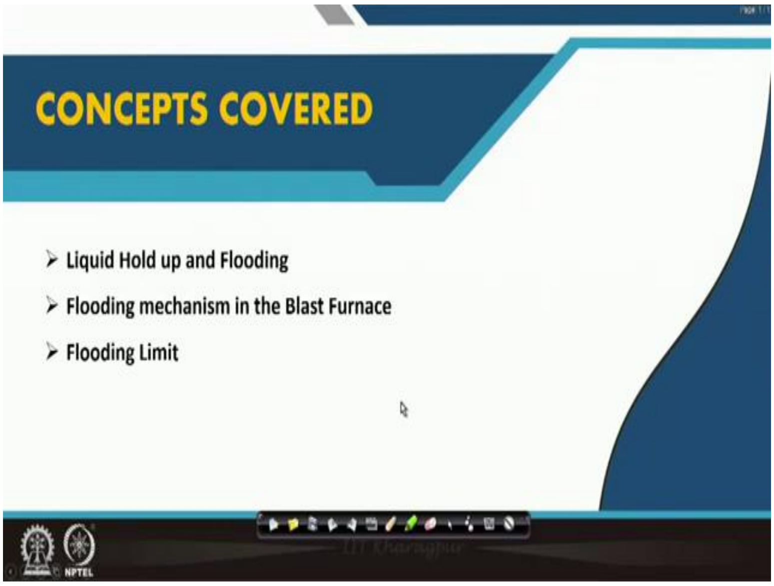
Iron Making and Steel Making

Prof. Gour Gopal Roy
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Kharagpur

Module – 03
Lecture - 13
Aerodynamics in Blast Furnace – Part 3: Flooding

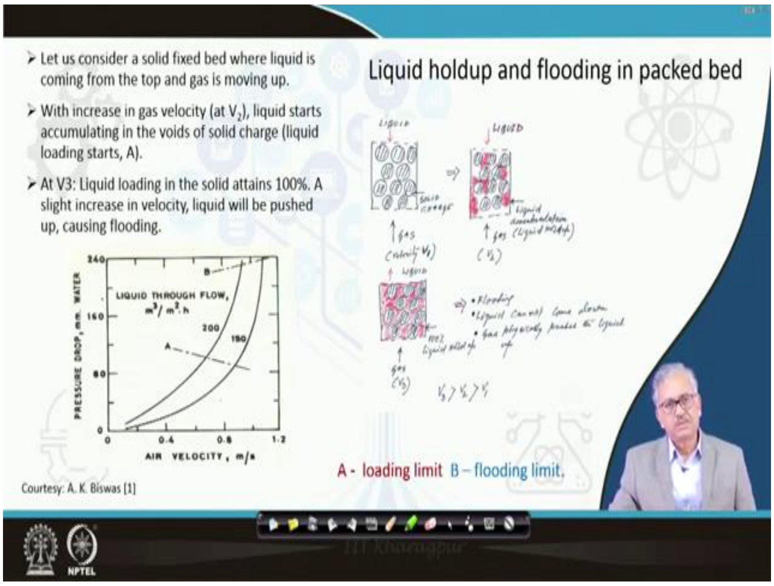
Welcome on Module 3 and this is Aerodynamics in Blast Furnace Part 3, and here we will discuss the Flooding phenomena. Flooding is a very important phenomena in the wet zone of the blast furnace. Just like channeling take place in the dry zone, the flooding is an unfavorable phenomenon in the wet zone, where the liquid is pushed off in the low temperature solid granular region above the cohesive zone and this liquid may solidify, form an arch and they can restrict the gas flow totally. That condition is called the hanging when blast furnace refuses to accept the air. So, this is called flooding and hanging and this is what we will discussed in this lecture.

(Refer Slide Time: 01:17)



Concepts covered in this section will cover holding and flooding phenomena in Gas-solid-liquid system. Followed by mechanism of flooding in blast furnace, concept of flooding limit and various remedial actions. Let us first consider a packed bed involving counter current gas liquid movement through a solid bed. In chemical engineering several studies have been made on such system. We will just consider a very simple system; let us consider a solid fixed bed in a laboratory cylindrical tube where the liquid is coming from the top and gas is moving up through the bed. .

(Refer Slide Time: 02:12)



With increase in gas velocity from the bottom, some sequence of phenomena evolves which are discussed pictorially in Fig. 13.1.

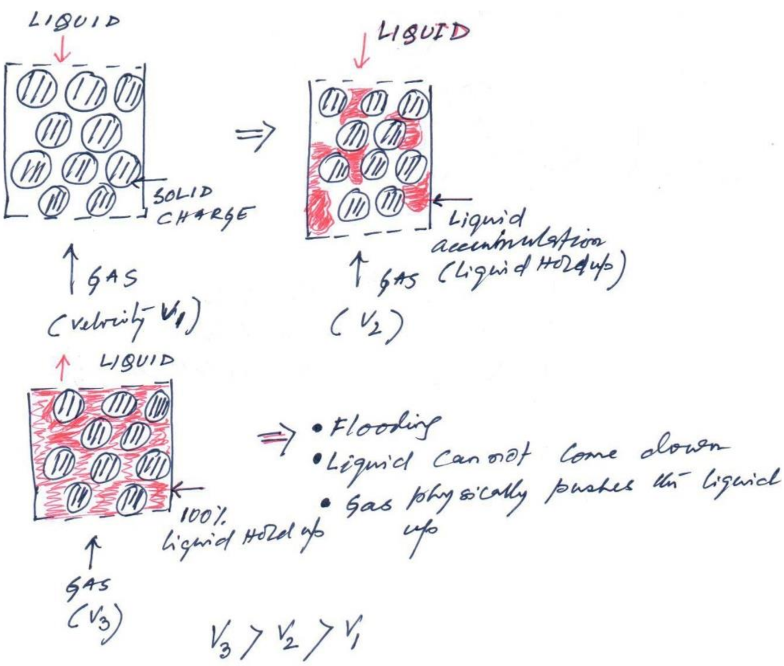


Figure 13.1 evolution of various phenomena with increase in gas velocity in a counter current gas, liquid flow through solid bed

Under steady state, whatever the liquid is poured from the top, same amount of liquid will come out through the bottom. But, if you progressively increase the gas velocity, what will happen? The frictional drag of upcoming gas will increase and as a result system will shift from steady state and all the poured liquid will not be able to come down and partially will be accumulated in the solid bed. This condition is called the liquid holding in solid bed. So with increase in gas velocity, system turns to a transient process and whatever the liquid is coming from the top; a part of it exits from bottom and the rest is accumulated in the solid bed. Fraction of liquid accumulation is called liquid holdup of the solid bed. And, with increasing gas velocity, this liquid holdup will also go on increasing. So, hold up may change from 10 percent, then 20 percent holdup, 30 percent, and so on, and finally the liquid may not at all move down. Beyond that point any further increase in gas velocity will push the liquid physically up and liquid will be blown off from the system and the condition is called the flooding. This process of holding and flooding may be characterized by measuring pressure drop.

The figure 13.2, shows such measurement of pressure drop against the gas velocity from a laboratory scale experiment.

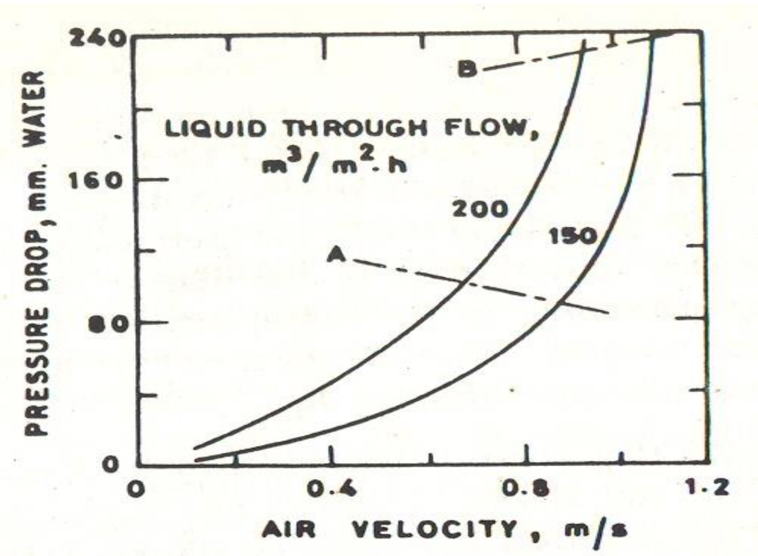
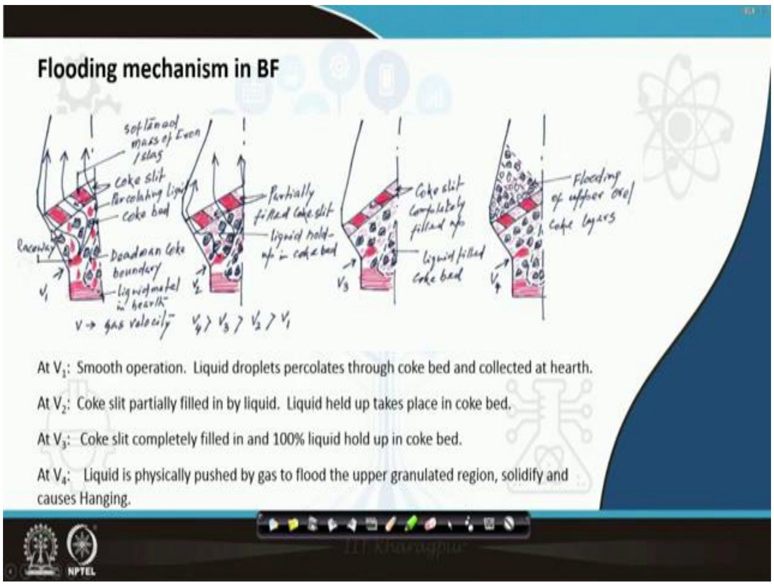


Figure 13.2 Variation of pressure drop with air velocity in a countercurrent liquid-air flow through solid bed (Courtesy: A. K. Biawas[1]).

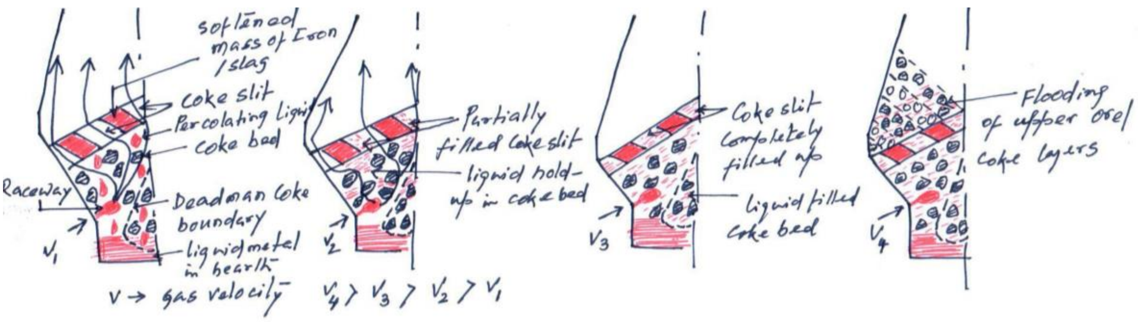
On Y-axis pressure drop of the bed in terms of millimeter of water is presented and on the X axis, it is the air velocity in the meter per second. Data are plotted for two different liquid throughputs. Liquid throughput means the volume of liquid (m^3) that is coming in per meter square of solid bed per hour. So, two liquid throughputs are presented one at 200 m^3/m^2-hr and other is at 150 m^3/m^2-hr. The onset of holding is designated by A and that of flooding by B. It may be observed that when the gas velocity increases, the onset of holding occurs at air velocity of 0.6 m/s for the case with liquid throughput of 200m^3/m^2-hr. And when the liquid throughput is 150 m^3/m^2-hr, the holding takes place at little higher velocity, at 0.9 m/s. These are the onset of holdup of the liquid; that is beyond this point liquid starts accumulating in the solid bed. Similarly, onset of flooding takes place at gas velocity of 0.9 m/s at liquid throughput of 200 m^3/m^2-hr and at 1.2 m/s at liquid throughput of 150 l/m^2-hr. These critical velocities for onset of flooding are not much far off from those velocities for onset of holding; although the corresponding pressure drop changes significantly. The corresponding pressure drop changes from 100 to 230 mm of water in case of liquid throughput of 200 m^3/m^2-hr. Obviously, the curve is quiet steep for transition from point A to B.

So, for a particular packed bed depending on the solid size, shape distribution and the liquid flow rate, there exist a certain gas velocity at which holding starts, and another velocity at which flooding starts. And once holding starts, flooding is not very far off and precaution should be taken.

(Refer Slide Time: 08:11)



Now, let us understand the mechanism of flooding in blast furnace. Figure 13.3 shows the schematics of mechanism of flooding in blast furnace.



(a) (b) (c) (d)

Figure 13.3 Schematics of mechanism of flooding in blast furnace

In the figure, cohesive zone has been shown in alternate layers of fused mass of iron and slag (shown in red) and then followed by a coke slit (shown as white space), then fused mass of iron and slag and followed by coke slit and so on. Raceway is shown at the tuyer location just at the bottom of the bosh. Gas streams generating from raceway passes through the coke slit and moves up to the top as indicated by gas line trace. Several such gas streams are shown crossing various coke slits and covering whole cross section of the bed; some of gas channel feeding the periphery, some of them feeding the center and some of them feeding the middle portion. Softened liquid mass is also coming down through the coke slit; and subsequently percolating through coke bed below is collected at the hearth. Solid bed below cohesive zone consists of loose coke bed and deadman coke and liquid crosses both of those before collecting in the hearth.

Loose coke come to the raceway and they get burn while the dead man cokes remain inactive, because the oxygen does not reach the dead man coke zone. Now, with the gas and liquid flow paths defined, what happens when the gas velocity is increased. Similar phenomena as we have seen in the packed bed, also happens here. Then, liquid also will get the resistance to come down and the condition never remains in steady state, as depicted in figure 13.3(a).

The process become transient with liquid holdup in the cohesive zone. Liquid will occupy a part of the coke slit through which the gas is passing because this liquid are not being able to come down under the enhanced gas drag. Eventually, liquid can occupy a large portion of the coke slit, that is why you can find the coke slit is partially filled up (Figure 13.2(b)). Now still the gas is finding path through the coke slit. Only thing is that gas velocity will increase through the narrow gas channel and increase in pressure drop may be staggering.

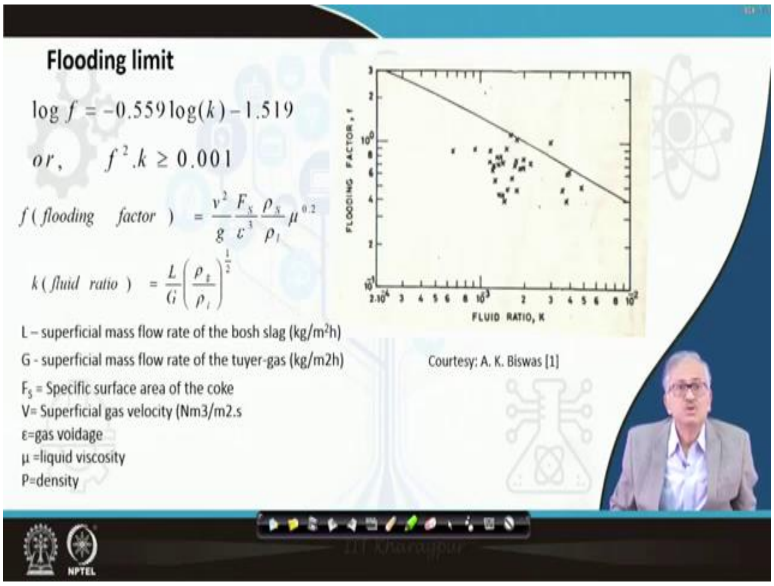
Now, if we just further increase the velocity, we can have some situation where all the coke slit become occupied by the liquid (Figure 13.3(c)).

So, basically from figure 13.3(b) to 13.3(c), with increase in gas velocity from V_2 to V_3, the coke slits have passed through different stages of liquid holdup, say 20%, 50% and so on and finally 100 percent for figure 13.3(c). At 100% holdup, or when the coke slit are completely filled with liquid, then the gas do not find any path to move through. If gas velocity is further increased beyond that point, gas will physically push the liquid to move up causing flooding of the upper region.

So, now, in this case (figure13.3(d)), liquid has flooded the upper solid granular region. When the liquid comes to an upper granulated zone at lower temperature, then liquid solidifies, form solid arch and stop the gas movement completely. This condition is called hanging, when furnace refuses to take air and production comes to a halt.

If the hanging take place, the problem is that it is very difficult to rectify. One thing you can do is to burn more coke and then somehow melt the solid arch and then only the furnace can operate. So again prevention of hanging is the solution. Indication of hanging can be assessed by monitoring the pressure drop in the wet zone through under burden probes and corrective action has to be taken.

(Refer Slide Time: 15:41)



Let us now understand flooding in a quantitative way. People has done some quantification of flooding in blast furnace using the Sherwood correlationship; this is the very well-known relationship in chemical engineering. You can see quantification of the flooding can be done using flooding factor, f and fluid ratio, k, such that f^2k must be greater than equal to 0.001 (equation 13.1). Definition of f and k are given by equations 13.2 and 13.3, respectively.

$$f^2.k \geq 0.001$$

(13.1)

$$f\,(\,flooding\;\; factor) \quad = \frac{v^2}{g}\frac{F_S}{\varepsilon^3}\frac{\rho_S}{\rho_l}\mu^{0.2}$$

(13.2)

$$k(\,fluid\; ratio) \quad = \frac{L}{G}\left(\frac{\rho_g}{\rho_l}\right)^{\frac{1}{2}}$$

(13.3)

The pictorial representation of Sherwood correlation is presented in Figure 13.4.

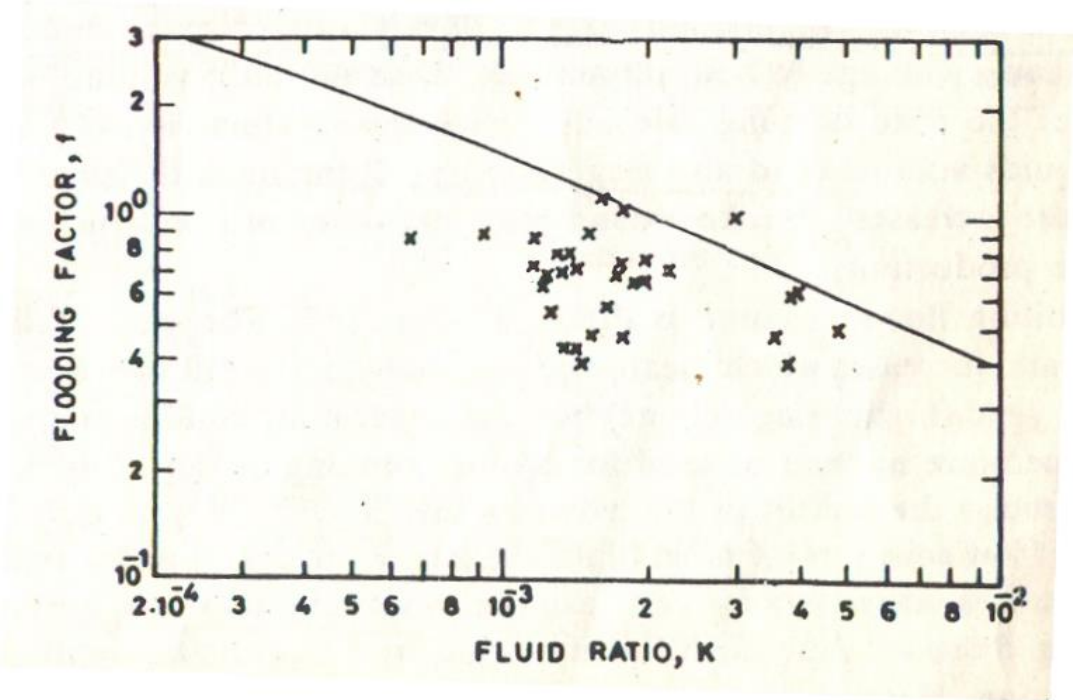
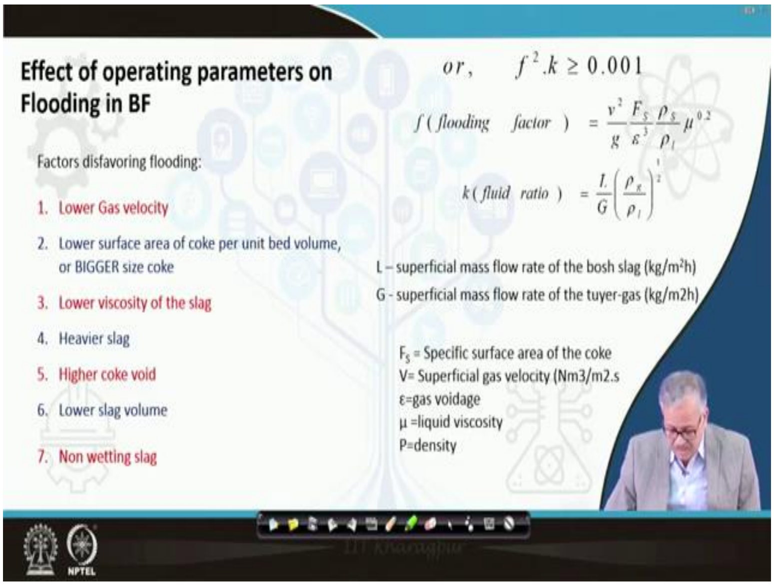


Figure 13.4 Relationship between flooding factor and fluid ratio and symbols data from different sizes of blast furnace (Courtesy A. K. Biswas [1])

The straight line shows the critical line for flooding, i.e., f^2k=0.001 plotted on log-log scale. So, if any data point lies above the straight line, then it is prone to the flooding; if data point lies below the line, it is not prone to the flooding. The symbols show the data from various sizes of blast furnaces-small, medium and large. Data near the line are from small furnace or furnaces with high operating intensity. It may be noted that with increase in the fluid ratio this line is coming down; that means that the propensity for the flooding is increased with increase in fluid ratio. Because, higher fluid ratio indicates higher liquid throughput that promotes flooding.

(Refer Slide Time: 19:25)



Now, let us analyze the factors affecting the onset of flooding in blast furnace. If you want to disfavor the flooding, flooding factor and fluid ratio should be low. We can now find out the favourable parameters on which *f* and *k* depends. So, one option should be the low gas velocity, that reduces the *f*. Physically, higher the gas velocity increases the resistance to the liquid flow promoting flooding.

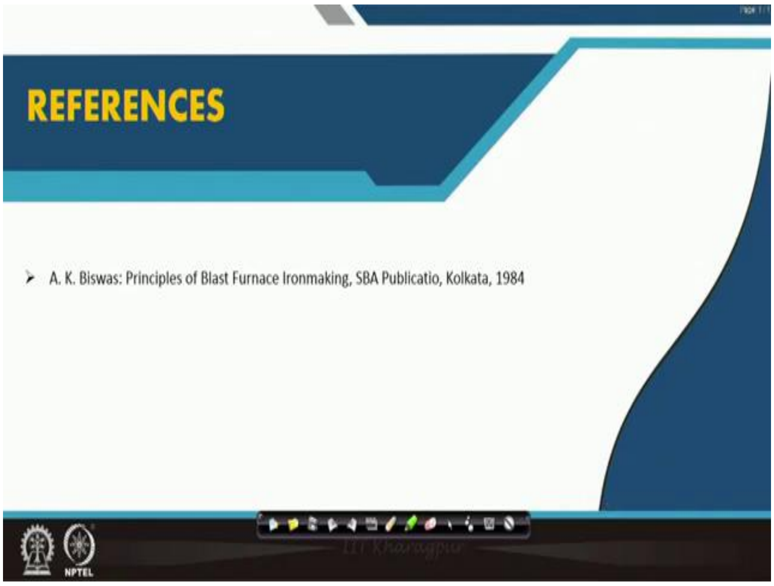
Second is the lower specific surface area of coke or bigger coke size that also reduces flooding factor and disfavor flooding. Physically, it may be understood that lower the specific surface area of coke, it will be less wetted by the liquid, disfavouring flooding. So, the bigger size coke at the cohesive zone will be required. That is why blast furnace coke is charged at a size of 90 millimeter where ore is charged at a size of 40 millimeter. Such size difference is kept, keeping in mind when the coke comes down in the wet zone their size is not reduced to very low through chemical degradation.

Lower viscosity of the slag also decreases *f* and disfavor flooding. Physically, lower viscosity will allow the liquid to come down easily with least resistance.

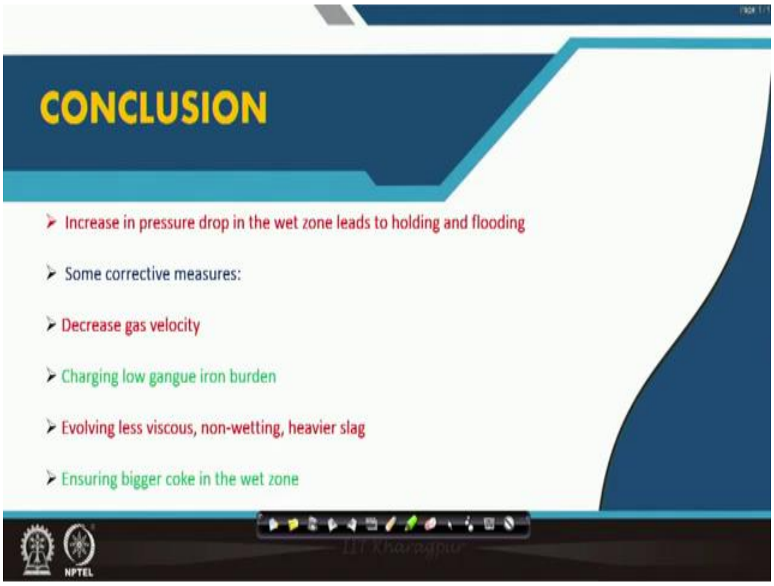
Then you should have heavier slag. If the slag is heavy, obviously, it will easily come down by gravity.

Higher coke void, also decrease *f* and disfavor flooding. Physically, higher the voidage more is the space for passage of gas and liquid. Lower slag volume, or lower liquid throughput, decreases fluid ratio, disfavor flooding. Also non wetting slag does not wet coke too much, consequently coke remain open for gas, disfavouring flooding.

(Refer Slide Time: 22:39)



(Refer Slide Time: 22:45)



Major reference is book of A. K. Biswas.

Conclusions are stated in the slide above.

Main point is that increasing pressure drop in the wet zone leads to the holding and flooding.

Some corrective measures to restrict flooding could be lower blast rate, bigger size coke in the cohesive zone, non-wetting and less viscous slag, less slag volume. Therefore, charging low gangue prepared burden could be helpful.

Thank you.