Iron Making
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Lecture - 35
Iron Making

So, now after this numerical let us see about the properties of the DRI which we get is so.

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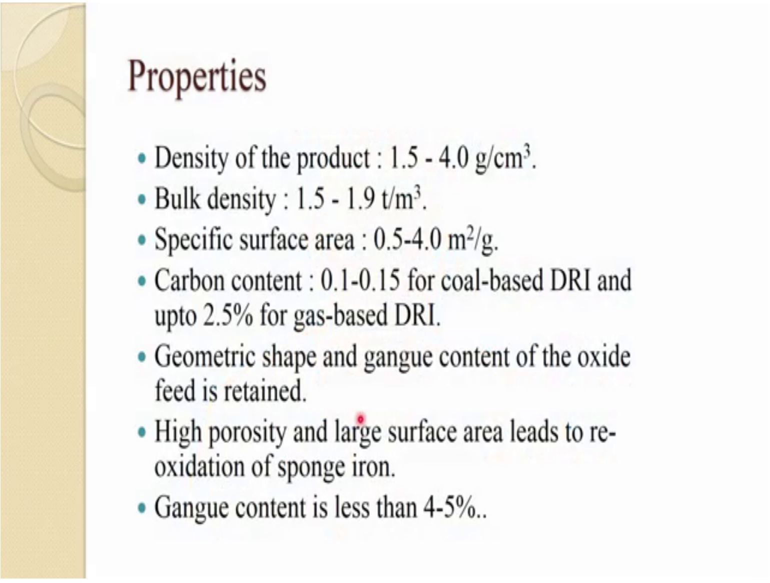

Properties

- Density of the product : 1.5 - 4.0 g/cm^3.
- Bulk density : 1.5 - 1.9 t/m^3.
- Specific surface area : 0.5-4.0 m^2/g.
- Carbon content : 0.1-0.15 for coal-based DRI and upto 2.5% for gas-based DRI.
- Geometric shape and gangue content of the oxide feed is retained.
- High porosity and large surface area leads to re-oxidation of sponge iron.
- Gangue content is less than 4-5%..

Usually the density of the product then this between 1.5 and 4 gram per centimeter cube or 1500 to 4000 kg per meter cube bulk density 1.5 to 1.910 again the tonne per meter cube specific surface area is about 0.5 to 4 meter square per gram carbon contains usually it is range between 0.1 and 0.15 for coal based DRI and up to 2.5 for gas based DRI. So, essentially as you can see till it is quite low the percentage of carbon into it. So, the melting point in that way becomes bit quite high.

So, geometric shape and gangue content of the oxide field is written, because there is no slag formation in this DRI. So, whatever gangue is there it is within that respond iron or directly choose irons which is retained high porosity and large surface area lead to re-oxidation of sponge iron. So, high porosity it is a due to the reduction of the oxide which creates a large surface area and that lead to the oxidation re oxidation of it vanity that comes in contact with air. So, gang containing less than 4.5 hour 4.5 percent.

So, that is why as usually then you get about 94 percent metallization of metallization from most of these processes and.

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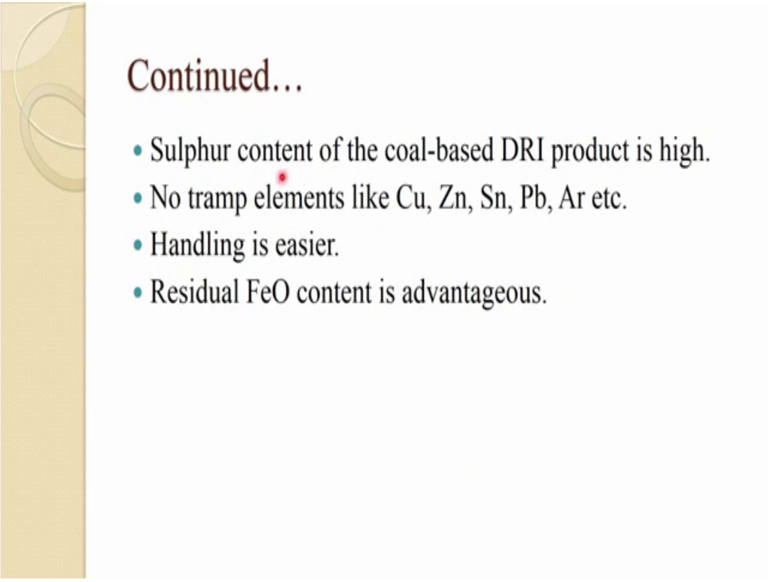

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- Sulphur content of the coal-based DRI product is high.
- No tramp elements like Cu, Zn, Sn, Pb, Ar etc.
- Handling is easier.
- Residual FeO content is advantageous.

Sulphur contained especially in the coal way DRI product is quite high, because there is no slag can take it. So, most of the sulphur content is retained in to that. So, it is usually quite high no tramp elements like copper, copper, zinc, tin, lead, arsenic, and etcetera. Handling is easier as a solid product. The residual FeO content is advantageous. So, some of the iron which is not reduce or the reoxidation is appear is formed.

This is sometimes advantages and in the later operation and the uses of DRI.

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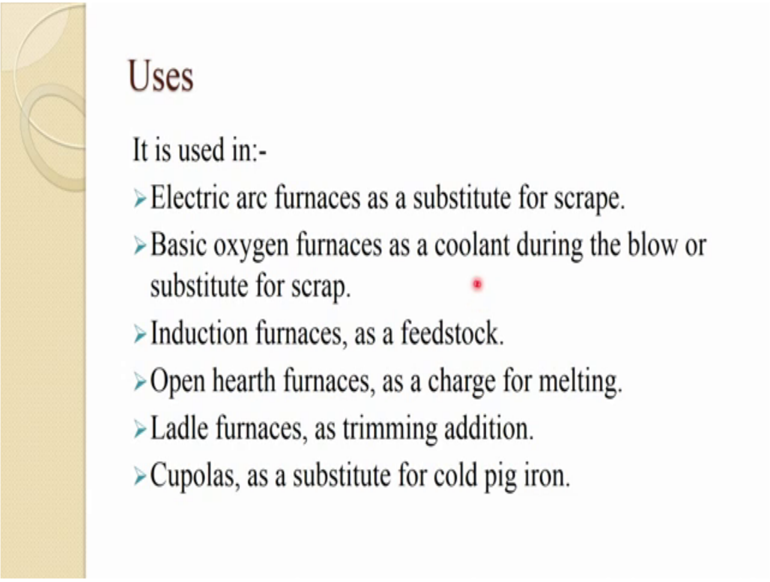

Uses

It is used in:-

- Electric arc furnaces as a substitute for scrape.
- Basic oxygen furnaces as a coolant during the blow or substitute for scrap.
- Induction furnaces, as a feedstock.
- Open hearth furnaces, as a charge for melting.
- Ladle furnaces, as trimming addition.
- Cupolas, as a substitute for cold pig iron.

Is usually electric arc furnace as a substitute for a scrap no? So, that for the scrap and the electric arc furnace when the scrape is not there it can be substitute for that for steelmaking. Similarly in the basic oxygen furnaces it is used as a coolant during the blow or substitute for scrap.

Induction furnaces as a feedstock it is used open arc furnace. Now which are not anyway in today the market much it is used as a charge for melting a ladle furnaces trimming addition cupola a substitute for cold pig iron. So, there are the different see many uses of this direct reduced iron and that is where it is used and you can do it them to make the steel directly through this operation. So, you do not need a liquid iron in this one.

But, economically if you consider is not that much useful when fun look at the economy why the viability is not that big.

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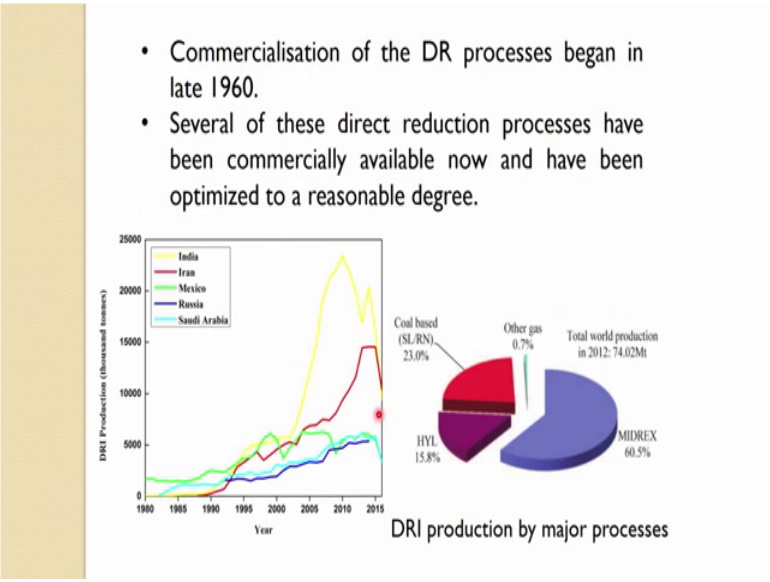

- Commercialisation of the DR processes began in late 1960.
- Several of these direct reduction processes have been commercially available now and have been optimized to a reasonable degree.

DRI production by major processes

So, commercialization of direct reduced processes began in late 1960. So, several of these direct reduction processes have been commercially available now and have been optimized to a reasonable degree. So, many processes started with that and is it now quite all technology and reasonably sort of optimized and understood.

Ah. So, not much scope improvement as such. So, and you can see from the latest figure of this India is the leading country in the production of DRI. So, the DRI production in 1000 tonnes. So, India started a little late a while some other countries is built in the Mexico and this thing they started quite early and even Russia and Saudi Arabia, but then they did not go that high the products and more or less a last 2, 3 decades is constant.

But for India and you can see from nineteen ninety or. So, Iran also the production is increasing it is quite high of the DRI to 2009 or. So, peaked and this one are also even 2015 it has reduce a bit, but not that much and this sharp drop is because the data would not available that time. So, it is somewhere here those data. So, it is quite iron in India is leading into this Arab Iran.

So, and if you, but anyway if you look at the production is it is there, but it is not very high if you see the commercialization of the process started in late 1960 and as I mentioned in the previous slide that because you get in the solid form the iron and what you need in the liquid form because finally, it has to be melted again. So, economically is not that much rival when it is started people thought it will overtake blast furnace.

So, the recent data so, the contribution of this DRI from 1990 to 1960 or so, it is it just increased by 3 percent. So, that shows the sort of the progress of this DRI and I certainly cannot compete the blast furnace or the iron making process and the DRI which is produced this shows the major processes. So, one is the MIDREX we will be talking about that this the major process and SL RN must lead or tricking based sort of one HYL and then there are few other process many other which comes there, but not that much commercialized.

So, total production of DRI is 74 million tones 2012. So, this is not really constitute about the 5 for the 5 percent of iron production. So, it is not very high due to those limitation of it, now if we come to the; now we will come to the actual processes after you understood about the kinetics; how does it work and what are the uses of it?

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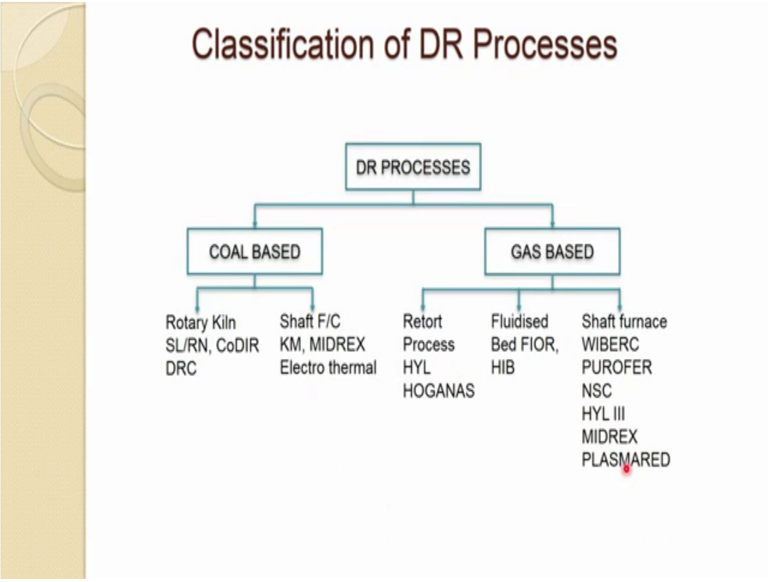

Classification of DR Processes

DR PROCESSES

COAL BASED

GAS BASED

Rotary Kiln
SL/RN, CoDIR
DRC

Shaft F/C
KM, MIDREX
Electro thermal

Retort
Process
HYL
HOGANAS

Fluidised
Bed FIOR,
HIB

Shaft furnace
WIBERC
PUROFER
NSC
HYL III
MIDREX
PLASMARED

Now, the classification of direct reduction processes we talked a lot about the gas natural gas as a reducing agent and then coal as reducing essence so; obviously, there are two classification of direct reduce process 11 is the coal based and another is gas based and coal based processes like Rotary Kiln SLRN there are many processes which are based on this then shaft like processes KM MIDREX Electro thermal I had. So, rotary can type with this shaft type of this.

In coal based where coal is choosed as the reducing agent and in the gas based you have a Retort, processes, HYL, HOGANAS and then some of them Fluidized bed one FIOR, HIB then shaft furnace where fluid you have gas based these are again a different this in the furnace steel one as for HYL III materials PLASMARED and other processes there are many other processes, but these are some important one, but really as we have seen in the previous slide MIDREX and these are the main and these two and these are the main processes which are commercially used and most of the are not more than ninety percent production of hr if DRI comes through only these three processes.

So, we will be talking little bit only about these two three processes which are similar to others it bitter only a little bit variation in the other one.

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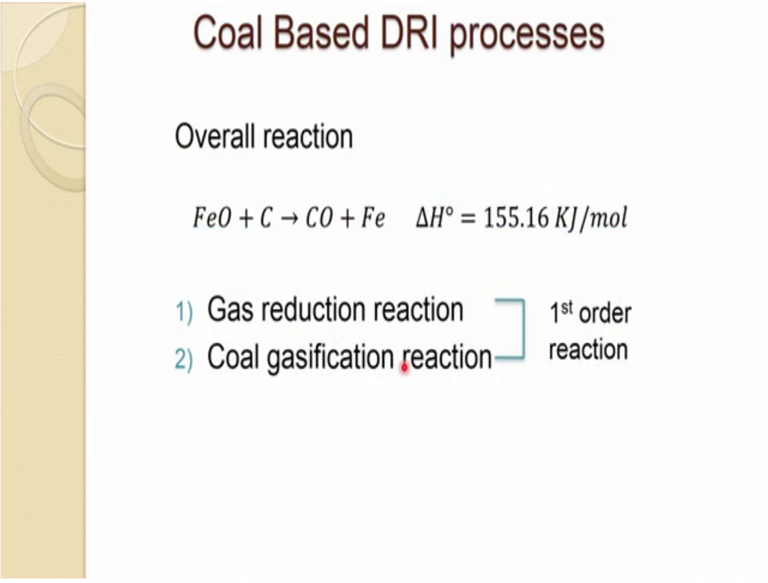

Coal Based DRI processes

Overall reaction

$$FeO + C \rightarrow CO + Fe \quad \Delta H^{\circ} = 155.16\ KJ/mol$$

1) Gas reduction reaction
2) Coal gasification reaction

1st order reaction

So, when we say coal based DRI. So, overall reaction in that one we have talked about this is that and a gas reduction reaction and coal gassification reaction is first order sort of reaction and this is the one which occurs and by which to produce the iron and so.

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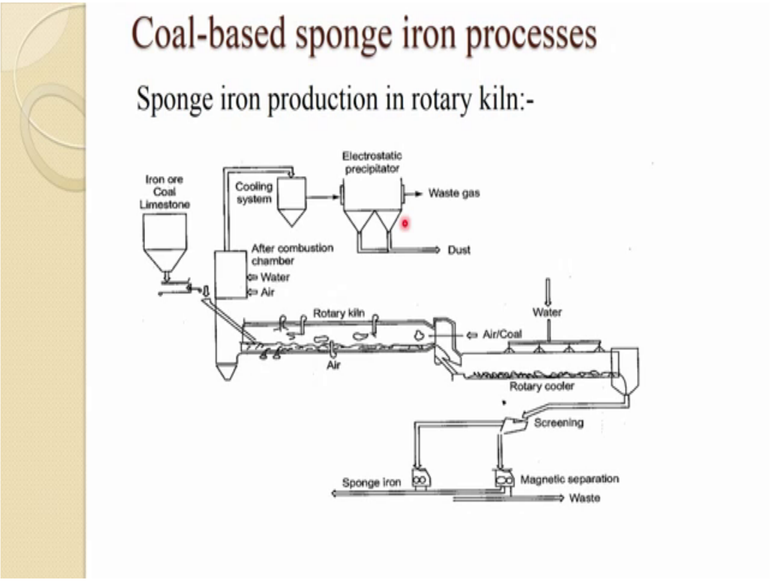

Coal-based sponge iron processes

Sponge iron production in rotary kiln:-

Rotary kiln which we said even slr and it is under same principle. So, sponge iron production in rotary kiln so, what essentially in this it is done that iron ore coal and limestone. So, like it sort of a composite they are mixed together and feed it sort of a composite pellet, spoon and they are put through to choose to the rotary kiln and they are case which is supplied through that and some time with the burners through which the fuel is supplied and mostly from this exit side.

So, this is the inlet side of the ore this is the exit side the air and coal is a supplied combustion occurs and this heat get transferred to the pellet and it is a slowly slow it is increasing it is increases slowly the temperature and the reduction mostly occurs in this region.

And the hot cases they sort of heat the material he has sort of a (Refer Time: 13:21) reduction type of thing and these hot gases then goes away from the other side where the inlet of the ore is and after the this cooling and combat combustion of those cases thorough it goes to the electrostatic precipitator to remove the dust and other in the waste gases and then the hot DRI comes into the rotary cooler where it is cooled and then it is get separated using the magnetic separation essentially the sponge iron could can be separated.

So, a sponge iron comes and waste goes another way. So, this is essentially the process for the rotary kiln based and coal based process processes by which directly reduce iron is produced.

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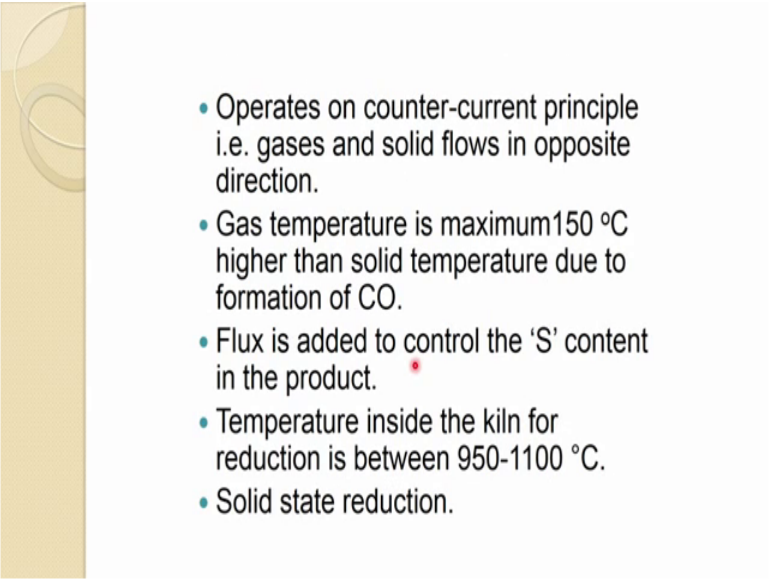

- Operates on counter-current principle i.e. gases and solid flows in opposite direction.
- Gas temperature is maximum150 °C higher than solid temperature due to formation of CO.
- Flux is added to control the 'S' content in the product.
- Temperature inside the kiln for reduction is between 950-1100 °C.
- Solid state reduction.

So, it is operates on counter current principle because the solid is coming from the direction gates are passing from that. So, it is a counter current principle gasses and solids flows in opposite direction gas temperature is maximum 150 degree Celsius higher than the solid temperature due to the formation of co.

So, maximum the temperature difference between solid and gas is about 150 degree Celsius usually it cross around 950 or a 1100 degree or so, flux is added to control the sulphur content in the product which is from one over here in this one and the temperature inside the kiln for reduction is between 950 to 1100 degree Celsius. So, it is a solid a state reaction which we have already discussed about those.

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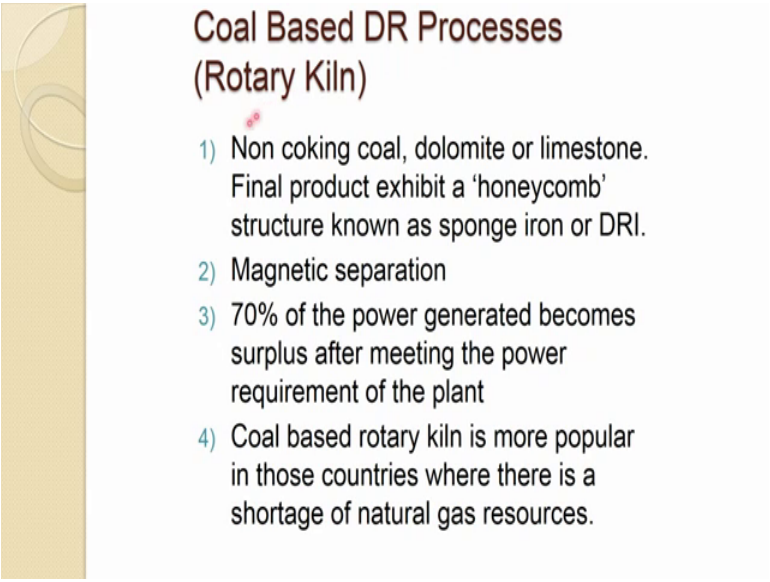

Coal Based DR Processes (Rotary Kiln)

1) Non coking coal, dolomite or limestone. Final product exhibit a 'honeycomb' structure known as sponge iron or DRI.
2) Magnetic separation
3) 70% of the power generated becomes surplus after meeting the power requirement of the plant
4) Coal based rotary kiln is more popular in those countries where there is a shortage of natural gas resources.

So, the these are sort of the condition in that rotary kiln and non coking coal dolomite or limestone and final product exhibit a honeycomb structure. So, with that is why you usually call it as a sponge iron or DRI magnetic separation is used to separate it with the waste and 70 percent of the power generated becomes surplus after meeting the power requirement.

So, here the cases which are coming it is combusted and suited for the profit supply and that it is mentioned 70 percent of the power generated becomes surplus after meeting the power requirement of the plant coal based rotary kiln is more popular in those countries where there is a shortage of natural gas resources. So, when nature gas resources are not there always one is there and also it is quite popular with one does not have a high ranking coal. So, coal based rotary kiln are popular in those countries.

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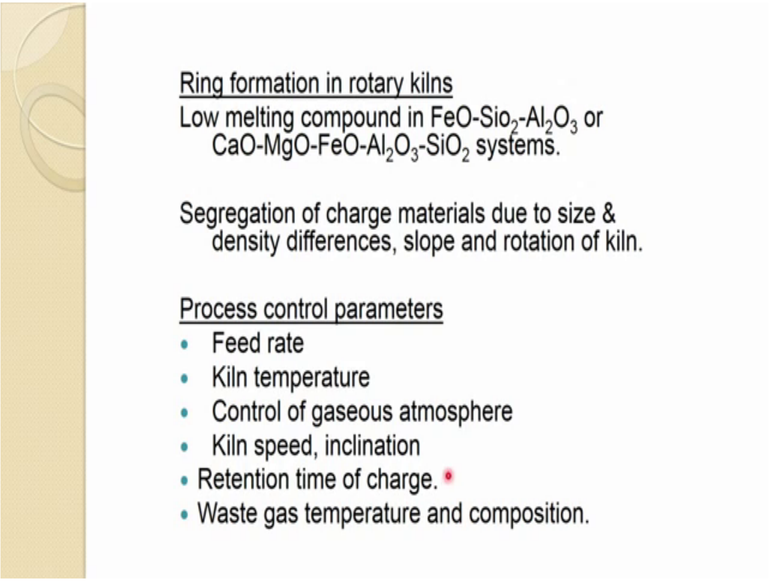

Ring formation in rotary kilns

Low melting compound in FeO-Sio_2-Al_2O_3 or CaO-MgO-FeO-Al_2O_3-SiO_2 systems.

Segregation of charge materials due to size & density differences, slope and rotation of kiln.

Process control parameters

- Feed rate
- Kiln temperature
- Control of gaseous atmosphere
- Kiln speed, inclination
- Retention time of charge.
- Waste gas temperature and composition.

The problem which is associated with this very often is a ring formation that ring formation into to the low melting compound of this iron silicate, aluminate, SiO 2 big oxygen ore, calcium, magnesium, iron oxide or not SiO 2 system that forms a low melting compound and which deposited around near on the wall of this and that forms a ring and that is why taking a rotaring formation which it is a ring information and that have major problem in this.

Segregation of charge material due to size density difference slope and rotation of the thin. So, as you send the material the name actually said rotary kiln which means it is rotate and it has a little inclination. So, for the natural rate of that it comes out the charge from here. So, when it is rotating usually the centrifugal force under that also works and rotation of course, is very small due to be actually the segregation of the particles of different size occurs, because by this there is not a close control on the particle size distribution.

So, do have a some range of the particle size. So, that is why this segregation occurred. So, smaller and bigger particle and then your reaction also get affected due to that process control parameters. Usually the feed rate kiln temperature control of gaseous atmosphere kiln speed inclination retention time of the charge waste gas temperature and composition is a sort of the control parameter which are associated with the rotary kiln based processes.

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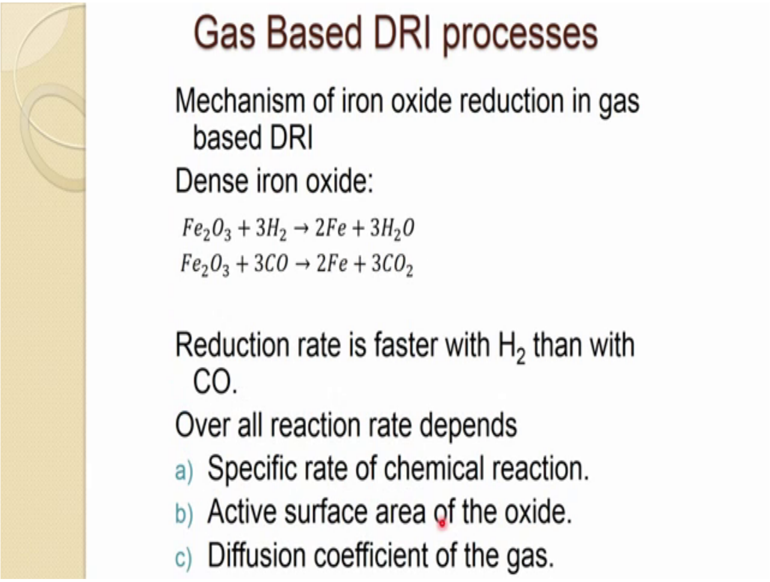

Gas Based DRI processes

Mechanism of iron oxide reduction in gas based DRI

Dense iron oxide:

$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

Reduction rate is faster with H_2 than with CO.

Over all reaction rate depends

a) Specific rate of chemical reaction.
b) Active surface area of the oxide.
c) Diffusion coefficient of the gas.

Now, gas based DRI processes it is mentioned mostly it to the natural gas as you do it. So, mechanism of iron oxide reduction is gas based DRI. So, then subsides reduce into metallic iron by hydrogen and co. So, that is the mixture of that you do it in the gas based one with the natural gas. So, reduction rate usually then is faster with the hydrogen than CO hydrogen it more reducing power and we have seen before even fa ca FeOh and CO system we discussed during the blast furnace one and we discussed Fe CO system also.

So, in that one we have shown that hydrogen it much more reducing power than co. So, overall reaction rate engage will depend a specific rate of chemical reaction active surface area of the oxide and the diffusion coefficient of the gas which is.

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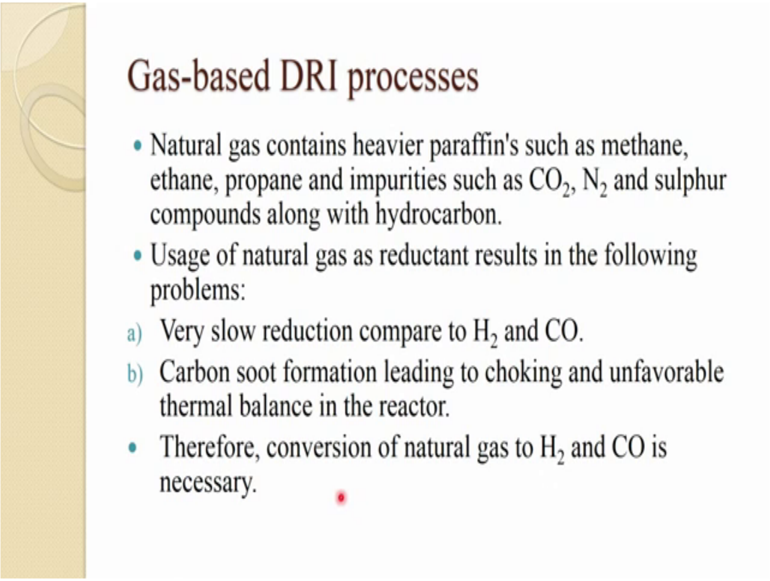

Gas-based DRI processes

- Natural gas contains heavier paraffin's such as methane, ethane, propane and impurities such as CO_2, N_2 and sulphur compounds along with hydrocarbon.
- Usage of natural gas as reductant results in the following problems:

a) Very slow reduction compare to H_2 and CO.

b) Carbon soot formation leading to choking and unfavorable thermal balance in the reactor.

- Therefore, conversion of natural gas to H_2 and CO is necessary.

Imported hydrogen is faster than the carbon monoxide. So, natural gas contains heavier paraffin’s such as methane, ethane, propane and impurities like carbon, nitrogen, sulphur, compound along with hydrocarbon.

So, usage of natural gas a reductant results in the following problem very slow reduction temp compared to hydrogen co. So, in this form the reducing power of the natural gas is very low and that is why; it is very slow reduction carbon soot formation occurs because heavy paraffin are there leading to choking and unfavorable thermal balance in the reactor therefore, conversion of the natural gas to hydrogen and CO is necessary and that is why where we need to reform our and previous and one of the slide we discuss a little bit about.

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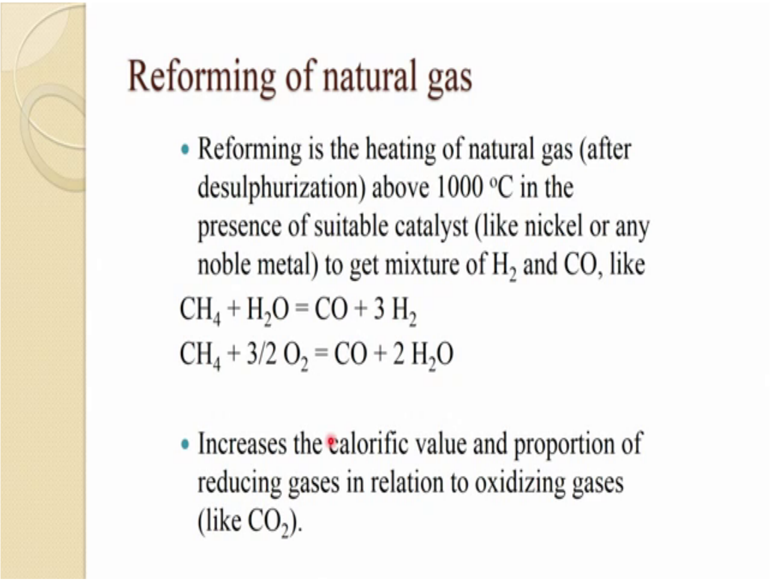

Reforming of natural gas

- Reforming is the heating of natural gas (after desulphurization) above 1000 °C in the presence of suitable catalyst (like nickel or any noble metal) to get mixture of H_2 and CO, like

$CH_4 + H_2O = CO + 3\ H_2$

$CH_4 + 3/2\ O_2 = CO + 2\ H_2O$

- Increases the calorific value and proportion of reducing gases in relation to oxidizing gases (like CO_2).

The reforming of the natural gas where we sold three more reaction and so, reforming is the heating of natural gas up to desulphurrization above 1000 degree Celsius in the presence of suitable catalyze usually it is nickel or other noble metal to get a mixture of hydrogen and CO like this sort of reaction where you get mixture of CO and hydrogen and this ray. So, can be controlled using the temperature pressure and catalyst. So, that treats upon the essential thing where you need this c on hydrogen as a reductant or reducing agent.

So, increases that this increases the calorific value and proportion of reducing cases in relation to the oxidizing gases like CO 2. So, reforming is an integral part of the natural gas.

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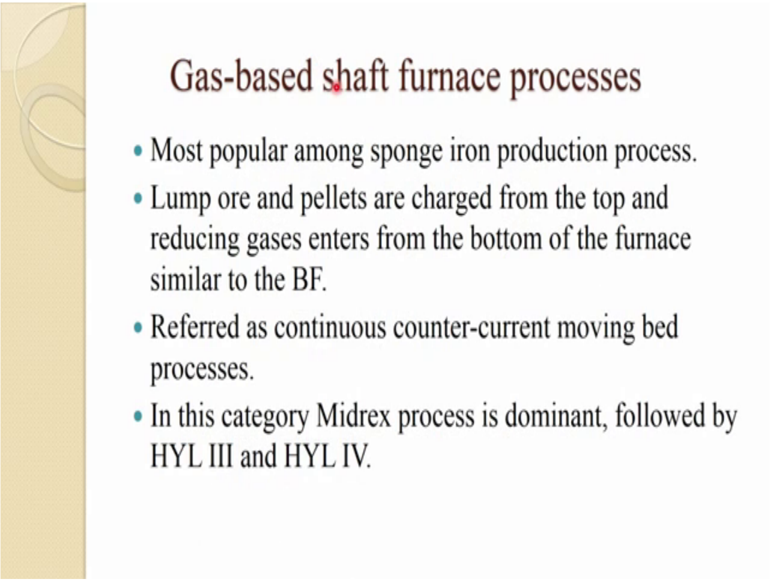

Gas-based shaft furnace processes

- Most popular among sponge iron production process.
- Lump ore and pellets are charged from the top and reducing gases enters from the bottom of the furnace similar to the BF.
- Referred as continuous counter-current moving bed processes.
- In this category Midrex process is dominant, followed by HYL III and HYL IV.

Based processes so, most popular among sponge iron production processes. This gas based one lump ore and pellets are charged from the top and reducing gases enters from the bottom of the furnace similar to the blast furnace. Referred as continuous counter-current moving bed processes.

In this category Midrex process is dominant dominating one and followed by I HYL III and HYL IV. So, we will talk a little bit about Midreix and HY L under the gas based and gas based are very similar to the blast furnace sort of process.

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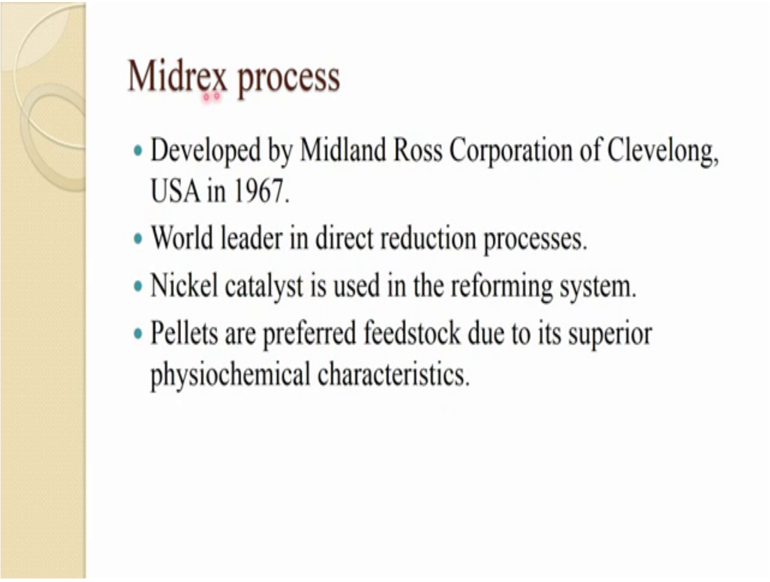

Midrex process

- Developed by Midland Ross Corporation of Clevelong, USA in 1967.
- World leader in direct reduction processes.
- Nickel catalyst is used in the reforming system.
- Pellets are preferred feedstock due to its superior physiochemical characteristics.

So, the Midrex process this is developed by Midland Ross Corporation of Clevelong, and it is a Cleve land it is Cleve land us in 1967.

So, as we said these processes started in late 1960 which we mentioned previously so, it is a world leader in direct reduction processes nickel is used as a catalyst in the reforming system pellets are preferred feedstock due to it is superior physicochemical characteristics and even the property can be controlled then you make the pellet instead of lump ore.

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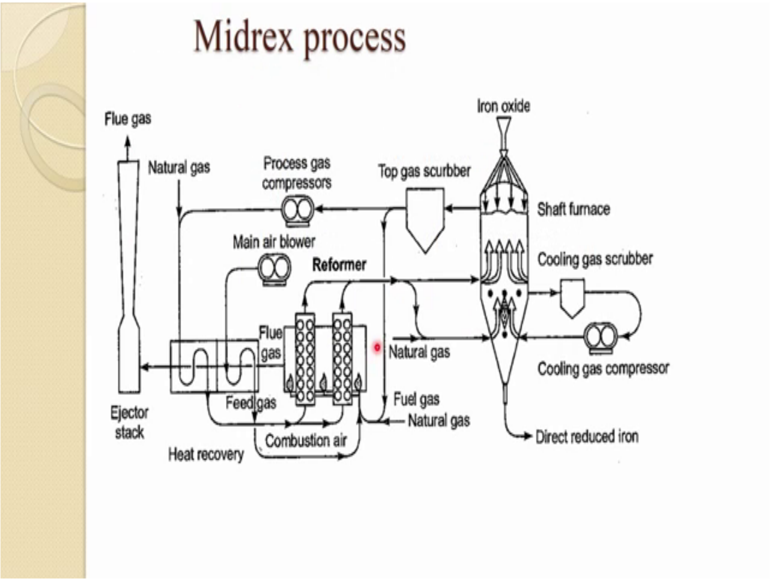

Midrex process

So, essentially in this one it is the natural gas is sand and get a bit heated up into this and goes to the reformer and the reformer where we said with the it reformed the gas and it gives a more CO and hydrogen. So, it is heated up and with the use of catalyst the reformed gas comes out of it from the reformer and it is fed into the main shaft or main furnace of that. So, this is the main furnace shaft from the top on oxide or on pellets are fed and from the bottom the this highly reducible somewhere middle it is a sand is reformed there.

So, most of the reduction occur over here and some in this one even from the side also descended with some natural gas and this keeps also a sort of a cooling effect. So, you can see that a cooling gas compressor and this gets. So, this highly reducible case reduce the iron oxide and the reduced iron in solid form. So, DRI comes out from the bottom and these less reduced gases are collected at the top using the gas scrubber to remove dust and other thing.

And part of it is because it still it has a sensible eye it is used for burning the reformer to heat up the reformer. So, it is formed due it as a fuel to burn this one these thing and this flue gases also used to reheat those natural gas which is coming out. So, the and then these gases goes out to this chimney as a flue gas and some of the top case is again recirculated and reformed into this.

So, this is also a heat recovery unit conversion unit and reforming unit and this is the main shaft with the; DRIs produced. So, this is essentially the basic principle of Midrex process on which it is worth's as you can see it is nothing just like the upper part of the blast furnace and that does not reach to the fusion temperature. So, just above the cohesive zone whatever it is occurring that the same phenomena are happening over here.

But here because C O nitrogen is air in terms of reducing gas and. So, more reducing power it is there and that is you get the DRI in that way. So, most of the shaft processes are operated in this, but Midrex is the one which is quite popular it can be agitated in many ways of quite flexible.

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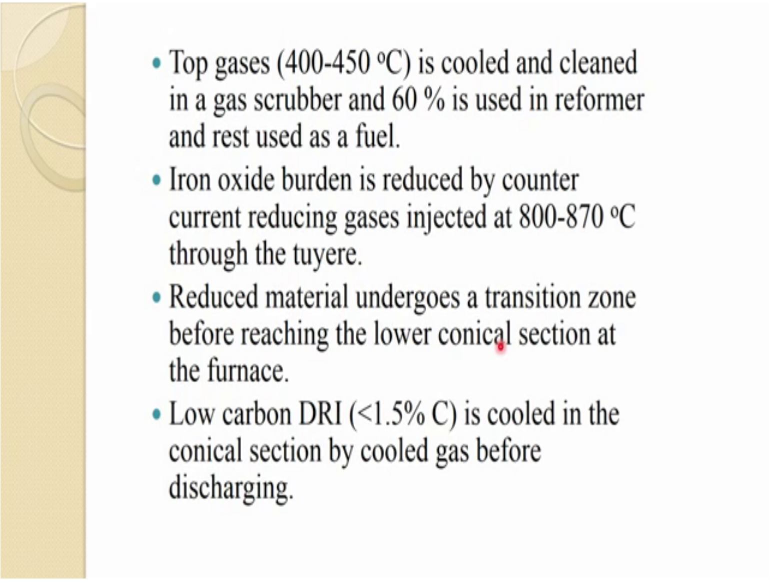

- Top gases (400-450 °C) is cooled and cleaned in a gas scrubber and 60 % is used in reformer and rest used as a fuel.
- Iron oxide burden is reduced by counter current reducing gases injected at 800-870 °C through the tuyere.
- Reduced material undergoes a transition zone before reaching the lower conical section at the furnace.
- Low carbon DRI (<1.5% C) is cooled in the conical section by cooled gas before discharging.

So, top gas temperature is between 400 and 450 degree Celsius this cooled and cleaned in a gas is scrubber and 60 percent is used in reformer and rest is used as fuel as I said some coals are again back with that and some coals as a fuel.

So, iron oxide burden is reduced by counter current reducing gas injected at 800 to 870 degree Celsius through the tuyeres. So, that this is actually tuyeres here and reduced material undergoes a transition zone before reaching the lower conical section at the furnace a where it is cooled down low carbon DRI less than 1.5 percent carbon is cooled in the conical section by cooled gas before discharging.

So, it has a very low carbon. So, melting point in that way is quite high. So, never reaches that high.

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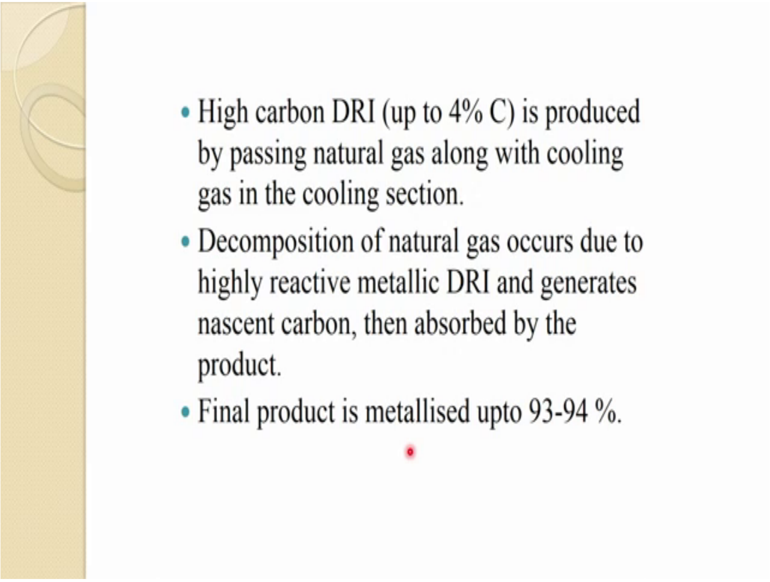

- High carbon DRI (up to 4% C) is produced by passing natural gas along with cooling gas in the cooling section.
- Decomposition of natural gas occurs due to highly reactive metallic DRI and generates nascent carbon, then absorbed by the product.
- Final product is metallised upto 93-94 %.

Melting point high carbon DRI up to four percent is produced by passing natural gas along with cooling is in the cooling gas section. So, you see the here natural gas along with the cooling you can get a high percentage of carbon which it probably the product reaction which we show to carbon deposits in the reaction may occur in and can increase it.

Decomposition of natural gas occurs due to highly reactive metallic DRI and generates nascent carbon then absorbed by the product. So, one this is also another way can increase the percentage of carbon into the DRI. So, final product is metallized up to 93 to 94 percent; so, very high degree of metallization.