Iron Making and Steel Making
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Module - 03
Lecture - 12
Aerodynamics in Blast Furnace - Part 2: Channeling

Good morning and welcome to the Module 3 - Aerodynamics in Blast Furnace Part 2. And in this lecture, I will discuss about the Channeling.

In the last lecture, I have discussed about the pressure drop. How to estimate the pressure drop in a blast furnace using Ergun equation. Ergun equation is a very well-known equation in a packed bed reactor to estimate the pressure drop and it is also used for calculating the pressure drop in blast furnace, and Ergun equation correlates the different packed bed parameters like bed voidage, velocity, particle diameter with pressure drop. We have shown that gas voidage has a very significant effect on the pressure drop. Pressure drop is very sensitive to the gas voidage; a slight increase in the gas voidage can decrease pressure drop by 3 to 5 times especially in the low voidage regime. Particle size also have an effect when the particle size is less than 5 millimeter; then heat, mass transfer and the flow resistance become very extremely high. And, also it is shown that is the effect of mixed bed on the pressure drop become significant at fine fraction of 30 to 40%, especially when the size of bigger particles becomes more than 50 times higher than size of smaller particles.

Now, this pressure drop basically gives an average estimate of the pressure drop in the blast furnace; but actually if you want to know the health of the blast furnace or health of the gas flow inside the blast furnace; instantaneous health of the blast furnace; then it is better to know the radial and the axial distribution of the pressure in the blast furnace and nowadays, different under burden probes are available using which the instantaneous and local pressure inside the blast furnace can be assessed and that is very helpful. So by knowing the dynamic evolution of pressure drop distribution, corrective action could be taken.

So, now let us understand one of the major irregularities in the blast furnace- the channeling. Channeling takes place when the gas passes through some selected channels in the solid bed. Under such situation gas is not utilized properly because gas does not interact with the most of the solid and it only passes through certain channels and that too at a very high velocity with a very low residence time.

So, the gas solid interaction become very less, and the thermal and chemical potential of the blast furnace gas is not utilized at all. As a result, it yields a less efficient furnace with higher fuel rate and lower productivity.

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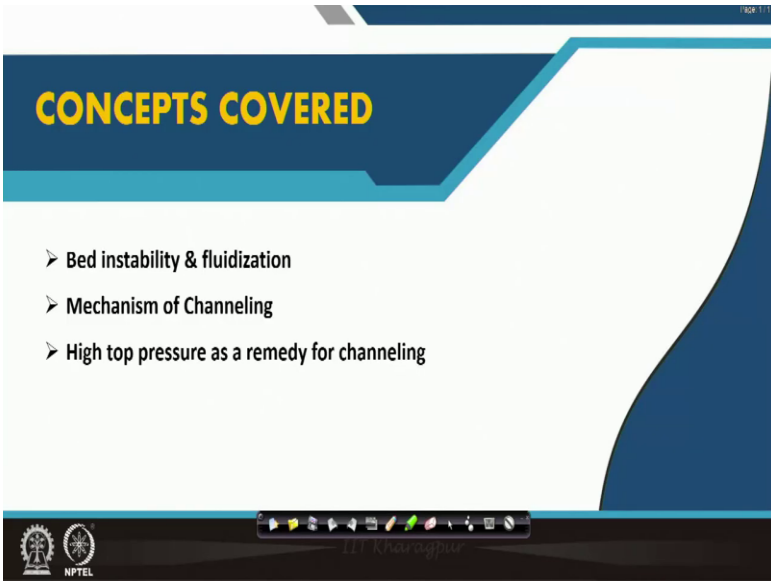

CONCEPTS COVERED

- Bed instability & fluidization
- Mechanism of Channeling
- High top pressure as a remedy for channeling

In this lecture we will fist discuss about the bed instability and fluidization. And then, the mechanism of channeling will be discussed. Finally we will discuss high top pressure as a remedy for the channeling. These are the basic concepts that will be covered.

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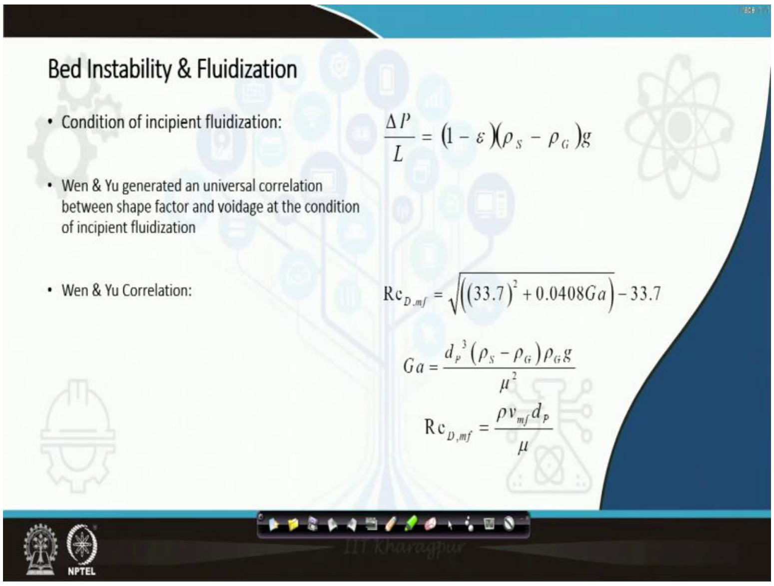

Bed Instability & Fluidization

- Condition of incipient fluidization: $\frac{\Delta P}{L} = (1-\varepsilon)(\rho_S - \rho_G)g$
- Wen & Yu generated an universal correlation between shape factor and voidage at the condition of incipient fluidization
- Wen & Yu Correlation: $Re_{D,mf} = \sqrt{\left((33.7)^2 + 0.0408Ga\right)} - 33.7$

$$Ga = \frac{d_P^{\,3}(\rho_S - \rho_G)\rho_G g}{\mu^2}$$

$$Re_{D,mf} = \frac{\rho v_{mf} d_P}{\mu}$$

What is fluidization? Blast furnace is a packed bed; but if you have fines, then fines can get fluidized. There exists a condition at the onset of fluidization, called the incipient fluidization. When gas flow rate through a packed bed increases, the pressure drop increases progressively due to frictional dissipation and more resistance to gas flow. Subsequently a point is reached, where the pressure drop across the bed just become equal to the apparent weight of the bed (equation 12.1).

$$\frac{\Delta P}{L} = (1-\varepsilon)(\rho_S - \rho_G)g$$

(12.1)

The RHS term of the equation 12.1 represents the apparent weight of the bed. (1-ε) represent the volume of the solid per unit volume of the bed. $(1-\varepsilon)\rho_s g$ yields the weight of the bed. $(1-\varepsilon)\rho_l g$ gives the buoyance and finally $(1-\varepsilon)(\rho_s-\rho_l)g$ yields the apparent weight of the bed, suspended in gaseous medium. While, ε, ρ_S, ρ_l represent gas voidage, density of solid and liquid, respectively. So, when pressure drop across the fixed bed become equal to the apparent weight of the bed, the condition is called the condition of incipient fluidization. Beyond this point pressure drop remains constant with increase in velocity and height of the fluidized bed increases. The dynamic balance between the frictional force and voidage keep the pressure drop constant. Wen and Yu developed an universal correlation between shape factor of the particles and gas voidage and finally yielded an universal correlation for the gas velocity at incipient fluidization, the galileo number, Ga, as shown equation 12.2.

$$\mathrm{Re}_{D,mf} = \sqrt{\left((33.7)^2 + 0.0408Ga\right)} - 33.7$$

(12.2)

$$Ga = \frac{d_P{}^3 \left(\rho_S - \rho_G\right) \rho_G g}{\mu^2}$$

$$\mathrm{Re}_{D,mf} = \frac{\rho v_{mf} d_P}{\mu}$$

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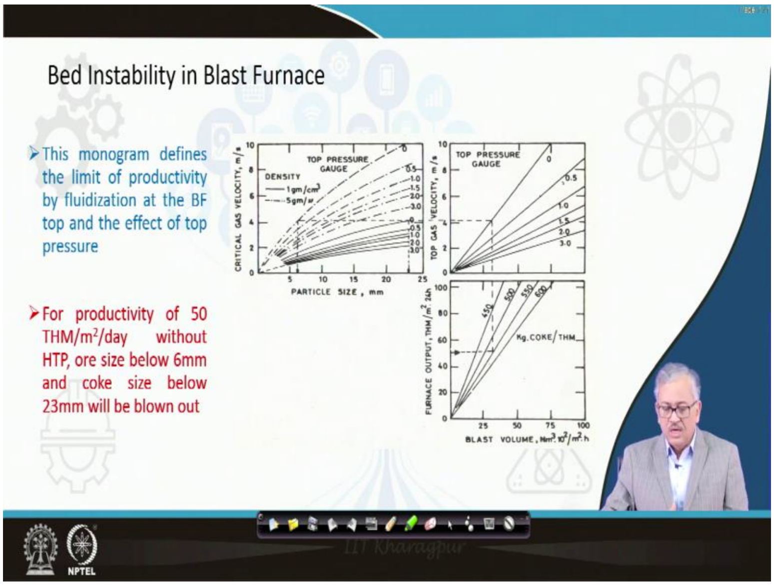

Bed Instability in Blast Furnace

- This monogram defines the limit of productivity by fluidization at the BF top and the effect of top pressure
- For productivity of 50 THM/m²/day without HTP, ore size below 6mm and coke size below 23mm will be blown out

The Figure 12.1 shows limitation on productivity caused by fluidization.

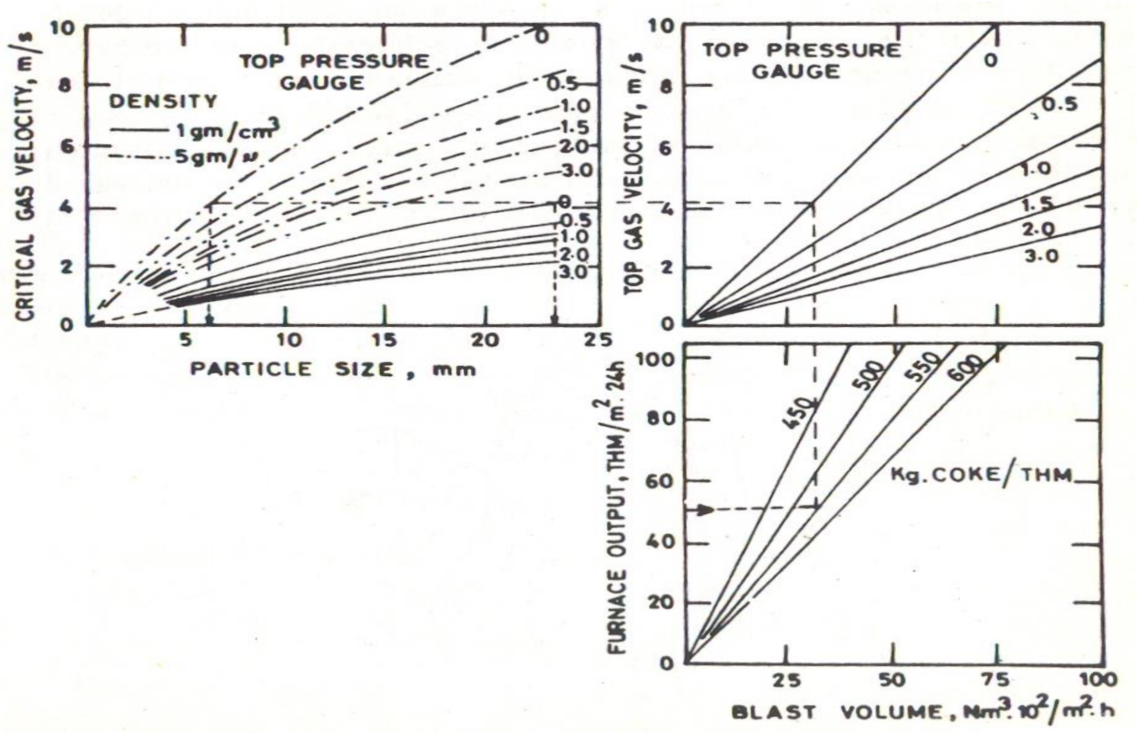

Figure 12.1 Limit of productivity caused by fluidization

The figure 12.1 depicts how increase in productivity may be limited by fluidization of particles in blast furnace at certain gauge pressure at the top. Let us analyze the figure. Suppose you want to produce iron at a productivity at 50 ton/m^2-day. Please note a productivity of 70 in this unit may be considered as benchmark value. If coke rate is 450 kg/THM, the linear gas velocity through the furnace at zero gauge pressure at top, is found to be 4 m/s, which exceeds the critical or minimum fluidization velocity for 6mm ore particle and 23 mm coke particles. So, the ore size below 6 millimeter and coke size below 23 millimeter will be blown out from the system. If gauge pressure is increased to 0.5, i.e. if the top pressure becomes 1.5 atmosphere, the linear velocity becomes 2.6 m/s, which is just sufficient to fluidize ore particles below 4 mm and coke particles below 17 mm.

So, when you want to increase the productivity, obviously, the blast rate increases. At the same time you have to keep in mind whether the resulting linear velocity through the blast furnace will fluidize some fines or not. Accordingly, top pressure has to be adjusted to restrict fluidization of fines. As will be subsequently seen that local fluidization of fines may lead to channeling.

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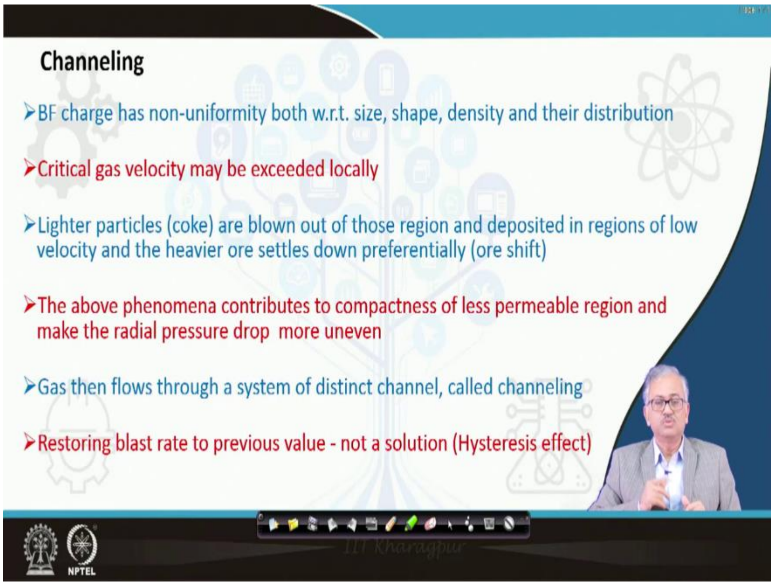

Channeling

- BF charge has non-uniformity both w.r.t. size, shape, density and their distribution
- Critical gas velocity may be exceeded locally
- Lighter particles (coke) are blown out of those region and deposited in regions of low velocity and the heavier ore settles down preferentially (ore shift)
- The above phenomena contributes to compactness of less permeable region and make the radial pressure drop more uneven
- Gas then flows through a system of distinct channel, called channeling
- Restoring blast rate to previous value - not a solution (Hysteresis effect)

Let us discuss a mechanism of channeling? Blast furnace charge are non-uniform with respect to size, shape, density and their distribution. There exists a very complex solid distribution across the cross section in the blast furnace with non-uniform bed permeability. So, local variation of pressure is evident. That is why the critical gas velocity for fluidization for fine particles may be exceeded locally. Presence of fines increases the resistance to gas flow and correspondingly increases the local pressure drop. So, if we just go on increasing the blast velocity or the linear velocity in the blast furnace, then time may arrive when the critical velocity may be exceeded locally at that fine rich location and lighter fine particles may be blown off in this region. When fine particles are blown off they create some vacancy between heavy ore particles, which roll towards each other under gravity consolidating the bed, such phenomena is called the ore shift. After fluidization the pressure drop is released and the settles over the consolidated region making the region more impervious to gas flow.

This phenomena is pictorially is presented in Fig. 12.2.

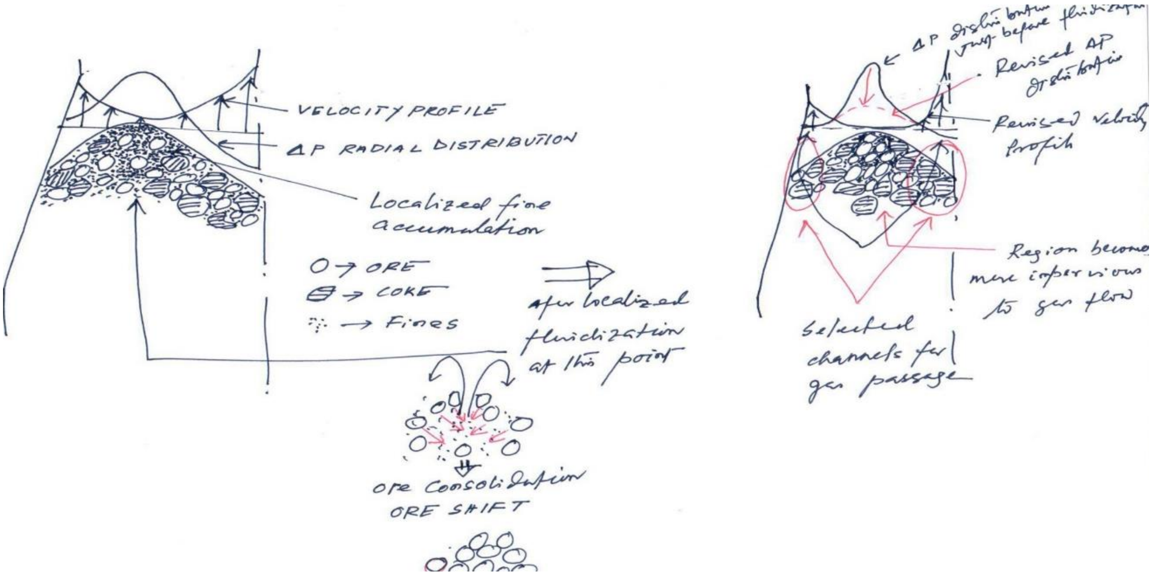

Figure 12.2 Schematics showing the mechanism of channeling by local fluidization.

The figure shows a M-stock profile, where ridges with fines are formed away from the wall and so that both the periphery and center remains more permeable to gas where the middle region remains less permeable to gas. A schematic representation of pressure drop and velocity distribution are also shown. Where pressure drop passed through a maximum and gas velocity passes through a minimum through the middle zone. When gas velocity is increased, the flow resistance in the in the middle region increases and pressure drops shoots up and exceeds the minimum fluidization velocity for fine particles in that zone. The fine particles is blown off from the region allowing the ore particles to consolidate through ore shift. After fluidization the pressure drop is released and the fine particles redeposit, and the region becomes more impervious to gas and entire gas only flow through center and periphery regions and depriving the middle region for gas interaction. This is just an example. Such local fludization can occur at several locations, making only certain channels permeable to gas flow-leading to channeling.

And, restoring it again, i.e, if you want to restore the blast rate to previous value, is not a solution because of hysteresis. So, prevention of channeling is better than its cure.

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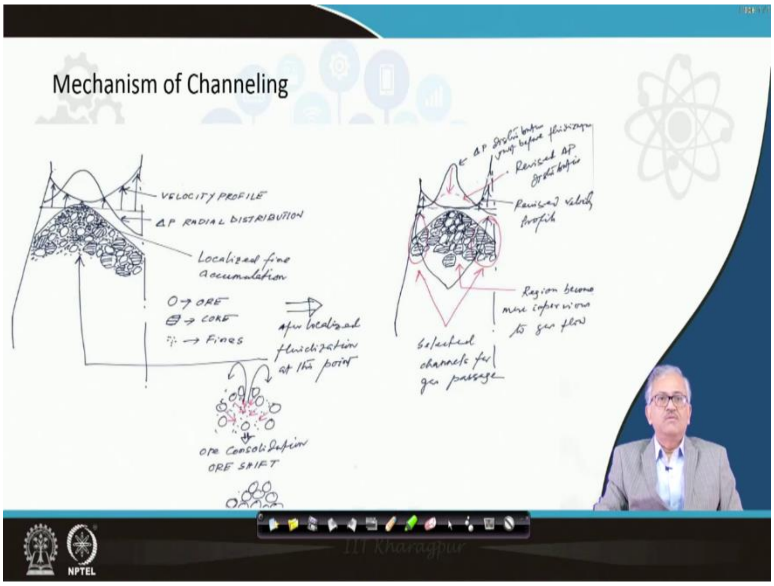

Mechanism of Channeling

For details, consult the book of A. K. Biswas.

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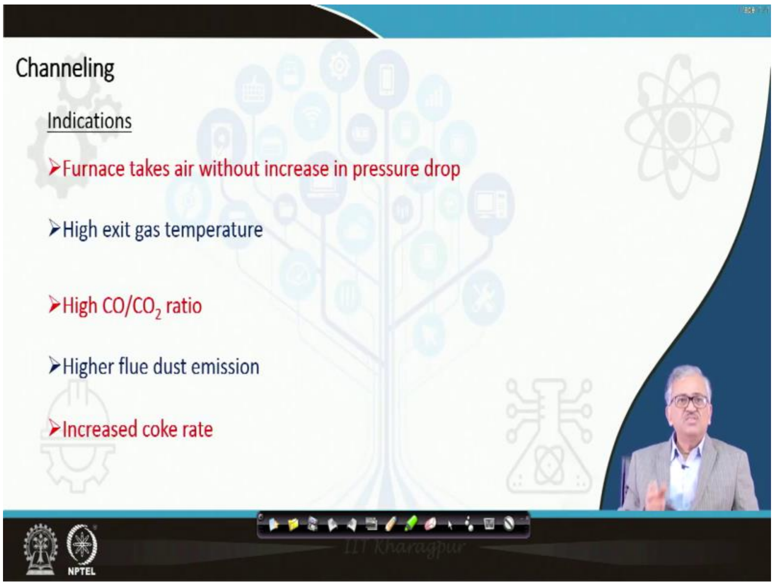


Channeling

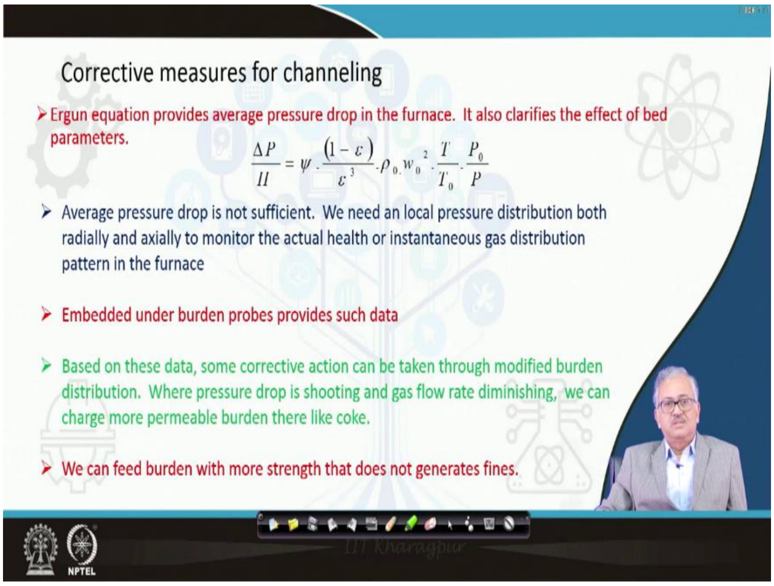
Indications

- Furnace takes air without increase in pressure drop
- High exit gas temperature
- High CO/CO_2 ratio
- Higher flue dust emission
- Increased coke rate

If channeling take place what are the indication you can find? Furnace takes air without increase in the pressure drop, because air passes through region of least resistance without much frictional loss.

Exit gas temperature becomes high because thermal potential of the gas is not utilized effectively. During channeling, the CO/CO_2 ratio becomes high; because the chemical potential of the gas is not utilized effectively.

High flue dust emission because of fluidization of fines. Obviously, the coke rate will also increase because gas remained under-utilized. So, these are some of the indications of channelling. (Refer Slide Time: 22:45)



Corrective measures for channeling

- Ergun equation provides average pressure drop in the furnace. It also clarifies the effect of bed parameters.

$$\frac{\Delta P}{H} = \psi \cdot \frac{(1-\varepsilon)}{\varepsilon^3} \cdot \rho_0 . w_0^2 \cdot \frac{T}{T_0} \cdot \frac{P_0}{P}$$

- Average pressure drop is not sufficient. We need an local pressure distribution both radially and axially to monitor the actual health or instantaneous gas distribution pattern in the furnace
- Embedded under burden probes provides such data
- Based on these data, some corrective action can be taken through modified burden distribution. Where pressure drop is shooting and gas flow rate diminishing, we can charge more permeable burden there like coke.
- We can feed burden with more strength that does not generates fines.

What are the corrective action for Channelling?

Ergun equation provides the average pressure drop and average pressure drop is not sufficient. You need to know the dynamic evolution of pressure drop distribution in the solid bed, which can be mapped using under burden probes. If we identify the locations of high pressure drop at certain time, real time measures should be taken to reduce the pressure drop in those region. One way could be by charging stronger and permeable charge in those region through bell less charging.

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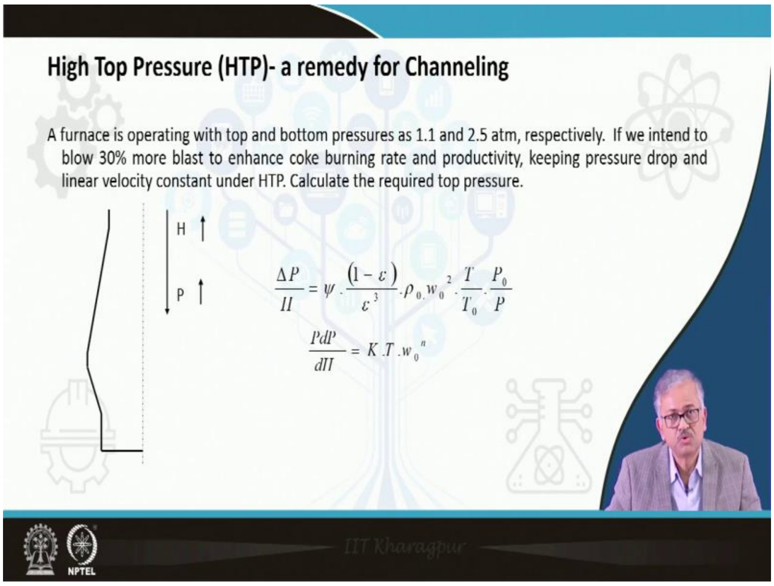

High Top Pressure (HTP)- a remedy for Channeling

A furnace is operating with top and bottom pressures as 1.1 and 2.5 atm, respectively. If we intend to blow 30% more blast to enhance coke burning rate and productivity, keeping pressure drop and linear velocity constant under HTP. Calculate the required top pressure.

$$\frac{\Delta P}{H} = \psi \cdot \frac{(1-\varepsilon)}{\varepsilon^3} \cdot \rho_0 \cdot w_0^2 \cdot \frac{T}{T_0} \cdot \frac{P_0}{P}$$

$$\frac{PdP}{dH} = K.T.w_0^n$$

In this slide, we will discuss the high top pressure as a remedy for a channeling.

Now, high top pressure means a devise to reduce the pressure drop in the furnace by increasing pressure at the top of the furnace. It can be achieved by restricting the outgoing gas. Charging mechanism, especially bell less charging offers such measures to increase the gauge pressure at the top, by restricting the outgoing gas flow. And, if you produce a high top pressure, the pressure drop in the blast furnace decreases because you are increasing top pressure, P_2 without affecting the lower pressure, P1.. So, if you want to increase the blast rate to increase the productivity, then obviously lower pressure P_1 increases and then if you increase the P_2 also using high top pressure, then it is possible maintain a restrict the rise in pressure drop with blast rate.

So, pressure drop will remain constant, but at the same time it would be possible to push some more amount of the air blast to increase the productivity. So, in that case, with high top pressure, you can maintain the pressure drop constant even at high blast rate.

So, let us see some quantitative calculation how you can do that. Suppose a furnace is operating with the top and bottom pressure as 1.1 and 2.5 atmosphere, respectively. Now, you intend to blow 30 percent more blast to enhance the coke burning rate and the productivity.

As a result, your pressure drop inside the furnace will increase, but you do not want that and want to keep the pressure drop constant by increasing the top pressure. So, to keep the pressure drop constant, what will be the high top pressure? The Ergun equation can be used for such calculation. Ergun equation can be represented by equation 12.3, where pressure drop varies with only pressure, temperature and superficial gas velocity (w_0, Nm^3/m^2-s).

$$\frac{PdP}{dH} = K.T.{w_0}^n$$

(12.3)

Integrating the equation and considering constant temperature

$$P_{av}\Delta P = K'.w_0^n$$

(12.4)

Where, Pav =(P_1+P_2)/2 and ΔP=(P_1-P_2). The empirical parameter, the exponent n can be taken as 1.75.

$$\frac{(P_{av})_2}{(P_{av})_1} = \left(\frac{w_{0,2}}{w_{0,1}}\right)^{1.75} = (1.3)^{1.75}$$

(12.5)

The average pressure drop with 30% enhance flow ratecan be obtained from equation (12.5) as 2.85.

Noting that pressure drop remains same at 1.4, the revised top pressure for case 2 may be calculated as 2.15.

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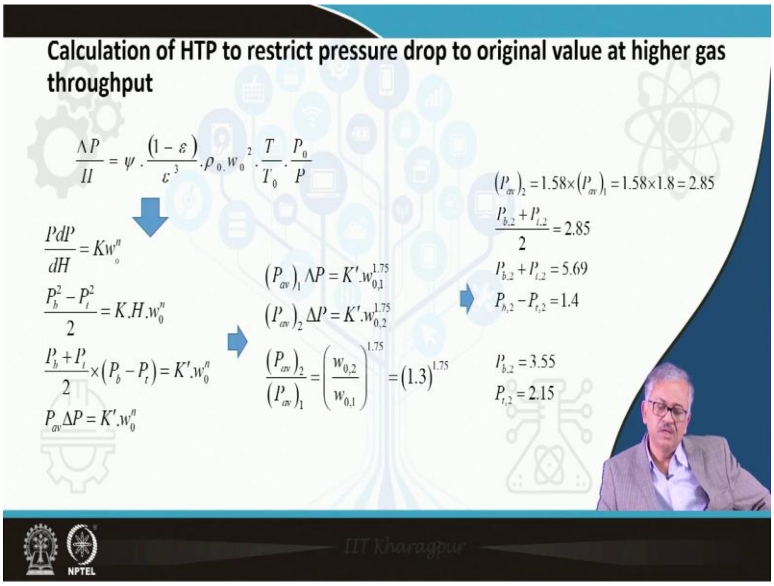

Calculation of HTP to restrict pressure drop to original value at higher gas throughput

$$\frac{\Delta P}{H} = \psi \cdot \frac{(1-\varepsilon)}{\varepsilon^3} \cdot \rho_0 \cdot w_0^2 \cdot \frac{T}{T_0} \cdot \frac{P_0}{P}$$

$$\frac{PdP}{dH} = Kw_0^n$$

$$\frac{P_b^2 - P_t^2}{2} = K.H.w_0^n$$

$$\frac{P_b + P_t}{2} \times (P_b - P_t) = K'.w_0^n$$

$$P_{av} \Delta P = K'.w_0^n$$

$$(P_{av})_1 \Delta P = K'.w_{0,1}^{1.75}$$

$$(P_{av})_2 \Delta P = K'.w_{0,2}^{1.75}$$

$$\frac{(P_{av})_2}{(P_{av})_1} = \left(\frac{w_{0,2}}{w_{0,1}}\right)^{1.75} = (1.3)^{1.75}$$

$$(P_{av})_2 = 1.58 \times (P_{av})_1 = 1.58 \times 1.8 = 2.85$$

$$\frac{P_{b,2} + P_{t,2}}{2} = 2.85$$

$$P_{b,2} + P_{t,2} = 5.69$$

$$P_{b,2} - P_{t,2} = 1.4$$

$$P_{b,2} = 3.55$$

$$P_{t,2} = 2.15$$

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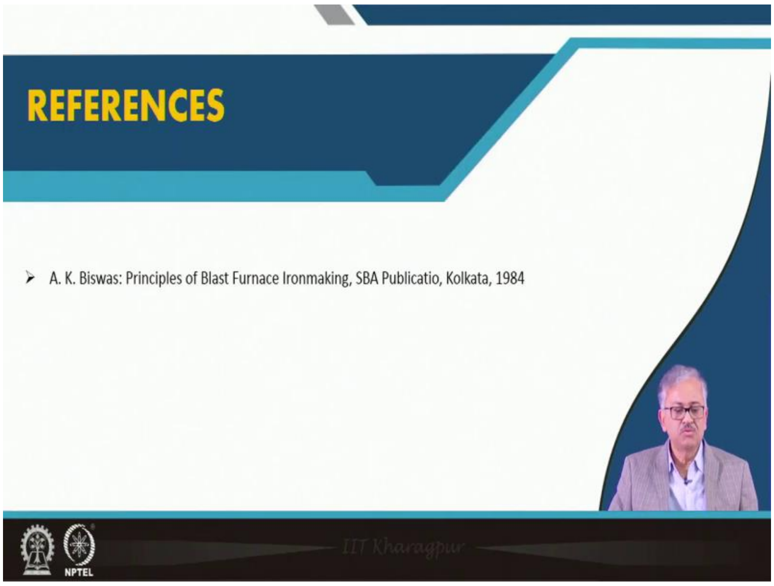

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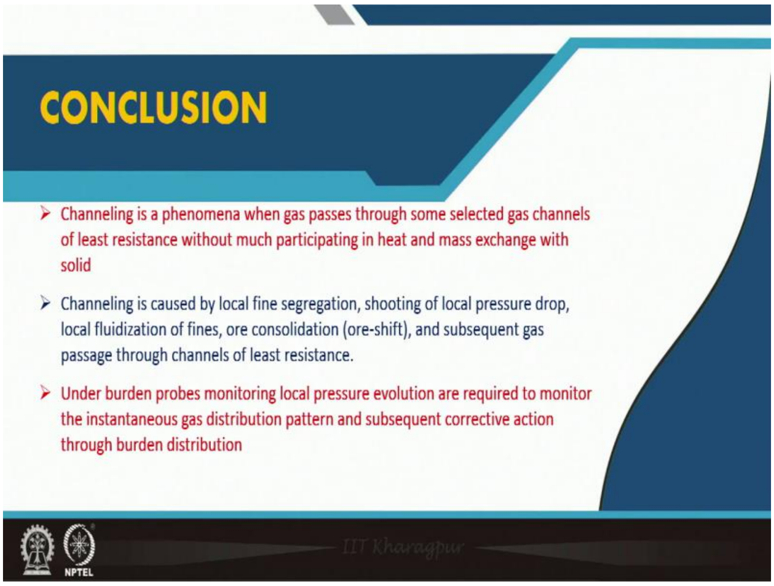

CONCLUSION

- Channeling is a phenomena when gas passes through some selected gas channels of least resistance without much participating in heat and mass exchange with solid
- Channeling is caused by local fine segregation, shooting of local pressure drop, local fluidization of fines, ore consolidation (ore-shift), and subsequent gas passage through channels of least resistance.
- Under burden probes monitoring local pressure evolution are required to monitor the instantaneous gas distribution pattern and subsequent corrective action through burden distribution

For further study, consult the book that is A. K. Biswas. What are the conclusion now? So, we have found that channeling is a phenomena when gas passes through some selected gas channels of least resistance without much participating into heat and mass exchange with the solid.

The channeling is caused by the local fine segregation. At enhanced velocity, pressure drop shoots up at location of fine segregation, leads to local fine fluidization, consolidation of the ore particles (ore shift) and then, re-deposition of the fine particle in the same area, makes the region impervious to gas leading to gas channels. Under burden probes monitoring the local pressure evolution are required to monitor the instantaneous gas distribution or instantaneous health of the blast furnace and subsequent corrective action through the burden distribution or the high top pressure have to be taken. Once channeling has taken place, then it is very difficult to return to the initial condition. So, when you get some indication of the channeling in terms of pressure drop, high temperature and CO concentration in the exit gas, some corrective action through burden distribution or high top pressure has to be taken.

Ergun equation can be used to calculate the average pressure drop in the dry zone of the blast furnace and it can also be used to back calculate the high top pressure while operating the furnace at higher blast rate without affecting the average pressure drop in the furnace.

In the next lecture, we will talk about the flooding and the blast furnace.