Iron Making
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Lecture - 24
Iron Making Lecture 24

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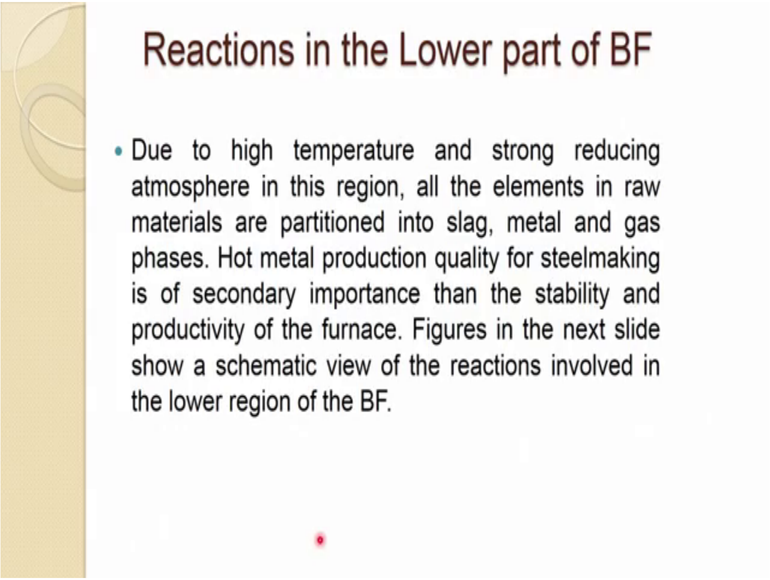

Reactions in the Lower part of BF

- Due to high temperature and strong reducing atmosphere in this region, all the elements in raw materials are partitioned into slag, metal and gas phases. Hot metal production quality for steelmaking is of secondary importance than the stability and productivity of the furnace. Figures in the next slide show a schematic view of the reactions involved in the lower region of the BF.

Now, we have not talked much about the we talked about the reaction in the upper zone of the blast furnace in detail and about the kinetics of it, but we did not talk much about the reactions in the lower part of the blast furnace we talked more about the aerodynamics of it, which is quite important for the smooth operation of the blast furnace, but of course, the reaction is also important.

So, now in this one I would be talking a bit about the reactions which are occurring in the lower part of the blast furnace. So, due to the high temperature and the strong reducing atmosphere, in this region all the element in raw materials are partition into slag metal and gas phases hot metal production quality for steelmaking is of secondary importance than the stability and productivity of the furnace. Remember a very important statement here. So, because sort of getting a right chemistry of the hot metal is not that important and also it difficult in the blast furnace to do that.

So, the main aim in the blast furnace is the stability and productivity. These are the very important factor in the blast furnace then rather than the chemistry of the metal of course, chemistry is important and one has to try as much as possible to control it, but beyond a certain limit you cannot do much in the blast furnace, because its sort of like a black box which is just a covered container, while they are still making operation is a batch type of operation, where you can easily manipulate the operation and can adjust the chemistry of the not only hot metal or the steel.

And so, that is why in the blast furnace chemistry we try to control as much as possible, but not the utmost way. But the utmost importance is about the stability and operational of the blast furnace. So, figures in the next slide. So, a schematic view of the reactions involved in the lower region of the blast furnace.

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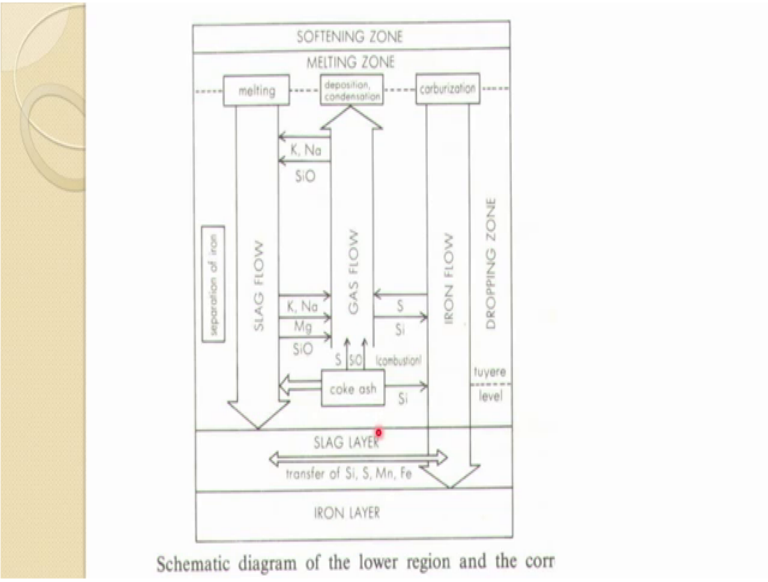

Schematic diagram of the lower region and the corr

So, we are restarting the say after the softening zone so, melting and a hearth region.

So, from the melting one zone as you know liquid comes out, and liquid it is in the form of select and the iron. So, slag is made of gangue material calcium oxide silica and magnesium these sorts of material, which are present in and the slag in FeO and the iron which is quite carburize sort of unsaturated. So, and at the tuyere level because the burning of the coke is occurring.

So, from the coke S we get sulphur and SiO. So, silicon is transfer to iron at tuyere level much from this coke and some silica and while iron it is sending it get transfer and, but sulphur caused to the gaseous phase. From the slag of course, some silica is already there and some silica can join from here coke S and, but due to high temperature even SiO is formed which goes with the gas flow and may even go to iron, but it also come back even to slag similarly magnesium at that temperature get vaporized.

So, we are talking at here near the tuyere level air temperature is high, potassium in sodium they get recirculated and when it settled down into the hearth iron goes to the bottom and slag floats top of the iron.

So, then the transfer of these silicon sulphur manganese iron occurs at the interface or when the iron droplets are traveling through the slag layer at that time the transfer of these phases occur. So, we would be talking now mostly about the some of some of the important reaction mainly silicon sulphur some manganese about it.

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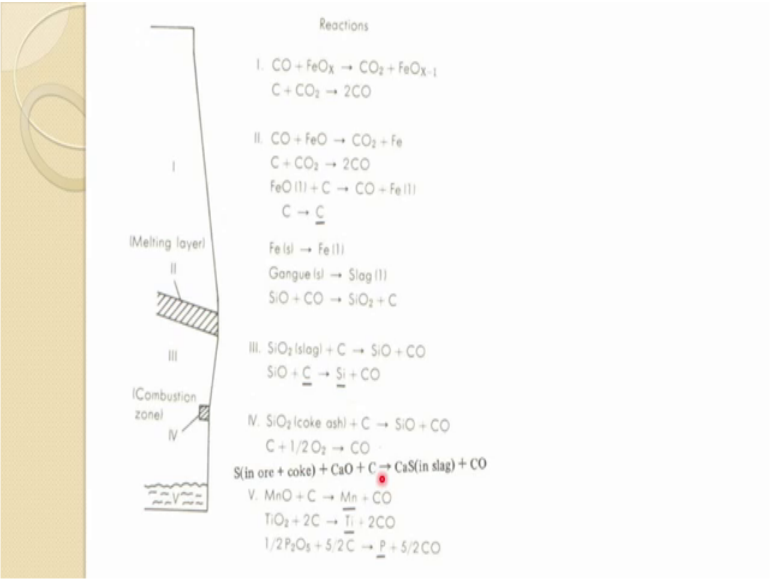

Reactions

I. $CO + FeO_X \rightarrow CO_2 + FeO_{X-1}$
$C + CO_2 \rightarrow 2CO$

II. $CO + FeO \rightarrow CO_2 + Fe$
$C + CO_2 \rightarrow 2CO$
$FeO\,(l) + C \rightarrow CO + Fe\,(l)$
$C \rightarrow \underline{C}$

$Fe\,(s) \rightarrow Fe\,(l)$
$\text{Gangue}\,(s) \rightarrow \text{Slag}\,(l)$
$SiO + CO \rightarrow SiO_2 + C$

III. $SiO_2\,(\text{slag}) + C \rightarrow SiO + CO$
$SiO + \underline{C} \rightarrow \underline{Si} + CO$

IV. $SiO_2\,(\text{coke ash}) + C \rightarrow SiO + CO$
$C + 1/2\,O_2 \rightarrow CO$
$S(\text{in ore + coke}) + CaO + C \rightarrow CaS(\text{in slag}) + CO$

V. $MnO + C \rightarrow \underline{Mn} + CO$
$TiO_2 + 2C \rightarrow \underline{Ti} + 2CO$
$1/2\,P_2O_5 + 5/2\,C \rightarrow \underline{P} + 5/2\,CO$

So, if you look at the blast furnace in the stake region you have a various form of iron oxides which get reduced into the lower one and whatever CO 2 formed it goes into CO and this a cohesive zone, because once the solid comes up to here mostly you get the boost tight in this region. So, CO reacted with tight.

So, iron is produce and in turn that CO 2 again react with carbon from CO and also in the liquid form because at that temperature FeO also can be in liquid form. So, carbon can react and form, iron in a liquid form and carbon even dissolved into the iron. And the gangue also at that time its a methyl which is coming out react with CO form SiO 2 and carbon under this condition in this zone near the combustion and driving zone SiO 2, which is there in the slag. In the gangue material react with carbon from SiO pepper gas is product and CO and this SiO reacts with the iron and which is the carbon dissolve carbon into it at high temperature. So, silicon get reduced. So, silicon is a absorbed by iron and CO is formed.

So, that is how the silicon pickup occurs in this region and SiO 2 from the coke is again goes into SiO you can come here and this react again with the oxygen to CO 2 his formed. And sulphur in the ore combined with the lime I am meant calcium sulphide which goes into the slag and at the in the hearth region manganese oxide can react to carbon and magnesium go into liquid iron. Similarly if there is a titanium that can also reduce and quote to the liquid iron and the phosphorus also goes to liquid iron. So, these are the important reaction which occurs in the lower part of the blast furnace.

So, all these element goes to liquid iron that is dissolve into this and this is sort of brief description of the reaction important reaction, which are occurring in the lower part of the blast furnace the silicon transfer is one of the most in fact, important reactions.

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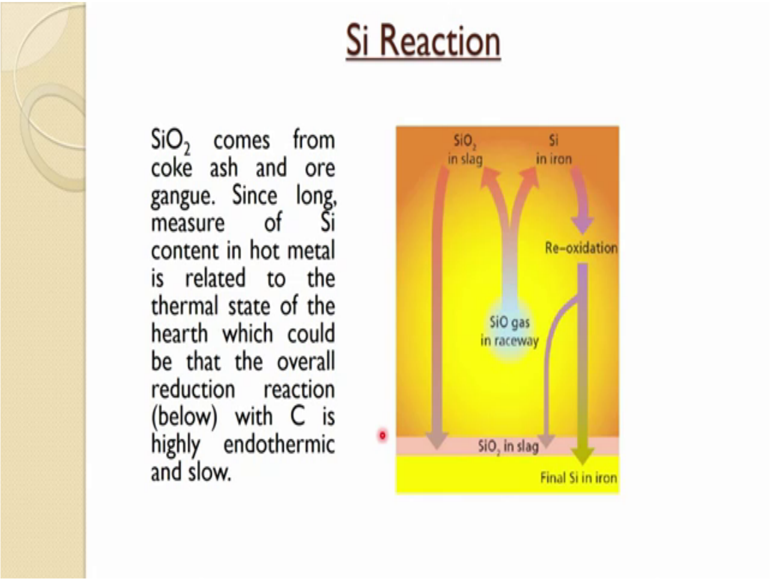

Si Reaction

SiO_2 comes from coke ash and ore gangue. Since long, measure of Si content in hot metal is related to the thermal state of the hearth which could be that the overall reduction reaction (below) with C is highly endothermic and slow.

So, we will be talking a little bit more about it. So, because historically if you see we will see here, SiO 2 comes from coke ash and ore gangue and since long measure of silicon content in hot metal is related to the thermal state of the hearth, which could be that the overall reduction reaction with carbon is highly endothermic and slow.

So, historically this silicon reaction has been related with the thermal state of the hearth, because it is due to be believed this SiO 2 this reduction occurs in the hearth reason and most of the silicon get transferred in that, and because this is a very endothermic reaction and that is the reason of the observing or measuring the temperature of the hearth liquid and other things the thermal state was very important. Historically what I am talking, but now it has been found this is not the thing by which they can get transferred to metal, it is mostly by a gaseous phase and you can see in these.

So, SiO 2 SiO gas is generated in the raceway region, which is a pure react with the carbon and this and absorb the silicon get up absorbs the metal and so, that is how the maximum silicon comes and in fact, when it is coming down, it reoxidized it gives away some of the silicon and which gives up final silicon content. So, SiO 2 in slag it keeps away actually and in the same thing this Si Si O also goes to the slag here. So, this is sort of a cycle we would be discussing a bit now.

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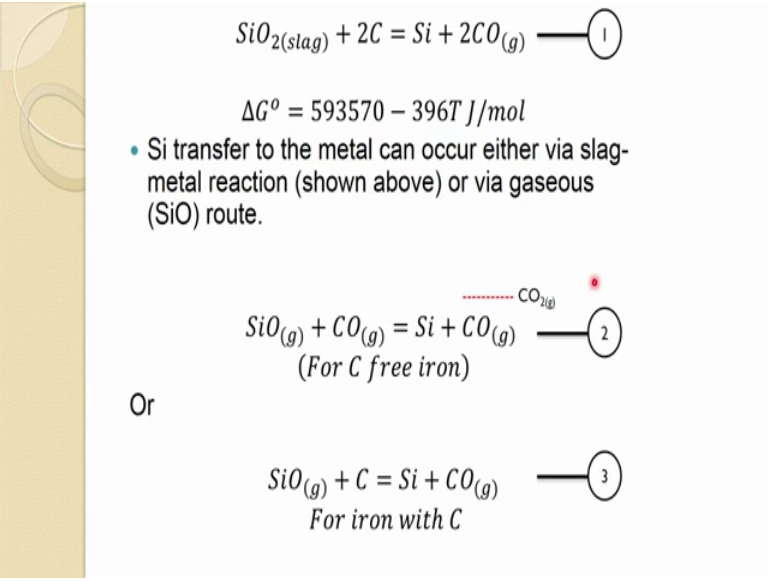

$$SiO_{2(slag)} + 2C = Si + 2CO_{(g)}$$ ①

$$\Delta G^o = 593570 - 396T\ J/mol$$

- Si transfer to the metal can occur either via slag-metal reaction (shown above) or via gaseous (SiO) route.

$CO_{2(g)}$

$$SiO_{(g)} + CO_{(g)} = Si + CO_{(g)}$$ ②

(For C free iron)

Or

$$SiO_{(g)} + C = Si + CO_{(g)}$$ ③

For iron with C

So, this normal that reaction in the hearth reason, we set with the slag and the carbon keep this is you can say even dissolved carbon or normal with metal or normal carbon that gives you the silicon which its dissolve into iron and 2 CO so; obviously, the reaction is quite endothermic this. So, this endothermic nature of the reaction you need that temperature in this.

So, silicon transferred to the metal also can occur either by a slag metal reaction. So, never and the other one is silicon transferred to the metal can occur either via slag metal reaction; so never or via gaseous route. So, this is where slag metal reaction and this is not possible what recent study has revealed. But via gaseous route they are two way for iron which is free of carbon, this reaction is possible to CO 2 gas not CO gas. So, Si O plus CO as Si plus CO 2 and where the carbon is there in iron this reaction is possible. So, this goes with the metal and CO. So, carbon in the metal react with the gas from CO and silicon goes in to the metal into iron.

So, mostly this is the reaction which is responsible for the silicon transfer in hot metal because SiO gas it generating and in the dropping zone and liquid iron, which is usually quite saturated with carbon. So, that carbon react with SiO gas ascending SiO gas and silicon get absorb iron to metal and this we do not have that much much gas usually iron free from carbon it could be at the upper part which is not possible.

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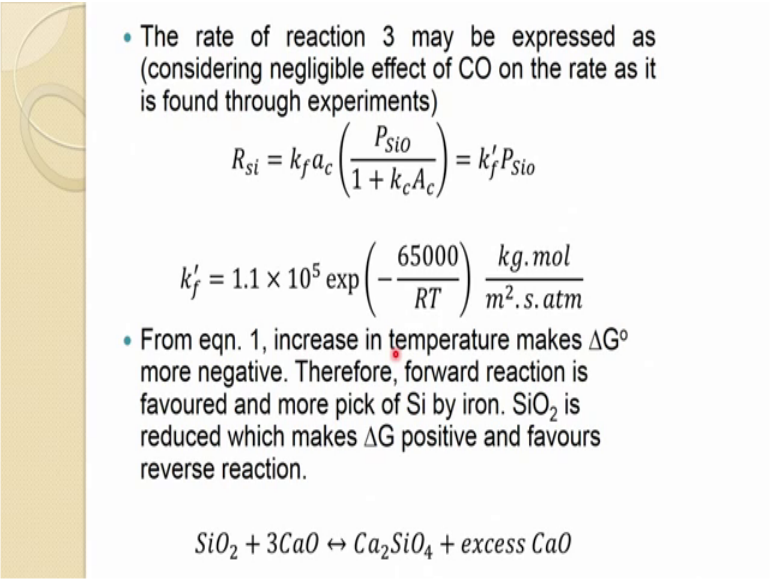

- The rate of reaction 3 may be expressed as (considering negligible effect of CO on the rate as it is found through experiments)

$$R_{si} = k_f a_c \left(\frac{P_{Sio}}{1 + k_c A_c} \right) = k_f' P_{Sio}$$

$$k_f' = 1.1 \times 10^5 \exp\left(-\frac{65000}{RT} \right) \frac{kg.mol}{m^2.s.atm}$$

- From eqn. 1, increase in temperature makes ΔG^o more negative. Therefore, forward reaction is favoured and more pick of Si by iron. SiO_2 is reduced which makes ΔG positive and favours reverse reaction.

$$SiO_2 + 3CaO \leftrightarrow Ca_2SiO_4 + excess\ CaO$$

So, the rate of this reaction the reaction, which is possible of this third reaction is express as follows. So, this is the rate of reaction for this and this is the rate constant activity of carbon and the area cross sectional area or interfacial area similarly and the rate carbon pa SiO partial pressure of silicon monoxide.

So, this term you put it in there. So, really rate of reaction is directly proportional to the partial pressure of SiO. And this rate constant is given by this expression. So, so, but this is again experimentally measured value and established value and it is used when your carbon percentage in iron is about 2.8. For saturated can 2.8 2.9 this is sort of in the blast furnace when it is dripping down, but for saturated carbon melt there is a different rate expression can be found. And now the equation 1 increase in temperature makes delta G more negative. So, if you increase the temperature therefore, the forward reaction is favored and not pick up of silicon iron.

So, in this way this reaction and more, but. So, SiO 2 is reduced which makes delta g positive and favorite the reverse reaction. So, nature naturally you need a very high temperature which it is not possible in the hearth region in that and this way this reaction silicon transport through this reaction it is not possible in the hearth region. Of course, quite a bit SiO 2 is combined with the lime which reduces this orbit increases and the basicity and in that way one can further probably increase this silicon transfer if one look at the kinetics of this reaction. So, it has been now well established now that almost all silicon transfer in the hot metal occur via gaseous phase in the dropping zone and near the tuyere and negligible amount of silicon transfer is occurred via slag metal reaction.

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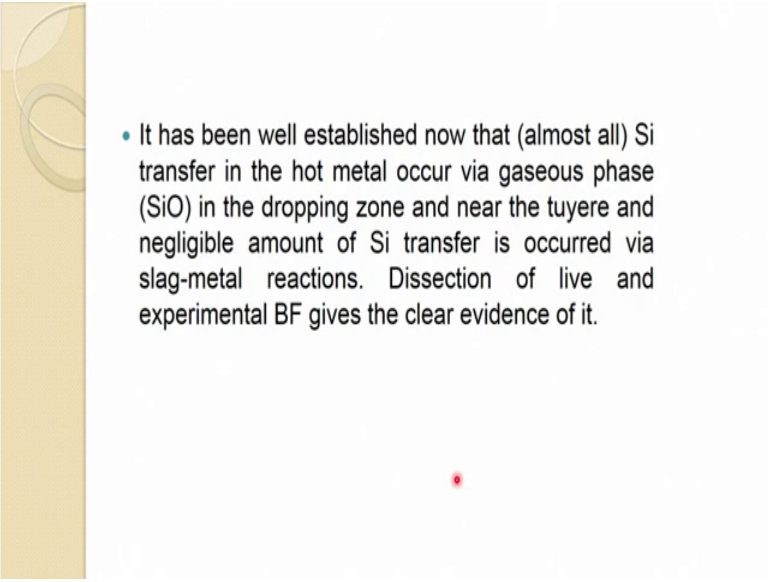

- It has been well established now that (almost all) Si transfer in the hot metal occur via gaseous phase (SiO) in the dropping zone and near the tuyere and negligible amount of Si transfer is occurred via slag-metal reactions. Dissection of live and experimental BF gives the clear evidence of it.

So, dissection of live and experimental blast furnace gives the clear evidence of it.

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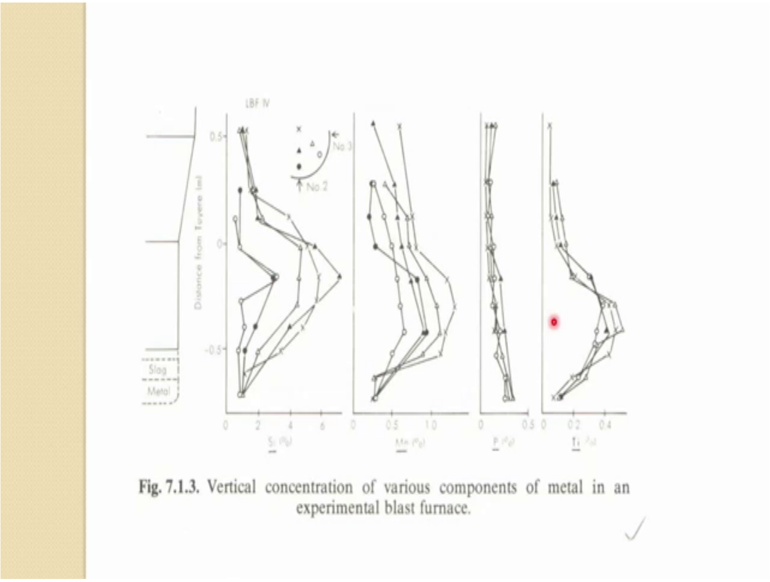

Fig. 7.1.3. Vertical concentration of various components of metal in an experimental blast furnace.

Now this is not the only one which has been found through the dissection of live or experimental blast furnace. In fact, it has been also found that. So, this is a tuyere level coke is surround surrounded around the raceway. So, even in the evidence has been found that silicon carbide is formed. So, with the carbon with the coke even SiO 2 can react and can form silicon carbide and through that even some of the silicon pick up and the hot metal is flowing through that silicon carbide sort of layer, then it can pick up silicon, but of course, the major one is the gaseous phase of silicon monoxide through which the silicon transfer occurs in the hot metal and these are the result of the experimental blast furnace.

So, this distant from the tuyere level; so this is tuyere level below and above 6.5 meters you. So, you can imagine that raceway is also there. So, you can see the silicon content at a just tuyere level is very very high. So, most of the silicon pick up is occurring SiO paper because its forming here and that depends in which radial direction that is how these points are given, so most of the SiO paper picks up by falling liquid metal and the types of the silicon. So, silicon pick up is quite high.

Similarly, in fact, you can see even the manganese pick up at that level is high and not that much phosphorus, but even the titanium is quite high because the temperature at this place is very high, mostly in the hearth region they equilibrium they try to equilibrate according to the thermodynamics, but most of the pickup is occurring in this region.

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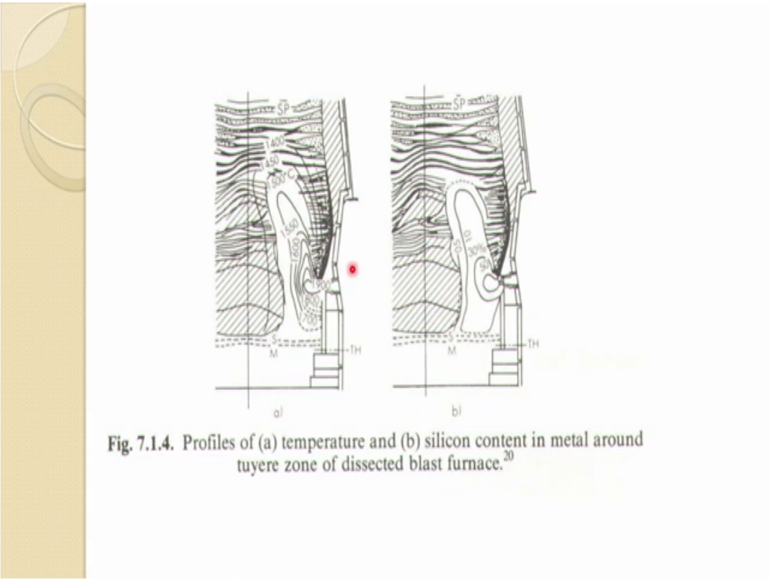

Fig. 7.1.4. Profiles of (a) temperature and (b) silicon content in metal around tuyere zone of dissected blast furnace.[20]

In fact, this is also another evidence it is found that temperature near the tuyere is like 1900 2000 1800 1700. So, these are the isotherm of the temperature near the tuyere region and this is the silicon content in the hot metal. So, directly related with the temperature and as the temperature is higher or SiO formation certainly is quite high. So, in this region one can expect a very high SiO formation and that which is also indicated by the metal which has been picked up through the zone. So, very high content of silicon and that is very well established silicon transparence occurring by a gaseous phase.

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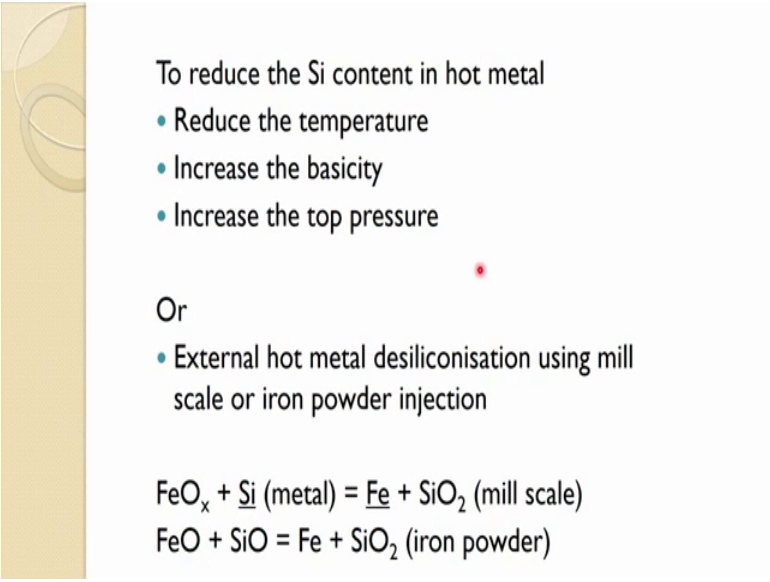

To reduce the Si content in hot metal

- Reduce the temperature
- Increase the basicity
- Increase the top pressure

Or

- External hot metal desiliconisation using mill scale or iron powder injection

$FeO_x + \underline{Si}$ (metal) = $\underline{Fe} + SiO_2$ (mill scale)

$FeO + SiO = Fe + SiO_2$ (iron powder)

So, in summary I would say also to reduce the silicon content in hot metal, reduce the temperature increase the basicity increase the top pressure or if you needed really very lost silicon content it is not possible through that, then external hot metal desiliconisation is necessary, which can be done using milli scale or iron powder injection in either in a torpedo car or other out outside process.

So, in milli scale the reaction would be like this. So, silicon get on silicon dissolve silicon form silica, and in by injecting iron powder again it forms silica and metal comes. So, you reduce the silicon content into that. So, the way you can control the silicon content and this is the mechanism.