Iron Making and Steel Making

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Lecture – 08

RIST Diagram Based on Heat & Material Balance in the Wustite Reserve Zone

Welcome. This is the 3rd lecture on the RIST diagram and there is a heat and material balance for blast furnace iron making. And this lecture, we will cover by RIST diagram based on heat and material balance in the Wustite reserve zone.

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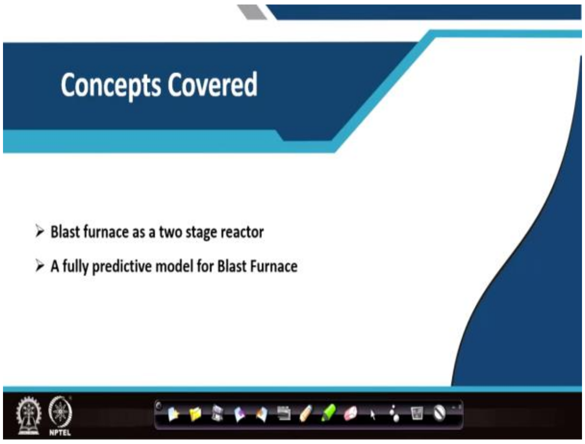

Concepts Covered

- Blast furnace as a two stage reactor
- A fully predictive model for Blast Furnace

The basic concept covered are: blast furnace as a two stage reactor; this is a very important concept and we have to understand that blast furnace can be conceived as a two stage reactor. And then we will develop a fully predictive model for the blast furnace where the operating line will be fixed by developing two fixed point on the operating line. So, optimum and the minimum coke rate can be predicted for a fixed charge in Blast Furnace.

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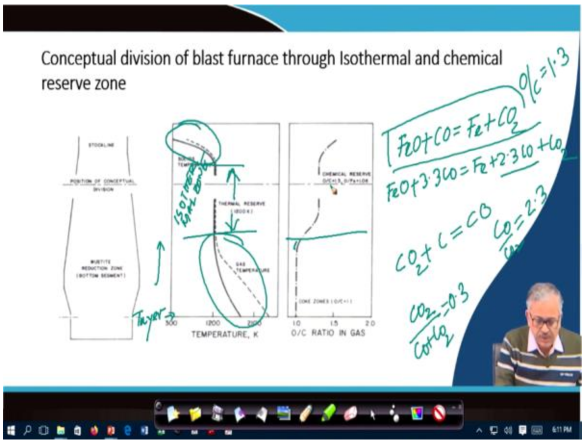


Conceptual division of blast furnace through Isothermal and chemical reserve zone

Now, we will discuss the conceptual division of the blast furnace through isothermal and chemical reserve zone. Now, let us see the temperature profile of gas and solid, the second diagram from the left. Here, solid line represents the axial temperature profile of the solid above the tuyer line and the dotted line represents that of the gas.

So, you can find that in the lower part of the furnace the gas is entering at around 2300 K (or say 2000ºC) from combustion zone and it loses its temperature to around 1200K(~900ºC) after heat exchange with the solid in the lower part of the furnace. The solid in turn enrich its temperature from 1200K to 1600K (~1300ºC). So, gas lo~~o~~ses around 1100K, while solid gains only 500K with in a very short distance in the lower part of the furnace. ~~,~~This ~~which~~ clearly indicates larger heat capacity of solid compared to that of the gas, which ~~and it~~ may be attributed to large endothermic reaction that goes on in the lower part of the furnace. ~~So, here the gas temperature, now the gas from 2000 degree centigrade to it is around 900 degree centigrade, 1200 you can see 1200, this is basically a 900 something, so 900 degree centigrade. So, gas temperature you can see decreases from 2000 degree centigrade to 900 degree centigrade, where the solid temperature increases from 900 to 1300 degree centigrade in this lower part of the furnace. So, obviously, in the lower part of the furnace, why it is like this because the heat capacity of the solid is very high, because of lot of endothermic reaction goes on, as a result the heat demand of the solid is very large.~~

~~So, the solid temperature increase from 900 to 1300 where the gas temperature decreases~~ and solid become almost constant, ending heat exchange. As you can see a large region in the middle part of the furnace where gas and solid temperature remains almost constant without any significant heat exchange, and this region is called the isothermal zone, or the ~~So, as a result no significant heat exchange take place. And this region the temperature is almost constant, in this region the temperature is almost constant and it is called the~~ thermal reserve zone~~ or isothermal zone~~. ~~You can call it also a isothermal zone. So, it is called the isothermal zone or the thermal reserve zone, a significant portion of the blast furnace where temperature of the solid and gas almost remain constant.~~

And in the upper part of the furnace, you can ~~find~~ again find some heat exchange between solid and gas. Here, the solid temperature increases from 30°C (~300K) to ~~degree to~~ (~1200K), where the gas temperature decreases from ~~900~~ 1200K to around ~~200~~ temperature gain by solid (900 K) is greater than temperature loss by gas (800K), which represent higher heat capacity of gas to ensure preheating of solid to 1200K. ~~So, there~~ exchange takes place separately both in the upper part and the lower part of ~~in this region; heat exchange take place in this region. And~~while ~~in~~ the middle zone remains without any temperature remaining almost constant at 1200K. ~~at 900 degree centigrade right.~~

Now, let us examine the ~~If you see the~~ chemical composition of the gas as it moves up above the tuyer level in the third diagram from left. ~~, gas composition how does it vary longitudinally as you move from the Tuyer above this above the Tuyer, so how does it vary?~~ The gas composition is represented by atomic ratio of oxygen to carbon. You can ~~find~~ see that the O/C ratio is one upto a significant distance up the tuyer level, indicating the gas composition is 100% CO in this region~~the gas O by C ratio is equal to 1 means therefore that gas is basically CO when the gas is completely CO, 100 percent CO then O by C ratio is equal to 1.~~

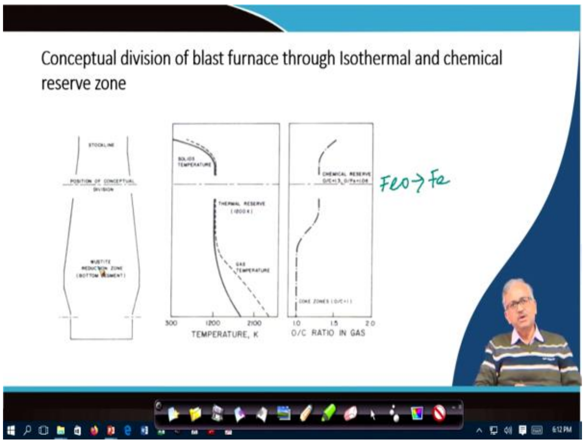
So, the gas composition almost remain CO up to this point; and beyond this point, you can find that the CO_2 is coming into the system as indicated by increase in O/C ratio beyond 1. ~~.~~ CO_2 is ~~coming~~ joining gas~~in~~ because the carbon gasification reaction slows down as up and ~~as the~~ temperature decreases. CO2 progressively increases in the gas as we move up with corresponding decrease in temperature, as indicated by increase in O/C ratio. It is because ~~, then this reaction that is the CO 2 in situ generation this reaction is called the~~ temperature at higher up in the furnace. ~~goes down as you move up. As a result the CO~~

Interesting it may be observed that gas composition become steady at the upper part of isothermal zone and remains steady for a certain length of the furnace. ~~So, as the gas CO 2 is increasing your O by C ratio increasing, O by C ratio is increasing indicating that is the CO 2 in the CO, CO 2 gas mixture is increasing right. So, with increasing, increasing, and then you can find again the O by C has become constant during this region.~~ In this ~~portion~~ region, the O/C ~~by ratio and O by C~~ ratio is around 1.3 ~~O by C ratio is 1.3,~~ and it is constant. What does it mean?~~,~~ ~~basically~~ Basically, ~~in this case here~~ what happens ~~that this reaction become in equilibrium that is~~ wustite-iron indirect reduction achieve~~d~~s the equilibrium here. ~~the Fe O plus CO basically forming Fe plus CO 2.~~

So, up to ~~this~~ the portion where O/C ratio =1, ~~there is~~the reduction is 100% direct reduction of wustite. Beyond that point as O/C ratio increases indirect reduction of wustite starts picking up and it comes to an equilibrium in the upper part of isothermal zone, where O/C ratio become fixed for certain length of the furnace at 1.3. Why the value is 1.3? As we have seen during thermodynamic lecture, that ~~is taking place basically what about the CO form in the lower part that is used up to into the indirect reduction, and you are generating the CO 2. And this CO 2 basically accumulating into the gas, yours O by C ratio is decreasing, and then it become constant for a certain length of the blast furnace that is called and then that portion this is come into equilibrium; this reaction come into equilibrium.~~

~~Basically out of 3.3 basically if you want to remove 1 gram atom of oxygen you require 3.3 mole of CO, only out of which 2.3 mole of CO will remain in equilibrium with the CO~~

~~2, and only 1 mole of CO will be used up to take out the ore oxygen ok. So, that is the~~


Conceptual division of blast furnace through Isothermal and chemical reserve zone

~~The this reaction become in the equilibrium, they come into the equilibrium condition equilibrium. So, you can find there is t~~This region in the upper part of isothermal zone is also called the chemical reserve zone or the chemical inactive zone~~ you can say~~. Since the gas composition become constant in the region, the furnace may be divided across the horizontal line cutting across this zone as shown; below and above which line material balance can also be carried out separately in the upper and lower part of the furnace. ~~So, in this region you can see, so if I cut this blast furnace this way, in this reaction there is a separate heat balance, there is a you can simply do the separate mass balance also, because I have an equilibrium line here that is here I have an equilibrium. So, this portion come to an equilibrium also.~~

So, blast furnace can conceptually be divided across the horizontal line passing through the upper part of isothermal zone that also includes the chemical reserve zone, such that separate~~I can separately make a~~ heat and material balance can be carried out on the upper and lower part of the furnace with reference to this line. The lower part is also termed as wustite reserve zone. ~~on this is also called the wustite reserve zone this portion is called the wustite reserve zone because wustite Fe O Fe comes into equilibrium in this zone ok. And also I can do a separate heat balance. I do not require this up part because I can perfectly do a separate heat balance here. And also you can see this O by C ratio also become constant in the upper part of this zone ok. So, I can make a separate heat and~~

~~material balance on this wustite reserve zone; and from there I can derive the operating line. So, that I will be doing basically.~~

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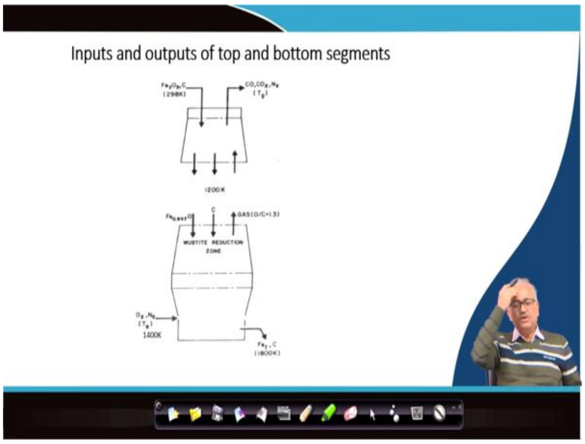


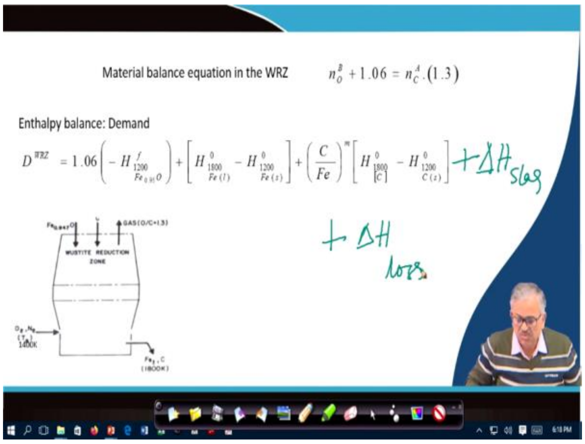
Inputs and outputs of top and bottom segments

The figure conceptually divides the blast furnace in two parts connected by the solid and gaseous streams. Since the gas composition from wustite reserve zone is fixed, if we do separate heat and material balance we can bring in another fixed point on the operating line fixing the line for optimum coke rate.

Let us see the gaseous and solid streams in the wustite reserve zone. ~~So, now you can see this is the scenario this is what this is the blast furnace if you can this is the way you can divide the blast furnace in two parts, this is the upper part, and the lower part ok. And this is called the wustite reduction zone or wustite reserve zone ok. So, here what are the input you can find from there in the upper part, here when the input is wustite basically solid will come as wustite.~~

~~And your air blast is coming through here at 1400 Kelvin ok. And the liquid iron is leaving at 1800 Kelvin. So, this is the system. So, I will just make a heat balance of the wustite reserve zone, heat and material balance and I can get the operating line ok. So, based on this data, again I can do later on the heat balance in the upper part heat and material balance, so that will give me actually what is the exit gas temperature, what is the exit gas~~

~~co that is the those things temperature also we can get. But exit gas composition from here~~



Material balance equation in the WRZ $n_O^B + 1.06 = n_C^A.(1.3)$

Enthalpy balance: Demand

$$D^{WRZ} = 1.06\left(-H^f_{\substack{1200\\ Fe_{0.95}O}}\right) + \left[H^0_{\substack{1800\\ Fe(l)}} - H^0_{\substack{1200\\ Fe(s)}}\right] + \left(\frac{C}{Fe}\right)^m \left[H^0_{\substack{1800\\ [C]}} - H^0_{\substack{1200\\ C(s)}}\right] + \Delta H_{slag}$$

$+ \Delta H_{loss}$

So, ~~now, let us go to this thing that is the first let us do~~ now the material balance (oxygen balance) in the wustite reserve zone is straight foward, which may be given by:

$$n_O^B + 1.06 = n_C^A.(1.3)$$

(1)

Oxygen coming through wustite, which contain 1.06 gram atom of oxygen per gram atom of iron produced. The gas leaving the wustite reserve zone is known at O/C=1.3.

Let us do the enthalpy balance. We can directly write the enthalpy balance equation in terms of heat demand and supply. The demand terms (D) may be written as:

$$D^{WRZ} = 1.06\left(-H^f_{\substack{1200\\ Fe_{0.95}O}}\right) + \left[H^0_{\substack{1800\\ Fe(l)}} - H^0_{\substack{1200\\ Fe(s)}}\right] + \left(\frac{C}{Fe}\right)^m \left[H^0_{\substack{1800\\ [C]}} - H^0_{\substack{1200\\ C(s)}}\right]$$

(2)

~~the enthalpy balance. Now, this is for the material balance. If you see the material balance ok, if you see the material balance is ok. This is n o B, that is n o B means that is the blast oxygen that is coming in per gram atom of iron produced. And what is the oxygen coming through the iron ore, ore is wustite. And 1 gram atom of wustite contain 1.06 gram atom of oxygen. So, this plus this ok, this is from the blast oxygen, this is the ore oxygen is equal~~

~~to n c A activate of carbon into O by C, this is O by C and O by C is equal to 1.3. So, this~~ term represents the sensible enthalpy of liquid iron that involves the sensible enthalpy for heating the solid iron from 1200K to its melting temperature at 1800K and latent heat of fusion for phase change from solid to liquid. The third term represents the enthalpy of dissolved carbon in hot metal, which includes sensible enthalpy for heating solid carbon from 1200K to 1800K and heat of dissolution carbon in hot metal at 1800K. $\left(\frac{C}{Fe}\right)^m$ represent the gram atom of carbon that dissolves in hot metal. ~~that is the liquid iron~~ demand terms, and ~~plus~~ you ~~have~~ may ~~other~~ add ~~term another,~~ another two terms: formation of slag and ΔH_{loss} that accounts heat loss through refractory in the lower part of the furnace. ~~of the slag because of slag formation, plus delta H of the loss and because~~

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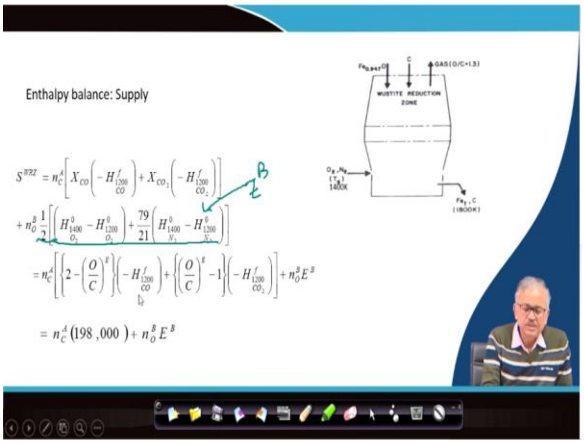

Enthalpy balance: Supply

$$S^{WRZ} = n_C^A\left[X_{CO}\left(-H^f_{\substack{1200\\CO}}\right) + X_{CO_2}\left(-H^f_{\substack{1200\\CO_2}}\right)\right]$$

$$+ n_O^B\frac{1}{2}\left[\left(H^0_{\substack{1400\\O_2}} - H^0_{\substack{1200\\O_2}}\right) + \frac{79}{21}\left(H^0_{\substack{1400\\N_2}} - H^0_{\substack{1200\\N_2}}\right)\right]$$

$$= n_C^A\left[\left\{2-\left(\frac{O}{C}\right)^g\right\}\left(-H^f_{\substack{1200\\CO}}\right) + \left\{\left(\frac{O}{C}\right)^g - 1\right\}\left(-H^f_{\substack{1200\\CO_2}}\right)\right] + n_O^B E^B$$

$$= n_C^A(198{,}000) + n_O^B E^B$$

Now if we consider the supply term then what are the terms that we have?

$$S^{WRZ} = n_C^A\left[X_{CO}\left(-H^f_{\substack{1200\\CO}}\right) + X_{CO_2}\left(-H^f_{\substack{1200\\CO_2}}\right)\right]$$

$$+ n_O^B\frac{1}{2}\left[\left(H^0_{\substack{1400\\O_2}} - H^0_{\substack{1200\\O_2}}\right) + \frac{79}{21}\left(H^0_{\substack{1400\\N_2}} - H^0_{\substack{1200\\N_2}}\right)\right]$$

$$= n_C^A\left[\left\{2-\left(\frac{O}{C}\right)^g\right\}\left(-H^f_{\substack{1200\\CO}}\right) + \left\{\left(\frac{O}{C}\right)^g - 1\right\}\left(-H^f_{\substack{1200\\CO_2}}\right)\right] + n_O^B E^B \tag{3}$$

The first term on RHS represents the heat generation by oxidation of carbon to CO and CO2 at 1200K with the cas composition defined by molar ratio of CO/CO_2 at 2.3. The second term represent the excess heat associated with oxygen and nitrogen of air blast as it enters at 1400K and leaves at 1200K. the second term without n_O^B represents excess sensible enthatpy of air blast per gram atom of oxygen in the air blast, and it is represented as E^B . So the product of n_O^B and E^B yields the excess enthalpy of air blast per gram atom of iron produced.

~~So, supply, what are the supply term is there? Then incase of the supply you see what are there one is that heat of formation of the CO and the CO gas is leaving at 1200. So, heat of formation of CO at 1200 and heat of formation of CO 2 at 1200. And with their multiplied by their respective moles of CO and CO 2 that is one thing that is basically the heat generation that is a supply.~~

the ~~And this term if you rearrange in terms of O by C, you can write like this that is the simple algebra manipulation and so finally, you can write this is equal to you can write like this that the n C A into this plus n O B of this. Because if I put the value of a enthalpy of formation of CO enthalpy formation of CO 2, sorry ok, this is the supply.~~

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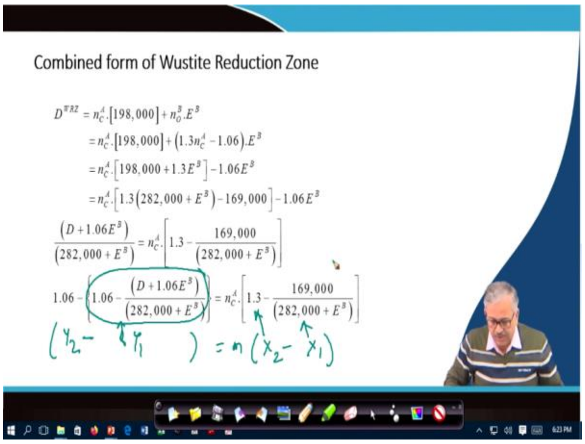


Combined form of Wustite Reduction Zone

$$D^{WRZ} = n_C^A.[198{,}000] + n_O^B.E^B$$
$$= n_C^A.[198{,}000] + (1.3n_C^A - 1.06).E^B$$
$$= n_C^A.\left[198{,}000 + 1.3E^B\right] - 1.06E^B$$
$$= n_C^A.\left[1.3\left(282{,}000 + E^B\right) - 169{,}000\right] - 1.06E^B$$
$$\frac{\left(D + 1.06E^B\right)}{\left(282{,}000 + E^B\right)} = n_C^A.\left[1.3 - \frac{169{,}000}{\left(282{,}000 + E^B\right)}\right]$$
$$1.06 - \left[1.06 - \frac{\left(D + 1.06E^B\right)}{\left(282{,}000 + E^B\right)}\right] = n_C^A.\left[1.3 - \frac{169{,}000}{\left(282{,}000 + E^B\right)}\right]$$
$$(Y_2 - Y_1) = m(X_2 - X_1)$$

Finally, the combined form of wustite reserve zone, by combining equation (1) and equation (3), and required algrabric manipulation, can be written as:

$$
\begin{aligned}
D^{WRZ} &= n_C^A.[198,000] + n_O^B.E^B \\
&= n_C^A.[198,000] + \left(1.3n_C^A - 1.06\right).E^B \\
&= n_C^A.\left[198,000 + 1.3E^B\right] - 1.06E^B \\
&= n_C^A.\left[1.3\left(282,000 + E^B\right) - 169,000\right] - 1.06E^B
\end{aligned}
$$

$$
\frac{\left(D + 1.06E^B\right)}{\left(282,000 + E^B\right)} = n_C^A.\left[1.3 - \frac{169,000}{\left(282,000 + E^B\right)}\right]
$$

$$
1.06 - \left\{1.06 - \frac{\left(D + 1.06E^B\right)}{\left(282,000 + E^B\right)}\right\} = n_C^A.\left[1.3 - \frac{169,000}{\left(282,000 + E^B\right)}\right]
$$

(4)

The equation is again written in terms of a straight line of the form:

$$y_2 - y_1 = m(x_2 - x_1)$$

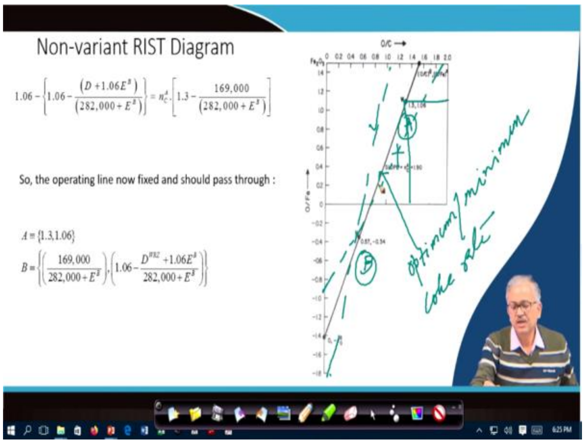
Here we find the straight line passes through two points $A(x_2, y_2), B(x_1, y_1)$, which are given as:

$$
\begin{aligned}
A &\equiv \{1.3, 1.06\} \\
B &\equiv \left\{\left(\frac{169,000}{282,000 + E^B}\right), \left(1.06 - \frac{D^{WRZ} + 1.06E^B}{282,000 + E^B}\right)\right\}
\end{aligned}
$$

Point A is a fixed point. B is also fixed if heat demand (D^{WRZ}) and excess enthalpy of air blast (E^B) are constant. For a fixed burden material, D^{WRZ}, is constant and for a constant blast preheat E^B is also constant. Therefore, point B is also fixed for a constant feed to the blast furnace. Point B is the thermal pinch point (H) and the point A is called the chemical pinch point (W).

~~And then let us see the combined form of wustite reduction zone. If I do the combine form that is there is the material balance and heat balance if we just combine and we eliminate the O by C from both of them, and then finally, the heat demand in the wustite reserve zone can be correlated like this, and some algebraic manipulation you can come here and finally here ok. So, these are just algebraic manipulation. What I have done demand is~~

~~equal to supply, and also I have eliminated the O by C from the material balance and the~~



Non-variant RIST Diagram

$$1.06-\left\{1.06-\frac{(D+1.06E^{B})}{(282,000+E^{B})}\right\}=n_C^A\cdot\left[1.3-\frac{169,000}{(282,000+E^{B})}\right]$$

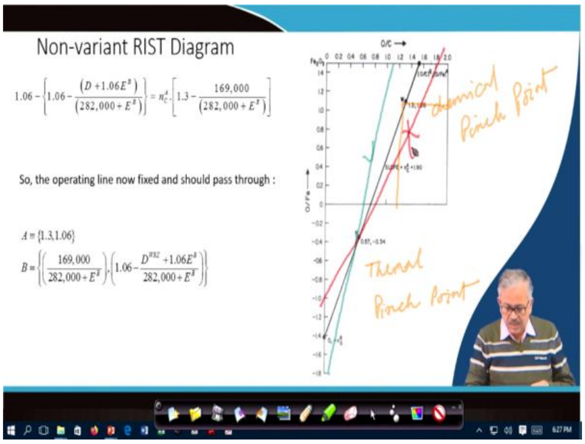
So, the operating line now fixed and should pass through :

$A=\{1.3,1.06\}$

$$B=\left\{\left(\frac{169,000}{282,000+E^{B}}\right),\left(1.06-\frac{D^{WRZ}+1.06E^{B}}{282,000+E^{B}}\right)\right\}$$

The point W represents the Fe-FeO equilibrium point. In other words, when the O/Fe ratio in the ore is 1.06, i.e., when the ore is wustite, the minimum gas composition of CO in CO/CO_2 mixture is 70%, or, maximum O/C ratio is 1.3. Therefore, any line (indicated by red line in the figure below) that exceeds O/C from 1.3, at wustite level (O/Fe=1.06) is not possible because it does not satisfy the Fe-FeO equilibrium. So, the operating range around the fulcrum H, is restricted by point W on RHS. Any operating line that does not exceeds point W (i.e., does not exceeds O/C from 1.3 at O/Fe of 1.06), as shown by green line in the figure below, is feasible; but always at higher coke rate than the optimum line passing through the point H and W. ~~So, we have two lines you can find from there as I say Y 2 minus Y 1, X 2 minus X 1, and then two points we are getting that is the X 1 Y, X 1 Y 1, this is basically X 2 and Y 2. So, A and B two points are there on the RIST diagram. So, you can find two points I have got, one point is that one point is this one, this is basically there is the point B, this is the point B this is the point B, and this is the point A this is 1.3, 1.06 this is the point A, and this is the point B. So, also this point here A and B, I have written basically here we are calling it as H, H is the thermal pinch point, and W is another point I am calling it A also here, basically that is basically W is basically called the chemical pinch point, this is another point is there.~~

~~So, now we get that this is the thing that is by doing the wustite reserve zone heat and material balance I get basically two point; one is called that is called the thermal pinch point H, another is called this point is called the chemical pinch point.~~



Non-variant RIST Diagram

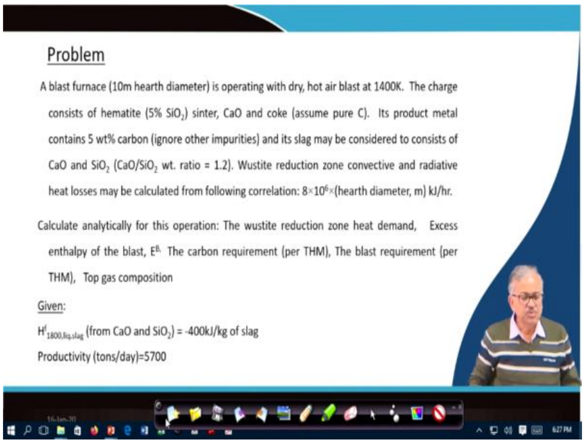
$$1.06-\left\{1.06-\frac{(D+1.06E^{B})}{(282{,}000+E^{B})}\right\}=n_{C}^{A}\cdot\left[1.3-\frac{169{,}000}{(282{,}000+E^{B})}\right]$$

So, the operating line now fixed and should pass through :

$$A\equiv\{1.3,1.06\}$$

$$B\equiv\left\{\left(\frac{169{,}000}{282{,}000+E^{B}}\right),\left(1.06-\frac{D^{WRZ}+1.06E^{B}}{282{,}000+E^{B}}\right)\right\}$$

~~This is the thermal pinch point, thermal pinch point; and this is called a chemical pinch point. And the line has to follow both this line ok. The line has to follow. But you can have a other line like this line is possible as I said, but this type of line are not feasible; no line can go beyond this point that is the thing. No line can go beyond this point this direction line can move, but that will be less efficient line, but this is the most efficient line, this is this optimum line is the most efficient line.~~



Problem

A blast furnace (10m hearth diameter) is operating with dry, hot air blast at 1400K. The charge consists of hematite (5% SiO_2) sinter, CaO and coke (assume pure C). Its product metal contains 5 wt% carbon (ignore other impurities) and its slag may be considered to consists of CaO and SiO_2 (CaO/SiO_2 wt. ratio = 1.2). Wustite reduction zone convective and radiative heat losses may be calculated from following correlation: $8\times10^{6}\times$(hearth diameter, m) kJ/hr.

Calculate analytically for this operation: The wustite reduction zone heat demand, Excess enthalpy of the blast, E^{B}. The carbon requirement (per THM), The blast requirement (per THM), Top gas composition

Given:

$H^{f}_{1800,liq.slag}$ (from CaO and SiO_2) = -400kJ/kg of slag

Productivity (tons/day)=5700

~~So, now,~~Now, consider the problem given in the slide above. ~~some problem that is a problem is a~~The blast furnace is operating with the dry hot air blast at 1400 K~~elvin~~. The charge consist of hematite, sinters, CaO, and coke. Its product metal contain 5 percent carbon, and its slag ~~maybe consider~~ consists of CaO and SiO_2 at a ratio of 1.2. ~~, all these~~

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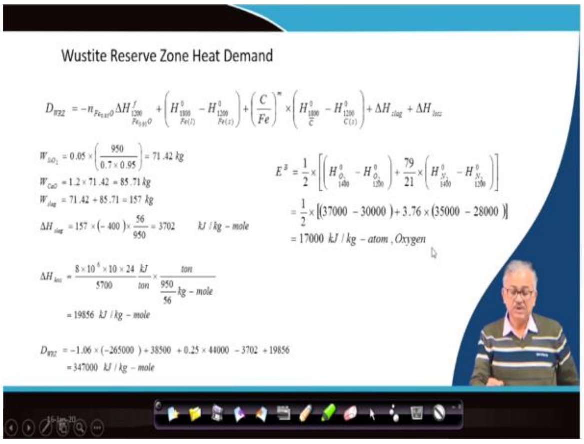

Wustite Reserve Zone Heat Demand

$$D_{WRZ} = -n_{Fe_{0.95}O}\Delta H^{f}_{\substack{1200\\Fe_{0.95}O}} + \left(H^{0}_{\substack{1800\\Fe(l)}} - H^{0}_{\substack{1200\\Fe(s)}}\right) + \left(\frac{C}{Fe}\right)^{m} \times \left(H^{0}_{\substack{1800\\\underline{C}}} - H^{0}_{\substack{1200\\C(s)}}\right) + \Delta H_{slag} + \Delta H_{loss}$$

$$W_{SiO_2} = 0.05 \times \left(\frac{950}{0.7 \times 0.95}\right) = 71.42\ kg$$

$$W_{CaO} = 1.2 \times 71.42 = 85.71\ kg$$

$$W_{slag} = 71.42 + 85.71 = 157\ kg$$

$$\Delta H_{slag} = 157 \times (-400) \times \frac{56}{950} = 3702 \quad kJ / kg-mole$$

$$\Delta H_{loss} = \frac{8 \times 10^{6} \times 10 \times 24}{5700}\frac{kJ}{ton} \times \frac{ton}{\frac{950}{56} kg-mole}$$

$$= 19856\ kJ / kg-mole$$

$$D_{WRZ} = -1.06 \times (-265000) + 38500 + 0.25 \times 44000 - 3702 + 19856$$

$$= 347000\ kJ / kg-mole$$

$$E^{B} = \frac{1}{2} \times \left[\left(H^{0}_{\substack{O_2\\1400}} - H^{0}_{\substack{O_2\\1200}}\right) + \frac{79}{21} \times \left(H^{0}_{\substack{N_2\\1400}} - H^{0}_{\substack{N_2\\1200}}\right)\right]$$

$$= \frac{1}{2} \times \left[(37000 - 30000) + 3.76 \times (35000 - 28000)\right]$$

$$= 17000\ kJ / kg-atom, Oxygen$$

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~~And so wustite reserve zone. So, what is basically the~~First, you have to first calculate the demand, all the terms ~~that~~ are given in the slide above.~~here. So, calculate the demand. And to calculate the demand basically you can see here all the demand term I have added, one is the~~Demand terms contains wustite ~~basically~~ decomposition, ~~then the~~ sensible and latent enthalpy of iron, ~~then the~~ sensible ~~latent~~ and solution enthalpy of the carbon, and then the heat loss due to slag and heat loss due to the atmosphere~~ ok~~.

$$D_{WRZ} = -n_{Fe_{0.95}O}\Delta H^{f}_{\substack{1200\\Fe_{0.95}O}} + \left(H^{0}_{\substack{1800\\Fe(l)}} - H^{0}_{\substack{1200\\Fe(s)}}\right) + \left(\frac{C}{Fe}\right)^{m} \times \left(H^{0}_{\substack{1800\\\underline{C}}} - H^{0}_{\substack{1200\\C(s)}}\right) + \Delta H_{slag} + \Delta H_{loss}$$

And according to this problem, I can calculate the weight of the silica and the weight of the calcium oxide, and then total weight of the slag. And based on the total weight of the slag, we can calculate what is the enthalpy of the slag that given ~~minus -~~ 400 per kg of slag. So, you can get ~~that thing~~it.

$$W_{SiO_2} = 0.05 \times \left(\frac{950}{0.7 \times 0.95} \right) = 71.42\,kg$$

$$W_{CaO} = 1.2 \times 71.42 = 85.71\,kg$$

$$W_{slag} = 71.42 + 85.71 = 157\,kg$$

$$\Delta H_{slag} = 157 \times (-400) \times \frac{56}{950} = 3702 \qquad kJ/kg-mole$$

$$\Delta H_{loss} = \frac{8 \times 10^6 \times 10 \times 24}{5700} \frac{kJ}{ton} \times \frac{ton}{\frac{950}{56} kg-mole}$$

$$= 19856\,kJ/kg-mole$$

$$D_{WRZ} = -1.06 \times (-265000) + 38500 + 0.25 \times 44000 - 3702 + 19856$$

$$= 347000\,kJ/kg-mole$$

And the heat loss can be calculated from its correlation with hearth diameter on per hour basis (kJ/hr), which could subsequently converted to kg-mole of iron basis by dividing with productivity and necessary unit conversion. Finally, heat demand of wustite reserve zone cal be calculated as 347,000 kJ/kg-mole of iron produced. ~~also one formula is there from there we can calculate it, because basically this is this much of kg Joule per kg mole of iron produced this will be the heat loss from that formula you can simply calculate. So, finally, you can calculate what is the total heat demand of the direct reduction a wustite reserve zone by this formula.~~

And excess enthalpy of the blast ~~also you can given you can calculate these value are taken~~ can be calculated from the data given as follows:

$$E^B = \frac{1}{2} \times \left[\left(H^0_{\underset{1400}{O_2}} - H^0_{\underset{1200}{O_2}} \right) + \frac{79}{21} \times \left(H^0_{\underset{1400}{N_2}} - H^0_{\underset{1200}{N_2}} \right) \right]$$

$$= \frac{1}{2} \times [(37000 - 30000) + 3.76 \times (35000 - 28000)]$$

$$= 17000\,kJ/kg-atom, Oxygen$$

The coke rate can be calculated as follows:

$$W \equiv (1.3, 1.06)$$

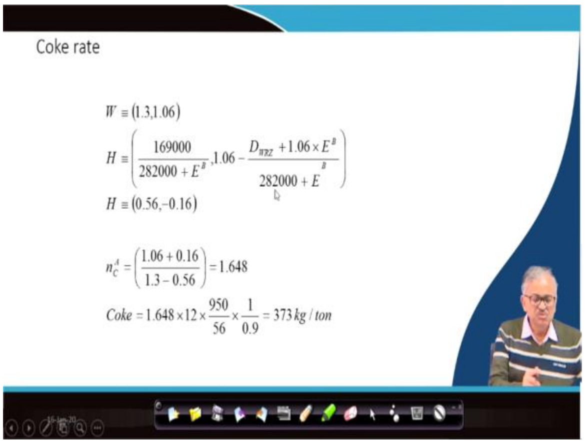
$$H \equiv \left(\frac{169000}{282000 + E^{B}}, 1.06 - \frac{D_{WRZ} + 1.06 \times E^{B}}{282000 + E^{B}} \right)$$

$$H \equiv (0.56, -0.16)$$

$$n_C^A = \left(\frac{1.06 + 0.16}{1.3 - 0.56} \right) = 1.648$$

$$Coke = 1.648 \times 12 \times \frac{950}{56} \times \frac{1}{0.9} = 373\, kg/ton$$

~~from the literature. So, you can do that is around 17000 kilo Joule per kg atom of oxygen ok, per kg atom of oxygen will be the excess enthalpy ok. And multiplied by the n O B that will give you the excess enthalpy that is coming out 17000 kilo Joule per kg mole of iron produced multiplied by the n O B then ok.~~



Coke rate

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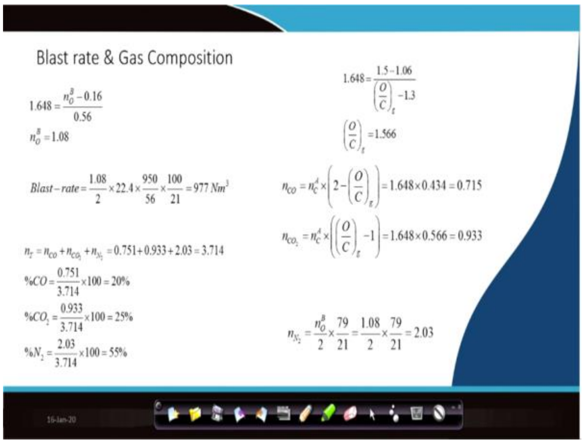
$$Coke = 1.648 \times 12 \times \frac{950}{56} \times \frac{1}{0.9} = 373\, kg/ton$$

~~So, then wustite reserve zone you have this point, there is a thermal pinch point, you have the this is the chemical pinch point is known its constant 1.3, 1.06, because basically this is the wustite equilibrium composition. And then the thermal pinch point is given like this.~~

~~You need to know what is the heat demand and the E B, and both the term we have~~



Blast rate & Gas Composition

$$1.648=\frac{n_O^B-0.16}{0.56}$$

$$n_O^B=1.08$$

$$Blast-rate=\frac{1.08}{2}\times 22.4\times\frac{950}{56}\times\frac{100}{21}=977\ Nm^3$$

$$n_T=n_{CO}+n_{CO_2}+n_{N_2}=0.751+0.933+2.03=3.714$$

$$\%CO=\frac{0.751}{3.714}\times 100=20\%$$

$$\%CO_2=\frac{0.933}{3.714}\times 100=25\%$$

$$\%N_2=\frac{2.03}{3.714}\times 100=55\%$$

$$1.648=\frac{1.5-1.06}{\left(\frac{O}{C}\right)_g-1.3}$$

$$\left(\frac{O}{C}\right)_g=1.566$$

$$n_{CO}=n_C^A\times\left(2-\left(\frac{O}{C}\right)_g\right)=1.648\times 0.434=0.715$$

$$n_{CO_2}=n_C^A\times\left(\left(\frac{O}{C}\right)_g-1\right)=1.648\times 0.566=0.933$$

$$n_{N_2}=\frac{n_O^B}{2}\times\frac{79}{21}=\frac{1.08}{2}\times\frac{79}{21}=2.03$$

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Blast rate can be calculated as:

$$1.648=\frac{n_O^B-0.16}{0.56}$$

$$n_O^B=1.08$$

$$Blast-rate=\frac{1.08}{2}\times 22.4\times\frac{950}{56}\times\frac{100}{21}=977\ Nm^3$$

The gas composition can be calculated as:

$$1.648=\frac{1.5-1.06}{\left(\frac{O}{C}\right)_g-1.3}$$

$$\left(\frac{O}{C}\right)_g=1.566$$

$$n_{CO} = n_C^A \times \left(2 - \left(\frac{O}{C}\right)_g\right) = 1.648 \times 0.434 = 0.715$$

$$n_{CO_2} = n_C^A \times \left(\left(\frac{O}{C}\right)_g - 1\right) = 1.648 \times 0.566 = 0.933$$

$$n_{N_2} = \frac{n_O^B}{2} \times \frac{79}{21} = \frac{1.08}{2} \times \frac{79}{21} = 2.03$$

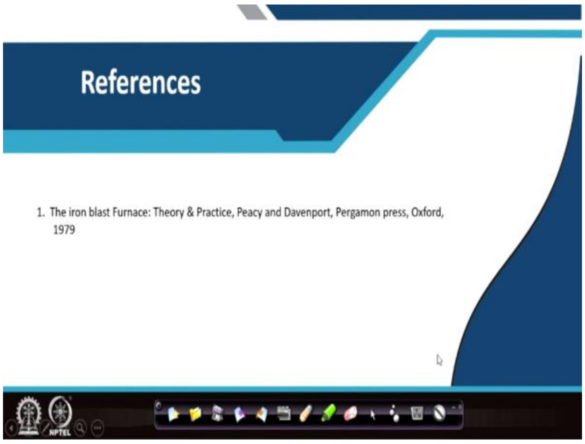
$$n_T = n_{CO} + n_{CO_2} + n_{N_2} = 0.751 + 0.933 + 2.03 = 3.714$$

$$\%CO = \frac{0.751}{3.714} \times 100 = 20\%$$

$$\%CO_2 = \frac{0.933}{3.714} \times 100 = 25\%$$

$$\%N_2 = \frac{2.03}{3.714} \times 100 = 55\%$$

~~So, then you can get the coke rate, then you can get the blast rate also, n O B you can calculate, slope you know. So, n O B can calculate. From n O B can calculate the blast rate, there is a normal meter cube. And then you can have O by C also you can calculate, because slope you know. So, simply you can get the O by C, and then you calculate number of moles of CO, number of moles of CO 2, number of moles of nitrogen, and then simply the gas composition you can get. So, this is a simple example, then these notes are there, you can follow it.~~



References

1. The iron blast Furnace: Theory & Practice, Peacy and Davenport, Pergamon press, Oxford, 1979

~~So, what we get from there? So,~~Reference is the book written by~~ this is also from the~~

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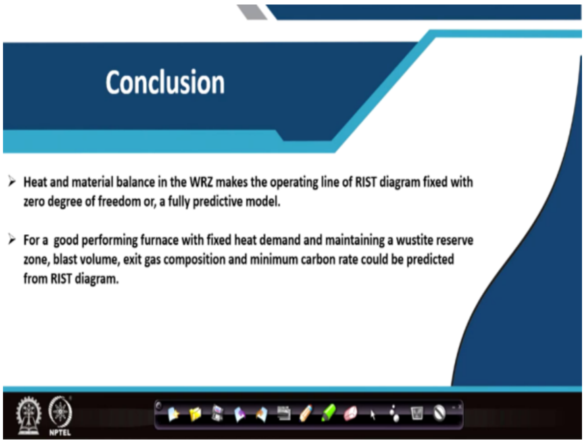

Conclusion

- Heat and material balance in the WRZ makes the operating line of RIST diagram fixed with zero degree of freedom or, a fully predictive model.
- For a good performing furnace with fixed heat demand and maintaining a wustite reserve zone, blast volume, exit gas composition and minimum carbon rate could be predicted from RIST diagram.

So, in conclusion we can say that because of the presence of a well defined thermal and chemical reserve zone in blast furnace, it is conceptually possible to divide the blast furnace into two zones and make heat and material balance separately.

H~~conclusion is that h~~eat and material balance is wustite reserve zone makes the operating line of RIST diagram fixed with zero degrees of freedom, and we get a ~~a ~~fully predictive model. ~~Fully predictive model means in the line we have two point, and two point mix is straight line fixed. S~~So, we are able to predict the minimum coke rate in a blast furnace operating at steady state with fixed charge.

The operating line is fixed by two points on the straight line-called the thermal pinch point (H) that ensures the heat balance requirement of the furnace and the chemical pinch point (W), that ensures the requirement of wustite-iron equilibrium in the upper part of the furnace.

~~have, so we can have a what is that called the minimum or optimum coke rate, but the furnace can operate along the fulcrum of the thermal pinch point, but it can be less efficient only. If the line moves on the left hand side, it is less efficient. On the right hand side, line cannot move because then you will not satisfy the equilibrium requirement of the Fe O Fe system.~~

So, for any condition this RIST diagram can be little modified for your blast furnace situation, and then you can predict the optimum coke rate, you can predict ~~what is~~ the exit gas composition, and ~~you what is the~~ blast rate. ~~and all these thing.~~ Hopefully this lecture will be helpful for heat and material ~~volume~~ balance, and the calculating different important parameters ~~in~~ for the industry.

Thank you very much.