-+ **Iron Making and Steel Making**

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

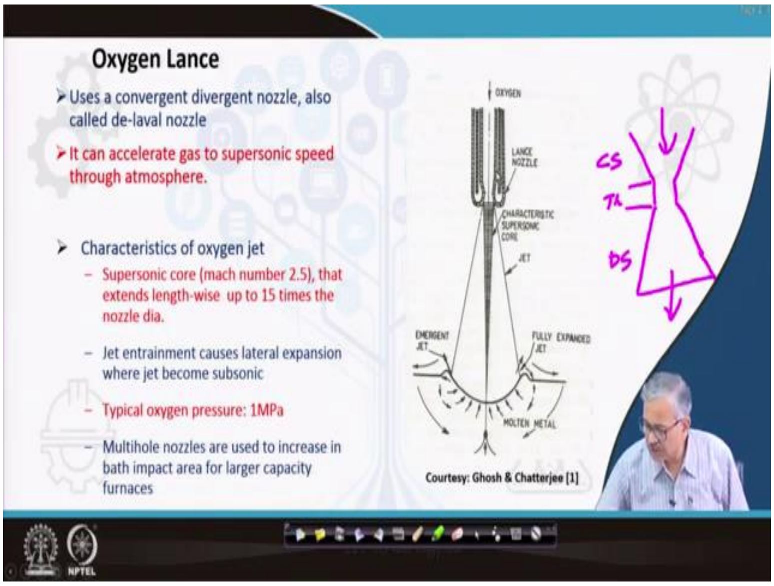
Module – 07
Lecture - 32
LD Steel making: oxygen lance and jet action & Decarburization

Welcome, in this lecture we will discuss about the oxygen lance, jet action and Decarburization.

(Refer Slide Time: 00:32)

So, first we will discuss about the lance characteristics; oxygen lance has a special nozzle to push the oxygen at supersonic speed. And then we will talk about the jet action; the interaction of the oxygen jet with the metal bath. Finally we will discuss the bath decarburization. Decarburization not only reduces the carbon in the bath during LD process; decarburization also has a role to play in forming foam and emulsion, which is the core of LD fast refining.

(Refer Slide Time: 01:49)



Now, let us first discuss with the oxygen lance. Figure 31.1 shows the schematics of oxygen lance and jet action. You can see the oxygen lance is water cooled. The nozzle is convergent–divergent type, also called the de-laval nozzle, which is capable of accelerating the oxygen jet at supersonic speed.

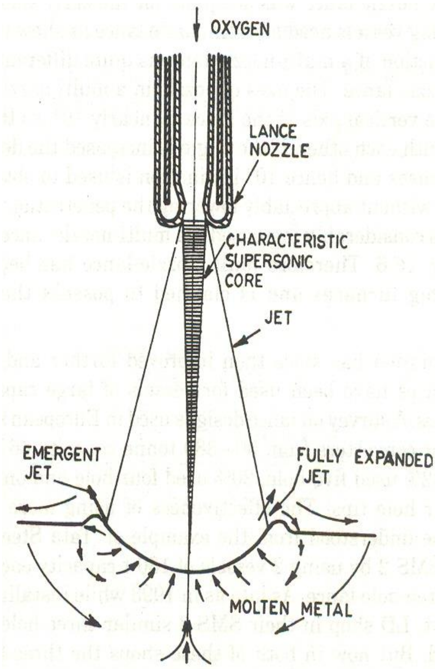
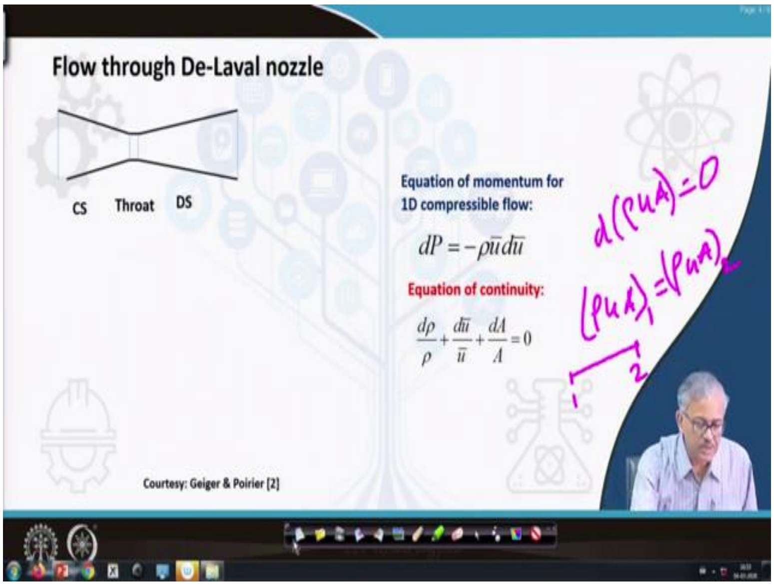


Figure 32.1: Schematics of the oxygen lance and jet action [1]

So, you can see that the nozzle is not a cylindrical nozzle; you can find there is a convergent section and there is also a divergent section, and a cylindrical section join them together, making it convergent-divergent type nozzle.

This type of nozzle it is also called the de-laval nozzle. With cylindrical nozzle it is not possible to produce a supersonic jet as it interact with the ambient atmosphere generating shock wave. In case of the convergent divergent nozzle, with proper design of various sections, oxygen can be accelerated to supersonic speed and it will emit at a pressure close to that of ambient atmosphere without making any energy dissipation through shock wave generation; and it will propagate through atmosphere retaining its energy until it interacts with the liquid bath. When the supersonic jet moves through the atmosphere it entrains atmosphere along with it and velocity in the entrained region drops to subsonic velocity. Therefore, the fully expanded jet contains a supersonic core with subsonic extended region. And some characteristics of the oxygen jet are as follows: The supersonic core has a mach number of 2.5; that is the velocity of oxygen jet is 2.5 times that of the velocity of the sound. The length of this supersonic core might be 15 times to that of the nozzle exit diameter. Second characteristic is that the jet entrainment causes lateral expansion where the jet becomes subsonic. Typical oxygen pressure at upstream end is approximately 1 MPa.

(Refer Slide Time: 10:18)



Now, let us understand how de-laval nozzle can accelerate the gas at supersonic velocity without any shock wave generation at the nozzle exit.

Figure 32.2 shows the schematics of convergent-divergent de-laval nozzle.

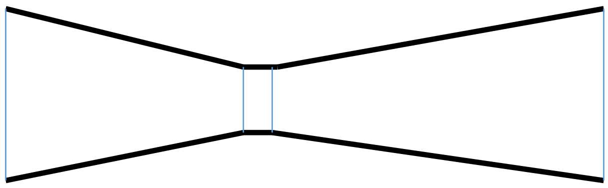


Figure32.2: Schematics of delaval nozzle

The nozzle has three portions; one is called the convergent section (CS), where nozzle converges to throat; then you have a throat that is basically a cylindrical section, and then there is a diverging section (DS), where nozzle is diverging out.

Equation of momentum for one dimensional compressible flow is presented by equation (32.1).

$$dP = -\rho \bar{u} d\bar{u} \tag{32.1}$$

Following Bernoulli's equation, you have in this case only the pressure head and the kinetic head. Here pressure drop across the line accounts for the increase in kinetic energy of the gas. For incompressible fluid, the equation of continuity can be written as shown by equation (32.2).

$$\frac{d\rho}{\rho} + \frac{d\bar{u}}{\bar{u}} + \frac{dA}{A} = 0 \tag{32.2}$$

Incorporating velocity of sound through pressure, density correlation (Equation (32.3)), the combined equation by amalgamating momentum and continuity equation, can be given as Equation (32.4).

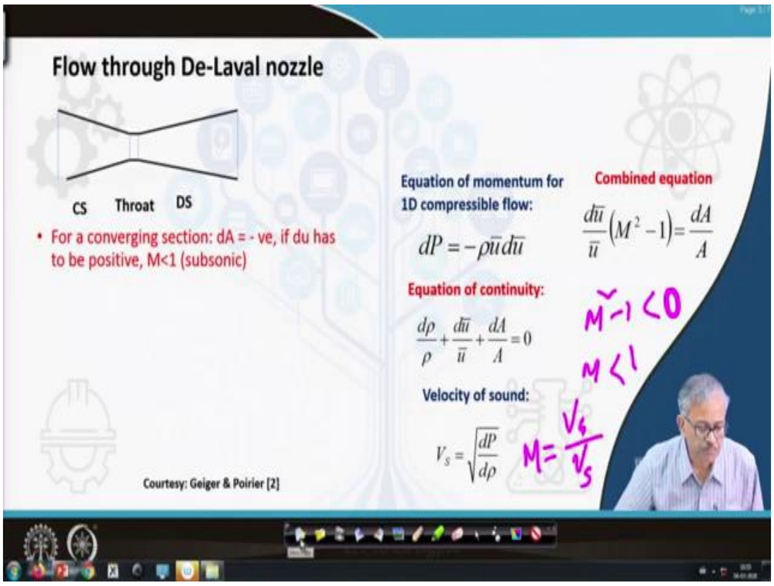
$$V_S = \sqrt{\frac{dP}{d\rho}}$$

(32.3)

$$\frac{d\bar{u}}{\bar{u}}\left(M^2 - 1\right) = \frac{dA}{A}$$

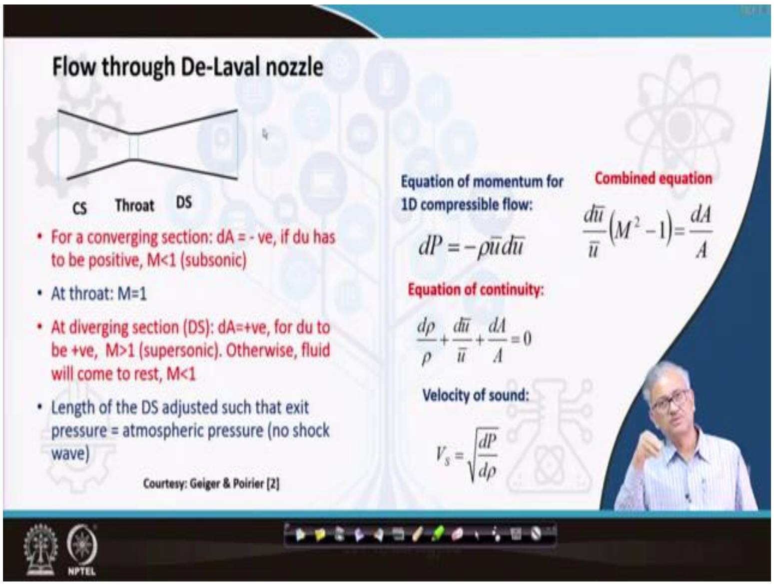
(32.4)

(Refer Slide Time: 13:29)



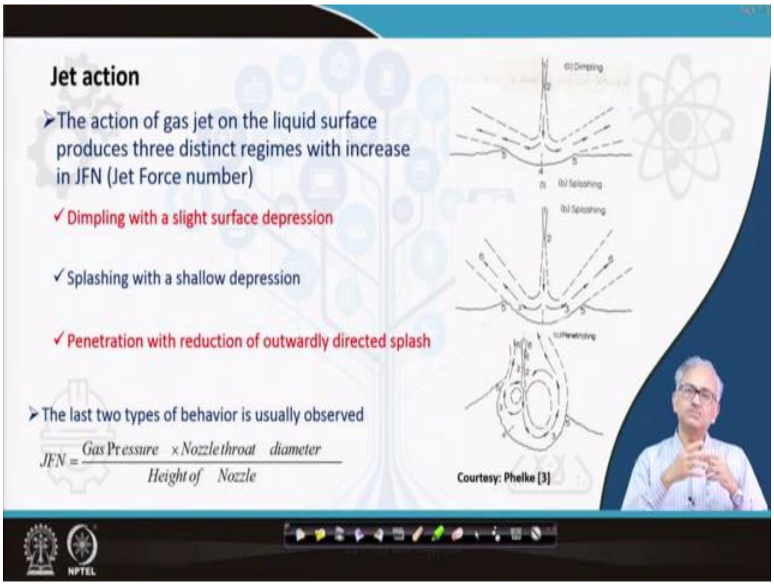
$\bar{u}$ represents the average velocity; because in a conduit, there is a distribution across the width.

Let us analyze the equation (32.4) for different sections. In the converging section, dA is negative. So, if you want to accelerate the gas, then du has to be positive, meaning M^2-1 is negative, or, M<1; that is the gas velocity will remain in subsonic range. At cylindrical portion dA is 0, since du can not be zero, M^2-1=0; so M=1and the velocity of the gas will attain the velocity of sound. (Refer Slide Time: 16:34)



Now, in the diverging section, dA is positive; to accelerate the gas du has to be positive; then M^2-1 has to be positive. So, M is greater than 1, or the gas will attain supersonic velocity. As the velocity of the gas through DS increases, the pressure of the gas will decrease and DS length could be designed in such a way that when the supersonic jet emerges from the nozzle, it pressure become comparable to that of the ambient pressure, such that no shock wave generates.

(Refer Slide Time: 19:22)



So, let us consider the jet action now. When the oxygen jet interacts with the liquid bath it forms some crater in the bath. The strength of the jet is characterized by Jet force number (JFN), defined by the equation (32.5).

$$JFN = \frac{Gas\ Pressure \times Nozzle\ throat\ diameter}{Height\ of\ Nozzle} \qquad (32.5)$$

Upstream gas pressure that is approximately 1 mega Pascal and fixed. Nozzle throat diameter is also fixed by design of nozzle. What actually could be varied is the height of the nozzle from liquid bath. So, by pushing the nozzle up and down, the nozzle height (H) can be varied and so the JFN. JFN increases when lance is lowered, or H is decreased, and vice versa.

And now depending on jet force number, you can produce the three regimes of jet penetration in the bath: one is called the dimpling with a slight surface depression, when JFN is low (Figure 32.3).

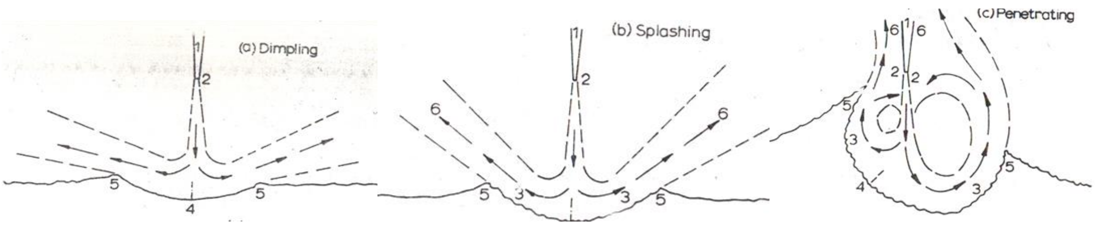


Figure 32.3: Regmes of jet penetration depending on JFN [3]

It causes lot of splashing of the liquid droplets on the refractory; not good for refractory life.

On increasing the Jet Force Number (JFN), splashing with shallow depression happens(Figure 32.4(b)). Here ejected droplets is mostly directed towards the emulsion phase above and some droplets might hit the refractory directly.

With further increase in JFN, or further lowering the lance, a distinct crater is formed and droplets ate directed vertically towards the emulsion phase. It forms a significant penetration of the jet into the bath; so it is also called the penetration regime and industrial vessel usually operate in this regime. With increase in JFN, oxygen partial pressure become more, so decarburization rate also become high. Simultaneously iron oxidation also increases.

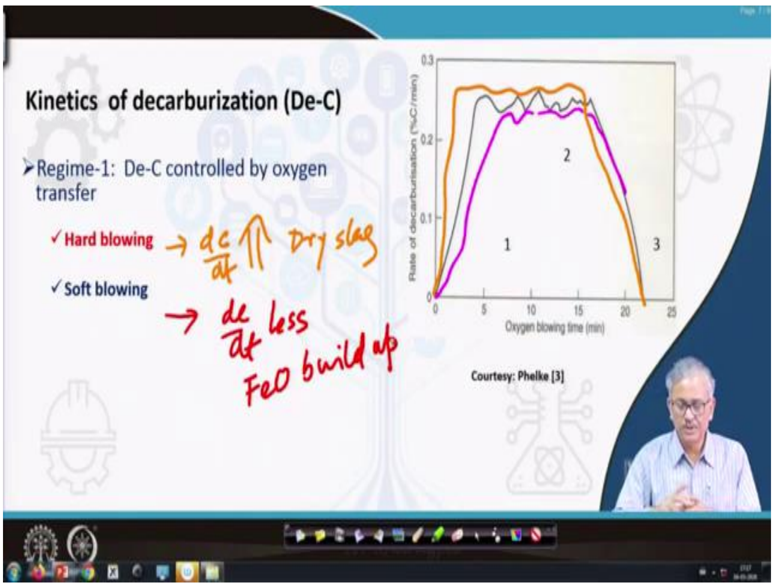
Under extreme case of JFN, preferential decarburization might occur (Equation 32.5) where rate of decarburization might exceeds the rate of generation of FeO and the slag might dry off in depleting FeO in slag. The condition is called the hard blow. On the other hand, soft blow is defined a situation when JFN is moderate such that FeO formation much exceeds the decarburization. With soft blow it is possible to build the FeO in the slag without sacrificing much carbon from the metal bath at initial stage of blowing.

$$FeO + CO = Fe + CO_2$$

(32.5)

Instead of single nozzle, use of multihole nozzles increase the bath impact area for large capacity furnace. For large capacity furnace it is not only just single nozzle, multihole nozzles are usually applied, where several non-overlapping jet interact with the bath.

(Refer Slide Time: 29:39)



Now, let us come to the kinetics of decarburization. Figure 32.4 depicts the variation of decarburization rate with the progress of blowing.

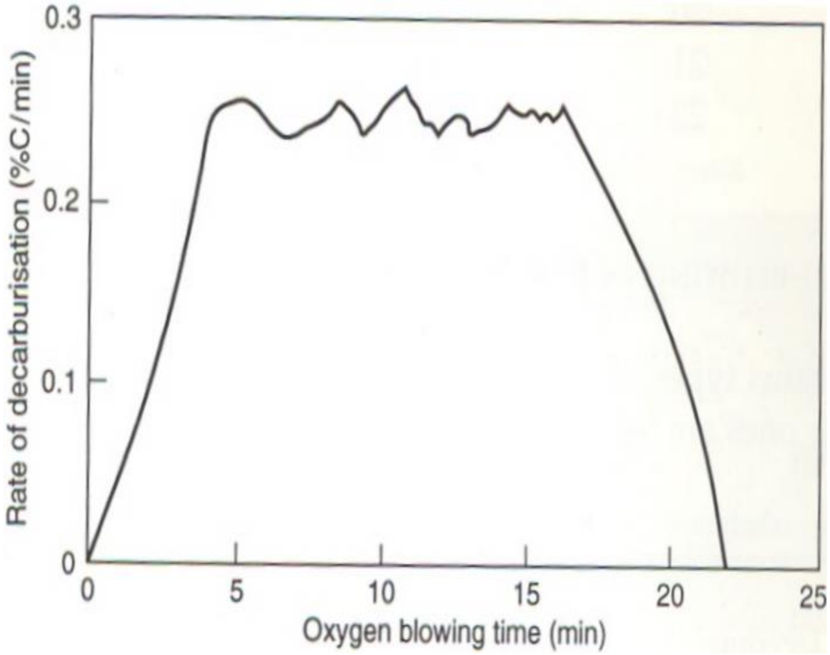


Figure32.4: Variation of decarburization with blowing time [3]

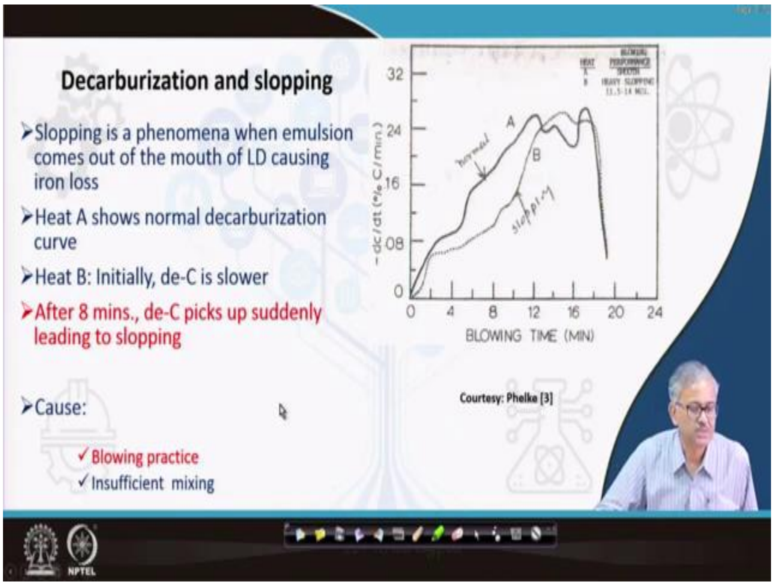
Three regimes could be observed: in the initial stage decarburization rate increases progressively to attain a steady state value and later decreases. So there are three distinct regimes; in the first regime, decarburization rate increases progressively; in the 2nd regime, it is stabilized to a steady state value and in the remime-3, decarburization decreases. In regime-1, the decarburization is controlled by the oxygen mass transfer. In this regime, there is plenty of carbon in the bath and the supply of oxygen controls the rate of decarburization. Here, the rate of decarburization is controlled by oxygen mass transfer; that means blowing practice has a role to play. Controlling decarburization using hard and soft blow through blowing practice is possible. So, the slope of the line can be tailored as par the requirement.

In regime-2, i.e, in the steady state regime, the carbon in the bath has decreased significantly. Under this condition the rate of decarburization depends both on the rate of supply of oxygen and carbon. Rate of supply of oxygen just match the rate of supply of carbon from the bath and attains somewhat constant rate of decarburization. Some serration in the curve is due to local segregation of carbon and oxygen due to insufficient mixing.

Finally in the regime-3, the bath carbon becomes very lean and the reaction does not depends on the oxygen supply and it solely become dependent of the rate of supply of carbon. So, this regime is controlled by mass transfer of carbon and the blowing practice has no role to play.

So, only regime-1, i.e., at initial stage of blowing, blowing practice has a role to play in controlling decarburization. For superfast decarburization, one can adopt hard blowing by increasing JFN, or, lowering the lance. Or, for building FeO in the slag at mild decarburization rate, one can adopt soft blowing with lower JFN, or moving up the lance. Initial soft blowing practice become effective to treat high phosphorus hot metal where decarburization has to be controlled to sustain the emulsion for a prolonged period to ensure total phosphorus removal.

(Refer Slide Time: 35:24)



Now, slopping is an important phenomenon in LD furnace and it is very much related to decarburization, which I will discuss here. In LD furnace, slopping is the phenomena, where the emulsion emerges out of LD mouth. Obviously, slopping is undesirable because it is cumbersome and causes loss of iron.

Figure 32.5 depicts two industrial heats where in one of the two heats slopping has taken place due to improper blowing practice.

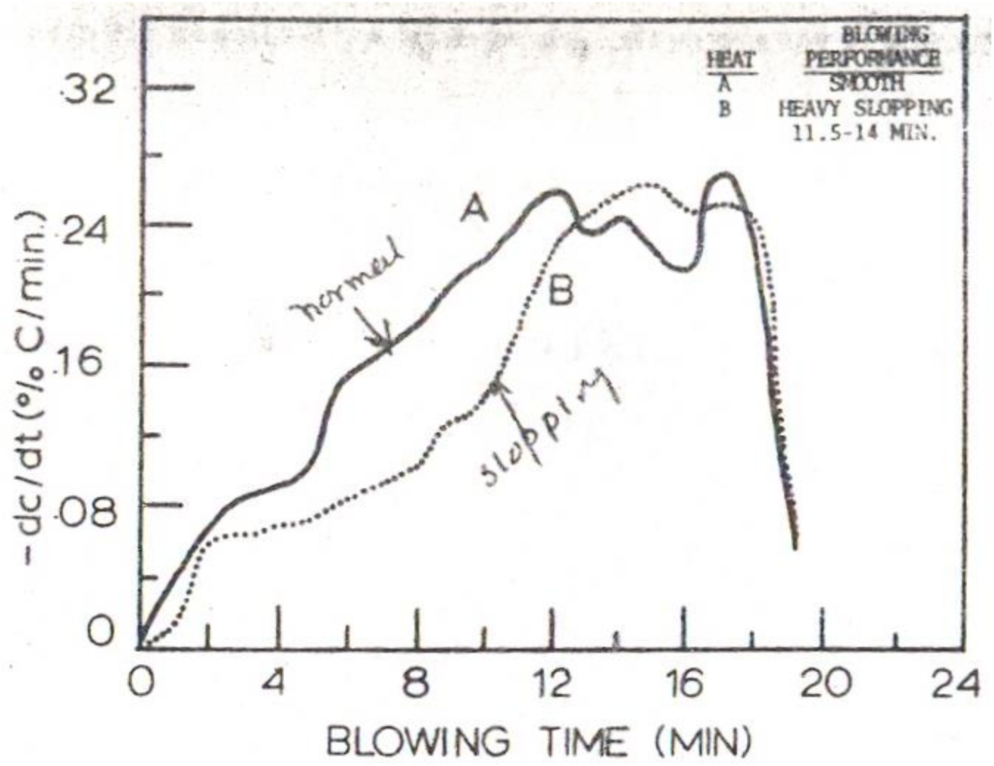


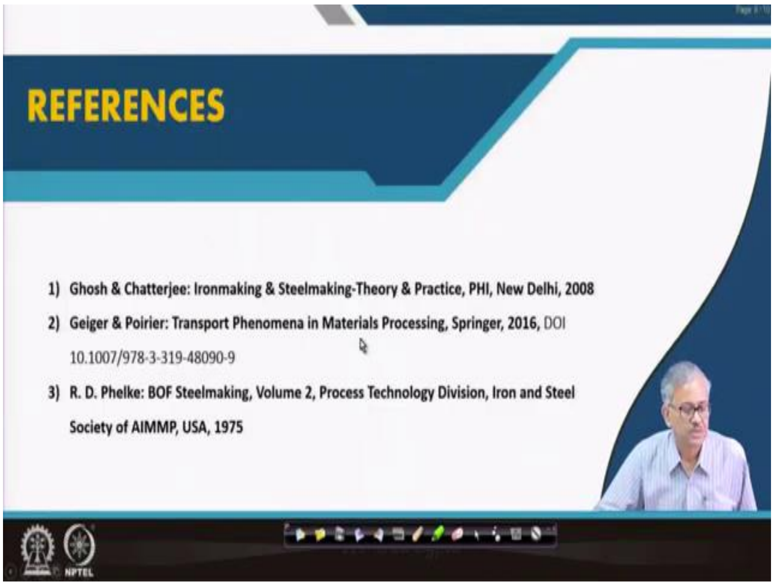
Figure 32.5: Industrial heats showing slopping arising out of improper blowing practice [3]

In heat A, during the first stage, in regime-1, decarburization is normal; that is the decarburization rate progressively increases till it comes to steady state regime.

In heat B, the first stage of decarburization appears to be abnormal; you can find here the decarburization rate does not increase for a certain blowing period and there is a sudden jump in the decarburization rate to catch up the steady state regime. And in this case the slopping has taken place. Because due to sudden increase in the decarburization rate; the foam height increases suddenly to reach the vessel top and then emulsion comes out of the vessel mouth, causing slopping.

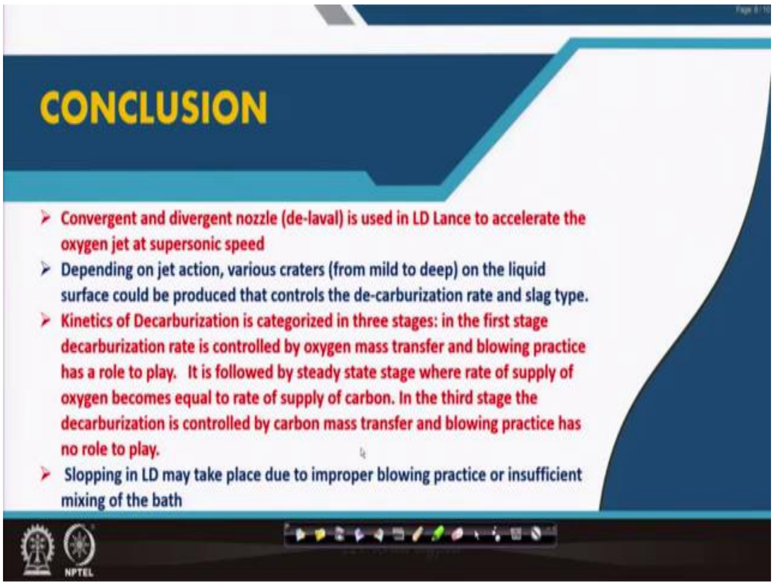
Slopping might also happen due to improper mixing in the bath. Usually the upper part of the LD vessel is nicely mixed up; but the lower part of the vessel is not properly mixed up; because the momentum of the oxygen jet does not reach significantly to the lower part of the bath. So, as a result the carbon may be accumulated into the lower part and they do not participate in the reaction too much. And suddenly when some carbon rich liquid from the lower part comes up and join the upper part that triggers a spurt in decarburization, and cause slopping.

(Refer Slide Time: 39:39)



Three references are mentioned in the slide above.

(Refer Slide Time: 39:43)



Conclusion: LD lance uses a convergent-divergent type nozzle, called the de-laval nozzle, which accelerate the oxygen to supersonic speed. The oxygen jet after emerging from the nozzle crosses through the ambient atmosphere with lateral expansion of the jet by entraining the ambient atmosphere and finally the expanded jet hits the bath. The strength of the bath is characterized by the JFN number, which can be controlled by changing the lance height from the liquid bath.

And depending on the jet force number, there exists three distinct regimes of jet bath interaction causing crater of different depth. At moderate JFN, crater of reasonable depth forms that ejects the droplets directly into the emulsion, without splashing to the refractory, which is desirable. Too high JFN is not good because it cases drying of slag, the regime is known as hard blow. A moderate JFN, it allows build up of FeO in the slag phase, called the soft blow, which is found to be beneficial to treat high phosphorus hot metal.

Usually, multi-hole nozzle are used where several non-overlapping jet interact with the bath expanding the interaction area on the liquid surface.

Decarburization rate with the progress of blowing passes through three different regimes: a progressive increase in decarburization rate, followed by a steady state regime and finally decrease in decarburization rate. In the regime-1, i.e., during the initial stage of blowing, decarburization can be controlled by blowing practice.

When emulsion comes out of the LD mouth, it is called the slopping, which is a cumbersome and causes iron loss. Improper blowing practice may cause slopping.