Iron Making and Steel Making
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Module – 04
Lecture – 17
Sintering of Iron Ore

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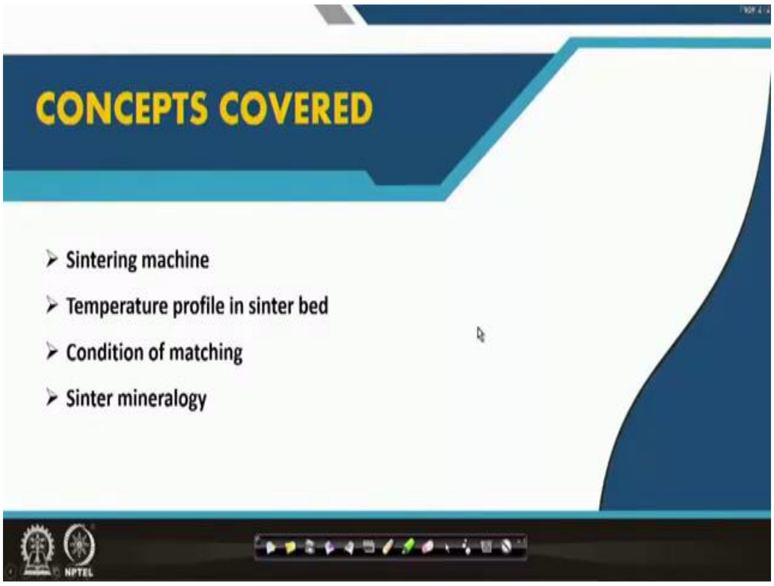

CONCEPTS COVERED

- Sintering machine
- Temperature profile in sinter bed
- Condition of matching
- Sinter mineralogy

In this lecture we will talk about the Sintering of Iron Ore. First I will talk about what is sintering and then sintering machine, temperature profile in the sinter bed, and sinter mineralogy.

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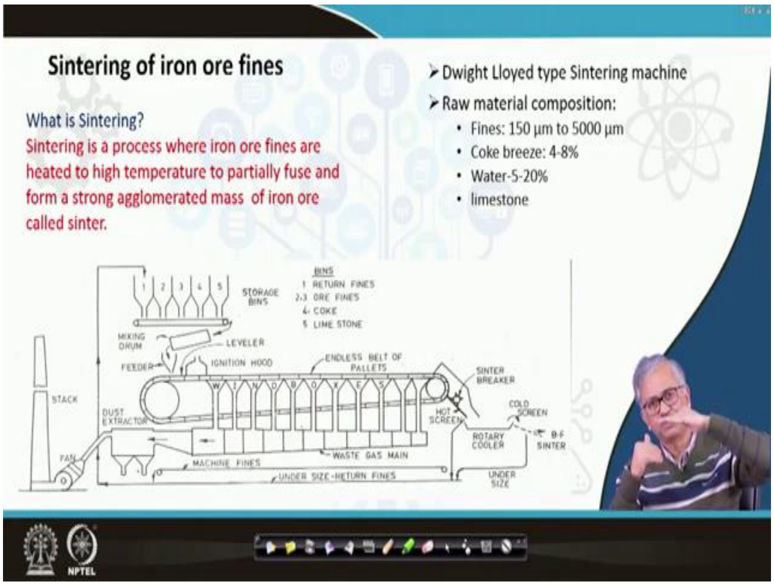

Sintering of iron ore fines

What is Sintering?

Sintering is a process where iron ore fines are heated to high temperature to partially fuse and form a strong agglomerated mass of iron ore called sinter.

- Dwight Lloyed type Sintering machine
- Raw material composition:
  - Fines: 150 μm to 5000 μm
  - Coke breeze: 4-8%
  - Water-5-20%
  - limestone

In sintering process iron ore fines are agglomerated in lumpy, hard and reactive mass, called the sinter. However, powdery fines are not acceptable here due to process limitation; ore fines greater than 150μm is acceptable. Iron ore fines is mixed with iron bearing solid waste like LD slag, EAF dust to a limited extent, and some amount of the fuel, usually 4-8% coke breeze (3-5mm), and also fluxing agent like lime(3mm). Subsequently, the mixture is heated to high temperature where iron particles are boned by fusion bond through incipient melting at particle surface. Diffusion bonding through atomic movement also forms another mechanism of bonding.

The machine that is used for the sintering is called the Dwight Lloyed type sintering machine. This machine is usually used in copper industry for preheating the copper ores. This machine is successfully used for all sintering purpose.

The machine is an endless belt of pallets. Pallets are rectangular hollow boxes with perforated bottom attached to chains that continuously revolve around this pulleys along with the pallets as shown in Figure 17.1.

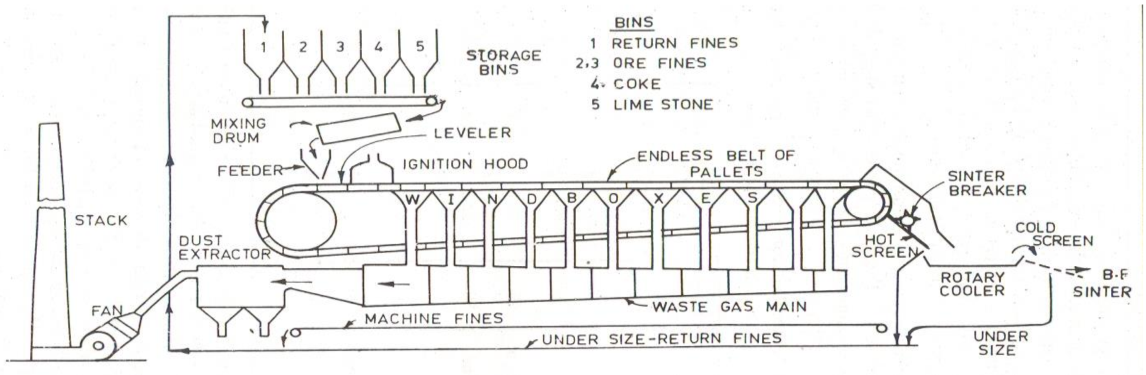

Figure 17.1 Schematics of Dwight Lloyed type sintering machine

Raw material in the pallet is ignited at the top and particles at the surface are agglomerated; subsequently particles are agglomerated across the bed. So, the combustion has to cross through the bed to the bottom to sinter the bed completely. In the machine, as shown in Figure 17.1, you can see some wind boxes at the bottom of the pallets that sucks air through the sinter bed in the pallets. When the air is sucked from the top it burns the fuel i.e., the coke breeze layer by layer and thus carries the combustion zone through the sinter bed. Heat exchange in sinter bed is excellent and it takes place from hot sinter to air in the upper part of the bed before the combustion zone reaches (preheating of air) and subsequently hot air pre-heat the sinter mix below the below the combustion zone.

Since efficiency of sinter bed depends on uninterrupted movement of air across the bed, a good permeability of the bed is essential. Besides the fines in the raw mix has to be granulated to the size of 8 to 10 mm, for optimum bed permeability. For granulation water (5 to 20%) is sprayed over the raw mix and granulated in a drum mixer before charging to pallets. Powdery fines are not allowed to control the growth of the granules below 10 mm.

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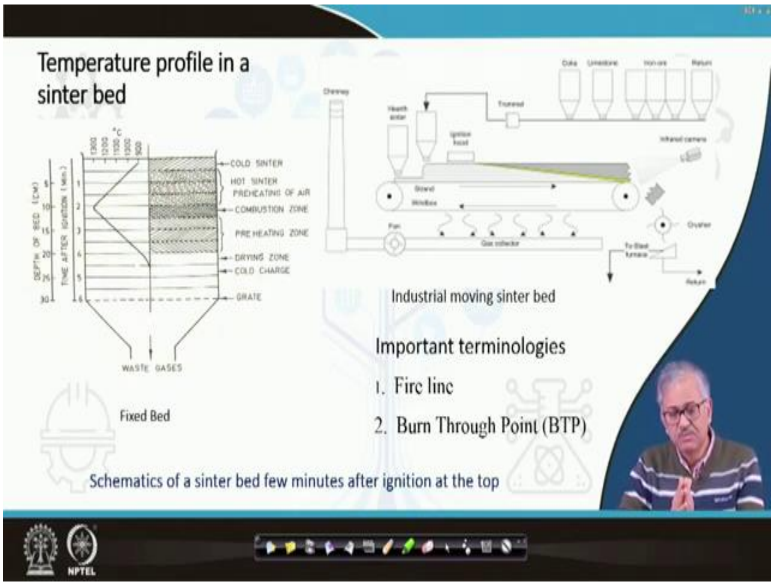


Temperature profile in a sinter bed

Fixed Bed

Industrial moving sinter bed

Important terminologies

1. Fire line
2. Burn Through Point (BTP)

Schematics of a sinter bed few minutes after ignition at the top

Let us understand the temperature profile in a laboratory batch sinter bed first.

Temperature across the axial direction in the sinter bed is monitored by placing thermocouples inserted inside the bed. The axial temperature profile at certain time after the top layer is ignited is shown in the figure 17.2.

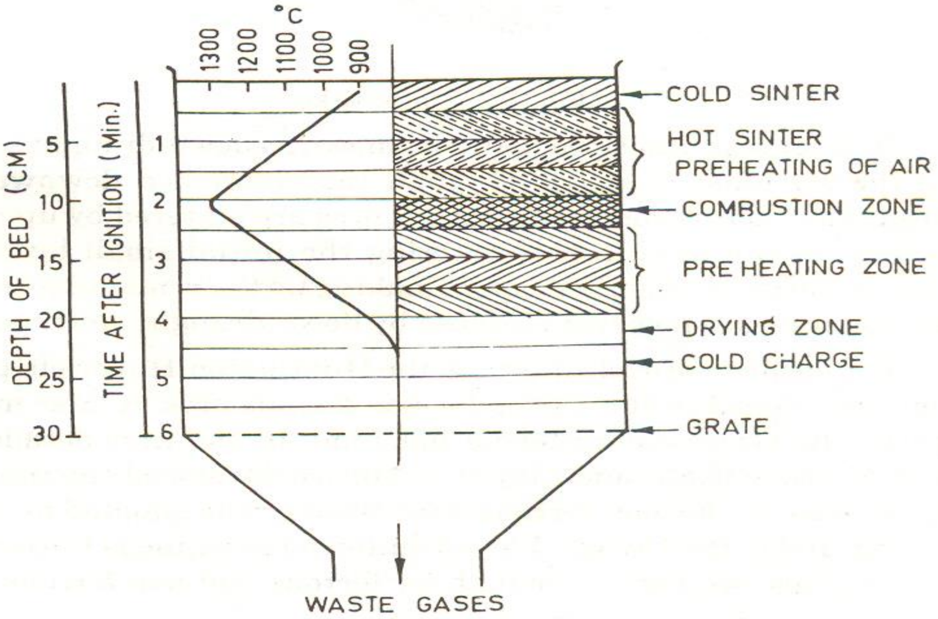
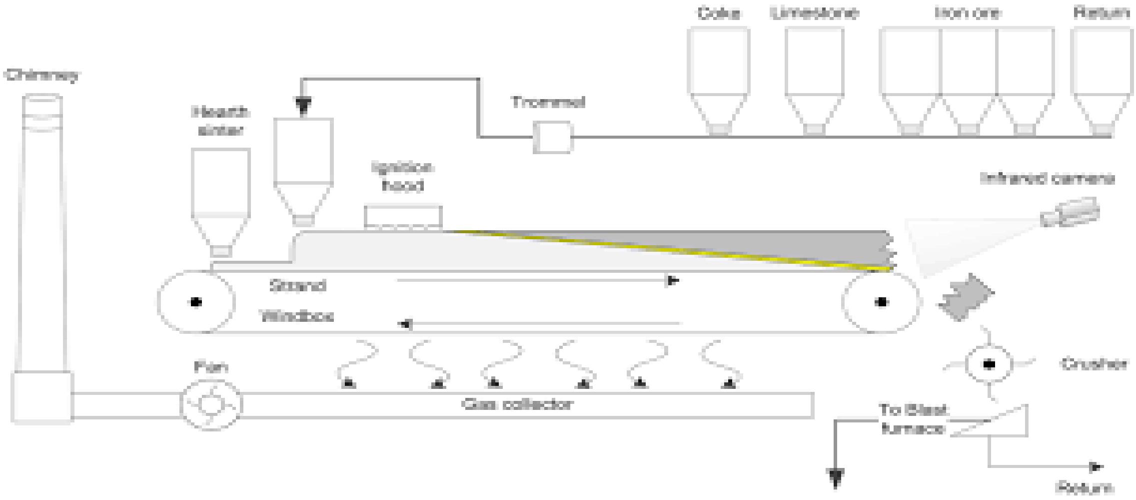


Figure 17.2 Schematic of axial temperature profile at certain time after the top layer is ignited in a laboratory batch sinter bed (Courtesy: A. K. Biswas[2])

The peak temperature is observed at a axial location representing the combustion zone. You can see the cold sinter at the top, followed by layer of hot sinters that preheats the passing air. Below the combustion zone, heat exchange takes place in reverse direction i.e., from air to the solid bed, preheating the raw sinter mix. Subsequently, air dries the raw mix below and finally comes out at room temperature, until the combustion zone moves to the bottom; when hot air emits from the bottom of sinter bed.

In the next moment, layer below the present combustion zone will be prepared for combustion and combustion zone will shift downward. So, here fire line moves in vertical direction till sinter bottom is reached.

Now, what happens in actual plant. The figure 17.3 shows how the fire line looks like in a sinter plant.



17.3 Schematics of fire line in a continuous sinter bed in a plant.

You can see the fire line moves to the bottom in an inclined line and not vertically as in batch sinter process; because here bed has a horizontal velocity component. At the end of strand, fire line has to reach the bottom, otherwise bottom part will not get sintered. So, there two terminology in plant: 1. Fire line that represents the combustion zone. The other is called the Burn Through Point, BTP. BTP represents the axial location of the pallets, where the fire line reaches the bottom of the sinter bed. When the fire line approaches the bottom of sinter bed the wind box temperature increases and reaches peak when the fire line reaches the bottom of the bed. So BTP is identified by monitoring the wind box temperature. BTP is usually achieved, just two three block ahead of the end of sinter strand. It is okay, because before the sinter comes to the end of sinter strand for crushing, it becomes cold by forced air cooling. But, if BTP is achieved prematurely, more than 2/3 blocks from the sinter end, then much of the sinter strand remain unutilized loosing productivity and in that case there is scope to increase the velocity of sinter strand, increasing the productivity.   If BTP is not achieved at the end of the strand, that means there are some raw sinter mix is left out at the sinter bottom, which has not been sintered properly. So, those will go as the return sinter, again loss of productivity. In that case proper measures has to be taken on the raw mix and granulation process ensuring proper bed permeability, or atleast the velocity of the strand should be reduce to match the BTP at the strand end.

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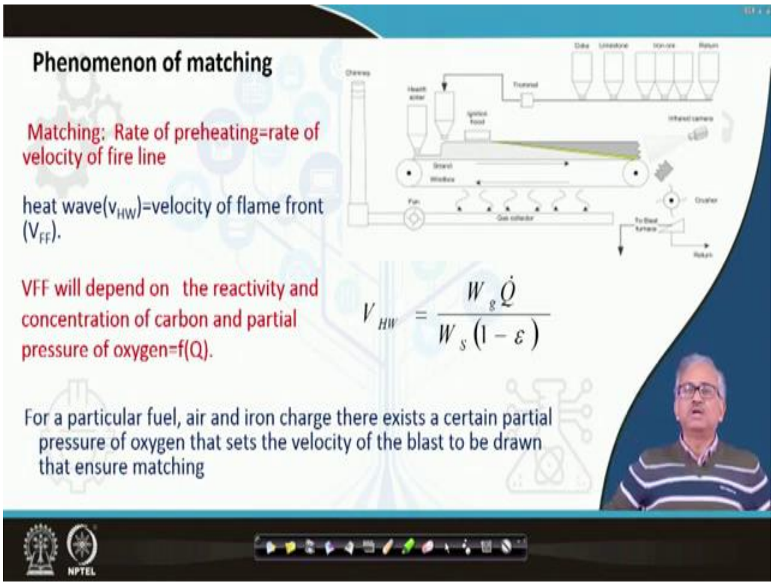

Phenomenon of matching

Matching: Rate of preheating=rate of velocity of fire line

heat wave(v_{HW})=velocity of flame front (V_{FF}).

VFF will depend on the reactivity and concentration of carbon and partial pressure of oxygen=f(Q).

$$V_{HW} = \frac{W_g \dot{Q}}{W_S(1-\varepsilon)}$$

For a particular fuel, air and iron charge there exists a certain partial pressure of oxygen that sets the velocity of the blast to be drawn that ensure matching

We have discussed that preheating of solid takes place below the combustion zone. When the combustion zone moves to the next layer, if it is preheated to the maximum extent, the temperature combustion will be maximum and bond generation will be better and we will get superior sinter. This can be ensured by complete heat exchange between the gas and solid before firing, which in turn means that when the velocity of solid bed preheating (cm of solid bed per unit time) matches with the rate of movement of fire line, or flame front (V_{FF}); this is called the condition of matching

Velocity of solid preheating, or the velocity of heat wave (V_{HW}) can be estimated by making a heat balance between gas and solid as represented by equation (17.1):

$$V_{HW} = \frac{W_g \dot{Q}}{W_S (1-\varepsilon)} \tag{17.1}$$

Where, W_g, and W_S are the heat capacities of gas and solid respectively. Q is the volumetric flow rate and εis the gas voidage of the bed.

And the condition of matching is: $V_{FF} = V_{HF}$.

Where, $V_{FF} = \frac{H}{t}$

$$\tag{17.2}$$

H= height of sinter bed and t is the time of sintering.

Velocity of heat wave depends on gas voidage, solid and gas heat capacities, and gas flow rate. For fixed raw charge, and granulation parameters, heat capacities of solid is fixed. Heat capacity of air is also fixed. So velocity of heat wave can be altered only by changing the air flow rate only.

Velocity of flame front depends on the reactivity of the carbon and the partial pressure of oxygen. Now, for a fixed coke breeze used in sintering, reactivity of the carbon remains constant. So, carbon reactivity is constant. So, what you can change is the partial pressure of oxygen to control the velocity of flame front. Partial pressure of oxygen can subsequently be controlled by altering volumetric flow rate of air. Thus, we see both the velocities of heat wave and flame front can be controlled by air flow rate and thus condition of matching can be achieved at a particular air flow rate.

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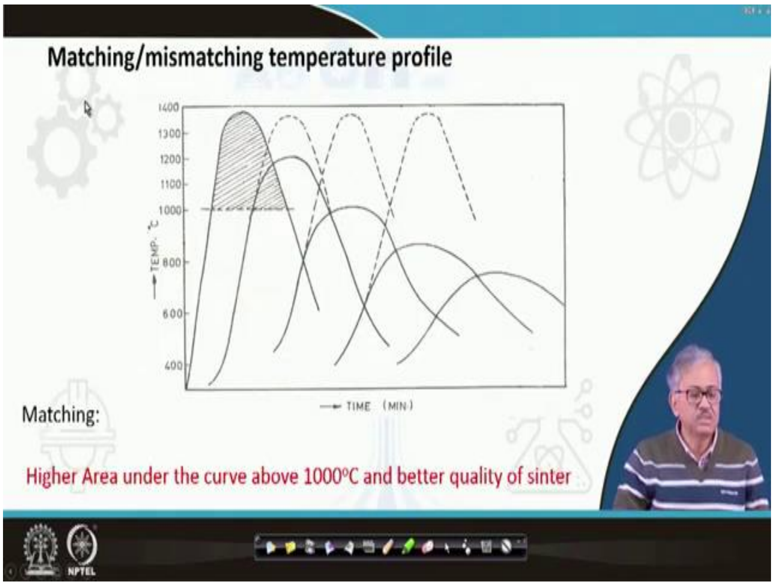


Matching/mismatching temperature profile

Matching:

Higher Area under the curve above 1000^{o}C and better quality of sinter

Figure (17.4) shows the thermal cycles at different locations under matching and mismatching conditions.

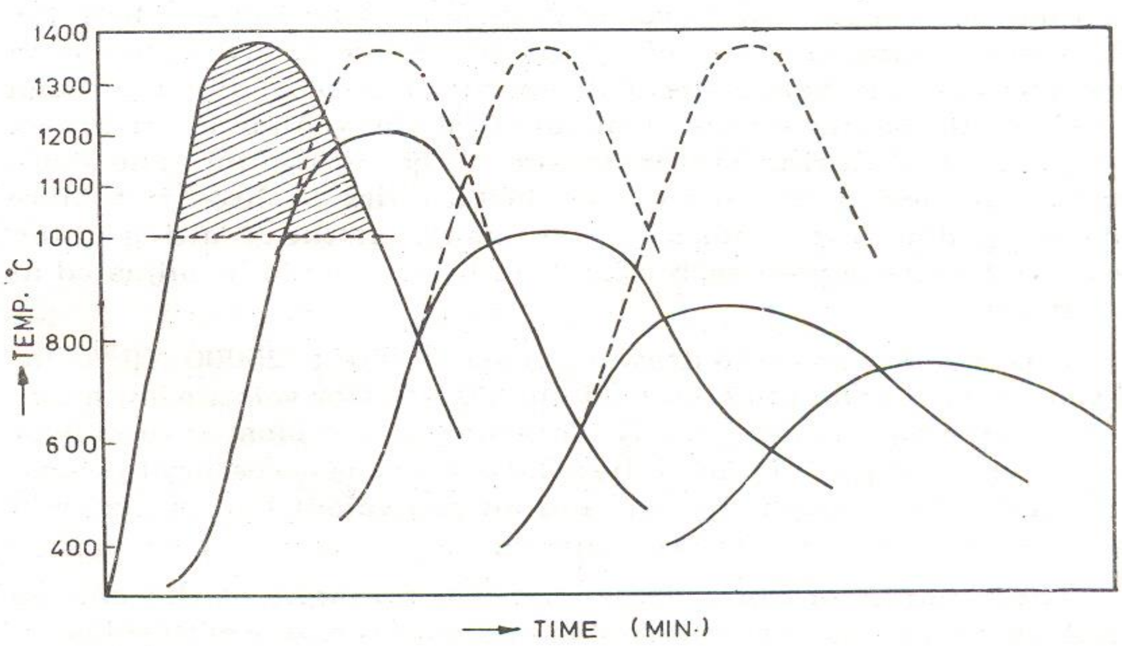
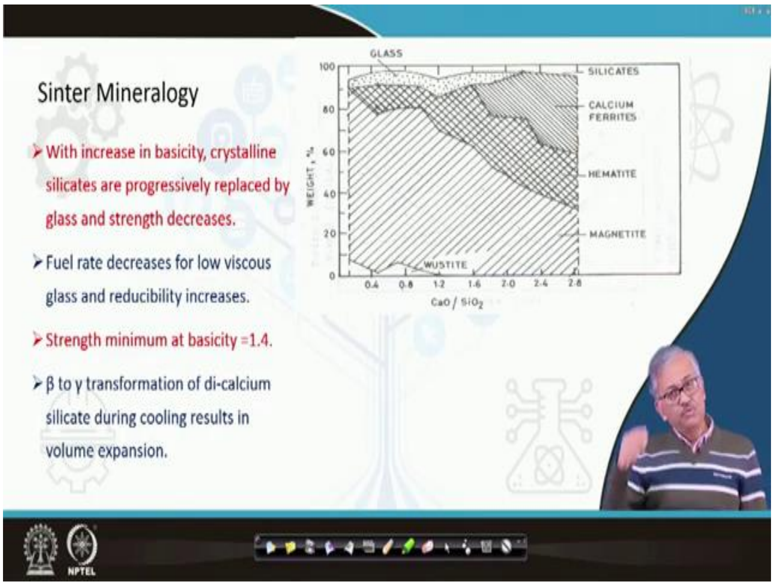


Figure 17.4 Thermal cycles at different locations under matching and mismatching condition (Courtey: R. H. Tupkary[1])

From thermal cycles at different locations (figure 17.4), it is seen that area under the curve above 1000^{o}C under matching condition, as shown by shaded area, is maximum. In subsequent curves, the dashed line show the extrapolated thermal cycles over the thermal cycles under mismatching condition at different locations (locations down the sinter bed). It is obvious that area under the curve above 1000°C is less and even absent for locations down the sinter bed for mismatch conditions. This area represents the extent of heating of the sinter mix above 1000°C; higher this area better is the quality of sinter because at higher temperature, especially above 1000°C, both the fusion and diffusion bonding could happen effectively. Therefore, under mismatch condition, when this area is small or absent bonding will be inappropriate or may not at all form. (Refer Slide Time: 27:26)



Sinter Mineralogy

- With increase in basicity, crystalline silicates are progressively replaced by glass and strength decreases.
- Fuel rate decreases for low viscous glass and reducibility increases.
- Strength minimum at basicity =1.4.
- β to γ transformation of di-calcium silicate during cooling results in volume expansion.

Let us now discuss the sinter mineralogy; that is very important because you can correlate various type of bonding and quality of sinter with the evolving mineralogy of sinter.

Figure 17.5 depicts the evolution of sinter minerology with basicity.

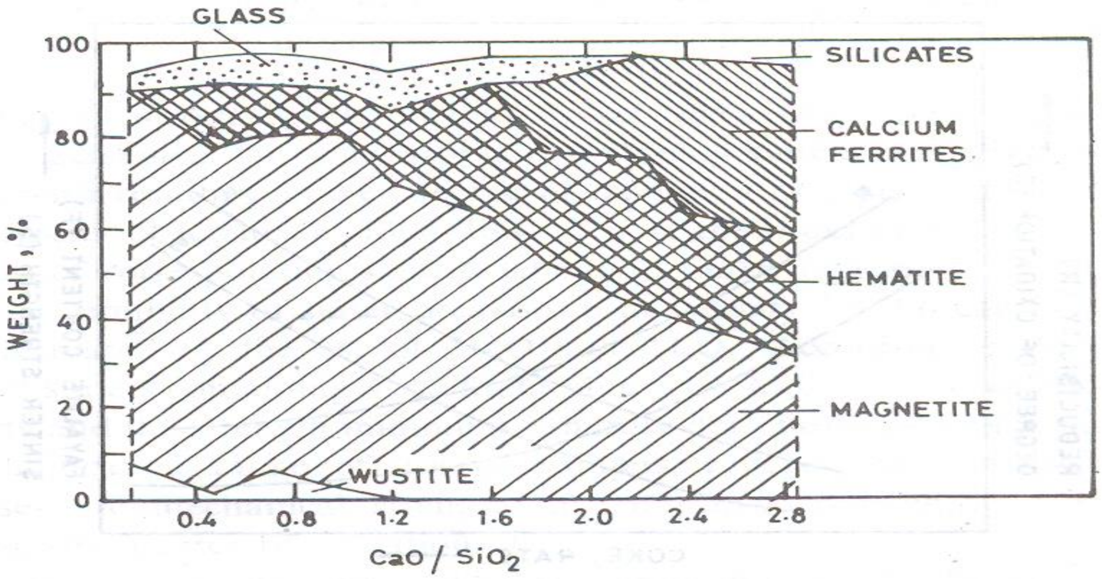


Figure 17.5 Evolution of Sinter minerology with basicity (Courtesy: A.K. Biswas[2])

It is seen that with increase in basicity (CaO/SiO_2 ratio in the sinter) how the sinter minerology changes. When lime is not added externally (except what comes through ore gangue) and the CaO/SiO_2 ratio is either zero or much less than 1, are called the acid sinter, where the major bonding elements are silicates. And the formation of silicate bonds require little higher temperature. So, higher fuel rate or carbon rate is required to generate higher temperature. But with higher carbon rate hematite is partially converted to magnetite and even to wustite. Higher percentage of hematite in sinter, increases its reducibility in blast furnace because hematite (HCP) to magnetite (FCC) conversion is accompanied with volume expansion that generates stress and micro fissures in magnetite crystal enhancing gas movement and reduction. Such transformation during sintering is not effective because fused slag fills this pores during sintering. Again magnetite to wustite transformation is not associated with stress and therefore magnetite is less reducible than hematite. Silicates forms strong bonds and therefore acid sinter are stronger but less reducible due to less hematite in sinter. Acid sinter also requires high fuel rate, high CO_2 emission -that is also another disadvantage. For making fluxed sinter lime is added externally in the sinter mix. With increase in CaO in the sinter silicates converts to glass (CaO-SiO_2-FeO) that fuse at much lower temperature, which reduces fuel rate and retains hematite in sinter and make it more reducible. But glass is less tougher than crystalline silicates. So with increase in CaO, sinter strength decreases but reducibility increases. With further increase in CaO in sinter beyond CaO/SiO_2 ratio of 1.2, it also starts precipitating crystalline ferrites and silicates. The sinter strength becomes minimum at CaO/SiO2 ratio between 1.4-1.6, which is attributed to phase transformation of di-calcium silicate from beta (bcc) to gamma (fcc), with accompanied volume change and stress, which develops weakness in the sinter.

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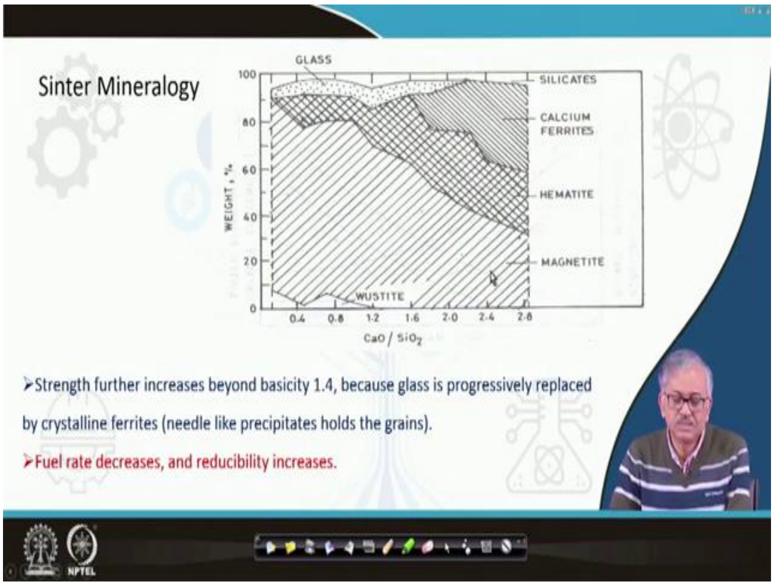

Sinter Mineralogy

- Strength further increases beyond basicity 1.4, because glass is progressively replaced by crystalline ferrites (needle like precipitates holds the grains).
- Fuel rate decreases, and reducibility increases.

If we further add CaO and CaO/SiO2 ratio go beyond 1.6, the glass gets complete replaced by crystalline calcium ferrite, which are needle like structures that holds the sinter particles tightly and thereby increasing strength. Fuel rate also decreases that restricts hematite conversion and making the sinter more reducible. Besides calcium ferrite keeps the sinter porous as it does not form liquid that can wet the pores and dissolve porosity.

Sinter could be self-fluxed, when the lime added is just sufficient to neutralize its acidic gangue. When the lime is added in excess to take care of acidic gangue of other iron burden in additions to its acidic gangue, is called the super-fluxed sinter. Fluxed sinter discard the addition of limestone and its associated endothermic dissociation in the blast furnace, decreasing the thermal load of the furnace.

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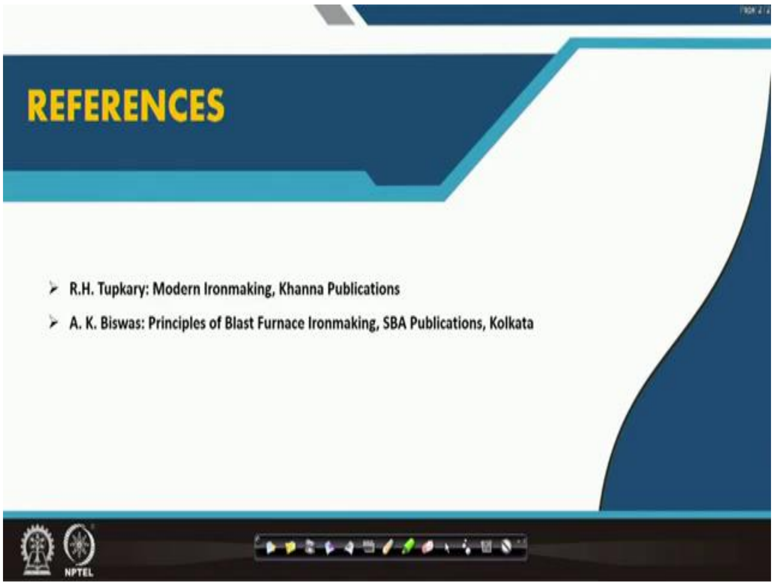

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Two reference is cited in the slide above.

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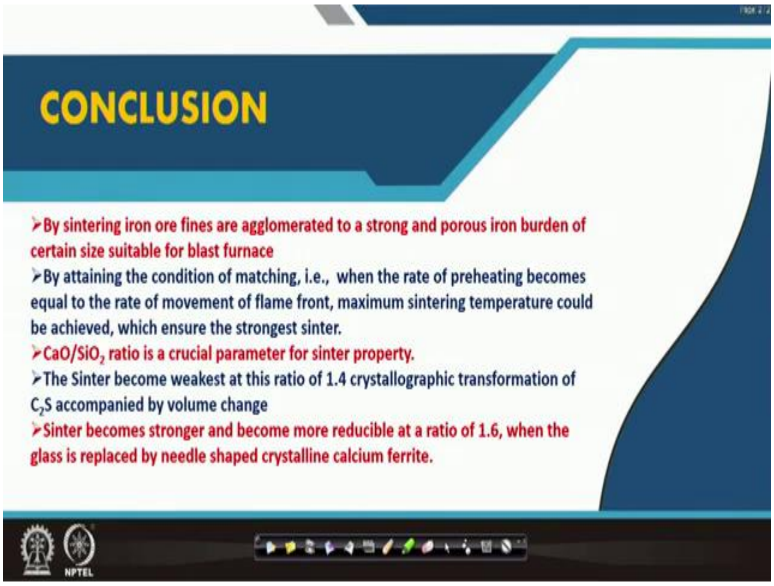

CONCLUSION

- By sintering iron ore fines are agglomerated to a strong and porous iron burden of certain size suitable for blast furnace
- By attaining the condition of matching, i.e., when the rate of preheating becomes equal to the rate of movement of flame front, maximum sintering temperature could be achieved, which ensure the strongest sinter.
- CaO/SiO_2 ratio is a crucial parameter for sinter property.
- The Sinter become weakest at this ratio of 1.4 crystallographic transformation of C_2S accompanied by volume change
- Sinter becomes stronger and become more reducible at a ratio of 1.6, when the glass is replaced by needle shaped crystalline calcium ferrite.

So, the conclusion are; by sintering iron ore fines are agglomerated to a strong and porous iron burden of certain size suitable for the blast furnace. During sintering process, the rate of preheat of solid (length per unit time) ensuring complete gas-solid heat exchange should be equal to the rate at which flame front progress through the sinter bed, which is called the matching. Under condition of matching the extent of heating of sinter bed becomes maximum improving its bonding quality. Matching can be ensured by an optimum air flow rate through the bed.

Sinter quality (strength, and reducibility) can be correlated to its minerology. Acid sinter are strong due to crystalline silicates but fuel rate is higher and reducibility is less (attributed to hematite conversion to magnetite and reducing the proportion of hematite in final sinter).

With increase in CaO in sinter, strength of sinter decreases due to replacement of silicates by glass. The strength become minimum at CaO/SiO_2 ratio at 1.4-1.6 where di-calcium silicate makes a phase transformation from BCC to FCC, causing stress and weakening of bonds. With further increase in CaO in sinter, glass is replaced by crystalline ferrites, whose needle like structure holds the sinter particles strongly and keep the sinter porous. Fuel rate decreases that retains hematite in sinter also. So the strength and reducibility both increases in basic sinter beyond CaO/SiO2 ratio 1.6.

Both self-fluxed and super-fluxed sinter is prepared to discard limestone addition in blast furnace and its associated endothermic dissociation, decreasing the thermal load of blast furnace.

Thank you.