Blast Furnace RAFT Calculator

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Abstract— In a blast furnace, there is a certain temperature called as Raceway Adiabatic Flame temperature (RAFT)[1] concluded as imperative for the efficient and effective functioning of the furnace by our research explained below. The RAFT is generated near the tuyeres purging hot blast, located above the hearth of the furnace. The hot blast from tuyeres gushes in at enormous velocities establishing a path for the gases to enter the coke region called a Raceway. Due to the force, some amount of coke gets entrapped in the raceway and reacts with the hot blast to form carbon monoxide which further elevates the temperature in that region, paving the way for RAFT. Our project revolved around the calculation of RAFT by controlling certain parameters and enforcing them in enthalpy balance equations. The RAFT hereby calculated was then adjusted to a certain influential temperature and the oxygen and moisture content of the blast required for the above adjustment was revealed. Furthermore, the oxygen and moisture content of the blast was chosen accordingly. The aforementioned process was executed in a calculator coded using python computer programming language.

Keywords: RAFT, Raceway, Tuyeres, Hot Blast, Iron Blast Furnace, Hearth

I. INTRODUCTION

Iron Blast Furnace is a tall shaft with a height of around 32 meters and a diameter of about 10-15 meters employed in the production of molten iron in the form of 'Pig Iron' required for steel making. The output of a blast furnace consists of molten pig iron, slag and blast furnace gases. The product utilizes iron ore mainly Haematite, coke as a source of carbon and energy for carrying out the chemical reactions inside the furnace, limestone, and dolomite as flux to slag out the impurities. The molten iron should be of uniform composition and produced at high rates. Temperature is one of the parameters which ensures the aforementioned requirements of the product. The critical hearth temperature of the blast furnace should not be less than 1800 K for tapping iron and the slag in the molten form. There are thousands of blast furnaces in the world with a net productivity of 500 million tons of molten pig iron per year. A schematic of the blast furnace operation is given in figure 1.

II. WHAT IS RAFT?

The hot blast is provided at the bottom of the furnace from the tuyeres (generally 15 to 40) embedded circumferentially at the hearth. It consists of preheated air made up of nitrogen and oxygen, at a velocity of 200-300 ms^{-1} and a pressure of 2 to 4 atmospheres so that the reducing gases produced to overcome the top pressure of the blast furnace[7] and move against the solid burden. These reducing gases lose heat to the incoming solid charge while ascending and thus cooling themselves in the process.

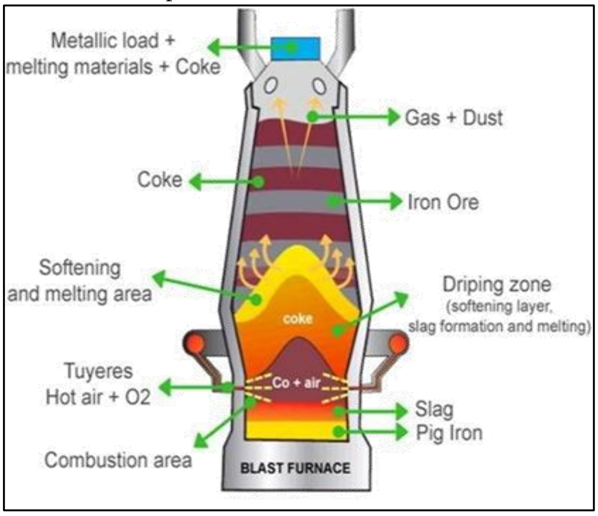

Fig. 1: Blast Furnace Operation

The rapid introduction of preheated air into the hearth (bottommost part of the furnace) of the furnace clears a raceway[5] which extends up to 2 meters inside as shown in figure 2.

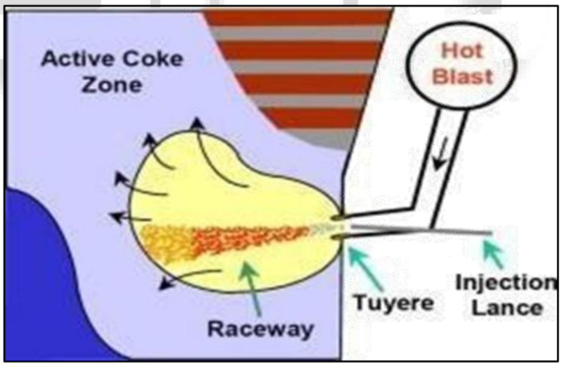

Fig. 2 Raceway schematic

This raceway is surrounded by coke in all directions. The coke is hurtled by the raceway, some coke is engulfed and used in the making of the reducing gas, CO[2]. The whole bed thus gradually moves downward. The formation of carbon monoxide is an exothermic reaction and is produced at the tip of the raceway along with hydrogen, thereby elevating the temperature of the raceway and paving the way for RAFT short for Raceway Adiabatic Flame Temperature. The oxygen reacts with the carbon in coke to produce carbon dioxide which manifests carbon monoxide on further reaction with the coke. This is in accordance with the Bernard reaction.

III. IMPORTANCE OF RAFT

RAFT is imperative in the functioning of a blast furnace. Since temperature is one of the most essential parameters for determining the proper functioning of the blast furnace and its productivity, there is a suitable range in which RAFT should lie. RAFT is majorly influenced by the critical hearth temperature. Critical hearth temperature hence RAFT should not be less than 1800K otherwise iron and slag cannot be tapped in the molten form. RAFT should be as high as possible for efficient furnace functioning and viscosity reduction of the molten iron for increased flowability. But certain anomalies can rise up if RAFT is too high.

The refractories start to wear out thereby exposing the blast furnace to abrasion. The permeability of the charge decreases and the descent becomes erratic. The decrease in permeability does not allow a sufficient amount of hot gases from the tuyeres to pass through the fusion zone, in turn, resulting in the low melting slag formation above the fusion zone. These problems can be precluded by generating appropriate RAFT which should not cross 2400 +/- 5K. This can be achieved by manipulating the oxygen enrichment and the moisture content of the blast. The control of RAFT has added advantage of procuring the melt containing constant composition metal.

IV. FACTORS AFFECTING RAFT

RAFT depends upon the critical hearth temperature as shown in figure 3, because of the fact that the hot blast is being purged and the raceway forms inside the hearth. The hearth consists of the molten slag and iron so, the temperature has to be greater than the melting point of iron. Including the superheat provision the temperature is maintained at 1800K. The salient features of fig. 3 are (a) flame temperature exceeds the critical hearth temperature (1800 K) when dry blast is preheated to 500 K or more. (b) flame temperature increases proportionally to blast temperature.

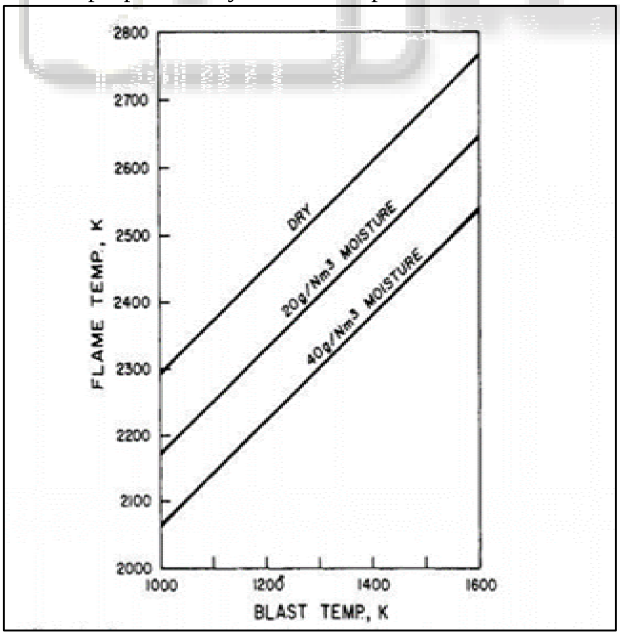

Fig. 3: Flame Temp v/s Blast Temp

Besides critical hearth temperature, the amount of oxygen, nitrogen, and moisture in the hot blast along with the hydrocarbon injection affects RAFT.

High amounts of moisture is avoided because it decreases RAFT due to the endothermic reaction (1). Hydrocarbon injection also decreases RAFT due to the endothermic nature of dissociation and lower temperatures than the incandescent coal.

A. *Importance of RAFT*

There is a maximum flame temperature above which the charge descent becomes uncontrollable and erratic and the permeability of the burden also decreases. This is caused by the overheating of the furnace due to the ascent of extensively hot gases from the raceways leading to premature low melting point slag formation above the normal fusion zone. The slag consists of CaO, FeO and SiO_2 with a melting point of around 1400K. The FeO present in the slag is eventually reduced causing it's melting point to increase resulting in the freezing of slag and cementing of slag particles over the normal fusion zone.

Excess flame temperatures can also cause abnormally high rates of alkali vaporization in the bosh resulting in

1) Reoxidation products being entrapped in the burden
2) Decrease in burden permeability.

The furnace overheating problems are precluded by generating an appropriate flame temperature (2400 +/- 5K) by manipulating the blast temperature, oxygen enrichment in the blast, humidity and hydrocarbon injection. An added advantage of adjusting the flame temperature is the continuous, constant and uniform supply of the molten metal.

Equations

$H_2O + C \blacktriangleright CO + H_2 \ \Delta H_{298K} = +131000$ kJ per (kg mole of H_2O). (1)

Blast Adjust	No	Yes
Iteration	100	100
T_HM	1800	1800
HM_Si	1	1
HM_C	4	4
HM_Mn	1	1
Coke_C	88	88
Coke_silica	12	12
T_blast	1200	1200
Blast_O2_en	21	21
Blast_moist	9	9
T_PCI	298	298
PCI_rate[3]	150	150
PCI_C	80	80
PCI_ash	20	20
PCI_moist	1	1
Blast_O2[4]	21	23.5819
Blast_moist	9	9.0
RAFT	2181.9957	2404.8909

Table 1: Calculating oxygen enrichment and moisture content in the blast through tuyeres

V. RESULT

The raceway adiabatic flame temperature is iterated against the important temperature range 2400 +/- 5K to procure the oxygen amount to be present in the injected hot blast along with the moisture content to maintain the aforementioned flame temperature.

VI. Conclusions

The following conclusions can be elicited from this study:

- Raceway Adiabatic Flame Temperature is imperative for the functioning of a blast furnace efficiently.
- For certain crucial reasons regarding the burden descent and the slag solidification, RAFT is adjusted in the temperature range of 2400 +/- 5K.
- Oxygen and moisture content of the injected hot blast from the tuyeres are some of the important parameters which determine the RAFT.

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