THERMAL ANALYSIS OF REHEATING FURNACE

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Abstract - *Thermal Analysis of Reheating furnace is carried out with emphasis on performance analysis of furnace and energy conservation.LPG required to heat one tonne of stab material to 1300^{o} C has increased a lot in the recent years. The increase in fuel consumption is due to heat losses through doors, walls and waste gases. To overcome this following steps are taken. Experimental observations are carried out in the existing reheating furnace. The heat balance calculations, leakage losses and thermal efficiency are calculated. Heat balance calculation shows more than 3 percentage increase in heat loses and 3 percentage decrease in thermal efficiency. Heat loses can be reduced by implementing high emissive ceramic coatings or High Density Infrared Transient Liquid Coatings on the furnace walls and by providing door seals and linings.*

Key Words: **Reheating Furnace**, **Performance analysis, Energy conservation, coatings.**

1. INTRODUCTION

The project area is the walking beam reheating furnace in the HRM of Salem steel plant. The main aim of the project is to improve the thermal efficiency of the furnace and energy conservation.

The different types of reheating furnaces available are furnished below.

Batch type furnace

In batch type furnaces, the charged material remains in a fixed position until the rolling mill temperature is reached.

Continuous type Furnace

In continuous type furnaces, the material moves while being heated. The material moves slowly from the charging side to the discharging side. In continuous type furnaces, there are pusher type and walking beam type.

Pusher Type

Here one slab pushes the other slab while charging, due to impact motion of the slab inside furnace, heated slab gets distracted.

Walking Beam Type

Here the slab is moving at the arranged direction through walking beam mechanism.

1.1 EXISTING FURNACE DETAILS

Walking beam is the type of furnace used in HRM. The reheating furnace is also known as “Walking Beam Furnace”. The total heat attained in the furnace is about 1200^{0}C – 1300^{0}C, which is enough to heat both stainless steel and carbon steel. The furnace is closed type. It was supplied and installed by M/s. ITALIMPIANTI Italy. Totally 11 slabs can be heated at a time. Heating time for one slab may be from 2 to 3 hrs. The furnace is constructed with refractory bricks which are made especially with aluminium oxide. For each 15 minutes, one slab is discharged. Walking beam mechanism does the charging and discharging of slab. There are totally about 9 beams inside the furnace in which 4 are moving and 5 are immovable one. The 5 nonmoving are ahead of the 4 moving one. The walking beam is performed by hydraulic mechanism which is connected to the base of beds using column.

FURNACE DETAILS

Main dimensions of the furnace are as follows.

Inside Furnace

- Length 17.100 m

- Width 11.300 m

Length of different zones (approximate)

- Recuperative 6.000 m
- Heating 6.500 m
  Upper heating zone
  Lower heating zone
- Soaking 4.600 m
  Upper soaking zone left and right side
  Lower soaking zone right and left side
- Number of Slab rows 1

2. PERFORMANCE ANALYSIS

The performance analysis is carried out to identify the existing furnace characteristics during working condition. The observations made during a trial on reheating furnace, the steel production rate, mass flow rate of fuel, preheating air, waste gases, cooling skids and their corresponding temperatures are furnished. Heat balance calculations are performed on second basis. The heat losses through furnace roof, side walls, hearth, charging side lower frontal wall, discharging side lower frontal wall, screen walls, duct before recuperator and side doors of charging and discharging are calculated. Then leakage losses are computed. Analytical analysis is made to find out percentage of over all leakage losses and thermal efficiency of the furnace.

2.1 HEAT BALANCE

Heat balance is a systematic representation of heat release and heat distribution in seconds, minutes, hour or per kilogram of fuel basis. The calculated heat balance is based on seconds. The calculations are done for austenitic and martensitic steel.

- Discharge temperature - Stainless Steel - 1250^{0}C
- 55 tons / hr production
- Reference slab - 170 X 1025 X 9500 mm

The heat balance calculation procedure is as follows

1 Cold steel = m_s C_p ΔT
= 55 x 10^3 / 3600 X 0.41855 X (30-0).
= 191.8254 Kw (0.82%)

2. Fuel = m_f X HV
= 1403 x 47,720.4
= 192602.4836 Kw (83.08%)

3. Oxidation Steel = m_s C_p ΔT
= 55x10^3/ 3600 X0.017X1.3073 X (1250-30)
= 414.232 Kw (1.78%)

4. Preheating air = m_a C_p ΔT
= 28,828.8 / 3600 x 1.067 x (418-30)
= 3315.279 Kw (14.3%)

5 Steel Heating = m_s C_p ΔT
= (55 -3.1) x 10^3 /3600 x 0.6675 x (1250-30)
= 11740.2125 Kw (50.06 %)

6 Waste Gases = m_f C_p ΔT

		=	23569.2 / 3600x 1000x4.178x (364-30)
		=	2711.5055 Kw (11.69%)
7	Cooling skids	=	$m_w C_p \ \Delta T$
		=	(600/3600) x 1000 x 4.178 x (34.4-30.1)
		=	2994.233 Kw (12.916%)
8	Heat loses	=	(1+2+3+4) - (5+6+7)
		=	23181.829563 - 19883.05519
		=	3298.7743 Kw (14.23%)

2.2 HEAT FLOW THROUGH FURNACE - EXPERIMENTAL

(i) Heat Flow Through Roof

The furnace roof is of detrick design. There is not any possibility of flame over it. The furnace roof is of suspension (or) hanging type, and their arrangements are shown in Fig. 4.2 & the physical properties of roof are given in Table No.4.1. The furnace shell is of 6 mm thick steel plate throughout the furnace to withstand thermal and mechanical stresses involved during operation of furnace. The furnace roof length is 17.1m and its width is 11.3m. The thermal conductivities of insulating materials and shell are given below.

Thermal Conductivities

K_A = 4.6725 W / mK

K_B = 3.488 W / mK

K_C = 3.0 W / mK

K_D = 1.04 W / mK

K_S = 45 W / mK

The observations taken on the unit during the test are given below

Temp. of Wall = 110^0C

Tem. Of Air = 30^0C

The heat transfer from furnace wall to atmosphere takes place by natural convection.

Bulk Temperature Tm = (110 + 30) / 2 = 70^0C

Properties of air at 70^0C from data table Ref. [7]

Density = 1.029 kg / m^3.

Kinematic Viscosity = 20.02 x 10^{-6} m^2 / S

Prandtl Number = 0.694

Thermal conductivity = 29.66 X 10^{-3} W / mK

Solution

Length (L) = Area/ Perimeter = 3.402m

Grashof No. (Gr) = $g\beta L^3 (\Delta t) / \gamma^2$

$$= \frac{(9.81 x 3.402^3 x (110-30))}{343 x (20.02 x 10^{-6})^2} = 2.247 \text{ x } 10^{11}$$

Reyleigh No. (Ra) = Gr x Pr = 0.694 x 2.247 x 10^{11}

= 1.56 x 10^{11}

For constant Wall Temperature

Nuselt No. (Nu) = **0.021 x $(Ra)^{0.4}$, (10^9 < Ra < 10^{13})** (Turbulent)

= 0.021 x (1.56 x $10^{11})^{0.4}$ = 630.186

Nu = ho x L /K

h_o = (630.186 x 29.66 x 10^{-3}) / 3.402

= 5.49 W / m^2K

h_i = 250 W / m^2K

Heat flow through roof

$$Q = \frac{A X \Delta t}{\frac{1}{h_o} + \left(\frac{L_A}{K_A}\right) + \left(\frac{L_B}{K_B}\right) + \left(\frac{L_C}{K_C}\right) + \left(\frac{L_D}{K_D}\right) + \left(\frac{L_S}{K_S}\right) + \frac{1}{h_i}}$$

$$= \frac{11.3 X 17.1 X (1300-30)}{\frac{1}{5.49} + \left(\frac{.19}{4.6725}\right) + \left(\frac{.064}{3.488}\right) + \left(\frac{.025}{3}\right) + \left(\frac{.064}{1.04}\right) + \left(\frac{.006}{45}\right) + \frac{1}{250}}$$

= 770134.1336 W

Similar Experimental analysis (thermal) is carried out and calculations are made for the following.

2.3 LEAKAGE LOSSES CALCULATION

			(Watts)
1.	Detric roof	=	770134.1336
2.	Left side wall	=	220206.942
3.	Right side wall	=	220206.942
4.	Hearth	=	459621.7585
5.	Charging side upper frontal wall	=	19378.69887
6.	Charging side lower frontal wall	=	135783.0443
7.	Discharging side upper frontal wall	=	20239.49484
8.	Discharging side lower frontal wall	=	149095.1074
9.	Screen wall	=	37068.224
10.	Charging door	=	54595.667
11.	Discharging door	=	90437.61706
12.	Duct (before recuperator)	=	74722.1465

Total	**=**	**2260484.1147**

Leakage losses = 3298774.34 (-) 2260484.1147

= 1038290.226

a. Percentage of overall leakage loss = $\frac{1038290.226}{3298774.34}$

= **4.4%**

b. Thermal efficiency of the furnace = $\frac{11740212.5}{3298774.34}$

= **50.06%**

Nearly 3% decrease in thermal efficiency of the furnace is found out due to heat losses and leakages.

3. FUEL & HEAT SAVING TECHNIQUES

The effective utilization of heat energy directly saves fuel, continuous research works are being done for saving fuel. Some techniques like furnace wall reflectivity, fuel dynamics and fuel burning methods are briefly discussed.

GENERAL HEAT SAVING TECHNIQUES

Energy savings opportunities in the furnace can be captured by :

- Improved operating practices
- Performing preventive maintenance and repair
- Making cost effective retrofits
- Enhancing the furnace design
- Using advanced materials, sensors and controls, and integrated processing.

3.1 GENERAL AREAS OF HEAT CONSERVATION IN THE FURNACE

Process heating energy use can be reduced by 10-30% by improving operations in the following four areas:

Heat Generation

Heat is generated most efficiently when complete combustion is achieved with a minimum amount of excess air. Efficient combustion optimizes fuel use and lowers the production of NOx, volatile organic compounds (VOCs), and CO_2. Some of the best techniques for improving combustion efficiency are listed below.

- ☞ Control air-fuel ratio.
- ☞ Minimize air leakage into the furnace.

Heat Containment

Relatively minor and low-effort maintenance tasks such as fixing air leaks, closing furnace openings, and maintaining insulation in the furnace walls and doors can improve heat containment. Collectively, such measures can save a considerable amount of energy. Techniques to improve heat containment are listed below.

- ☞ Install proper insulation.
- ☞ Maintain proper furnace pressure. Prevent air leakage.
- ☞ Reduce radiation losses.

Waste Heat Recovery

Waste heat recovery systems extract energy from furnace exhaust gases and recycle it back into the process.Significant efficiency improvements can be achieved by using the recovered heat to preheat the combustion air or charge material, generate steam, heat water, or supply heat to other processes.

- Preheat combustion air.
- Preheat the charge/load.
- Cascade waste heat.

3.2 PROMINENT AREAS OF HEAT CONSERVATION IN THE FURNACE

Furnace Wall Reflectivity

Surface coating of refractory leads to reflection of highly polished surface.

High Emissive ceramic coating

The following High emissive ceramic coating can be carried out for saving of fuel.

i) Zirconium Oxide & Zircon - Alumina

- Zirconium Oxide & Zircon - Alumina - Silica non-toxic & non-inflammable material.
- Coating is applied with spray gun 3-4 Kg.f /Cm^2, pressure to a thickness of 50-60 microns.

Approximate saving of fuel = 21.6% of energy.

Life of ceramic coating is 1-2 years and it depends on furnace temperature.

The specifications of coating materials are given below

Appearance:	:	Grey powder
Use Limit	:	1500°C
Coverage	:	3 Kg. / m2
Density	:	1.51 gm/cc.

ii) High-density infrared transient-liquid coating

The high-density infrared (HDI) transient-liquid coating (TLC) process utilizes a unique technology to produce extremely high-power densities of 3.5 kW/cm^2. High-density infrared (HDI) provides a fast, controllable method for metal-heating applications

Other preferred coatings :

Table -1 Preferred Coatings

Specific application	Coating material
Thermal Barrier	Zirconium Oxide
Resist Fretting	Aluminum Bronze
Particle Erosion	Calcium Zirconate
Shielding	Pure Aluminum
Oxidation Resistance	Cobalt-Molybdenum
Resist Fretting	Molybdenum
Resist Particle Erosion	Fused Nickel-Cobalt
Resist Corrosive Gases	Nickel Chromium
Oxidizing Atmospheres	Nickel Chromium

4. CONCLUSIONS

The thermal analysis of reheating furnace gives exact analysis of combustion of fuel. Calculated values of combustion and air fuel ratio perfectly match with the practical one. Non-luminous gas radiation inside the furnace is calculated from the experimental data and the values determine the appropriate radiant heat flux for heating the steel slab.

Heat balance calculation shows more than 3% increase in heat losses & nearly 3% decrease in thermal efficiency of the furnace, due to the aging factor of refractory materials and leakages. Leakage losses were found to be more than 4% of the total heat losses.

It has been found that high emissive ceramic coating conserves fuel & heat by reducing the heat losses through furnace wall. Installing proper door seals, gaskets and door linings for the doors in the furnace, can conserve more heat and fuel. Further improvement can be done by experimental study.

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