Introduction to Ancient Indian Technology.
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Lecture-36.

We can start this lecture with a thought process. `Power doesn't corrupt a person it reveals the corrupted mind of a person'. In the last lecture we discussed about how the iron was being used in ancient India and we had taken several examples and also evidences for that. And today we will be discussing about Iron Smelting Process that was used in Ancient India. The traditional Iron Smelting Process contains six steps.

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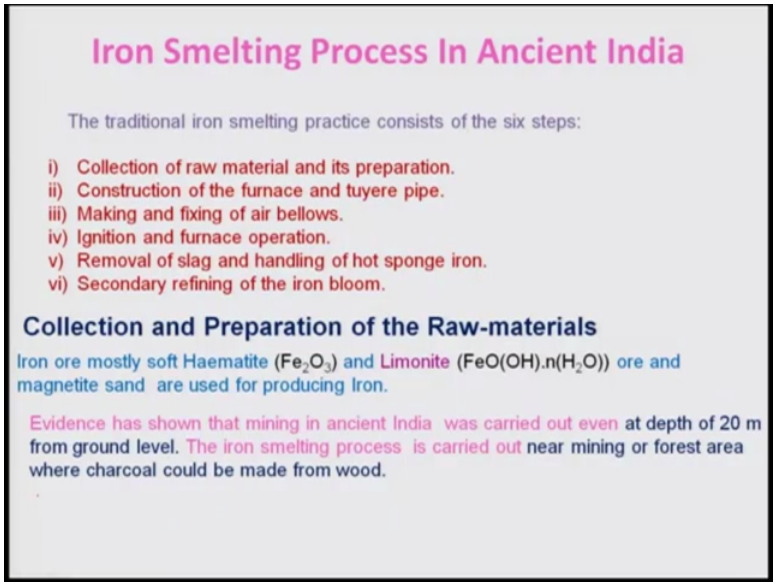

First is of course one has to collect the raw material and one has to prepare it properly. Construction of furnace and tuyere pipe is also very important. And one has to make and fix air bellows properly. and ignition and furnace operation, removal of slag and handling of hot sponge iron. 2nd is refining of iron bloom is also another way you know process one has to use it.

And collection and preparation of raw materials is very important and let us see how ancient people were doing it. And we know that there is a several ores like Haematites and Limonites ores were being used and also some of the Magnetites sand were used for the production of the iron. And evidence is there that mining in ancient India was carried out even at the depth of 20 metres from the ground level. And generally the people wherever they will get iron ore, they will try to smelt it there itself and or they can choose another place particularly forest

area where the wood charcoal you know will be available or they can make the charcoal from the dry wood in the forest.

And it is not only the man who will be you know involved in the smelting process, women also were involved earlier time during the smelting process. And particularly for transporting the ore and dig it out after performing puja. Puja or the worship was very important and generally, it has been carried out by women for the successful smelting of iron.

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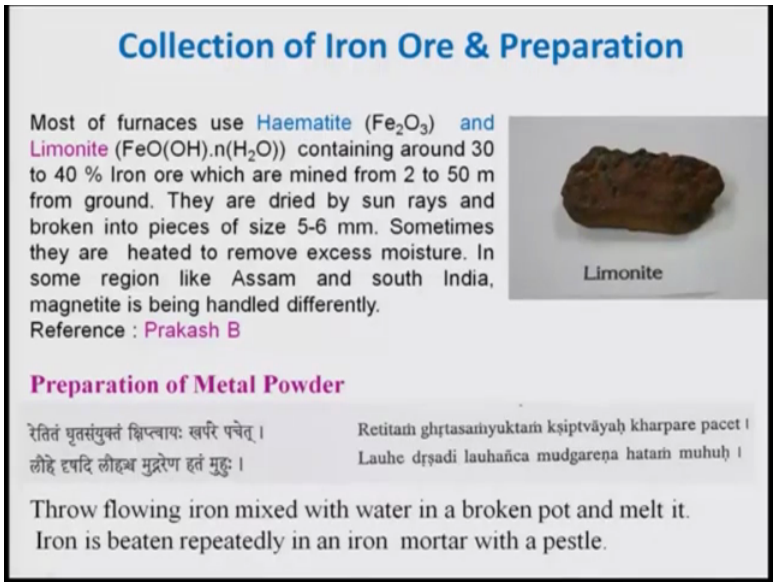

So, if you look at the iron ore and has to be collected and one has to identify that and most of the furnaces use Haematites and Limonite containing around 30 to 40% ore, iron ore which are mined around from 2 to 50 metres from the ground level. And once they get this iron ores from the mines, they will be trying to dry it using the sun rays and also they were breaking into the pieces of size something 5 to 6 mm.

Sometimes if moisture is more in the iron ores what they will be they will be heating it at a low temperature so that excess moisture will be removed and in some regions like Assam or South India Magnetite is being handled differently. Because Magnetite is a different kind of ore, iron ore has to be handle, beside this you know they were also producing metal powders. There is a shloka which the meaning is that, throw the flowing iron mixed in water in a broken pot and melt it and then after washing the iron ore they will put into the iron mortar and also pound it with the pestle, so that there will be powder.

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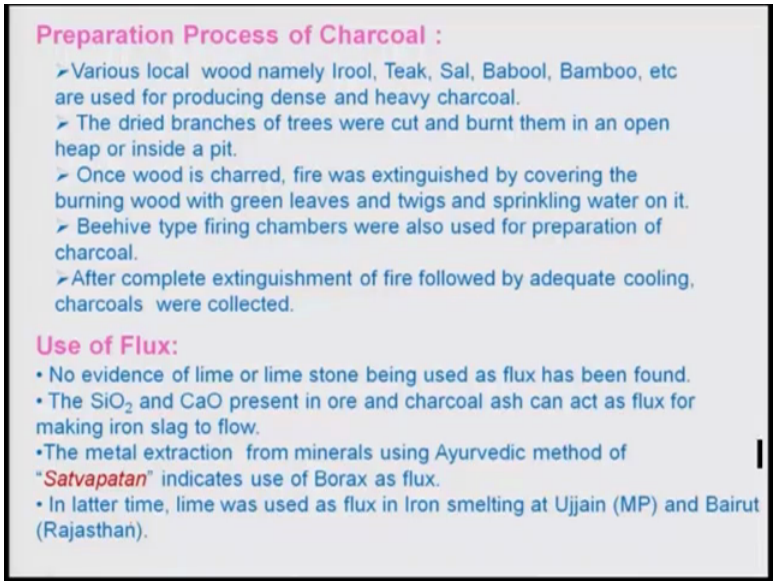

The preparation process of Charcoal and what evidence suggests that various local woods namely Irool, Teak, Sal, Babool or Bamboo etc., are used for producing dense and heavy charcoal. Because you need to have the charcoal which will be dense and heavy for this kind of work and they were aware that which wood will be giving and they were always relying on the local material instead of getting from outside in the way do in the present time.

The dried branches of trees were cut and burnt them in an open heap or inside a pit so that you know pyrolysis will be occurring and the gases will go out and the carbon will be remaining. And once the wood is charred, fire was extinguished by covering the burning wood with green leaves and twigs and sprinkling water on it. And beehive type firing chambers were also used for preparation of charcoal. This is a very good design if you look at this is being a you know mimic from the nature like if you look at the honey bee they are having beehive kind of things. After complete extinguishment of fire followed by adequate cooling, charcoals were collected and also the proper size of the charcoal is to be collected.

And they used also and there is no evidence of lime or lime stone being used as flux but however the Silica SiO2 and CaO present in the ore and charcoal ash can act as a flux for making iron slag to flow. The extraction from material used by the Ayurvedic method that is `Satvapatan' indicates use of Borax as a flux. We will be discussing about that how they were using you know the Borax and in the particularly Ayurvedic method of making iron. In latter time, lime was used as a flux in iron smelting in Ujjain, M.P. and Bairut, in Rajasthan, right. So, these are the kinds of fluxes, flux material what they were using to remove the slag during the smelting process.

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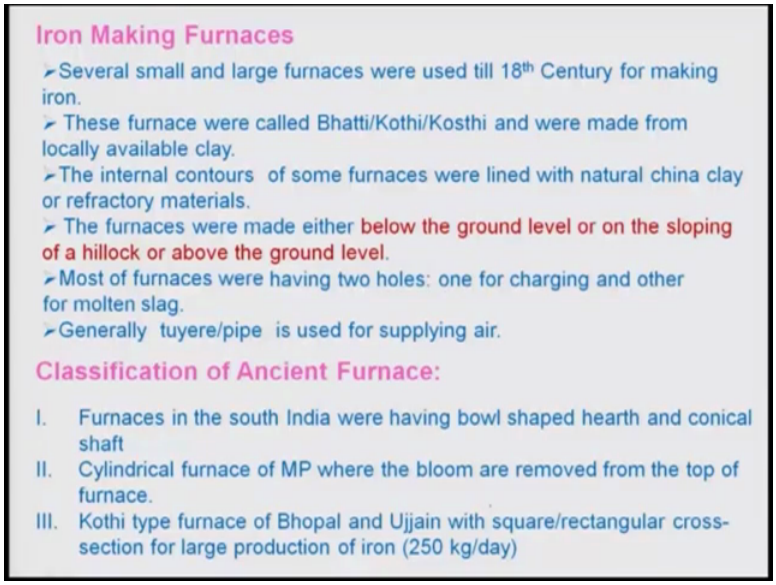

And there are various kinds of furnaces are being used in ancient time and these furnace types will be varying from region to region. However I will be discussing few of them because of paucity of time. And so, several small and large furnaces used till 18th century for making iron. Of course after that Britishers having their own factory in other places and they discouraged the people to have local irons, that is why those you know methodology were lost and of course in modern India we are not bothered about the indigenous manufacturing of the iron by the local people.

And these furnace were called Bhatti, in some places Kothi, Kosthi were made from locally available clay. The if you look at these are very simple and lot of innovations you know being used by the various people to make them different and also to use the local material. The internal contours of some furnaces were lined with natural china clay or refractory material. The like what is even in today in blast furnaces that you know the furnace lining are being used you know particular refractory materials are being used as furnace liners. The furnace were made of either below the ground level or on the sloping of a hillock or above the ground level, there are various kinds you one can see.

And most of furnaces were having two holes one for charging and other for the passage of molten slag. And generally tuyere and the pipe, pipes were used for supplying air. And Classification of Ancient Indian Furnace if you look at furnace in South India were having bowl shaped hearth and conical shaft, cylindrical furnace of Madhya Pradesh where bloom were removed from the top of the furnace. Kothi type furnace of Bhopal or Ujjain with a

square or rectangular cross section for a large production that means getting something 250 kg per day which is a quite a huge amount if you compare to other furnaces at that time.

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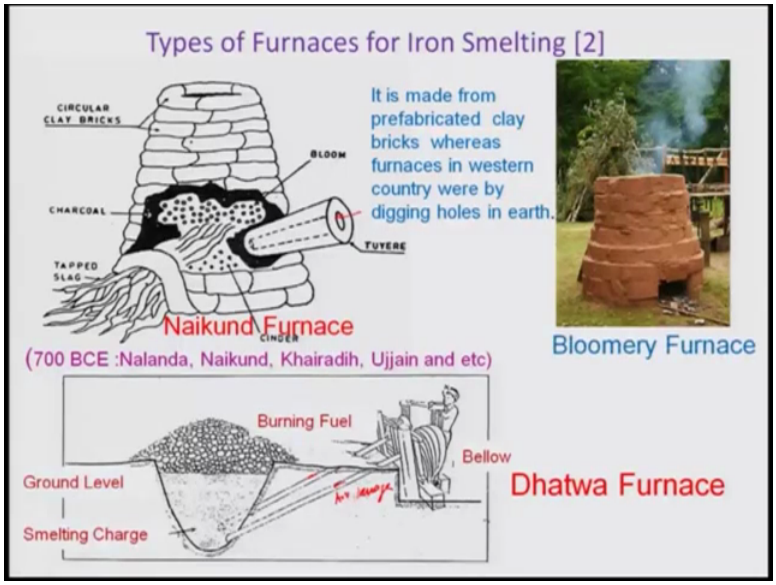

And let us look at furnace which is known as Naikund Furnace and which is quite old it goes back to 700 BC in Nalanda this Naikund and even Khairadih and Ujjain and other places you can find. And this is a very simple furnace which is being used like they use the clay bricks and there is a tuyere what is basically supplying the air to be sucked in and then this charcoals which are there so also iron and the blooms these are the iron blooms and the slag at the will be moving out of this in this passage. And a typical one which will you might have seen in somewhere even poor people use it now-a-days, but of course it is not been practiced very much. And it is made from prefabricated clay bricks whereas the furnace in western country were made by digging holes in the earth right, in ancient time.

So, there is another Dhatwa Furnace, if you look at here the smelting charges are there again in the ground also it has been made. And these are the burning coals and you are having a bellows here that will be giving the air will be coming through that, and the you know bellows one can press it that air will be sucking in and going, these are air passages. This is another kind of furnace which was there in ancient India.

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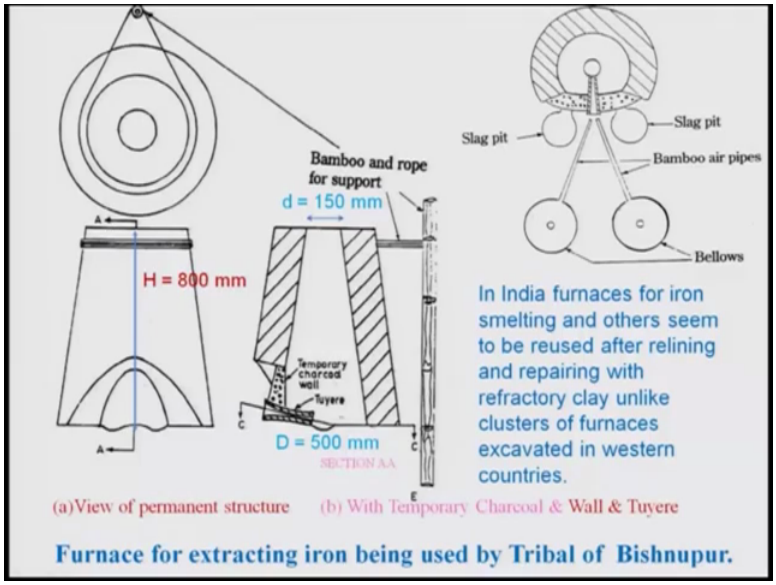

And let us look at a furnace which was used earlier days by Tribal of Bishnupur. And this is the cross section, if look at this is having a conical shape and this is the tuyere and the diameter here is around 500 mm and on the top it is 150 mm diameter. And it is having what you call support for with the help of a bamboo and rope will be there. And if you take a of course you know this height is 800 mm if you take this cross section you will get this one that is the shape.

In India furnaces in iron melting and others seem to be reused after refining relining it and repairing with refractory clay unlike the cluster of furnace excavated in western countries which were not having liners and they were using once and then after that they will not use it. That is the difference between the technology in ancient India what were it was there.

Let us look at how you know they were doing this kind of a putting this air, there is a as I told there is a bamboo will be there and then if I take this cross section here, you know this is the slag pits which is being not shown in this figure. And these are of course the blooms, iron blooms, this is the tuyere pipe which will be connected to the bamboo air pipes and these are bellows. Bellows will be made of something hide or else what you call skin and on which top of which you know people will be jumping on it so that it will take air and this is the diaphragm will be moving up and down and then sucking air then going out. I will be showing a figure about that.

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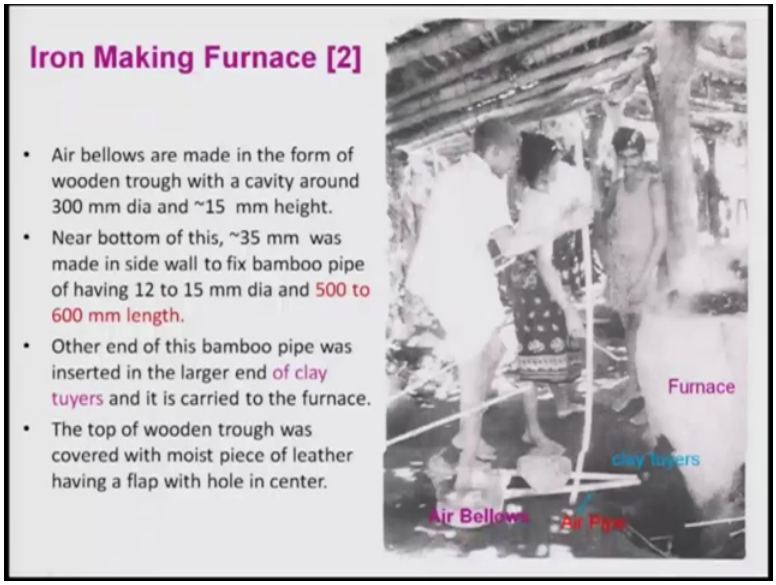

So, if you look at what I was telling, this is one and with the help of a stick you know, he will be balance and you need to have balance that. This is the bellows right, on which will be like you know jumping on it rhythmically right, and this is the tuyere, they use this, this as look at clay tuyere which are being used, they are pipes through which air will be passing through it, this is for air pipes right. And Air bellows are made in the form of wooden trough with a cavity around 300 mm dia and 15 mm height. And near bottom of this 35 mm was made in the side wall to fix bamboo pipes are having 12-15 mm diameter and 500-600 mm length.

Other end of this bamboo pipe was inserted in the large end of the clay tuyeres like from here they will be things and it is carried to the furnace because the bamboo will get burnt you know therefore you will have to use a clay pipe. That means they are using combination of the bamboo and the pipe. The top of the wood trough was covered with moist piece of leather and here the leather will be there, this is the place and leather having a flap with a hole in the center. It will be moving up and down so that through which air will be coming, going in and then passing through that.

And there will be also what you call a valve which will be closing it you know so that air will get into this leather and then after that it will be go up and then this air will be when you push it air will be getting into this pipe. This is a indigenous pump you know pump system and which were operated by the what you call muscle power. And one has to do with rhythmically that means if you do this thing you will have to also develop your mind not only physical labour is required also the mind coordination is important for operating this kind of bellows.

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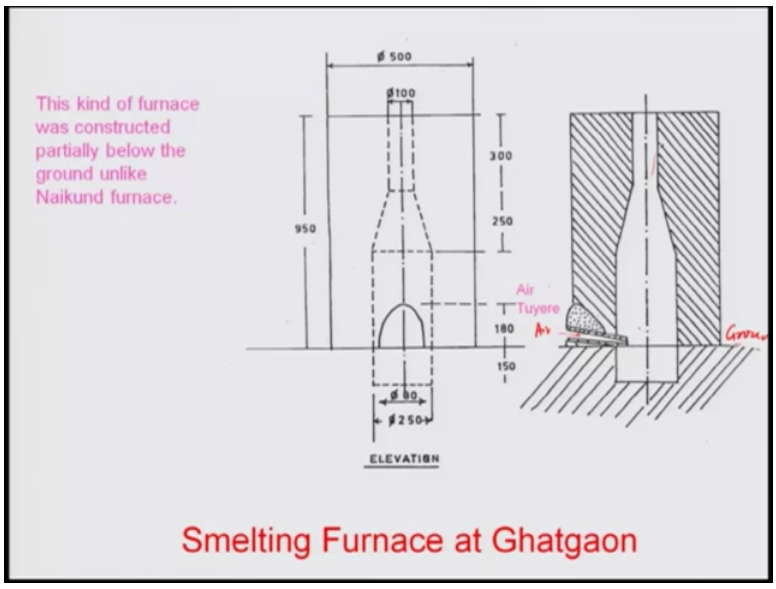

So, let us look at another smelting furnace at Ghatgaon and which is shown, this is like acting like a what you call natural draft, this is the tuyere through which air is passing through it of course all the dimensions are given here if you take a drawing of this. This kind of furnace was constructed partially below the ground because this portion is a ground level right, unlike the Naikund furnace which is which is on the on the top right above the ground. So, as I told this is the air tuyere or the air pipe you can say through which air will be passing, getting into this furnace for the combustion to occur and then so that reduction of the iron will be taking place.

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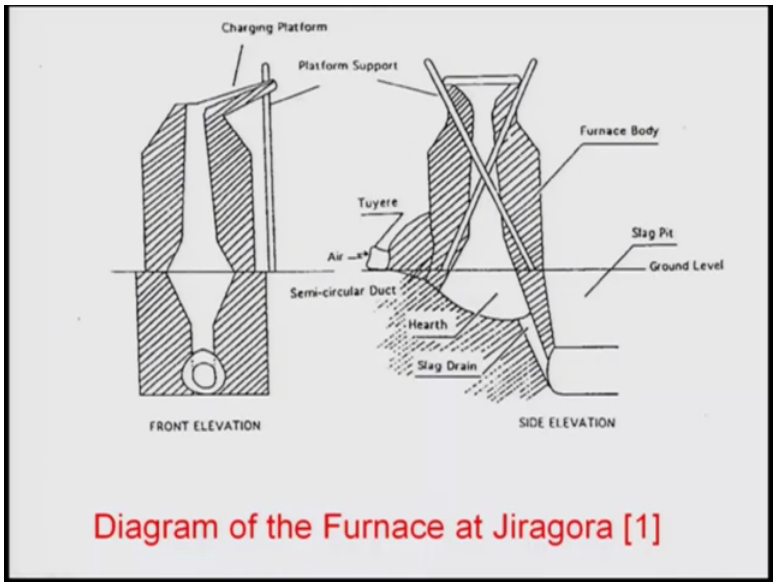

There is a another furnace which is at Jiragora and which is having of course a similar support but here having what you call slag drains and this is your hearth which is below the ground level and this is a slag pit if you look at the this will be a slag pit kind of thing where slag will come and then you know be deposited there and you can remove. And this is your air passage tuyere which will be having. So, if you look at there are several designs one can see across the various parts of the country. And they were using their creative power to develop themselves and of course these are the support platform for this structure to remain.

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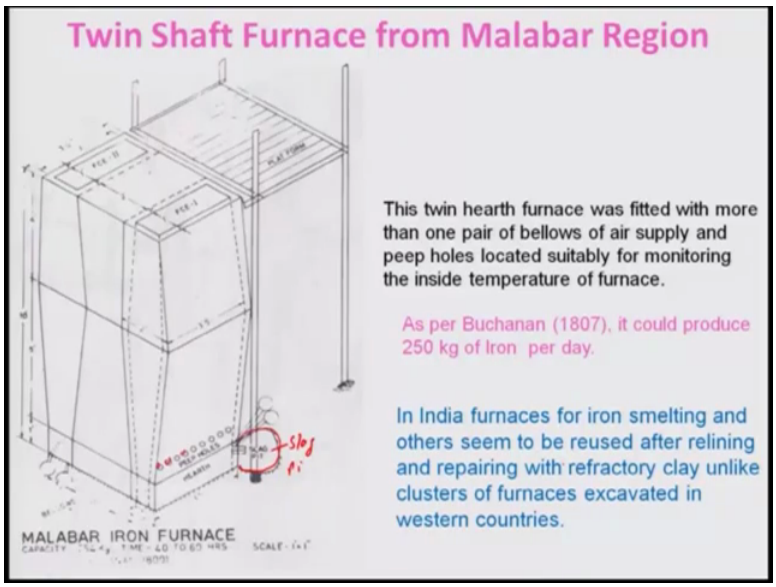

And there is another Twin Shaft Furnace from Malabar region and this I have shown here. This is the phase one and this is the phase two kind of things, these are the pipe holes, right, through which this is the slag pit right and this is the hearth. And if look at this is there is a platform where you can take this out and I think this this twin hearth furnace was fitted with more than one pair of bellows for supply of air and peep holes were located suitably for monitoring the inside temperature of furnace. That is very interesting that means you know, you can remove these holes and then see whether doing well or not accordingly you will have to you know supply the more amount of air or reduce it.

As per the Buchanan, it could produce 250 kg of iron per day. It was in 1807 if look at something around 110 years back we were having this technology, unfortunately today it is not there. In India furnaces for iron smelting others seems to be reused after lining and repairing with the refractory clay unlike clusters of furnaces excavated in western countries. This is the thing which I had repeated, which I had told earlier and now being repeated. So, that is the you know beauty of the ancient Indian furnaces which were used for making iron.

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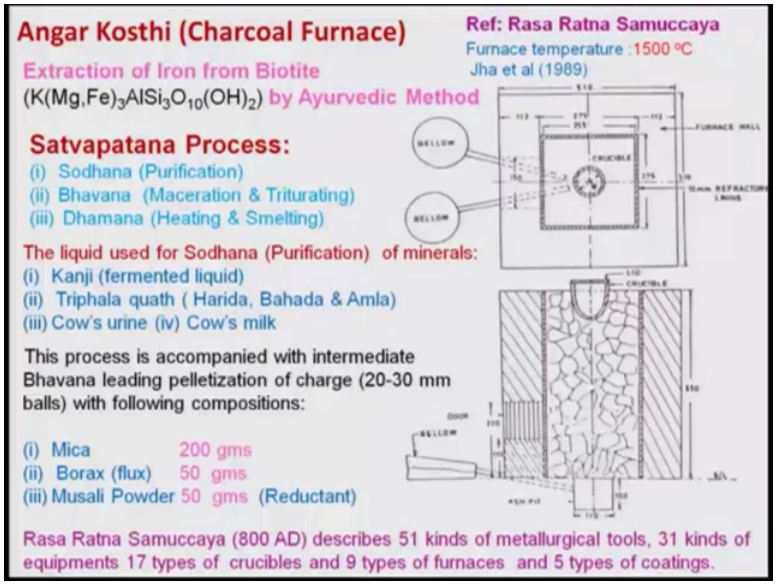

Let me talk about another type of furnace which was being mentioned, which is being mentioned in Rasa Ratna Samuccaya and in this furnace one can get around 1500 degree Celsius. But other furnaces people are claiming you cannot go beyond 1200 degree Celsius right. In this case this is the figure which is shown here it is similar to that earlier that means bellows will be there, with a tuyere and these are the what you call the charge, charge means having you know coal and other things will be there and here they will be using a crucibles right and this will be charcoal and through which air will be coming over here right, and they burnt out and then they it will burn here and then this thing.

And then generally this is being used for extraction iron from Biotite, Biotite formula is given and this is being used for basically for Ayurvedic medicines. Satvapatana Process that is the shodhana purifications Bhavana, the Maceration and Triturating and Dhamana - is heating and smelting. And the liquid used for Shodhana of minerals like Kanji, fermented liquid, basically if you look at it is a very sour butter milk you can think of. And Triphala quath Harida, Bahada and Amla right is a Ayurvedic materials and Cow's urine and Cow's milk. So, these are the ways by which they will be purifying the minerals.

And this process is accompanied with intermediate Bhavana leading to palletization of charge like 20-30 mm balls they will be making which is made of Mica around 200 gms, Borax 50 gms, Musali powder 50 gms. Of course this will be acting as a reductant and this will be mix with this iron powders and then will be kept in this crucible and then you will heat it with the help of bellows and then which can go to the very high temperature 1500 degree Celsius the material. And the problem with this kind of method is that you will get you will be getting

iron in a small quantity, not in a 250 kg per day. And Rasa Ratna Samuccaya, describes 51 kinds of metallurgical tools and 31 kinds of equipments, 17 types of crucibles and 9 types of furnaces and 5 types of coatings.

That means if you look at there is a plethora of knowledge about the smelting process and the tools which are being mentioned about in this text. But now one has to look at it carefully and also look at what can be used today and how this knowledge can be transferred to the people particularly not about textual knowledge rather practical knowledge. That has not been done and unfortunately I wish that some of you should take it up, not that you will depend on the government to do that rather individual has to do it.

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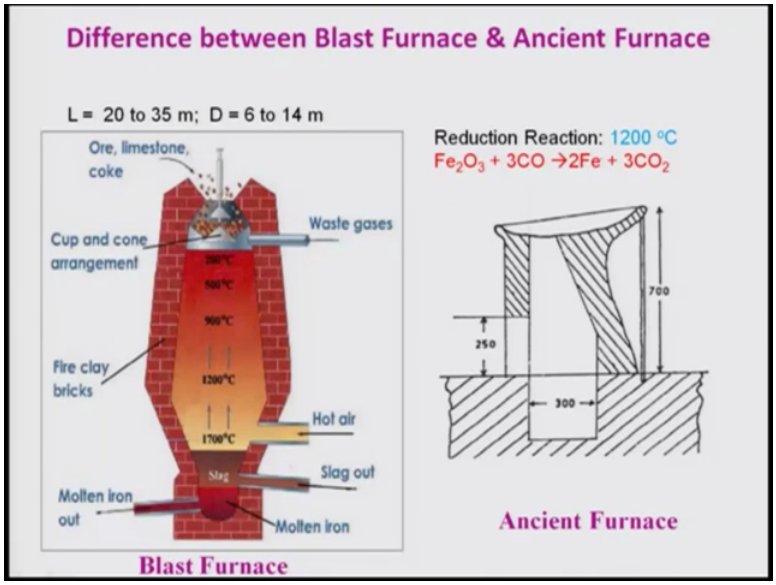

Now, we will be discussing about the difference between the blast furnace which is being used for iron in modern time this is the one of the workhorse for producing producing the iron from the iron ore and this is quite huge. If look at this is the furnace which is coming containing the iron ore and lime stone and coke they will be putting it here and there is a also the temperature is being maintained, these are the fire clay and bricks of course lining will be there. And this is the cup and cone for arrangements so that it will be flow very nicely and the temperature is being maintained properly that is very important and 1700 maximum temperature it can go up to.

And you will be using hot air it is you know is very important where as in our traditional, we used to the cool air I mean normal or ambient air. And the slag which will be coming out slag out of course you will get the molten iron out kind of things. But the length if you look at it is

20 to 35 metres it is quite huge. Of course the diameter is 6 to 14 metres and it can produce something 100 you know tons to may be 1000 of tons of iron, this is very huge.

Now, you want to you know compare with our earlier one with the blast furnace, this is very small, something height will be 700 mm like this is in meter you know, and this will be diameter will be 300 or may be 400 mm outer diameter. But this technique of blast furnace is quite you know involved and complex in nature the chemistry. But here and this even one has to go for 1700 degree Celsius where as the ancient process is the direct reduction reaction occurring at 1200 degree Celsius.

Fe2O3 will be reacting with Carbon monoxide will be getting into iron and carbon dioxide. And if you compare both the thing this one ancient furnace and blast furnace, blast furnace is quite complex and nobody can really change it you know that quickly you know because it is so huge. Whereas anybody can change this small furnace and you can innovate a lot of things and do that. And this is a lower temperature therefore being used as a result the you wi as a result you will can also you no, cost will be very lower. But the quality of the iron one has to also look at it.

But what people found that this quality is comparable with the blast furnace, and but the quantity here it will be very less as compared to the blast furnace where the quantity will be high because it is very huge. And so, therefore we need to I mean at least go back to this process this ancient furnace which will be with the people but now the blast furnace is with the company,, right there is a difference. And the knowledge if you will go for ancient furnace the knowledge will be with the common people who will be using it.

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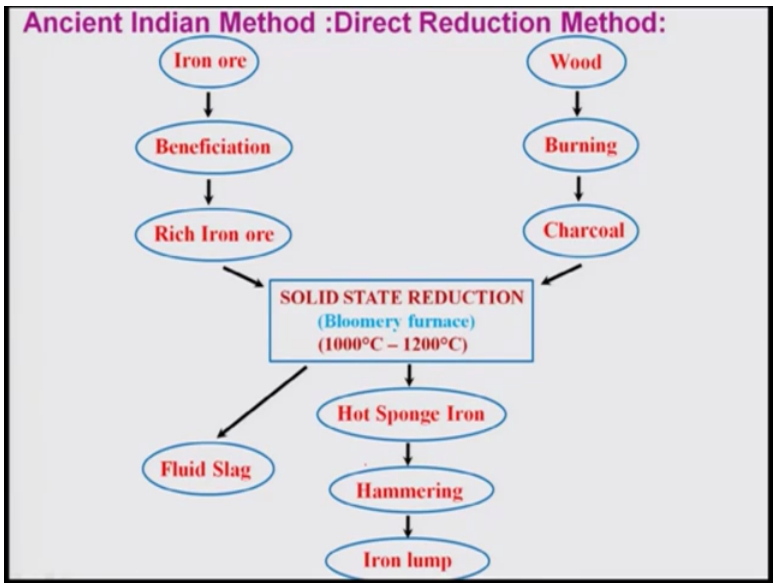

And if you look at there is a direct reduction method which is being used in ancient Indian furnace, that is iron ore you will have to do this beneficiation and then rich iron ore you will get that is two and then wood burning you will get the charcoal. And this solid state reduction which is a known as also the Bloomery furnace that is being used in ancient India which will be operated around 1000 degree Celsius to 1200 degree Celsius unlike in blast furnace 1700 degree Celsius you need to maintain. For that you will have to use lot of energy for that and also the extra of course you will get a fluid slag fluid slag which is very easy to remove it.

And you will land in getting hot sponge iron and now this of course people have you know talking about sponge iron which is cheaper than the iron being made in the blast furnace. And you just hammer it and then you will get the iron lump which is very easier process of getting iron in the ancient method which is best on the direct reduction of the iron ore.

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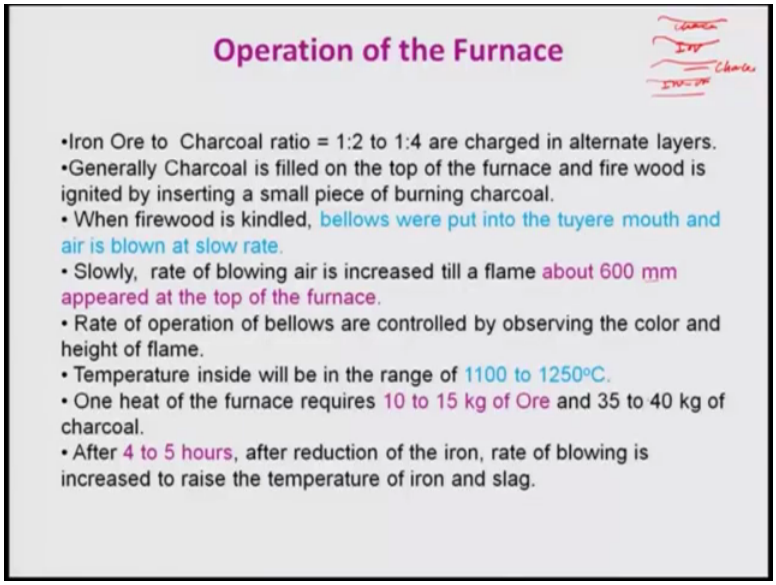

So, Operation of the Furnace if you look at Iron ore to charcoal ratio people had used something 1 is to 2 to 1 is to 4 and this is to be charged in alternative layers. That means you know if there is a iron here, iron ore and there will be also the charcoal right, layer by layer, there will be iron here and there will be charcoal, it has to be placed, generally charcoal is filled on the top of the furnace and fire wood is ignited by inserting a small piece of burning charcoal right. And when fire wood is kindled, bellows are put into the tuyere mouth and air is blown at a slower rate. The rate of you know air entering into the furnace will be small.

And slowly rate of blowing air is to be increased till the flame about 600 mm appeared at the top of the furnace. That means when you are igniting the because you are igniting from the top, so, therefore once this flame increases you know then after that like rate of operation of bellows are controlled by observing the colour and height of the flame. And temperature inside will be ranging something 1100 to 1250 degree Celsius. And one can also the you know change this air flow rates depending on what temperature you want. And one heat of furnace requires around 10 to 15 kg of ore and 35 to 40 kg of charcoal.

And if you look at today, we are using the coal and which is not sustainable, but whereas charcoal is sustainable. That is also another important point one should keep in mind. Because if you grow the trees and then use it properly then we can make it sustainable. After 4-5 hours, you know reduction of iron the rate of blowing is increased to raise the temperature of iron and slag. And then of course one can keep it and then remove that thing. So, this operation goes on far kind of thing but these are all manual driven furnaces.

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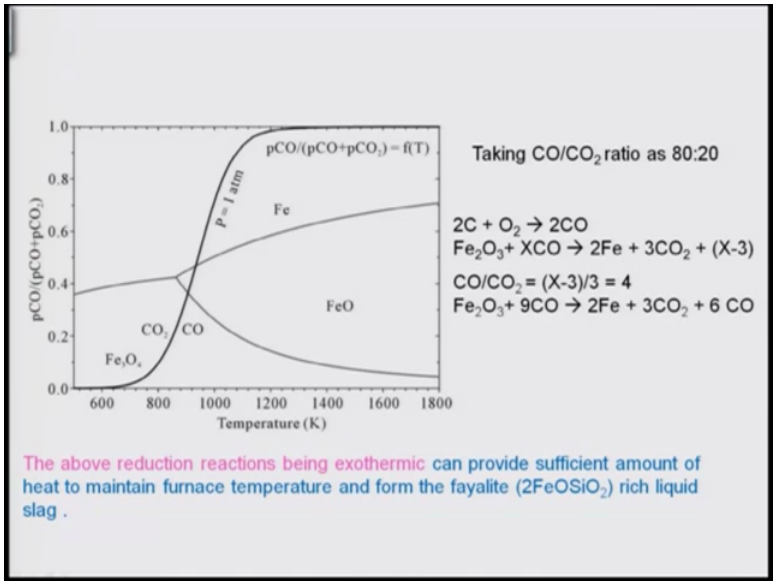

And if you look at that we have already discussed this, if you look at carbon is reacting with oxygen going to the carbon monoxide and carbon monoxide is reacting with the Fe2O3 getting to the iron and carbon dioxide. Now if you take ratio of this carbon monoxide to carbon dioxide 80 is to 2 that means you know this is basically 4 kind of thing, carbon monoxide to carbon dioxide ratio. That you will get somewhere a you know this, if you look at this a partial pressure CO divided by partial pressure of CO++ pressure of carbon dioxide you will be getting around something 0.8 kind of things. So, around 1200 or 1000 to 1200, you will get basically the iron easily right in that even atmospheric pressure condition right. That is the good thing that this furnace being operated atmospheric pressure so, which is you can get if you maintain this temperature 1000 to 1200 kind of thing you will get air on.

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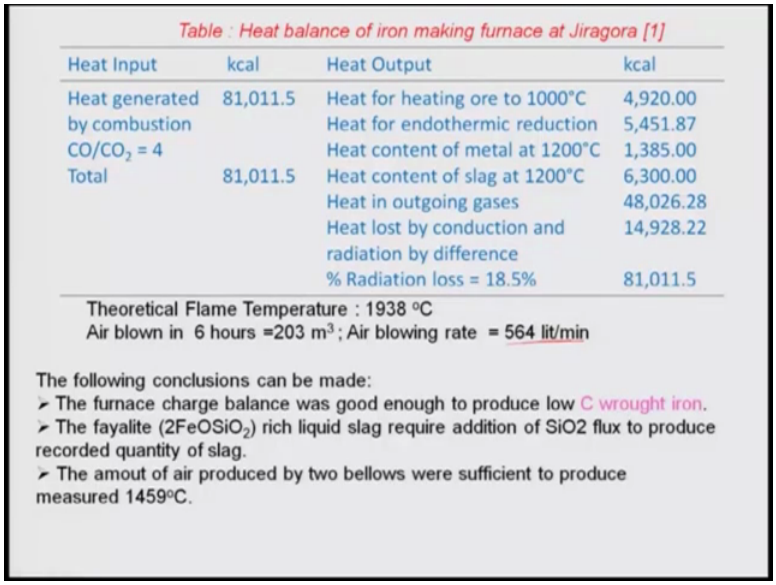

The above reduction reactions being exothermic can provide sufficient amount of heat to maintain furnace temperature and form the fayalite rich liquid that is the slag, so that which can be removed easily. And of course people have done various heat balance of iron making furnace at Jiragora this addition to work and where people are trying to follow the ancient procedure and see that they have done all these calculations as I told CO/Co2 = 4. And they were getting that heat for heating the ore to 1000 degree something, you know they have done carried out heat balance something 4920 kcal, heat for endothermic reduction 5451 kcal, and they have done all these calculation they are finding out the radiation loss is around 18.5 percent, one can reduce it you know then you can also enhance its efficiency. And the air blown in 6 hours is something 203 meter cube, air blown rate is 564 litre per minute kind of things they are giving, that is the kind of air.

The conclusions can be made out of this analysis that is the and also this discussion, the furnace charge balance was good enough to produce low carbon wrought iron. And the fayalite rich liquid slag requires addition of Silica flux to produce recorded quantity of slag. And sufficient amount of air produced by two bellows to produce a measured temperature of 1459 degree Celsius which they had conducted experiments they could measure. So, one can see that, that means the method being used by in ancient time can be replicated even today.

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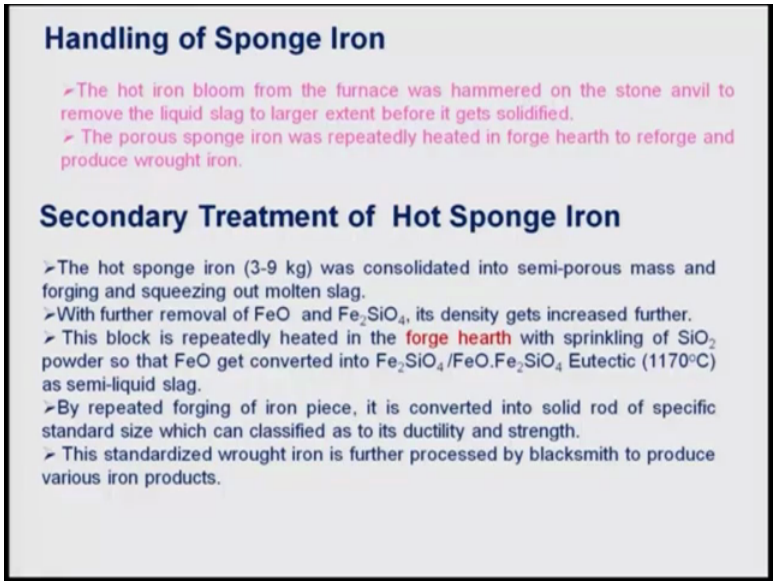

And we will be looking at how they handling the sponge iron. The hot iron bloom from the furnace was hammered on the stone anvil to remove the liquid slag to a larger extent before it gets solidified. That means once it is removed you know it quickly has to be hammered so that slag can be removed. And porous sponge iron was repeatedly heated in the forge hearth to reforge and produce wrought iron. That means this sponge iron will be converted into the wrought iron by the heating it and also with applying the force.

And secondary treatment of hot sponge iron is basically being done in the following way that is The hot sponge iron that is something 3 to 9 kg was consolidated into semi-porous mass and forging, squeezing out the molten slag. With further removal of FeO and fayalite its density gets increased further right. And this block is repeatedly heated in the forge hearth as I mentioned in the just now. Sprinkling of Silica powder so that Ferrous Oxide gets converted into you know this Eutectic as a semi liquid slag at 1170 degree Celsius.

By repeating the forging of iron piece is converted into solid rod of specific standard size which can be classified as to its ductility and strength. Of course this process is being managed by the judgement and also the by the person who is doing it, so therefore the quality is also one concern. And that means one has to very very carefully do that. And this standardized wrought iron is further processed by blacksmith to produce various iron products.

So, if you look at that this is basically you know like the process which is being this is the process of iron smelting and also the secondary treatment of hot sponge iron was discussed

just now. And from this one can conclude that there is a very nice and systematic procedure were available at the time and which of course we lost but it can be revived provided we do some little bit research and then also transfer the this knowledge to the people who can manage it. So, this will be a can be developed as a cottage industries and where the knowledge will be with the people. And also there they can utilize the creativity with that. So, with this I will stop over. In the next lecture we will be discussing about basically a various metal making processes of iron and how they were making a product and other things. Thank you very much.