Thermal Efficiency in Steel Reheating Process

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Abstract—**In this study, the energy consumption by the process of steel billet reheating in an industrial steel reheat furnace at the Libya Iron and Steel Company (LISCO) is considered. It is known that in the steel industry, one of the processes requiring the most energy is the process of reheating the steel prior to hot rolling. A comprehensive mass and heat balance was performed on the furnace, taking into account all actual entering and exiting furnace parameters. Furnace thermal efficiency was found to be low and heat losses from different areas of the furnace were considerable.**

Index Terms: **heat balance, material balance, reheat furnace, steel reheating, thermal Efficiency.**

I. INTRODUCTION

Steel reheating is a process where the steel stock is rendered soft by heating it up to high temperature between about 1100 to 1250 °C. There are many studies conducted on steel reheating covering wide areas of energy efficiency, heat transfer, scale formation and productivity[1-4]. It is well known that industrial steel reheating furnaces with their different types are the most energy consuming units. They are used to heat many tons of cold steel of different shapes using liquid or gaseous fuels. The lifetime of these furnaces may span for tens of years of operation. The thermal efficiency of the newly installed pusher type billet reheat furnaces, for example, is about 65%. Due to the aggressive nature of the in-furnace atmosphere, i.e., high temperatures, oxidizing environment and positive pressures, their heating efficiency decline with time of operation. There are many factors that contribute to this decline of heating efficiency which include wall fouling, air infiltration, water cooling, windows openings and mill delays. In this study, a comprehensive material and heat balance was performed on an industrial steel billet reheat furnace at the Libyan Iron and Steel Company (LISCO). Heat losses from the furnace will be evaluated and the furnace thermal efficiency will be calculated and compared with the thermal efficiency specified by furnace manufacturer at furnace installation.

Received 7 August 2016; revised 9 August 2016; accepted 4 September 2016.

Available online 7 September 2016.

A. Furnace Description

The pusher type steel billet reheat furnace at LISCO is a unit of 17 meters long, 13 meters wide and 6 meters high, Figure. 1. The wall of the furnace is multi-layered with insulating materials of different kinds. It consists of a central water-cooled stage above which billets are mechanically pushed. The furnace is direct fired with a total of 32 burners using heavy fuel oil. The production rate of the furnace is about 70 tons per hour of steel billets being heated to approximately 100°C.

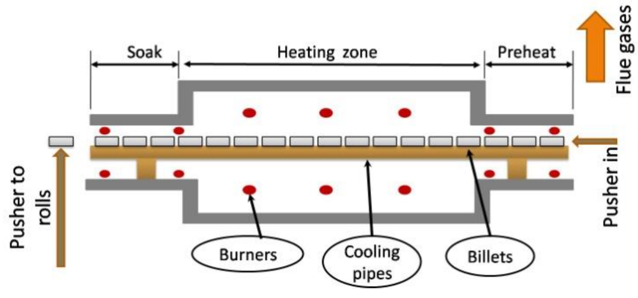

Figure 1. Side View of Pusher Type Steel Billet Reheat Furnace at Libyan Iron and Steel Company (LISCO).

II. MATHEMATICAL TREATMENT

In order to determine the thermal efficiency of the steel reheating process using a pusher type reheat furnace, a comprehensive heat and material balance is conducted on the reheat furnace at LISCO. The general heat balance equation applied is:

$$[Heat\ in\ with\ input\ material]-[Heat\ out\ with\ output\ materials] + [Heat\ of\ combustion]-[Heat\ losses]=0 \quad (1)$$

A. Assumptions

In performing the heat and material balance on the steel reheating operation, the following assumptions were made:

- The heating operation is conducted without any mill delays, and hence, steel flow rate is constant. In reality, mill delays are encountered quite often which would affect furnace efficiency.
- Combustion takes place at 300oC. This temperature is taken as approximately the average temperature between combustion air temperature and fuel temperature.

- Complete fuel combustion is considered. Since the furnace occupies large space where combustion takes place and excess air is used, this assumption would be reasonable.

B. Fuel Composition

The fuel used for combustion is a heavy fuel oil with complex composition of carbon, hydrogen and sulfur, where its exact chemical formula is not known. However, in order to calculate the chemical composition of combustion products it is necessary to know the percentage of carbon, hydrogen and sulfur in the fuel. From the heats of combustion of carbon, hydrogen and sulfur [5], and the heating value of the fuel, fuel chemical composition can be calculated. Considering one kilogram of fuel, the following equation can be written.

$$X + Y + 0.0021 = 1 \ (kg) \quad (2)$$

Where X and Y are the weights of carbon and hydrogen in one kilogram of fuel (plus the sulfur content of 0.0021 kg). The total heat in one kilogram of fuel, i.e., the heating value of the fuel, can be written as:

$$\Delta H_{c,C} \ X + \Delta H_{c,H} \ Y + \Delta H_{c,S} \ x \, 0.0021 = HV_{Fuel} \ (kJ) \quad (3)$$

Where $\Delta H_{c,C}$, $\Delta H_{c,H}$, $\Delta H_{c,S}$ *and* HV_{Fuel} are the heats of combustion of carbon, hydrogen, sulfur and heating value of fuel, respectively. Solving (2) and (3) simultaneously gives the weight percentages of carbon and hydrogen in the fuel.

C. Mass Balance

In order to calculate the heat balance on the furnace all input and output materials flow rates must be determined. These inputs and outputs are shown schematically in Figure. 2.

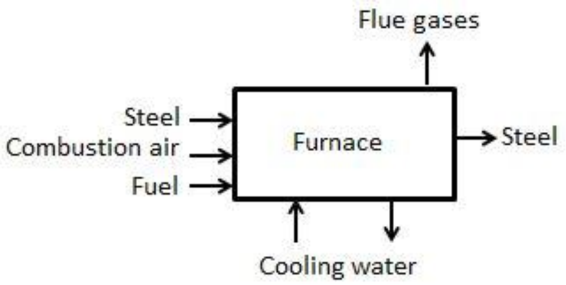

Figure 2. Schematic of the Parameters Considered in Performing the Overall Heat and Material Balance.

The values of the different parameters used in the heat and material balance is given in Table I. These values are measured directly from input and output furnace parameters.

The volumetric flow rates of combustion products (CO_2, H_2O and SO_2) are calculated based on measured input fuel and combustion air flow rates, calculated fuel composition and by the use of the following stoichiometric overall fuel combustion reaction:

$$C + 2H_2 + S + 3O_2 = CO_2 + 2H_2O + SO_2 \quad (4)$$

Steel charging rates and cooling water flow rates are taken as specified in Table 1, collected from the furnace operators.

Table 1. Value of the Different Parameters Used in the Calculation of Heat and Material Blance (from Furnace Operators)

Parameter	Value	Units
Fuel flow rate	2800	*l/hr*
Fuel temperature	90	^oC
Combustion air flow rate	28000	Nm^3/hr
Combustion air temperature	450	^oC
Steel charging rate	70	*ton/hr*
Steel exit temperature	1100	^oC
Cooling water flow rate	245000	*l/hr*
Cooling water exit temp.	37	^oC
Fuel heating value	10298	*Kcal/kg*
Fuel density	0.9061	*Kg/l*
Sulfur in fuel	0.21	*Wt.%*
Steel specific heat	0.17	$Kcal/kg\text{-}^oC$
Flue gas temperature	850	^oC

D. Heat Balance

A total heat balance was conducted on the reheat furnace taking into account all elements entering and leaving the furnace. These elements include fuel, combustion air, steel, cooling water and flue gases. Figure.3 is a schematic of the general furnace heat balance where the temperature of each component in the balance is shown. The main heat source for the heating process is the combustion of fuel oil according to the overall reaction given in (4). The total heat of reaction at 300 ^oC can be calculated as:

$$\Delta H_R^{300^oC} = \Delta H_R^o + \sum_{i=1}^{N} n_i \int_{25}^{300} C_{p_i,OUT}(T) \, dT - \sum_{i=1}^{N} n_i \int_{25}^{300} C_{p_i,IN}(T) \, dT \quad (5)$$

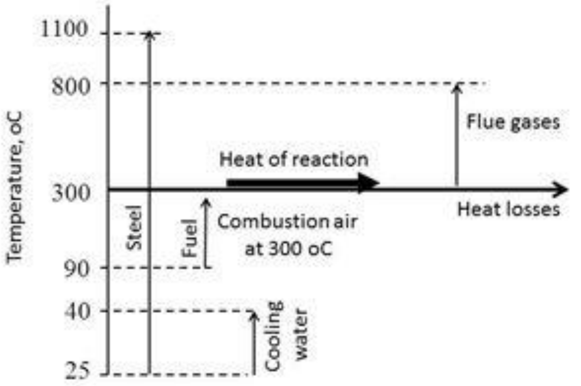

Figure 3. Schematic of the Parameters Considered in Performing the Overall Heat Balance.

where n is the number of moles of each component in the reaction process, C_p is the specific heat of each component and i denotes the particular component. Heat of reaction at the standard conditions is calculated as:

$$\Delta H_R^o = \sum_{i=1}^{N} n_i \Delta H^o_{f_i,(products} - \sum_{i=1}^{N} n_i \Delta H^o_{f_i,(reacants)} \quad (6)$$

where ΔH_f^o is the heat of formation listed in tables for different chemical compounds [5]. The heat associated with combustion air, cooling water, and flue gases are calculated from the equation:

$$\Delta H_{Total} = \sum_{i=1}^{N} n_i \int_{T_1}^{T_2} C_{p_i}(T)\, dT + \Delta H_t \quad (7)$$

Where T_1 and T_2 are the reaction temperature and temperature of off gas, respectively.

E. Process Efficiency

The efficiency of the reheating process can be calculated from the equation:

$$\eta = \frac{Energy\ out\ with\ steel}{Total\ input\ energy} x\,100 \quad (8)$$

III. RESULTS AND DISCUSSION OF RESULTS

The fuel chemical composition calculated from (2) and (3) is given Table 2. The fuel composition is calculated based on knowledge of fuel heating value and the elements present in the fuel, where carbon, hydrogen and sulfur are the only elements considered in the calculations.

Table 2. Calclated Composition of Fuel Oil Used in the Steel Reheating Opertion

Name	Simple	Wt.%
Carbon	*C*	88.03
Hydrogen	*H*	11.76
Sulfur	*S*	0.21

Based on measured flow rates of fuel and combustion air fed to the furnace, and using (4), with fuel composition shown in Table 2 , volumetric flow rates of combustion products were calculated and shown in Table 3.

Table 3. Calculated Combution Products Volumetric Flow Rates at Normal Conditions

Component	(Nm^3/hr)	
	IN	OUT
Fuel oil	2800 (l/hr)	
Combustion air	28000	
CO_2		3865
$H_2O_{(g)}$		3341
SO_2		3.7
O_2 (excess)	With combustion air (6 vol.%)	43
N_2	with combustion air	22120

The heat of combustion using (5) and heats associated with input and output components, using (7), were calculated and given in Table 4.

Table 4. Calculated Quantities of Heats in and out of the Furnace

Component	J/hr	
	IN	OUT
Combustion air	1.604×10^{10}	
Fuel oil	5.036×10^{6}	
Steel		7.671×10^{10}
Cooling water		2.124×10^{6}
Flue gases		3.804×10^{10}
Combustion energy	1.535×10^{11}	
TOTAL	1.700×10^{11}	1.148×10^{11}
Furnace heat losses = 5.5 X 10^{10} (J /hr)		

The output energy distribution is shown in Fig. 4, where the useful energy associated with the heated steel accounts for about 45% of the total input energy to the furnace. Heat losses which calculated as the difference between total heat input and the energy associated with the heated steel and the flue gas, accounted for about 32%. This energy losses is from opening the charge and discharge doors, furnace walls and leaking side windows.

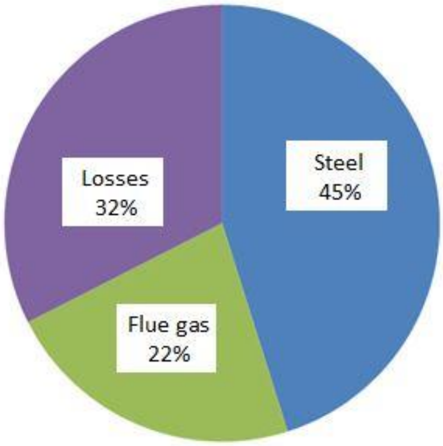

Figure 4. Output Energy Distribution in the Reheating Process of Steel Billets in the Reheat Furnace.

The energy recovered from the flue gas to the combustion air accounted for about 9.5% of total input energy. This energy raised combustion air temperature by the use of the thermal exchangers from ambient temperature to 450 ^{o}C, which is considered as additional input energy to the reheating process. The process thermal efficiency calculated by equation (8) is 45% which is quite low for such a furnace where the manufacturer specified a thermal efficiency of 65% at furnace installation.

IV. CONCLUSION

Calculations of the overall heat and material balance on the pusher type steel billet reheat furnace at LISCO showed a furnace thermal efficiency of 45%. This indicates a decrease in furnace performance. Heat losses accounted for about 32% of total input energy to the furnace. From physical inspection of the furnace, this performance can be increased by conducting some maintenance on the furnace to lower heat losses through wall hot spots, windows and other wall openings.

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