Steel Making

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Module No.#01

Lecture No.#13

Modern Steelmaking I, Oxygen Steelmaking

Let me discuss today, fundamentals of converter steel making technology.Ihave said while discussing converter steel making practice, I said over there, that typically liquid steel is tapped in every, around 60 minutes, irrespective of converter capacity.

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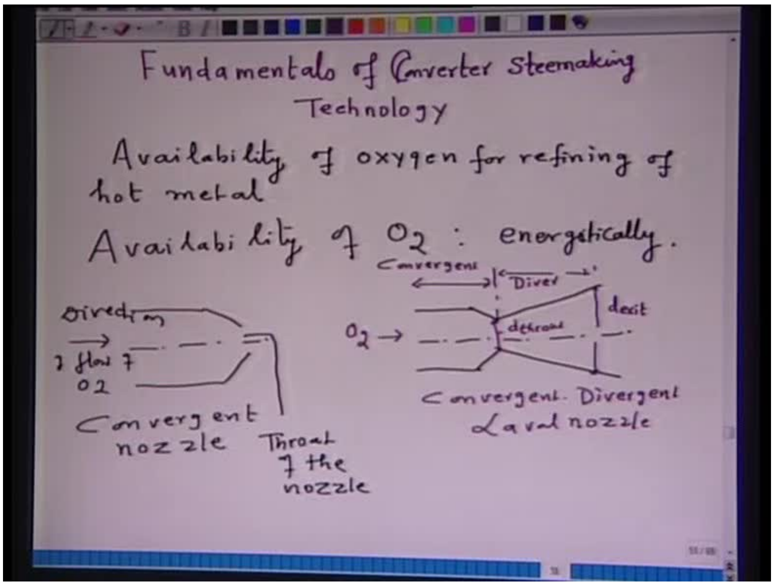

Now, it is always a curiosity how this happens.So, I have thought about it and it is the availability of oxygen for refining of hot metal, is probably the main cause of very small tap to tap time, of the order of 60 minutes, and this tap to tap time does not depend upon the converter capacity.Whether a converter is 50 tons or a converter is 400 tons, a tap to tap time is approximately of the order of 60minutes.This depends upon the availability of oxygen supplied, and at the end of the lecture, you see whether it dependson available of oxygen supply or not.

So, the availability of oxygen;let us see how oxygen is available in converter steel making. So, availability of oxygen…Oxygen during the refining of hot metal in converter, is available energetically.This energetic supply of oxygen is obtained by passing a certain flow rate of the oxygen through the nozzle.That is, whenever a certain amount of gas passes through a nozzle, an energetic form of gas supply is achieved.Now, there are two different types of nozzles.One, I will draw it for you; this is a sort of convergent nozzle.

This is a convergent nozzle.This is the direction of flow,for example, of oxygen.This, a minimum cross sectional area, this is called throat of the nozzle.So, this convergent nozzle is characterized by decrease in the flow cross sectional area, as the flow proceeds and the cross sectionalarea attains minimum, which is called throat of the nozzle.Another type of nozzle is a convergent divergent nozzle, which has been sketched over here.This is the convergent portion and this is the divergent portion.

So, this particular portion is convergent portion and this particular portion is divergent portion.This is again the direction of flow of oxygen, that means the cross sectional area of the flow passage decreases first, attains a minimum value, which is called throat of the convergent divergent nozzle, and after attaining the minimum cross sectional area, the cross sectional area further increases in the direction of the flow and this nozzles, they are called convergent divergent nozzle or they are also called Laval nozzle.And these nozzles are characterized by, this is the d exit, that is the exit diameter of the nozzle.This diameter is d throat, that is diameter of the throat.There a minimum cross sectional area is attained.

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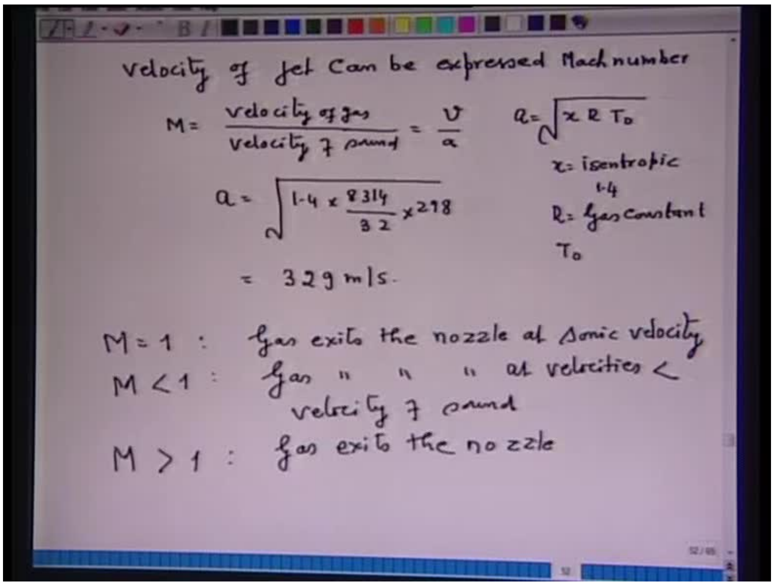

Velocity of jet, it can be expressed in terms of Mach number.What is the Mach number?Say Mach number is velocity of gas upon velocity of sound, that is v upon a.Now, a can be calculated by kappa R T 0,where kappa is the isentropic exponent of the gas and its value for all diatomic gases is equal to 1.4.R is gas constant.That is universal constant, divide by molecular weight of the gas.T0 is the temperature.Now, suppose, if I want to calculate the velocity of sound, of oxygen at temperature 298Kelvin, then a, that will be equal to 1.4 into 8314 divide by 32 into 298.So, a comes out to be equal to 329 meter per second, that means, this is the velocity of sound.

So, thus M is equal to 1, that means gas exits the nozzle at sonic velocity. M less than 1, gas exits the nozzle at velocities smaller than velocity of sound and M greater than 1, gas exits the nozzle at velocity greater than the velocity of sound.

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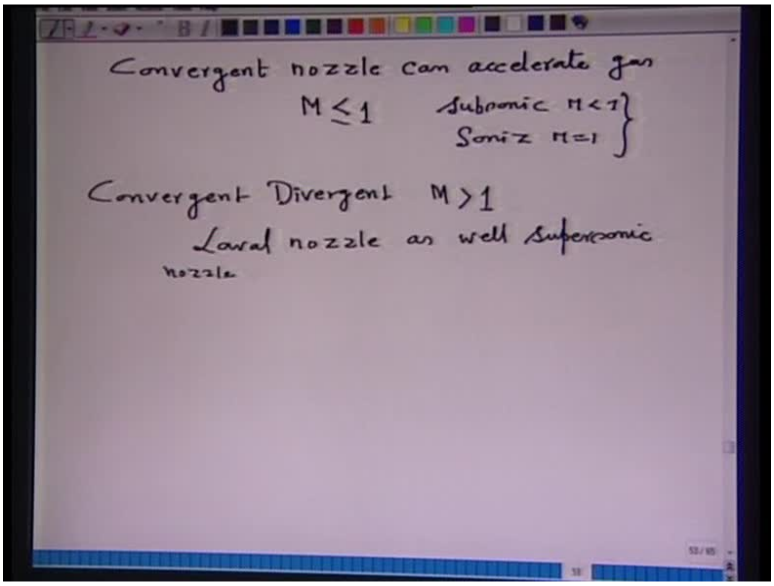

So, convergent nozzle can accelerate gas from some velocity to maximum up to M less than or equal to 1.So, these type of nozzles are called subsonic, when M is less than 1 and sonic, when M is equal to 1.So, such nozzles are called subsonic to sonic nozzle, depending on the value of Mach number at the exit of the nozzle.

Whereas, convergent divergent nozzle can accelerate the gas to any value, where M is greater than 1.So, these nozzles are called Laval nozzle, as well as supersonic nozzles. The acceleration of gas to any value of M greater than 1 is achieved by appropriate design of the nozzle, through maintaining a ratio of d exit to d throat which is a function of stagnation pressure of oxygen supply.

In converter steel making, Laval nozzles are used.As such, in our lecture, we will be concentrated on Laval nozzle.Gas velocity at the exit of the nozzle, it corresponds to M equal to 2 to 2.4 inalmost all converter steel making operation.

Flow rate of oxygen is of the order of 3 normal meter cube per minute per ton, which converts to 660 normal meter cube per minute for a 220 ton converter.The pressures of oxygen supply, it varies between 10 to 14 bar.

In all converter steel making, multi nozzles are used.The said amount of oxygen is supplied through 3 to 6 nozzles and the number of nozzles, it depends upon the capacity of the converter.Let us see, first of all, the behavior of gas when it exits a single nozzle.

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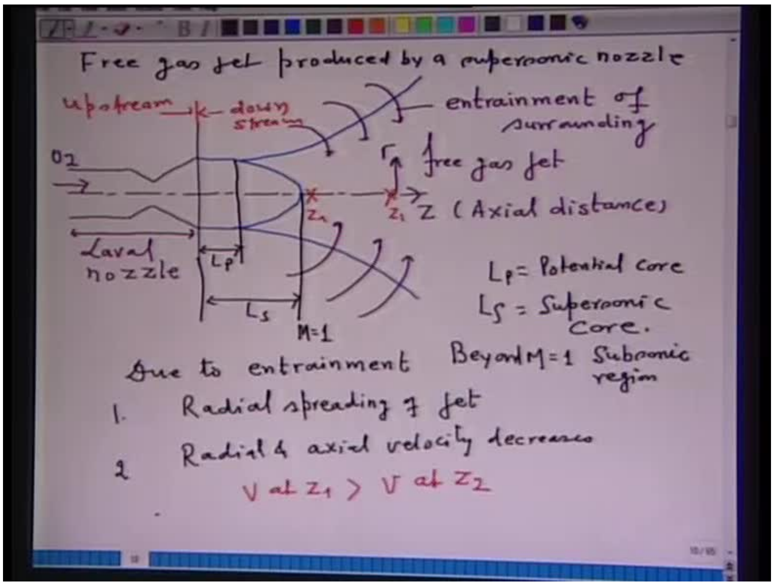

Now, a gas exiting the nozzle spreads in the surrounding and is called a free gas jet, as shown in this particular figure.So, this is a free gas jet produced by a supersonic nozzle.So, this portion is the free gas jet.You see that, the jet begins to be spread as the gas exits the nozzle.Now, this particular portion is the Laval nozzle.This is the direction of flow of,for example, oxygen.

Now, as the gas exits a nozzle, it is spreads into the surrounding because of the entrainment of the surrounding.So, surrounding is entrained this way.This is the entrainment of surrounding.

What will happen due to entrainment of surrounding?The gas velocity will decrease.As the gas moves downstream the nozzle, why it will decrease, because, jet will spread.So, if I show, this is the directionz, which is the axial distance and this direction is r, which is the radial distance.So, you note from here or from this particular diagram, as the gas exits the nozzle, you note that the jet begins to a spread.That means, as the jet moves downstream the nozzle, the radial is spreading of the jet begins.

But a supersonic nozzle is characterized by delay in the radial spreading of the jet up to a certain length downstream the nozzle.So, I say, this is the upstream of the nozzle.This is the downstream of the nozzle.This is, if I say L p, this L p is the potential core or length of potential core.

That means, in this portion of the length, the velocity of the jet radially and axially, is same as that of velocity at the exit of the nozzle.That means, jet does not spread in this particular region and this length may be of the order of 6 to 7 times the diameter of the exit of the nozzle.However, it depends upon the pressure also.

Now, the jet begins to spread beyond the length of the potential core.So, this particular length, in fact from here to here, this is L s, is the supersonic core.Or you can call also, that from here to here the length of the supersonic core beyond the potential core.The M of the jet is equal to 1.

Beyond M is equal to 1 region, that is the subsonic region, downstream the nozzle.Due to entrainment of surrounding, number 1, radial spreading of jet.As a result, mass of the jet, at any point downstream the nozzle, will increase.Why, because of entrainment of the surrounding.

So, as you move downstream axial distance more and more, mass of the jet will be more and more.Second point, this is what is happening.The radial and axial velocity decreases.That means, if I note here point z 1 and point z 2, then velocity at point z 1 downstream the nozzle, is greater than velocity downstream the nozzle at z 2.

So, you must note very carefully from here, these two important things.One is the radial spreading of the jet and the radial spreading occurs because of entrainment of the surrounding.As a result of entrainment of the surrounding, the main part of the jet, if it consist of oxygen, it gets diluted, number 1.Number 2, the radial and axial velocity, they decay as we move downstream the nozzle.

So, this is in short, the behavior ofgas jet, when a gas discharges into the surrounding.Now, in the converter steel making, multi nozzles are used.The behavior of multi nozzle jets, that depends upon number of nozzles and inclination angle of each nozzle, with the excess of the lance.That means, if I take theflow rate of the gas constant, I allow the gas to flow through a single nozzleand I allow the gas to flow through multi nozzle, then the, then the jet produced by single nozzle will be somewhat harderas compared to that produced by the multi hole nozzles..

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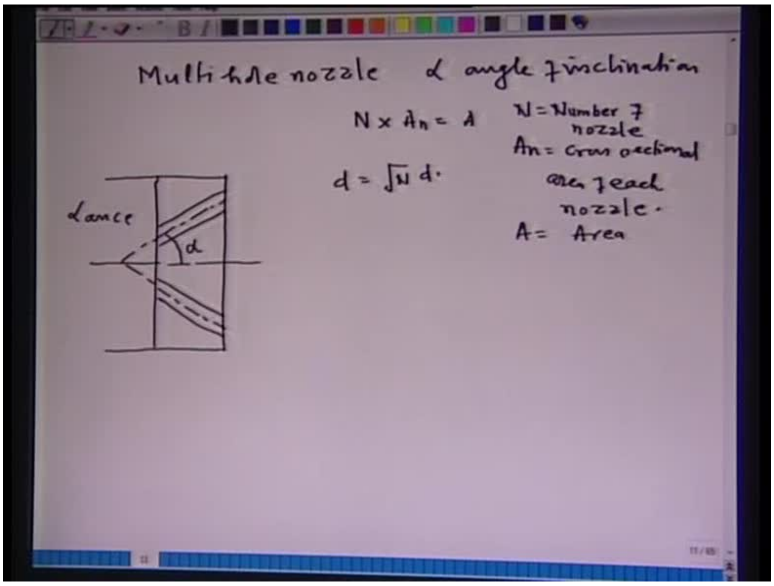

This is the angle of inclination, alpha is the angle of inclination of each nozzle with the excess of the lance.This is the lance, is the excess of the lance and alpha is the angle of inclination.Now, this angle of inclination will decide whether the jet produced by independent nozzle will coalesce downstream the nozzle or will not coalesce downstream the nozzle.

So, multihole nozzle, theydivides the flow rate such that,N into A n, that is equal to A, where N is the number of nozzle, number of nozzle,A n is a cross sectional area of each nozzle and A is the area of a corresponding single nozzle.

So, if you put it, pi by 4 d squared, then we get d that is equal to root N into d n.For multihole nozzle, the coalescence of the jet will depend upon the angle of inclination ofeach nozzle.

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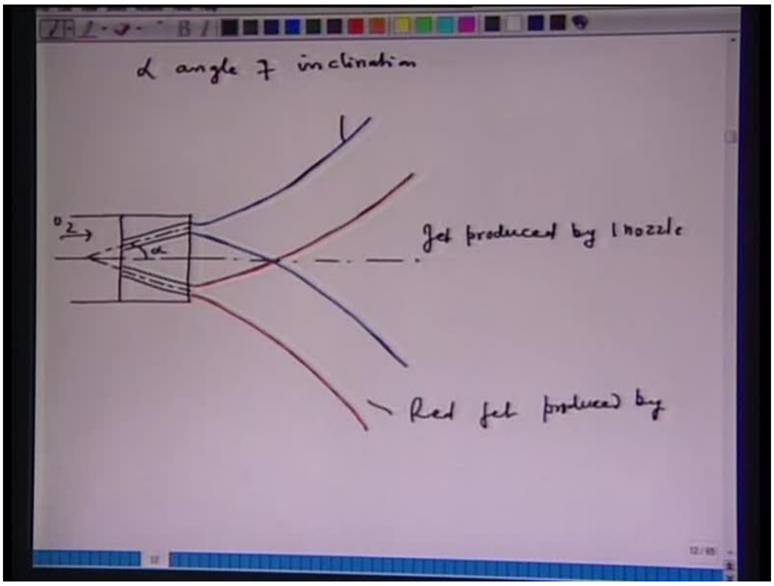

So, in this figure I have shown that, how the angle of inclination affects the jet coalescence.In this particular figure, the flow rate of oxygen is coming in this direction and this is, the blue one is the jet produced by 1 nozzle and red one is jet produced by another nozzle.

So, you can see, how both the jets are coalescing just downstream the nozzle.Now, if I increase the angle, then obviously the jet coalescence will be delayed and jet, no doubt, jet will coalesce also, but, they will coalesce after a very long downstream distance.

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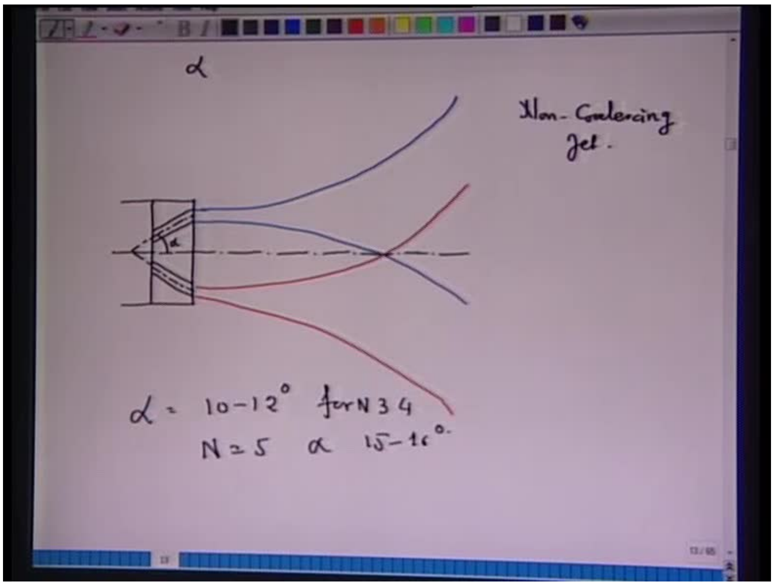

In this figure, what I have done, I taken alpha as, such that, the jet issued from each nozzle, they coalesce at a higher distance downstream the nozzle.

So, this coalescence and non-coalescence of the jet is a very important part of the converter steel making.So, this particular thing is an example of non-coalescing jet.Why it is important?A coalescence jet is very similar to that of single jet.A single jet produces a single jet.If a 4 nozzles,4 independent jets.If the angle of inclination very small for example, 3 degree or 4 degree then they will coalesce just downstream the nozzle.So, the effect is that of a single one.

If I increase the angle of inclination, then I may get 4 independent jetsand on account of that, I am rather heating a larger surface area as compared to that of a single jet.But, the non-coalescence will depend upon the angle of inclination.No doubt, if I increase the angle of inclination, then the jet will non-coalesce, but, their increasing the angle of inclination, will also affect, that the jet mayhit the side wall.So, one needs to take a compromise between what angle should be there and what an angle should not be there.

Normally, say alpha is 10 to 12 degree for three hole.Iwill just write down, alpha equals to 10 to 12 degree for N equals to 3 and 4 number of nozzle.For N is equal to 5 alpha is of the order of 15 to 16 degree.

From refining point of view, the behavior of jet, isimportant.Behavior of the jet, it depends on the surrounding of the convertor.In the convertor, as I have said, the blow begins and the oxygen jet is surrounded by the hot atmosphere.

So, the surrounding is different.As the blow continues, the surrounding of the jet changes, it starts with the brown fume and taken over by the red fume and then taken over by the carbon monoxide flame.So, the surrounding is also changing as the blow progresses.Some 25 to 30 percent of the blow has proceeded, then the surrounding further changes, then the jet may submerge into the slag.

So, the surrounding has become now, a slag, which is loaded with gas bubble and droplets of metal.So, what I mean to say is that, that surrounding in the converter is changing from start of the blow to end of the blow.So, in such a situation, it is important to know how the jet behavior depends upon.

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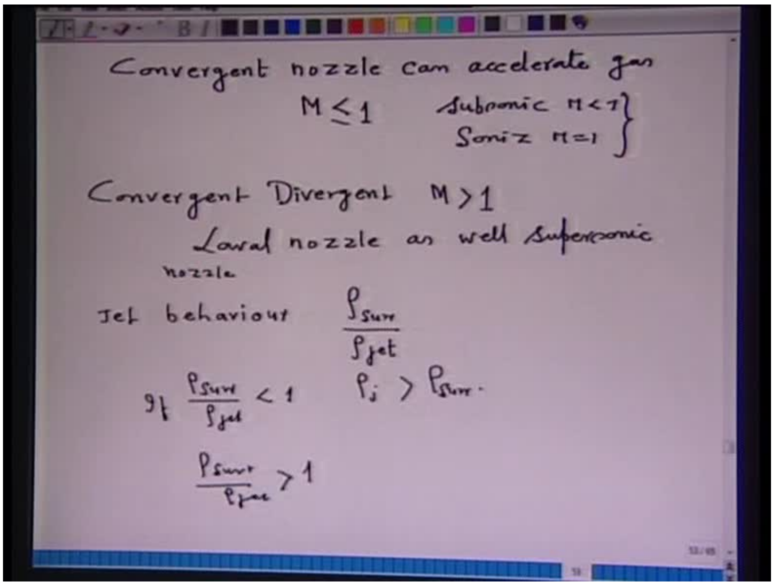

So, in fact, the jet behavior, it depends upon the density ratio or that means, density of surrounding upon density of jet.A ratio equal to 1, the density of jet is that of surrounding.So, it is with that reference, I am now comparing a ratio, when it is less than 1 or when it is greater than 1.

So, if the ratio, that is if rho surrounding upon rho jetis less than 1, that is rho j is greater than rho surrounding, then jet is denser than the surrounding . Spreading of the jet will be very slow.How slow, it will depend upon what is the value of the ratio rho surrounding by rho jet.That is how decreased it is less than 1.In this particular case, length of the potential core, length of the supersonic core, will be longer as compared to when the ratio is equal to 1.

If this ratio, say rho surrounding upon rho jet is greater than 1, that means jet is lighter than the surrounding.Jet spreads faster as compared to that of the surrounding, when the ratio is equal to 1.The faster spreading of the jet will decrease the length of supersonic core as well as length of potential core.In converter steel making, that, the surrounding is continuously changing.

So, that point is to be considered and on account of the change in the surrounding, it is very difficult to calculate the velocity of the jet at any point of time.Because, for calculation of the velocity of the jet, you must know the ratio of density of surrounding upon density of jet.If that ratio is uncertain, then it will difficult to say, what is the velocity at which the bath is hit at the time of the blow, that is action of free oxygen jet.

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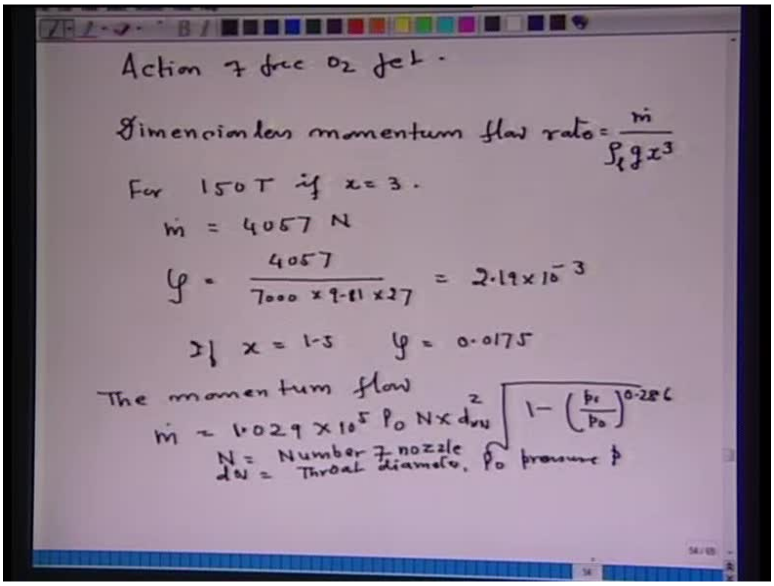

Now, as I have said, it is difficult to find out the velocity, but, we know that mass of the jet increases downstream the distance.Velocity of the jet decreases.So, the momentum of the jet,that is,m into v is conserved downstream the nozzle.That means, the momentum flow rate within the jet is constant and that is a very important property.

Now, we define a term, which is called dimensionless momentum flow rate.In order to define the action of jet, at a particular distance and that is equal to m dot upon rho l g into x cube, where m dot is the momentum flow rate, rho l is the density of the liquid in kilogram per meter cube, x is the distance.

Now,for example, for 150 tons converter capacity, if x is equal to 3, dimensionless momentum flow rate number can be calculated.M dot can be calculated.Then this m dot,it comes out to be equal to 4057Newton and if I calculate now, the dimensionless flow rate number psi, that is equal to 4057 upon 7000 is the density of hot metal, into 9.81 into 27.So, this becomes equal to 2.19 into 10 to the power minus 3.If x I take equal to 1.5, where x is the large distance, then this number psi, that is equal to 0.0175.What this says?

The value of the dimensionless momentum flow rate number increases as the lance distance decreases.That means, now we have got a parameter in hand, which can describe the effect of oxygen free gas jet in terms of refining.

Now, as I said that, it carries the momentum flow rate and so on.So, we can determine the momentum flow rate within the jet by the following equation.That is, m dot,that is equal to 1.029into 10 to the power 5P0 into N into d star N square 1 minus p upon P0 raised to the power 0.286.

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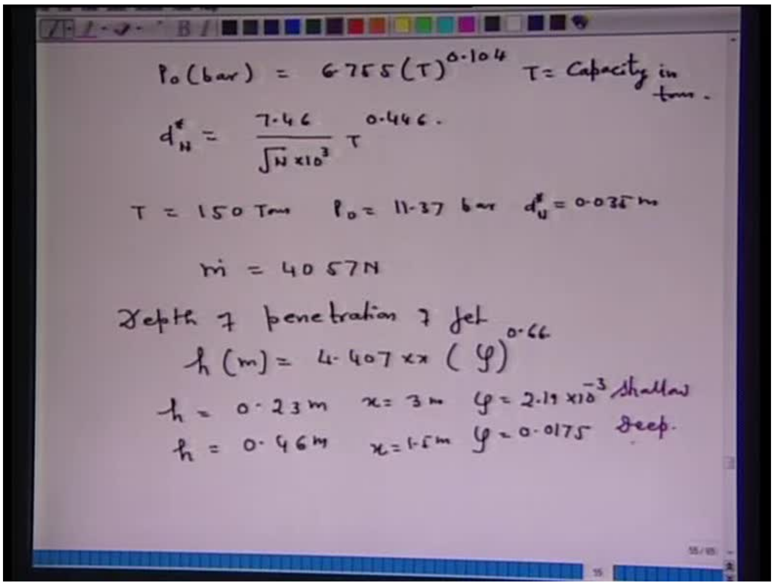

Here N is the number of nozzle, d N is the throat diameter,P0 is the pressure, supply pressure rather, and p is the atmospheric pressure.Now, this pressure P0, it can be calculated by P0 in bar, that will be equal to 6.755T raised to the power 0.104, where T, that is equal to capacity in tons.

Throat diameter can also be calculated as a function of converter capacity and number of nozzles, say d star N, that is, throat diameter, that is equal to 7.46 upon root N into 10 to the power 3T raised to the power 0.446.

Now, as I have calculated earlier, now I have given you the equation, in illustration, I can do it, if I take converter capacity as 150 tons, then P0 comes out be equal to 11.37 bars and d starn, that comes out to be equal to 0.035 meter.So, I can calculate now, m dot,that will come out to be equal to 4057 Newton, as the value I used earlier.

Now, depth of penetration ofa jet which is hitting the bath vertically, it can be determined by an equation h in meter, that is equal to 4.407 into x into dimensionless momentum flow rate number raised to the power 0.66.

So, if I take now h, say is equal to 0.23 meter, x is equal to 3 meter and psi is equal to 2.19 into 10 to the power minus 3.So, what I have done, I have calculated the value of h which is equal to 0.23 meter for a distance 3 meter and dimensionless flow rate number psi is 2.19 into 10 to the power of minus 3.

Now, if x is equal to 1.5 meter, earlier I have calculated this value was equal to 0.0175, this h, that was equal to 0.746 meter.The first where h is equal to 0.23 meter is called a shallow penetration.

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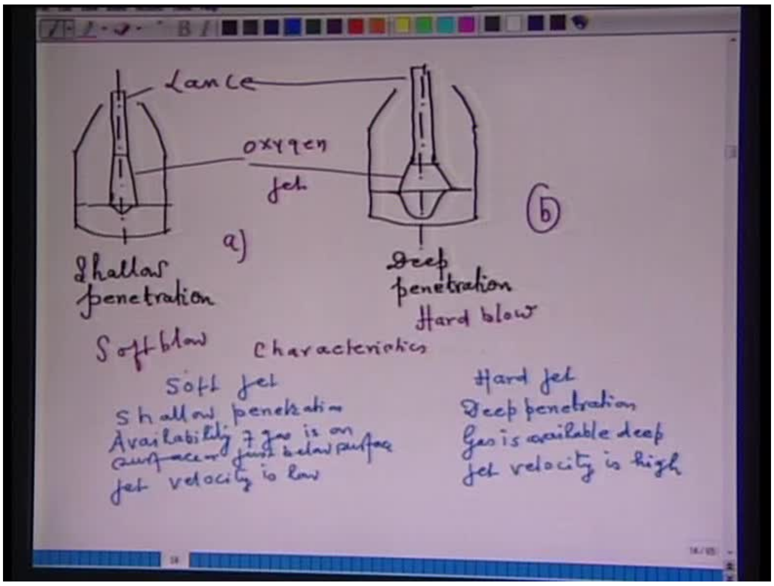

And, one with 0.46 meter which is called a deep penetration of the jet.And this shallow and deep, I have shownin this particular figure, where you note that, this is a sort of a profile of a converter, this is the lance, this is the oxygen jet.So, in one case, the distance between the bath and the lance is greater, in a, in b, the distance between the bath and the lance is lower.

So, if I increase the distance, then the penetration of the jet in to the bath is shallow,whereas, if I decrease the distance, the penetration of the jet in the bath is deep.So, in the terminology of refining, this particular practice is called soft blow, where this is called hard blow.

So, what you note from here, that a jet or a free gas jet which is produced by the constant volume flow rate of the oxygen can be made soft or hard, or between the two extremes soft and hard, the jet can be made progressively harder and to end at the hard jet.Because, how, if from the soft blow mode I progressively decrease the lance distance, then I am progressively increasing the depth of penetration and progressively I am making the jet harder.

So, the characteristics of soft and hard jet are as follows.This is the soft jet.This is the hard jet.For the soft jet, I have shallow penetration.Here I have deep penetration.This is one important characteristic.Another important characteristic, the availability of gas is on surface or just below the surface.

What is here, gas is available deep, intothe bar.That is one very important property of the hard jet.Third, jet velocity is low,whereas, the hard jet, jet velocity is high and as a consequence, the droplets are produced by the hard jet.

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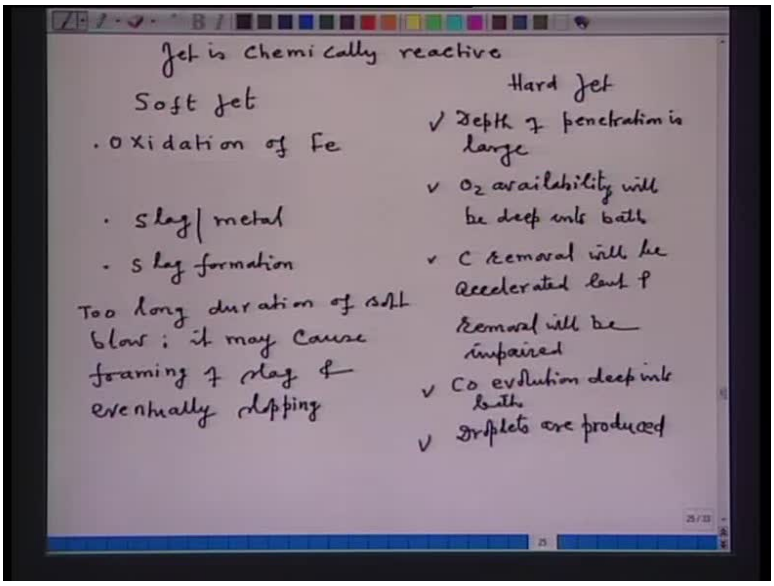

So,for example, if the jet is chemically reactive, then, what thissoft jet and hard jet means?A chemically reactive jet means, again the jet has mass and velocity.So, mass of the jet will be consumed or it will be distributed or it will be diverted and velocity of the jet will be usedto create the mechanism for faster mass transfer reaction.

So, in the light of soft and hard jet, what are the effects that it can induce in to the bath?Iwrite down here soft jet.A soft jet will promote oxidation of iron.In terms of slag metal reaction, soft jet promotes slag metal reaction.

So, a soft jet, it promotes slag formation.So, too long duration of soft blow is not good because, it may cause foaming of slag and eventually, slopping.I have taken two extremes, soft jet and hard jet.Hard jet, the depth of penetration will be large, as just we have seen in the calculation.What does it mean?

Now, that means, oxygen availability will be deep into the bath.What does it mean?That means, now, here, the carbon reaction can be accelerated, because oxygen is abundantly available in the bath.So, it will react with the carbon.

But, if phosphorus is to be removed, which is a slag metal reaction, then phosphorus removal will be impaired.So, I will write down here, oxygen availability will be deep into the bath, on account of which carbon removal will be accelerated, but, phosphorusremoval will be impaired.Simply because, phosphorus removal is a slag metal reaction.

Another important feature of this hard jet is that, since carbon monoxide evolve deeper into the bath, so, a better circulation in the bath as long as CO is being produced is there.So, that means CO evolution deep into the bath and which will create good agitation condition in the bath.Another important feature of this hard jet is that, the droplets are produced.

Now, when the droplets are produced and when these are entrain into slag, because of the high interfacial area, the reaction rate will be faster.So, in summarizing the effects of hard jet, the hard jet is preferred for carbon removal rate and inducing faster mechanism of refining reaction,whereas, soft jet accelerates slag formation and this soft and hard jet fix very well into the concepts of converter steelmaking, because, steelmaking involves oxidation of impurities through slag formation.

So, what we are having, by having a soft jet we can promote slag formation.By hard jet we can promote carbon oxidation, but, if you want to carryout both reactions simultaneously, a slag metal reaction which is a phosphorus removal, a gas metal reaction which is a carbon removal, if you want to carryout both of them simultaneously, then we can create a condition from soft jet to progressively harder jet and eventually we will stop the blow at the hard jet.

So, what I mean to say from here is that, take soft blow and progressively harder blow is the fundamental concepts of converter steel making and almost all converter steel making, in all industry, they have this particular concept of refining of steel, that is starting with the soft jet, making it progressively harder during the blow and eventually, finishing the heat, with somewhere between the soft and hard blow.

So, that is why, the tap to tap time interval for all the converter capacities does not depend upon the size of the converter.Because, the refining schedule is attained bychanging the lance distance in terms of soft and hard blow, is independent of the capacity of the converter.

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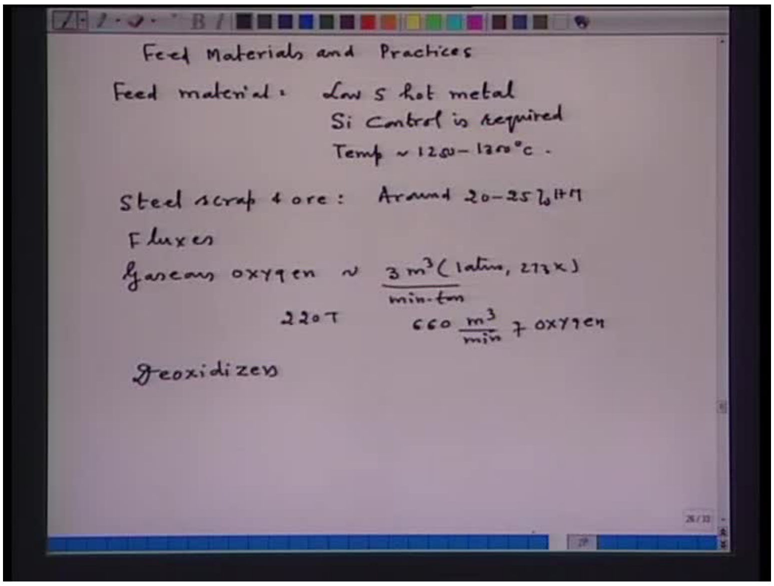

So, let us take now the feed materials and practices.Now, feed material say, one requirement is low sulphur hot metal.Why low sulphur hot metal, because in steel making, sulphur removal is not possible.Then silicon control is also required.For larger is the amount of silicon, more Si O 2 will formand more will be the volume of the slagand also silicon retards the dephosphorization.

Temperature is approximately1250 to 1300 degree Celsius.Then the feed material also, we have steel scrap and ore, say around 20 to 25 percent of hot metal is scrap discharge.Now, one of the important requirement, in case of scrap, is the tramp element.

The tramp elements like lead, antimony, tin, zinc, they are present in the scrap and as such they will pass into the liquid metal or they will createlarge amount of fumes and they may pass through the exit gases, if during steel making, their boiling point is crossed..

So, the control of tramp element is also an important issue while using scrap as a charge material.We use also fluxes, lime, magnesia sometimes, depends, then of course,, gaseous oxygen, approximately 3 meter cube at 1 atmosphere and 273Kelvin per minute per ton and if you have capacity,for example, 220 tons, then we require 660meter cube per minute of oxygen.

So, that much amount of oxygen we should have, if you blow for 20 minutes and you know, what is the amount of oxygen. Then, we also require deoxidizers to kill the steel.

Now,practice, typical, heat, first of all, lining is inspected for any repair.If it requires to be repaired, thenlining isrepaired before starting the heat, then charging of hot metal andscrap, then lance is brought and oxygen begins to blow.

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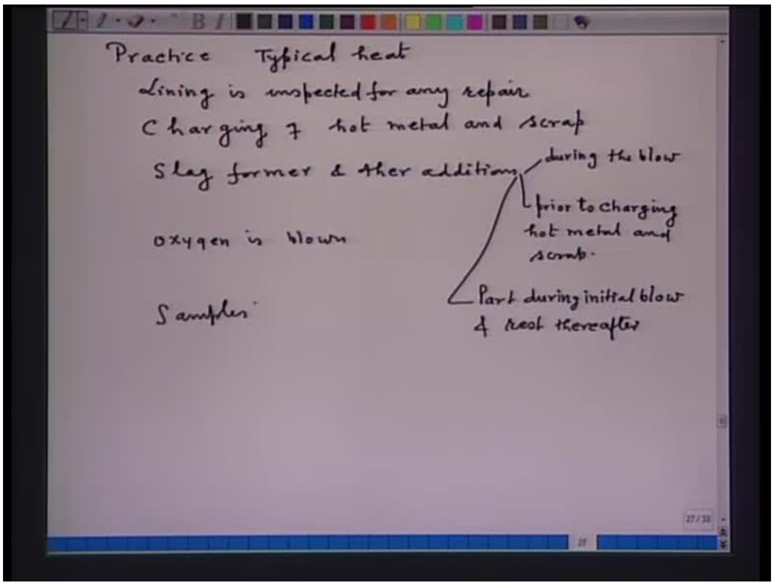

In some practices, the slag former and other additions, they are done during the blow.It depends, I mean, it varies, from practice to practice orprior to charging hot metal andscrap,or part during initial blow and rest thereafter.

So, what is being said here, these are all thevariations that vary from practice to practice. Some practice prefer to charge all in the beginning.Some practice during the blow, some practice part during the blow and later during the period.It all varies, but, does not matter, all that it requires, whatever amount is required to charge, it has to be chargedduring the refining operation.

Then oxygen is blown, as I have said, oxygen is blown through a lance placed vertically above the bath.Now, here oxygen blow has to be controlled and the oxygen blowing continues for15 to 20 minutes and during the blow the lance is raised or lowered, such that, the slag forming and oxidizing reactions remains within the control.

So, what is important here, a lance schedule has to be developed.Now, the lance schedule development requires some cautions.Slag forming reaction should be there, carbon monoxide devolution should be continuously there.

So, raising or lowering of the lance, should go within the extreme of slag formation and CO evolution.That means, at no point, lance distance should be such,so that slag expels from the mouth of the converter.At the same time, lance distance should not be so low or should not be too low, so that it allows only carbon reaction and no phosphorus reaction.

That means, the control of lance distance right from a start of the blow to the end of the blow is a very very important exercise for any steel making operator, who is working on the converter steel making.

Now, in fact, these profiles are developed, they are fitted into the practice and then the practice follow the same profile.So, at the end of the blowing, the samples are taken, analyzed for thespecified chemistry and then steel is being tapped.

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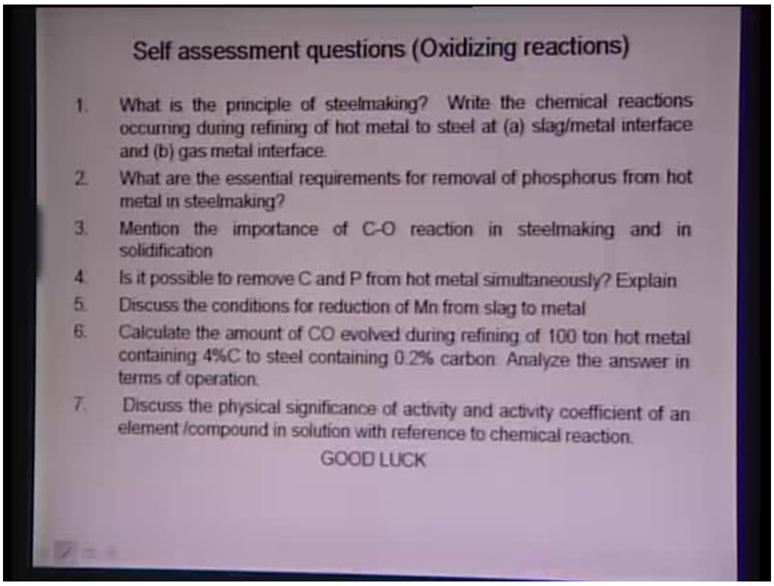

So, here are the questions for your self assessment on the oxidizing reactions.What is the principle of steelmaking?Write the chemical reactions.What are the essential requirements for removal of phosphorus from hot metal in steelmaking?

Question number 3, mention the importance of CO reaction in steelmaking.4th,5th,6th and 7th,I had already discussed their answers.Please read the question and see that you are able to answer.

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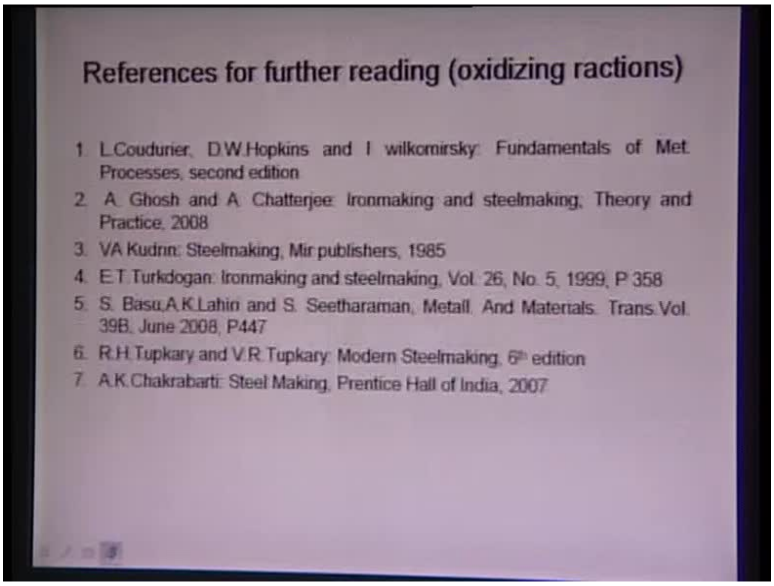

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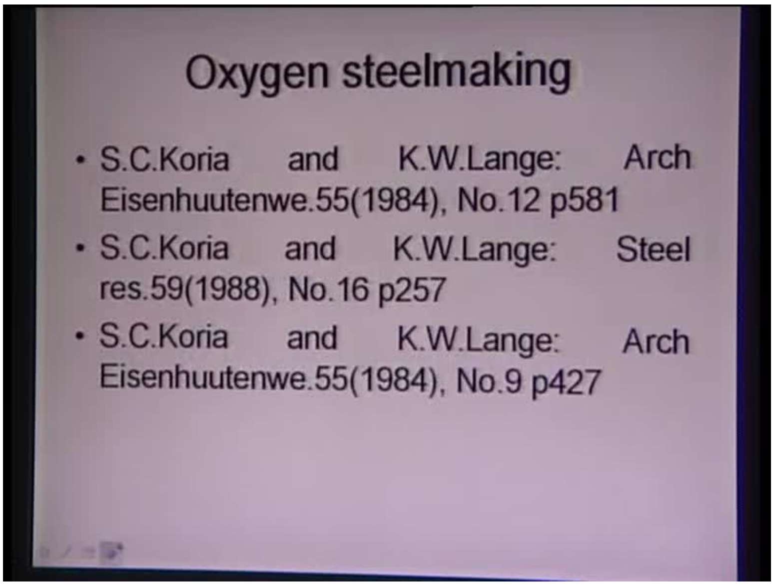

Here are some references for reading on the oxidizing reaction andthese are the references for oxidizing reaction.

Thank you.