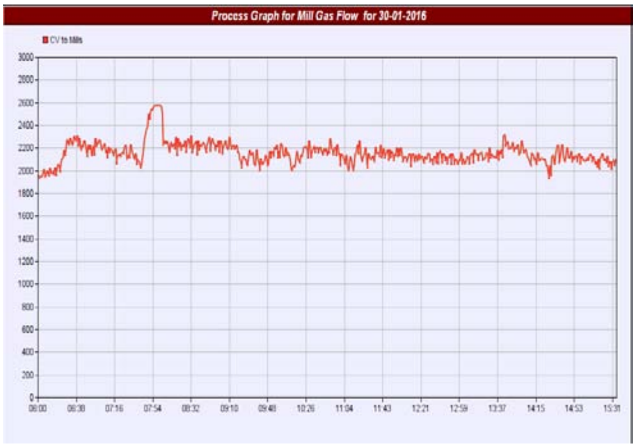

Figure 2.3: Variation in C.V of mixed gas

Oxygen analyzer (Fig 2.4) is installed in preheating zone of reheating furnace to predict the real time oxygen concentration to control Air/Fuel (A/F) ratio automatically. As oxygen analyzers are not very much reliable in high temperature zone therefore A/F ratio is manually fixed to less than 1 in soaking [3], Top and bottom zone. Oxygen concentration of high temperature zone is monitored theoretically from Oxygen concentration in flue gas.

Furnace pressure is adjusted during the discharging of metal to reduce the inhalation of air in furnace and a feedback control based is used to correct any errors from theoretical mode.

Figure 2.4: Oxygen Analyzer

2.2 Closing of Inspection Doors

Opening and closing of furnace doors play a very important role in maintaining the required temperature and Oxygen concentration as mentioned in section 2.1. Heat loss due to openings can be calculated by computing black body radiation at furnace temperature, and multiplying these values with emissivity (usually 0.8 for furnace brick work), and the factor of radiation through openings [4].

> Total heat loss = (Black body radiation) x (area of opening) x (factor of radiation) x (emissivity)

Table 2.1 is a theoretical estimation of heat loss through door opening.

Radiation Factor	0.8
Emissivity	0.8
Black body radiation content at 1280°C	32.0 kcal/cm2 per hr.
Area of opening	79,600.00 cm2
Heat lost through the door opening	**16, 30,208.00 kcal/hr. (6.50 % of total heat input)**

Table 2.1: Heat Loss through Door Opening

Therefore following modification were executed to reduce heat losses through inspection/Discharging door.

2.2.1 Modification of discharge doors using insulating blanket

During the discharging of billets, opening area of furnace is subjected to constant thermal change as a result bricks are cooled and heated as door opens and closes. This results in spalling of firebricks causing damages in refractories. This in turn leads to loosening of furnace wall and creates operational difficulties in closing and opening of door.

In order to overcome the aforementioned problems related to the constant thermal change on opening and closing of furnace door. A furnace door must be provided which is light in weight, unaffected by thermal variations, inexpensive to maintain and convenient for the furnace operators to use.

This was achieved by providing an insulating blanket to the discharging door of furnace.

2.2.2 Stainless Steel Anchors

For the same reasons as mentioned in section 2.2.1 it is paramount to install a discharge door which can respond to continuously changing requirement of closing and opening for the fast rolling process. Thus for the smooth operation of discharge door stainless steel anchors were installed which will not only support the discharge door but also resist the corrosion due to oxidizing environment of furnace.

2.3 Minimization of skin losses

During rolling process as the furnace picks up temperature, side walls and roof gets heated up to 200 – 300 degree C. This results into a temperature gradient between walls, roof and outside environment. Due to natural convection and thermal radiation furnace lose heat or in other way skin losses begin to happen [4]. Table 2.2 is a theoretical estimation of heat loss through skin losses.

Side	Surface Area	Average Surface Temp. (°C)	Surface Losses kcal/sq m/hr	Total heat loss kcal/hr
Left	40.00	250	4524.45	1,80,978.00
Right	40.00	260	4846.45	1,93,858.00
Top	130.00	230	3910.45	5,08,358.50
Front	11.70	200	3064.45	35,854.07
Back	11.70	400	10404.45	1,21,732.07
Heat lost due to surface heat (kcal/hr.)				**10,40,780.63 (4.15 % of total heat input)**

Table 2.2: Heat Loss Due to Skin loss

Skin losses happen mainly due to inefficiency or failure of fire clay refractories of furnace. High temperature zones such as soaking zones and heating zones are subjected to abrupt changes due to dynamic requirement of rolling mills. Repairs, mill check-ups, sudden cobble result in continuous switching of furnace from operational to non-operational state. This results in temperature variation in refractory walls causing spalling and loosening of walls thereby causing failure of furnace walls and roof.

replacement of refractories in a phased manner were planned during repairs of reheating furnace. Each side wall was allotted to specific repairs for its 100 % removal and replacement. Highest wall temperature was observed at the back side of furnace (table 2.2). Thus a repair plan with 3 month repair cycle for back side and 6 month repair cycle for other sides were incorporated. This not only reduced the skin loss but also provided the required furnace availability.

2.4 Replacement of MG Sets with VVVF Drives

Replacement of Motor-Generator (MG) sets for operating the furnace roller table section 220-222, 320-322 with three no. of VVVF drives at Merchant Mill with in-house resources (Drives are old drives removed from other applications earlier after commissioning of IPU projects)

The following technological benefits have been obtained from these drives:

1. Speed regulation is precise
2. The control system is having high dynamic response
3. The over load capacity of the drive is very high and hence the number of tripping due to over load is very less.

Energy intensive old MG sets (58.8% efficiency) were replaced with VVVF drives (97-98 % efficiency) which were not purchased but were reclaimed ones from other applications. It has resulted in *energy savings of 408 MWH and cost savings of Rs. 22.7 lakhs.*

3. Modernization of Reheating Furnace

Although many modifications has been taken into operation but still pusher type reheating furnaces currently operating in mill areas of Bhilai Steel Plant are not the full proof solution to achieve specific energy consumption closer to global benchmarks.

Through our dedicated efforts to comply with global benchmarks, we have improvised the modernization of energy intensive pusher type reheating furnaces by more energy efficient walking beam type reheating furnaces. Figure 3.1 is an indicative of specific energy consumption of Bhilai steel Plant prior (6.4-6.8 Gcal/tcs) and post modernization (5.9 Gcal/tcs).

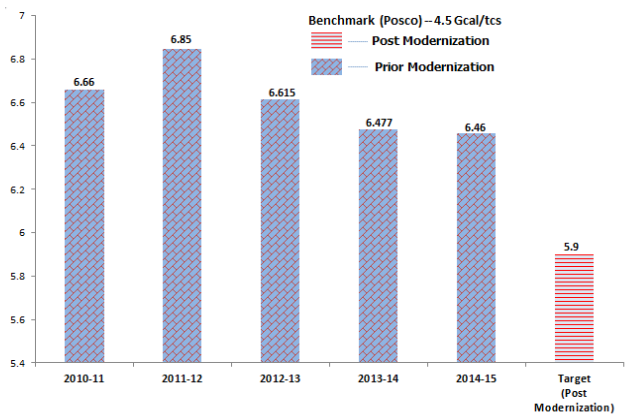

Figure 3.1 Specific Energy Consumption (Gcal/tcs)

3.1 Walking Beam Type Reheating Furnace

The walking beam type reheating furnace (fig 3.2) shall be modern furnace with the state of art facilities for uniform heating of charging for rolling with minimum energy consumption. This modern furnace will achieve lower fuel and power consumption, better temperature uniformity of discharged stock with minimum scale loss, superior surface finish and close tolerances as compared to traditional pusher type reheating furnaces. Walking beam reheating furnace has been developed to achieve low specific fuel consumption of 0.3Gcal/t and scale losses limited to 0.6% [5].

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 2.5hours with average velocity (pushing rate of 24m/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

Figure 3.2 Walking Beam Type Reheating Furnace, BSP

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.

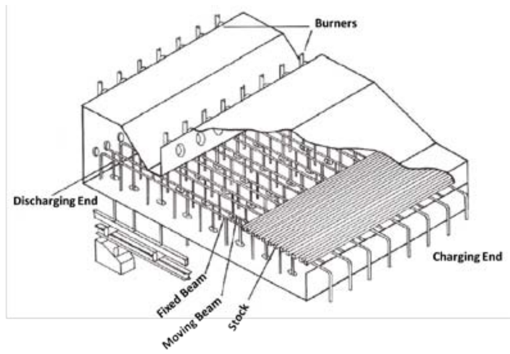

Figure 3.3 Walking Beam Type Reheating Furnace

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 3.3 [6].

3.1.1 The operational advantages in walking beam reheating furnace are:

1. Removal of scale in soaking zone is done very easily and no solid heath builds up since there is no solid hearth.
2. No pilling up of blooms/billets/slabs.
3. Fast and easy removal of slabs/billets/blooms from the furnace to taken up repair work.
4. Movement of slabs/billets/blooms in the furnaces can be varied as per requirement.
5. Differential temperatures in soaking zones can be maintained to have a temperature difference between front and tail ends of long blooms/billets.
6. DCS/PLC controlled operations enables in maintaining optimal thermal regimes.
7. Forced draft combustion for achieving optimal level of O_2 in flue gas.
8. Metallic combustion air and fuel gas preheating system for optimum heat utilization.

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

9. Optimization of combustion regimes.
10. Optimization of thermal regimes.
11. 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:

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

The DCS/PLC control system functions are:

1. Furnace material tracking.
2. Online mathematical model.
3. Control of desired temperature regimes and air-fuel ratio are possible.
4. Control of furnace pressure will reduce air ingress and in turn control on oxygen inside furnace.
5. Operation interaction for control of temperature is lesser.
6. The set values of zonal temperatures – automatically controlled.
7. 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.
8. Furnaces pressure control maintains positive furnace pressure.
9. Interlocking and sequential control with respect to charging and discharging.
10. Safety for abnormal conditions.
11. Records of various inputs and maintaining the data base.

3.1.3 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 desire 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/billets 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 from lower mean discharging temperatures, leading to increased yield and the models can reduce the energy consumption by 3% to 6% [6].

3.1.4 Discharge Temperature

The fuel consumption in a reheating furnace depends not only on the mean discharge temperature, which itself dependent 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.

3.1.5 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 10 to 20 per 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.

Charge (stock) preheating:

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 considerably 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 3.4 shows the potential for fuel saving by hot charging [6].

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.

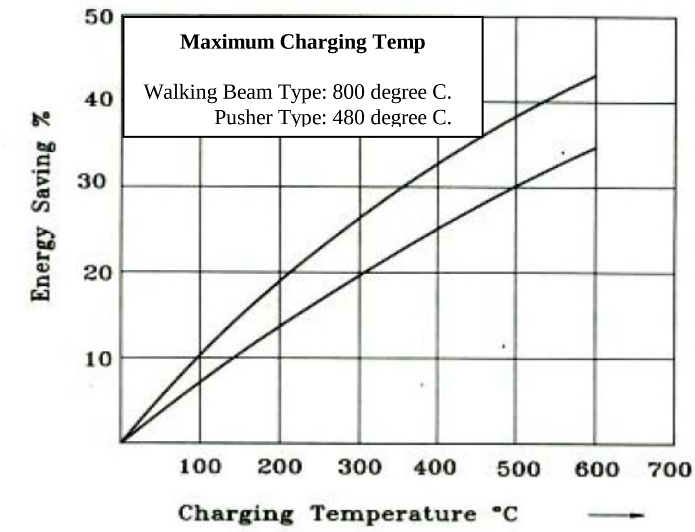

Figure 3.4 Fuel Saving by hot charging of billets

This method is now being employed in compact boilers and compact industrial furnaces as well. The energy contained in the exhaust gases can be recycled by using it to pre-heat the combustion air.

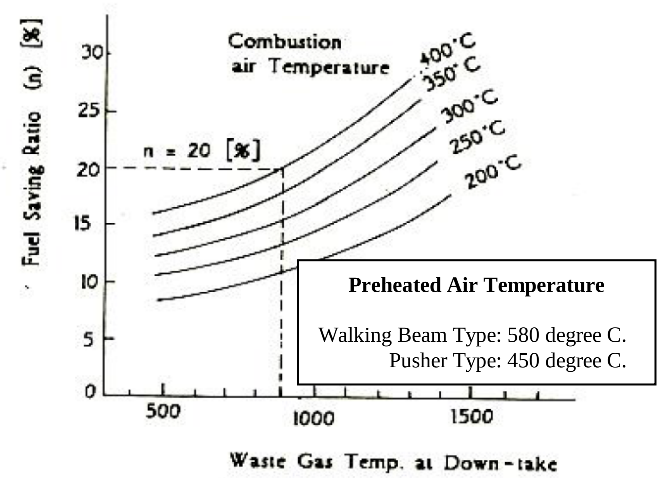

Figure 3.5 Fuel saving by preheating of Combustion Air

A variety of equipment is available; external remunerators are common, but other techniques are now available such as self-recuperative burners. For example, with a furnace exhaust gas temperature of l000°C, a modern remunerator can pre-heat the combustion air to over 580°C, giving energy savings compared with cold air of up to 35% [6], shown in figure 3.5.

4. Conclusion

Heat and energy loss through flue gasses, door openings and due to unburnt oxygen are the major losses in pusher type reheating furnace. These losses need to be precisely monitored and controlled for efficient operation.

Oxygen analyzers installed in preheating zones (lower temperature) along with feedback system can prove to be the major factor in controlling the Air/Fuel ratio and counterbalancing the inhalation of excess oxygen through discharge door. Modification of discharge door through insulation and complete replacement of refractories in a phased manner are of utmost importance for reducing heat losses in pusher type reheating furnace, Moreover any inefficient wasteful practices employed during operation of furnace should be closely observed and monitored.

Modernized Walking beam type reheating furnace along with DCS/PLC systems is proving to be the major step of Bhilai Steel Plant towards achieving global standards of specific energy consumption i.e. 4.5 Gcal/tcs and scale loss less than 0.6 %. Specific energy consumption of furnace can be reduced down by almost 50% from 530 Mcal/input to 260 Mcal/input through modernization of pusher type furnace to walking beam furnace.

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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