Iron Making
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Lecture – 04
Iron Making Lecture 4

Now, we will move on to the raw material up to the day section of the blast furnace and in the raw material we would be dealing with the iron ore, coke, (Refer Time: 00:28). So, mostly about the iron ore and coke.

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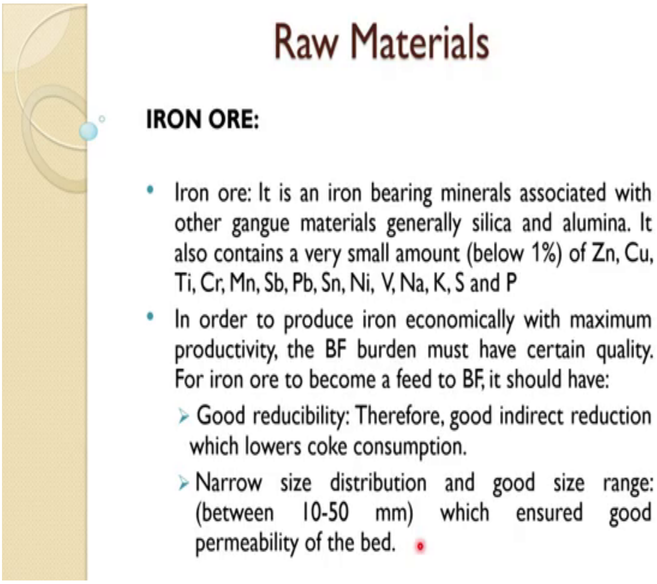

So, iron ore it is an iron bearing mineral associated with other gangue material generally silica and alumina. Some magnesia and others are there, it also contains a very small amount less than 1 percent other element zinc, copper, titanium, chromium, manganese, antimony, lead, tin, nickel, vanadium, sodium, potassium, sulfur and phosphorous. As we discuss this sodium potassium they are quite harmful and mostly the phosphorous course into the metal sulfur also some amount (Refer Time: 01:18).

In order to produce iron economically with maximum productivity the blast furnace burden must have certain quality. So, for iron ore to become a feed to blast furnace it should have following quality, one is the good reducibility which means that should be have a good indirect reduction which lowers the coke consumption. So, this is very important. So, good reducibility should have narrow size distribution and good size range. So, when we say good size range usually are between the 10 to 50 mm and it is preferably it should have a very narrow size range maybe 80 percent of it should be around of 40 mm or so.

So, that ensured the good permeability of the bed. So, both things have very important because that is directly affect a productivity and the efficiency of the blast furnace.

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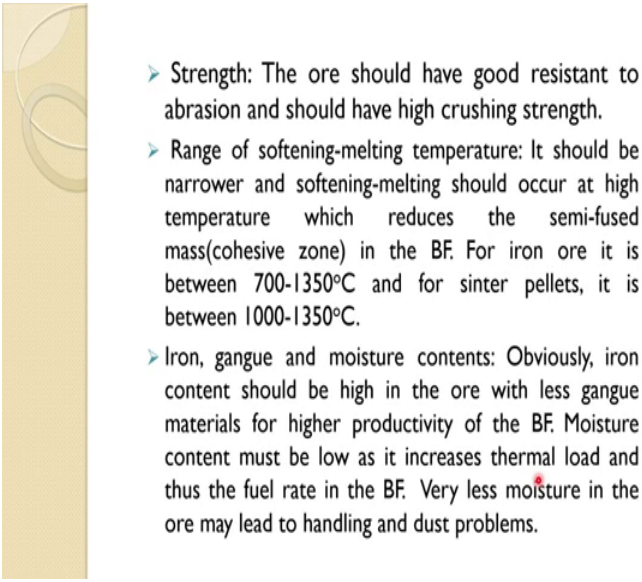

Then, the strength of the ore should have a good resistant to abrasion and should have high crushing strength. So, this two are very important, having a good resistant and good crushing a strength and range of softening melting temperature it should be narrower and softening melting should occur at high temperature which reduces the semi fused mass that is cohesive zone in the blast furnace. So, for iron ore it is between 700 to 150 degree Celsius, and for sinter pellet us it is between 1000 to 1350 degree Celsius. And for sinter pellet it is between 1000 to 1350 degree Celsius. And another one is iron gangue and moisture content; obviously, iron content should be high in the ore with less gangue material for higher productivity of the blast furnace.

Moisture content must be low as it increases thermal load, and thus the fuel rate in blast furnace. Very less moisture in the ore may lead to handling and dust problem. Now when we talk about the all this properties when we said strength good resistant abrasion. Usually the natural ore they are not very good resistance they do not have a very good strength and resistant to abrasion, and that is why nowadays the practices people do not use natural ore that much or in the percentage as a feed to blast furnace.

Similarly as you can see in the second point softening melting point is for the natural ore lamp ore it is between 700 to 1350 degree Celsius and again this is not acceptable in the modern blast furnace because it gives a high resistance to the permeability of the gases and this increases the mass zone very high in the blast furnace, which really decreases the productivity and does not give a smooth operation to the blast furnace.

So, again natural ore are not that much preferred in bulk as a feed in the blast furnace same thing is true about the iron gangue and moisture content if it is a quite a lot gangue material then volume of the slag increases and the coke consumption also increases, should have a less moisture content. But these two points are very critical operating the blast furnace at 100 percent lamp ore.

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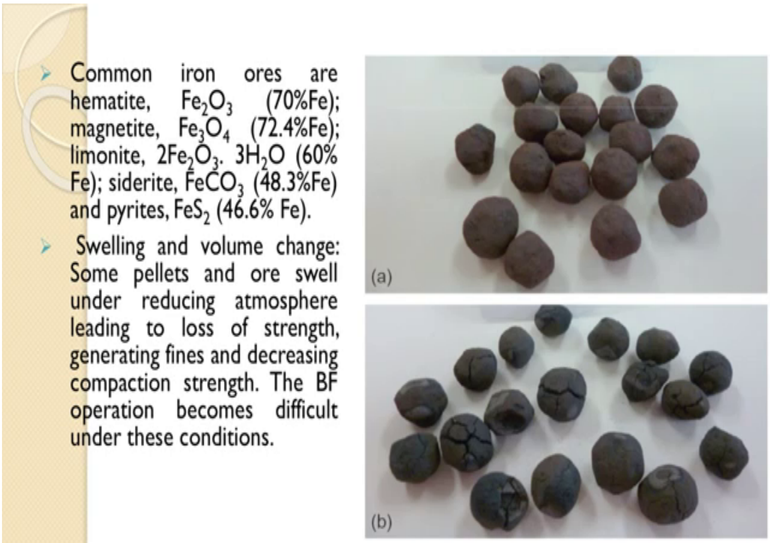

Pellets (a) prior to and (b) after reduction

So, common iron ore are hematite and which has about 70 percent carbon then magnetite, limonite, siderite and pyrites.

So, pyrite the one which has the sulphur associated with it. So, these are the quite common iron ore. And because when you do the mining of this iron ore lots of points are generated. So, usually you make the pellet. So, swelling and volume change. So, some pallet us and ore even the ore swell under reducing atmosphere leading to loss of strength, generating fines and decreasing compaction strength.

So, the blast furnace operation becomes difficult under these conditions, at in this figure you can see these are the green pellet us and these are after the reduction and you can see the cracking and disintegration swelling of the pellet has occurred which is not acceptable as a feed in the blast furnace because that will create permeability and other problem and blast furnace and same thing is true for the lumpy iron ore. So, swelling should be minimal and these are sort of the requirement of the iron ore or sinter or pellet us as a feed material to the blast furnace.

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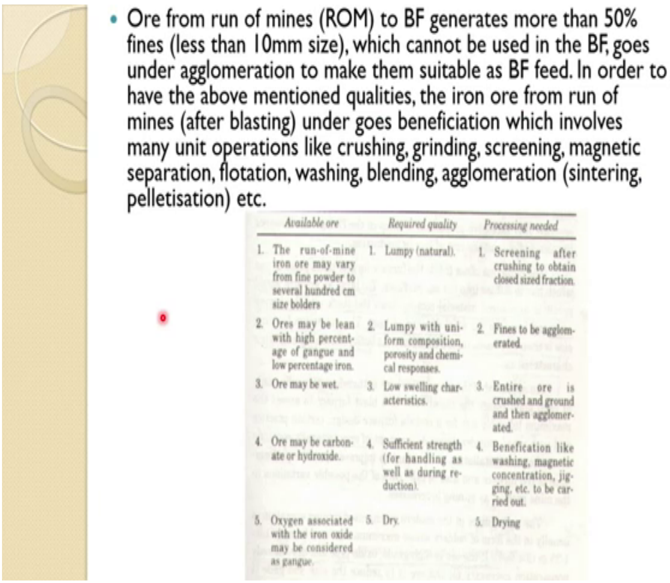

Available ore	Required quality	Processing needed
1. The run-of-mine iron ore may vary from fine powder to several hundred cm size bolders	1. Lumpy (natural).	1. Screening after crushing to obtain closed sized fraction.
2. Ores may be lean with high percentage of gangue and low percentage iron.	2. Lumpy with uniform composition, porosity and chemical responses.	2. Fines to be agglomerated.
3. Ore may be wet.	3. Low swelling characteristics.	3. Entire ore is crushed and ground and then agglomerated.
4. Ore may be carbonate or hydroxide.	4. Sufficient strength (for handling as well as during reduction).	4. Benefication like washing, magnetic concentration, jigging, etc. to be carried out.
5. Oxygen associated with the iron oxide may be considered as gangue.	5. Dry.	5. Drying

In order to now, about this properties many test has been sort of devices and which we will see in the following slides. But before that the run of mines when due to the mining after blasting to blast furnace generates more than 50 percent fines, and which is about less than ten millimeter in size which means this cannot be feed directly to the blast furnace.

So, these fines under goes agglomeration like a pellet making pellet or sinter to make them suitable as blast furnace feed. We would be talking about agglomeration later, how do they make it? So, in order to have the above mentioned qualities the iron ore from run of mines under goes to the beneficiation which involves many unit operation like crushing, grinding, screening, magnetic separation, flotation, washing, blending agglomeration etcetera. So, this I will shows the available ore which is the air and water the required qualities for that and what you have to do to reach that required quality of the ore. So, processing needed.

So, from the run of mines iron ore may vary from fine powder to several 100 centimeter sizes. So, naturally you need a lumpy natural ore. So, what you need? You have to screen it crush it to get the right side or may be lean with high percentage of gangue and low percentage of iron, but what you need a lumpy with uniform composition porosity and chemical responses. So, essentially it goes under agglomeration is the palletization or sintering ore may be wet having a lot moisture.

What you need? Low swelling characteristic for that, so the entire ore is crushed and ground and then agglomerated. If the ore may have a carbonate or hydroxide and what you need a sufficient strength for handling as well as during the reduction. So, beneficiation like washing magnetic concentration jigging etcetera is carried out before this can be used for as a blast furnace feed.

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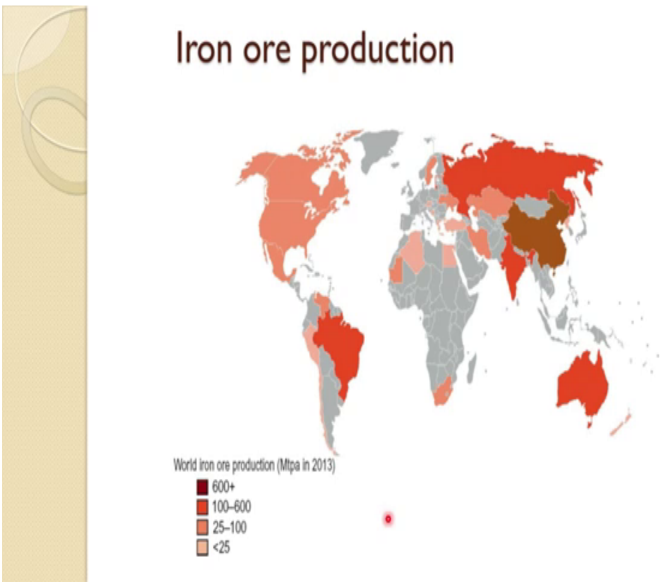

Similarly, about the oxygen associated with iron oxide may be considered as gangue. So, what you need a drying operation to get to dry material this few slide will tell you about these operation the this one tells the iron ore production in the world. So, as you can see most of the production is in China. So, that is more than 600 million ton per annum according to 2013 figure India between 100 to 600 million ton per annum. So, India, then

Russia and Australia they are into or this category Africa not actually the let in American and then other countries which are below that.

So, that shows India is having a very high iron ore production.

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This shows the view of iron ore mines since this is the hematite one and you can see how the iron ore are mine and taken away from there to processing plant.

I think this figure shows magnetic separation of iron ore.

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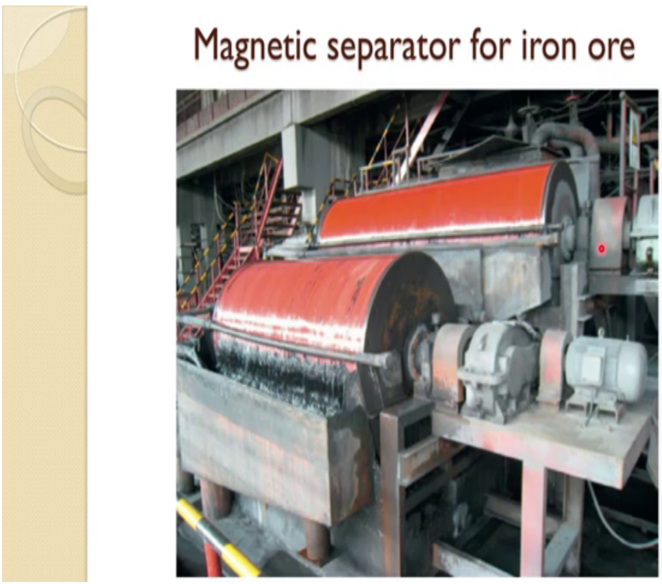

You can see how it is a low intensity magnetic separator.

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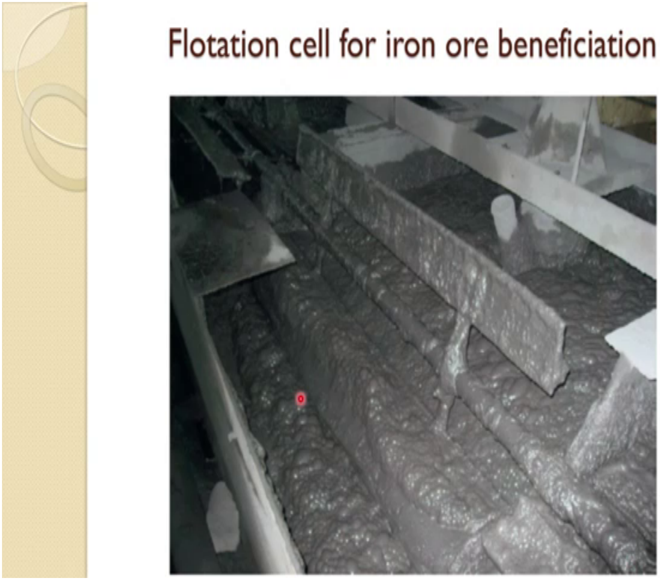

So, or is attest to it and you separate that one and make it concentrate. So, this is magnetic separation. Sometime you also apply the flotation, so this is the flotation cell for which you increase the concentration of the hematite.

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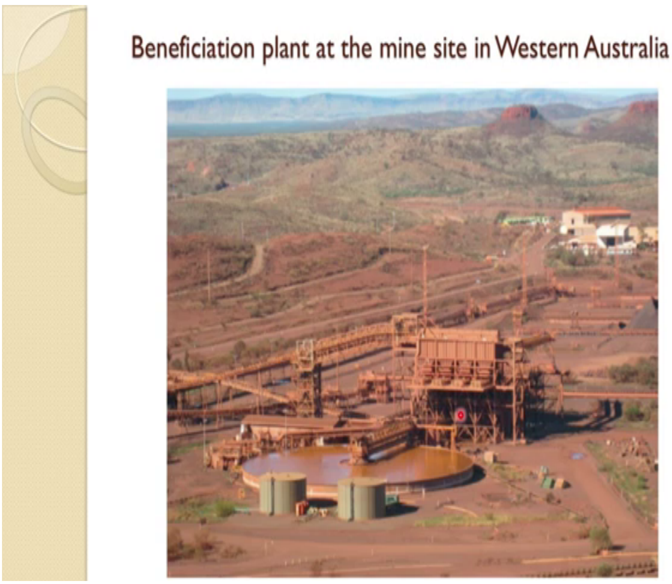

So, or remove other impurities. So, this is floatation cell which is used. And this is a beneficiation plant at the mine site in Western Australia where you can see its getting upgraded the iron ore after mining immediately at the plant site being upgraded.

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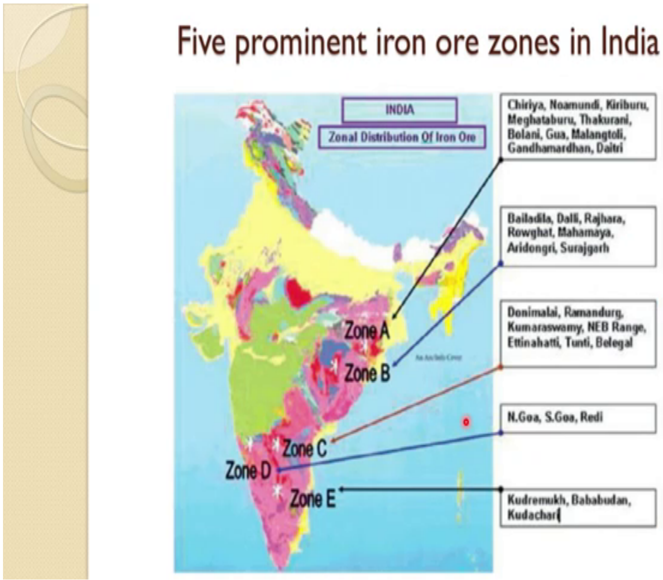

And this tells a little about the availability of iron ore in India. So, mostly it is in the eastern region which he divided in the in 5 zones. So, zone have a as you have Noamundi, Kiriburu Bolani Gua of the iron ore is available and then in the zone we Rowghat Mahamaya. Those are the places then in zone C, zone D you have a been, zone D is little Western Site Goa and then here also its Kumaraswamy and NEB range and then in zone E you have a Kudremukh and other places. So, these are the major places in India where iron ore is mine.

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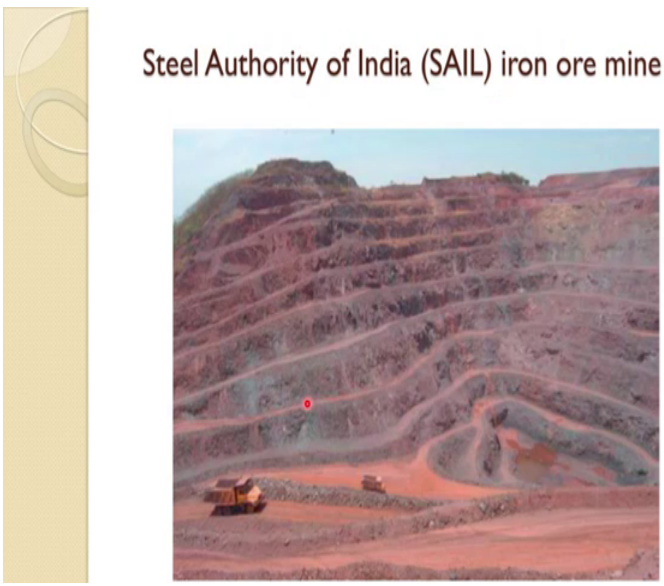

And this is a typical view of the iron ore mines in India which is on why steel authority of India limited, SAIL.

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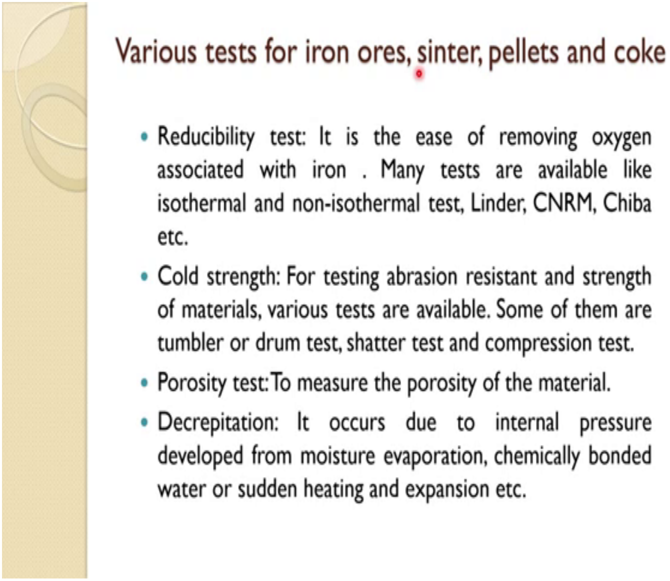

So, when we talked about the quality of iron ore which mean we need many sort of test to make sure you can get the right quality. So, one of the test and this is applicable almost for most of the raw material. Coke has a little different test we will come to that. So, ore, sinter and pellet.

So, reducibility test. So, it is the ease of removing oxygen associated with iron. So, many test are available like isothermal and non isothermal test. So, we are not going much into detail of this. But, these test are mentioned here Linder, CNRM, Chiba. These all are used for reducibility test then about the cold strength which is mostly for resistant to abrasion and strength of the material to test this. So, some of them are like tumbler test drum test or shatter test due to impact and compression test. So, all these test are important to know the strength of the material.

Then the porosity test also come into the pictures how porosity or ore sinter which is necessary and this pore may have a internal pore and outer one. So, all these becomes important in order to understand the permeability of the blast furnace. Decrepitation it occurs due to the internal pressure developed from moisture evaporation chemically bonded water or sudden heating and expansion due to with the pellet even ore they go under decrepitation, which generate dust and fines. So, it is necessary to have the test to make sure it has a very low decrepitation.

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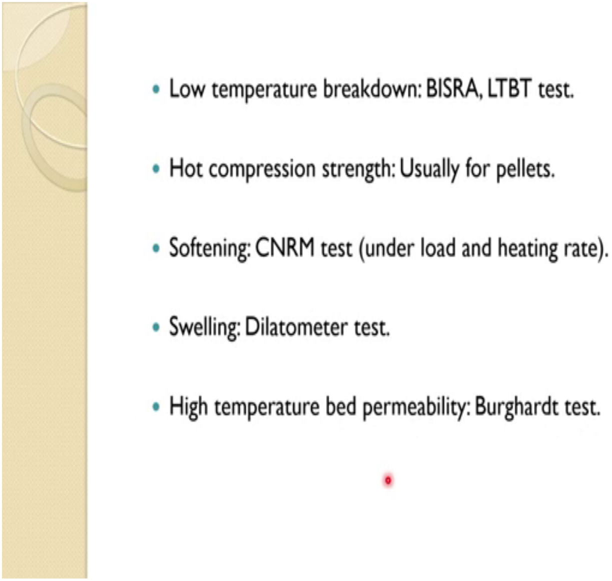

Then you have a low temperature break down. So, for this you have a BISRA or LTBT low temperature test because that make sure pellet ore sinter ore iron ore, it has in break down during reduction at low temperature another by it will create the permeability problem again and dust problem.

Hot compression is strength this is necessary especially for the pellet because when very high blast furnace 30 meter high it is a lots of very high load is there and the pellet should be able to be stand that sort of lot. So, compression strength is tested for the pellet. Softening test is again very important to which usually should be at high temperature. So, for that one is CNRM test is done under loading and different heating rate. Then swelling is another parameter especially pellet us or even iron ore. So, for that one you need a dilatometer test which major, majored about the swelling.

High temperature bed permeability. So, that is about Burghardt test. So, at high temperature when fusion is occurring or semi solid marks is a happening which reduces the permeability. So, it is very necessary at what temperature range this is happening. So, proper gas in the blast furnace can be taken with respect to the gas flow or permeability.

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Burden requirements along with the key phenomena in various zones of BF

Zone	Description	Key reactions/ phenomena	Operational conditions	Quality requirements	Physical/chemical properties
Lumpy zone	From stockline to the surface of the cohesive zone	• Drying and preheating • Indirect reduction of iron ores • Carbon solution reaction	Permeable burden and even gas distribution to favor indirect reduction	• Appropriate size distribution • Resistance to breakdown during charging and due to compression in the furnace • Resistance to decrepitation due to thermal shock • Resistance to disintegration due to low-temperature reduction • High reducibility	• Size distribution and mean particle size • Tumble and abrasion indexes • Decrepitation index • Low-temperature reduction disintegration index • Reducibility index • Cold crushing strength • Swelling index
Cohesive zone (softened mass)	Starts when the ferrous material becomes softened and deformed and finishes when liquid starts dripping	• Indirect and direct reduction of FeO • Carburization of reduced iron by CO • Carbon solution reaction	As narrow as possible, and the root of the cohesive zone needs to be as low as possible	• High softening temperature • Low dripping temperature	• Softening temperature • Dripping temperature • Width of cohesive zone • *S* value
Lower part of blast furnace	Below the cohesive zone, including active zone, raceway as well as stagnant coke zone and hearth	• Coal and coke combustion in raceway • Gas/metal and slag drops and gas/coke reactions in active zone • Molten iron/coke, molten slag/coke, and molten slag/metal reactions in stagnant coke zone and hearth	Good slag chemistry	• Good slag fluidity and low viscosity	• Chemistry of ferrous materials to control impurities such as P, S, Al_2O_3, TiO_2, Zn, Na, and K

So, the burden requirement along with the key phenomena in various zones of blast furnace actually it is a summarized in this table. So, if you look at the and lumpy zone or the upper zone in one way that is a near this throat and stake region what we described in the first lecture.

So, from stockline to the furnace of the cohesive zone. So, main phenomena which are occurring here drying and preheating indirect reduction of iron ore and carbon solution loss, so operational condition permeable burden and even gas distribution to favor indirect reduction. So, quality requirement appropriate size distribution resistant to breakdown during charging and resistance to decrepitation, resistance to disintegration, due to low temperature reduction and high reducibility. So, these ore laws quite a good requirement up to the stake zone.

So, size distribution and mean particle size tumble and abrasion index which is uses for the resistant to breakdown decrepitation index, low temperature reduction, integration index, reducibility, cold crushing strength, swelling index. So, these are the test which we I have already described in the previous slides. So, these are the one which are needed in this zone to make sure these qualities are made up to the stake zone in the cohesive zone. As you know it is start softening and softening of the material in this zone and toward the end of the cohesive zone it is a start melting and dripping.

So, mostly the indirect reduction in some direct reduction takes place in this. So, what you need you need a as narrow as possible this cohesive zone. So, the quality for that high softening temperature, low dripping temperature and these are the test softening temperature dripping temperature width of cohesive zone s value. These are the test which are done for the raw material to make sure it is quite narrow and more high temperature. And the lower part of the blast furnace where everything is in liquid state accept the coke.

So, this is below the cohesive zone where as went your and hearth is there. So, coal and coke combustion in the raceway gas metal and slag drops and gas coke reaction molten iron, coke molten slag coke these reaction occurs in this region. So, what you need a good slag, chemistry, good slag fluidity, low viscosity. So, chemistry of ferrous material is to control the impurities such as phosphorus sulphur alumina titanium oxide even silica also comes here in this. So, these are the major, these are the requirement for the any material or any feed the for the blast furnace should satisfy this one. So, these are the test you do it to make sure it is suitable as a blast furnace feed.

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Typical values of various tests of burden materials

Burden materials	Units	Lump	Pellets	Sinter
TI (tumble index)	% +6.3 mm	>80–85	>90	>65
AI (abrasion index)	% −0.5 mm	<10	<3	<7
CCS (cold crushing strength)	kg	N/A	>250	N/A
DI (decrepitation index)	% +6.3 mm	<15	N/A	N/A
RDI (reduction disintegration index)	% +2.8 mm	<25	N/A	<35
RI (reducibility index)	%	>60	>70	>65
SWI (swelling index)	%	N/A	<20	N/A

So, typical values of the test like when you say the about the tumble index for strength and other for lump ore a natural one. So, in this range for pellet and sinter and different similarly abrasion index, then cold crushing strength, then you have a decrepitation, reduction disintegration, reducibility index and swelling index. These are the typical values which are needed for the blast furnace burden material, and one should make sure up to the test they are falling within this range.

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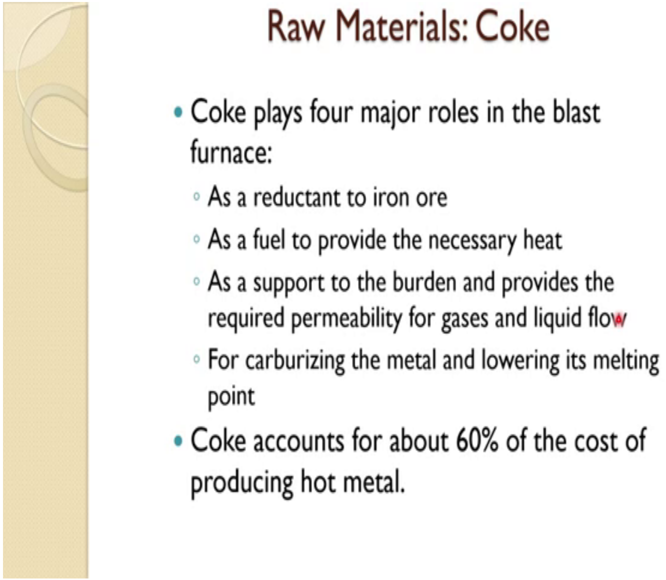

Next we come to the raw materials, coke, another major constituents of the feed material in blast furnace. So, iron ore then the coke. So, coke plays mostly the four part in the blast furnace as a reductant to iron ore, as a fuel to provide the necessary heat, as a support to the burden and provide the required permeability for gases and liquid flow, for carburizing the metal and lowering its melting point. So, remember this is iron has a very high melting point more than 1500 degree Celsius. But due to this carburizing decision of the metal and other impurities it is goes down up to 1200 or so, where it can melt. So, this is very important role this carbon play.

Similarly, because the height of the blast furnaces are increasing you need a very good strength coke and which can provide the permeability does not crush under that high loads. So, it is really provide the support to the burden and of course, its acts as a fuel near the raceway at the tuyere level which is where it wants and it is a reductant.

So, coke accounts for about 60 percent of the total cost of the producing the hot metal. So, you can imagine how much percentage of cost is associated with the coke production and because, so it is very important to have a good quality coke because without that you cannot produce a good quality with iron and high productivity you cannot reach.

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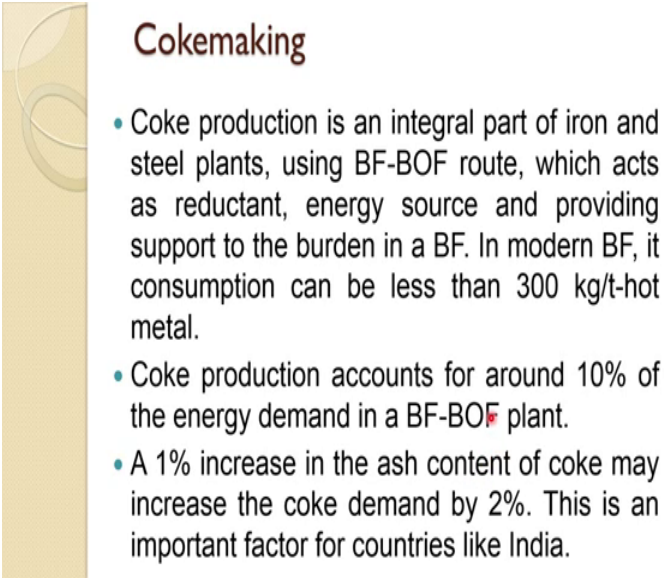

So, we will talk more about little coke making. So, coke production is an integral part of iron and steel plants using blast furnace and basic oxygen furnace route which acts as redundant energy source and providing support to the burden in a blast furnace. In modern blast furnace consumption is around 3000 kg per ton of hot metal is (Refer Time: 25:28) be decade ago almost 900 to 1000 kg per ton of hot metal.

So, one can see how much progress has been made in this area where this has been reduced almost one-third or less than that the consumption or coke. So, coke production accounts for around 10 percent of the energy demand in a blast furnace or and BOF plant. 1 percent increase in the ash content of coke may increase the coke demand like 2 percent.

So, this is an important factor for countries like India. So, India has a very high ash content in the in the coal and that coal cannot be used directly to make the coke. So, usually you do the beneficiation of the coal. So, most of the coal mines in India are associated with the washing system washery, where they try to reduce the ash content as much as possible. So, Indian coke goes up to 25-28 percent ash, while in the blast furnace it is required 10 percent or so.

So quite a lot of one ash to remove an as you can see 1 percent increment in ash coke demand increases by 2 percent. So, that is why in India most of the coke we also import from other countries.

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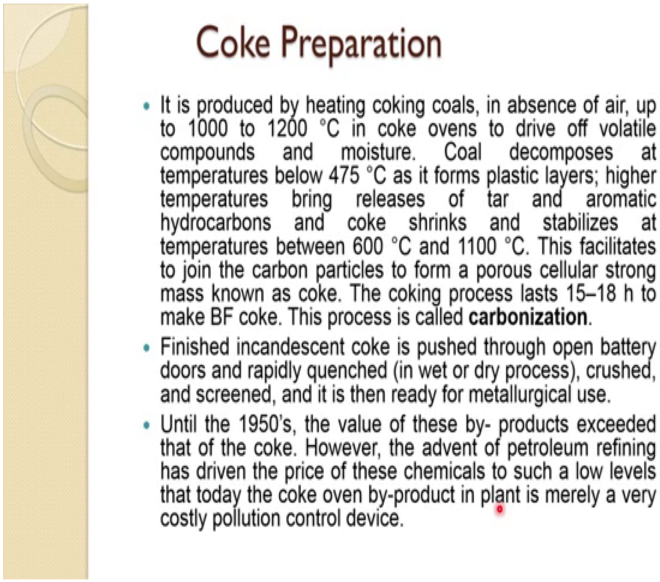

Coke preparation, so it the coke is produced by heating coking coal. So, naturally when we said about the as percent and other thing which means all the coal are not suitable for the for making coke. So, the coal which are suitable to make the coke are known as coking coal. So, this is this by coke is produced by heating the coking coal in absence of air between 1000 and 1200 degree Celsius in coke oven, where it drives off the volatile compound and moisture.

Coal decomposes around 475 degree Celsius and it forms plastic layer. It becomes also a bit (Refer Time: 28:14) sort of thing. So, it found plastic layer higher temperature bring release of tar and aromatic hydrocarbons, and coke shrinks and stabilizes at temperatures between 600 and 1100 degree Celsius. So, this facilitate to join the carbon particles to form a porous cellular strong mass known as coke. This is very important, so cellular strong porous mass is formed. The coking process lasts 15 to 18 hours to make the blast furnace coke and this process is called carbonization the overall.

This finished incandescent coke is pushed through the open battery door and rapidly quenched in wet or dry process crushed and screened and it is then send to the of course, blast furnace as a feed.

So, until 1850 the value of these by product which you are getting tar aromatic hydrocarbons all these things exceeded that of the coke. So, coke you know there was really making quite a lot money by from this by product. However, the advent of petroleum refining has driven the prices of these chemical to such a low level that today the coke oven by product in plant is merely a very costly pollution control device.

In fact, due to this the problem is arising nowadays how to control the pollution and coke making a the man written in the whole integrated plant towards the pollution. And that is why more and more pressure the integrated plant to reduce the consumption of coke and that is how due to that pressure this consumption of coke has come down up to 3000 or 300 kg per ton of hot metal when it used be around 900 or 1000. One of course, this factor and that is also becoming quite expensive affair to produce the coke in this way.

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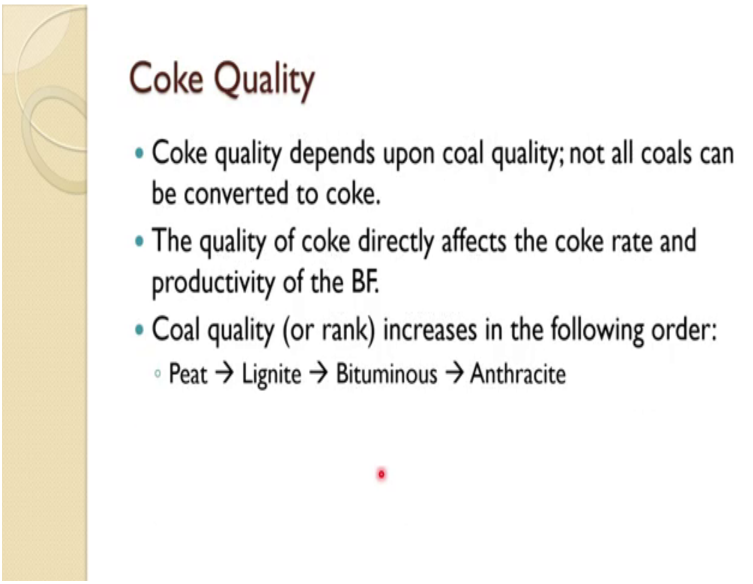

So, coke quality, so coke quality depends upon coal quality as we discussed before not all coals can be converted to coke the quality of coke directly affect the coke rate and the productivity of the blast furnace. Because this is the one which is giving the permeability to the material in the blast furnace through which gases can escape and heat and mass transfer can occur. If we do not have a good quality coke is very difficult to produce the good quality began and with the high productivity.

So, coal quality or the rank increases in the following order peat lignite bituminous anthracite anthraces the highest one which has the high rank and very high fixed carbon peat and lignite material in this one.

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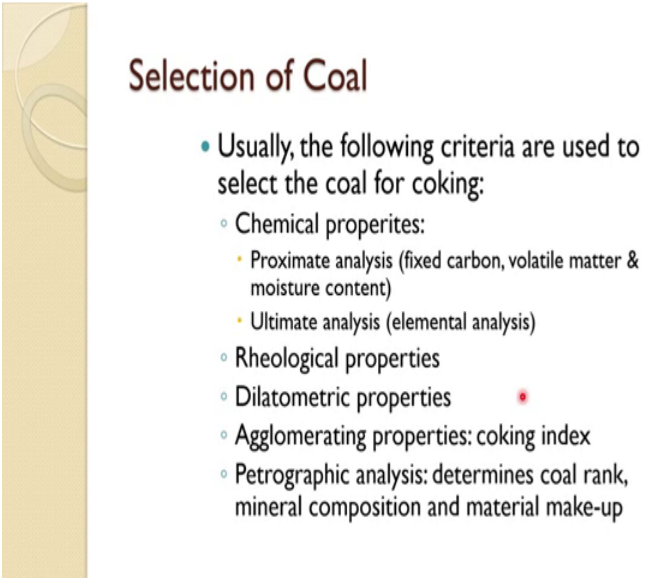

So, when you are selecting the coal usually they are some criteria to select that or you perform some test. So, one is about the chemical property. So, you do proximate analysis. So, mostly in this one you determine the fixed carbon volatile metal matter and moisture content then another is a ultimate analysis and where you do the determination of the elements which are present in the coal, like sulphur, phosphorus and so on.

Rheological property, this is a this mention during the making during the carbonization process that is coal under goes with various form and one it becomes also fluid or plastic. So, those properties are also very important to know for the coking process because that will affect the coking process, and that will directly affect the quality of the coke. Dilatometric properties again when the coke is start getting fusion and gaseous product is start coming up, so its swells and then it exert the pressure. So, this properties are very important to know how the coal is going to where during coking in order to take care above the coke oven design and other thing.

Similarly, the agglomeration properties which is using by coking index one is that after finishing all this evaporation and other tar and other material how it is agglomerate. And of course, the petrographic analysis with determines the coal rank mineral composition and material make up because based on that you select the coal which could be suitable for the coking purpose. So, these are the few test which one has to look at it before selecting the coke proper coal for the coking purpose.