Non-ferrous Extractive Metallurgy

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Module No. # 01
Lecture No. # 04
Mineral Benefication Techniques

Friends, in the previous lecture I have talked about sources of metals and we have seen that we can get metals in the form of minerals and ore from land mass and they are distributed all over the earth's crust. We can get metals from the sea, not only sea water but marine organisms and manganese nodules in the sea floor. And we have seen that another source of metals is metallurgical waste or metal scrap. Because from them also we can extract metals which are known as secondary metals. Today we concentrate on getting metallic values from ores and minerals available in land masses-- in land deposits.

Now, very rarely, these days we find mineral particles on the surface ready for a extraction process; maybe there was a time when there were boulders of ores or mineral, which were suitable for extraction by our ancients But now a days we need some kind of a dressing of the ores to prepare them for subsequent extraction processes.

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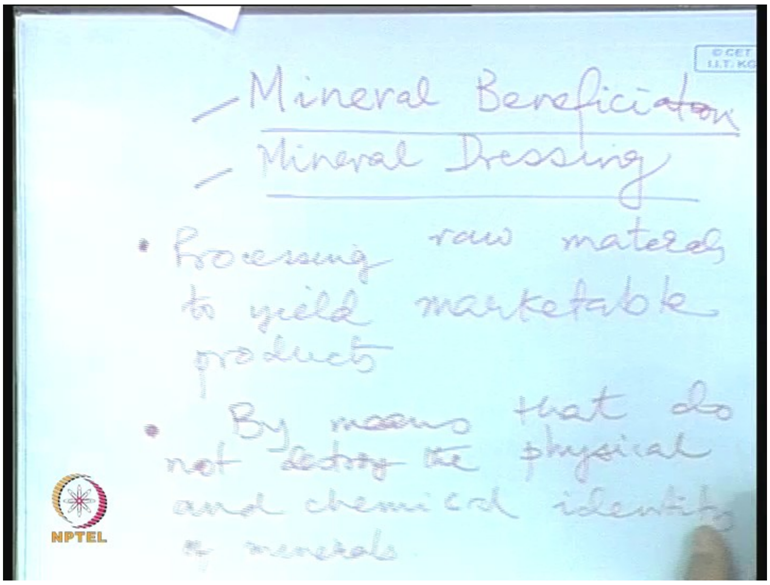

There are two words which both mean the same, one is mineral beneficiation and the other is mineral dressing. Different people prefer different terminologies. Essentially, mineral beneficiation or mineral dressing can be defined as processing raw materials- that is the ore-- to yield marketable products from what has been mined from somewhere. The industry would like to buy ore in processed form - something that can be readily used in the industry. What one has to supply to the industry that can go for in the extraction process straightaway. That means, that having taken the ore out of a mine we have to dress it up, we have to do something to it to make it more acceptable to the industry.

In mineral beneficiation, this is done by means that do not destroy the physical and chemical identity of minerals. This means that while we do a lot of thing, to the ore that we have got we do not change the chemical identity. We call these steps unit processes. Unit operations change chemical nature as we will see later.

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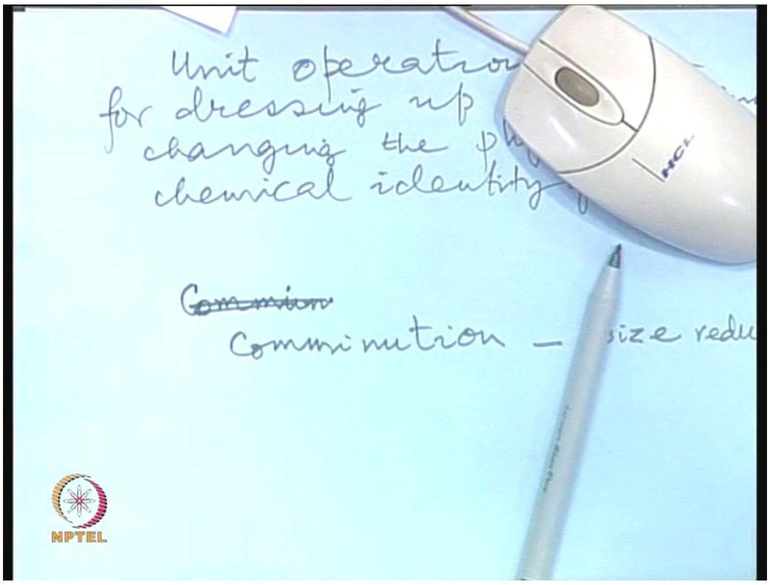

Unit operations are for dressing up ores without changing the physical and chemical identity. Say, for example, you have an ore which has a lot of unwanted materials called gangue materials .As I have said earlier these can be sand and alumina silicates. One may not like to carry them forward into extraction processes. Suppose, we find a method of taking them out, without doing anything with the mineral and the mineral stay as such. Suppose, the particles are too big, you can crush them and ground them to make them finer, you have not changed the chemical or physical identity. This would be called a unit operation. And mineral beneficiation techniques essentially mean such operations, where while you are making the ore more acceptable to the industry you are not changing the basic nature, chemical or physical nature.

However, the technologies have now changed a great deal and there are occasional exceptions to this. Suppose there is an iron ore an iron ore where there is in some mineral containing FeO, we can do magnetizing roasting to convert the oxide to Fe_3O_4 by means heating in slightly in oxidizing atmosphere. Then the ore can be concentrated by magnetic treatment.

This is not, strictly a unit operation, it becomes unit process because, you are playing with the chemical nature of a mineral .But sometime this is accepted within the scope of unit operations in mineral beneficiation, There are also some situations where we take out a mineral value by chloridizing it and the metal value comes out as a vapour, as a gas or as a liquid. We can separate the metallic value. This can be called as a unit operation. In mineral beneficiation but generally it is the physical operations or unit operations which come under the definition of mineral beneficiation.

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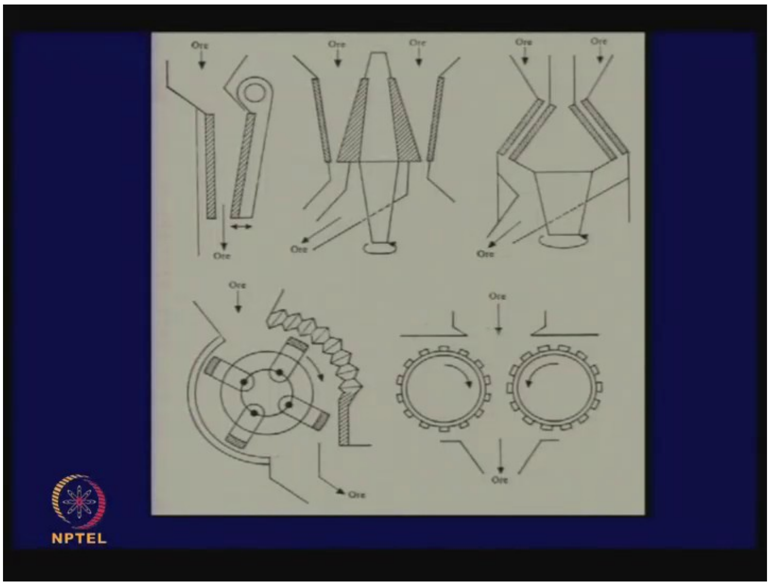

Now, in the most common operation in mineral beneficiation is crushing and grinding using various equipments. I am showing some very basic equipment’s. You have big particles of ore, you feed them into a device where these are banging against it all very hard surfaces. Very often the walls are tungsten alloys. Gradually the particles are broken down into smaller pieces and finer particles coming out. There can be other kinds of devices like this. The ore is made to pass through smaller and smaller openings so that crushed particles come out. Then there is the device which is rotating all the time and, so, the breakage is much more efficient. There is another device where the ore comes into the periphery and forced to enter through a narrow passage. The whole thing, of course, is rotating as you see in the picture and the ore comes out as in finely crushed form.

There also these devices called mills, the ore coming here is something rotating all the time and its ore particles get crushed between two hard surfaces as they are hit by hammers. The technical name for this sort of operation is comminution, we may call it crushing and grinding, but comminution is a more technical term, which is actually a unit operation for size reduction.

Now, obviously, this operation requires a good amount of energy. A rough estimate is that you need 5 kilo watt hour per ton to 25 kilo watt hour per ton depending on the kind of equipment you are using or how hard or how brittle the ore particles are. Very often, comminution is the first step in mineral processing because it achieves several thing. Not only the particle size is reduce, but you also create new surfaces while you liberate minerals.

What do we mean by the words-- liberation of minerals? To understand that, you must understand what normally is an ore particle like. A particle of ore or rather a mass of ore would comprise agglomerates of various mineral particles. Different kinds of mineral particles have agglomerated in nature over millennia and they form a mass in which there are different minerals. There also gangue materials. They have been all crushed together.

Now, we want to treat the mineral values by some processes to extract metal values-- one metal or more metal., so we need to liberate them from each other and from the gangue materials this is very effectively done if you break things up. When you have a single mineral-- single mineral particles agglomerated together-- we call them free particles, and when there are different minerals together in an aggregate, we call them locked particles.

So, essentially by size reduction we try to unlock the minerals and of, course, we can always talk about degree of locking or degree of liberation. The more liberated they are the freer particles or more OF single mineral should be available in the mass.

The definition of degree of liberation is this. It is the percentage of mineral phase occurring as free particles in relation to the total of that mineral occurring in free or locked forms. And conversely, the degree of locking of a mineral is the percentage occurring as locked particles in relation to the total occurring in free and locked forms. Now, we need not go into these details but, essentially, you get the idea that we have to breathe ores particles to free the mineral particles, one kind of from the other kinds. Now, when we reduce the size, then this happens quite automatically.

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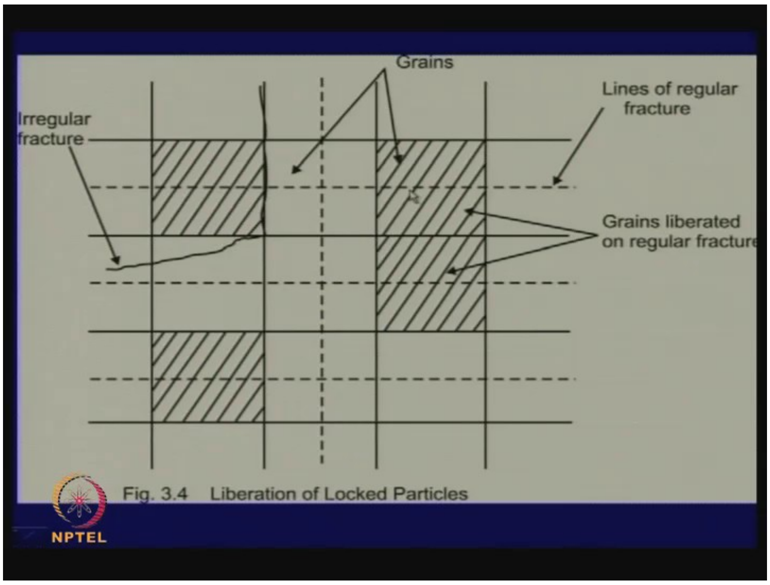

Fig. 3.4 Liberation of Locked Particles

Now, here is a schematic representation of a of a mass of ore, where there are different kinds of minerals locked up, and this is one kind of mineral, this is another kind of mineral, the white one, and this is the hatched one. And when size reduction takes place, and this is broken, may be lines of fracture could be here, the lines of fracture could be here and very often the lines of fracture go along the inter granular boundaries, by grain you mean one kind of particle, a mineral particle this is one grain, this is another grain, which is another mineral particle.

So, very often, it will crack along these lines and they will get liberate. Now, sometimes there can be this kind of fracture also, means not only it will go along the boundaries of different grains, but across a particular mineral that can also break, but no matter what happens. One thing is sure, if you break the aggregate into smaller sizes, you liberate more of the minerals from one another or from the gangue, and this will happen even if the cracks are along the grain boundaries or even if it goes through some grains it does not matter, we need this.

So, when you have reduce the size with communition, then you are creating much larger surface area and this will be advantages in processes, where we need larger surface area like if you want to go for leaching and dissolution in a in a acid or in an alkali, the larger the surface area, the better will be the rate of dissolution. So, not only we are creating larger surface area by breaking the particles, we create new surfaces areas, new surfaces which may be more active than the old surfaces, because they have not been ((whether)) they are fresh, they are ready to react with environment. So, the communition achieves many things, it achieves liberation of grains, means one kind of particles from the other kind of particles gets liberated from the gangue material, unwanted material by using the size we create larger surface area, we also create new surfaces which are more active.

There are some processes, where we might like to have larger particles like at one time, the blast furnace operation required fairly large particles, because in the blast furnace you need to have porosity, but today the tendencies not to have natural particles, we actually take finer material make sinters out of them, sinters are again larger particles we create the porosity in the bed, very few processes today would like to have large particles, most of them would operate on fine particles. Of course, the degree of finest, that we need will depend on the processes we operate.

If you have a fluidized bed processing in a fluidized bed, where you have the particles or fluidized by a gas coming from the bottom screen. Obviously, they have to be fine smaller particles, because then they are easily fluidized, but then if they are too fine, then they will fly off.

So, there is there is a size limitation, there should be fine, but not too fine. In mineral beneficiation techniques like floatation, we want finer particles, we want large surfaces, which will attach the particles, will attach to soap bubbles and float down. So, unless the particles are very fine, this soap bubbles will not able to carry them up, it is like when you do washing with soap, the dirt comes out with the soap bubbles, but you know if they had been large particles floatation will not work.

So, we need finer particles in many processes as I said, if there are surface properties involved the surface is coming to picture, finer particles are lighter in weight, they are purer in terms of the mineral value. So, the crushing and grinding would be one of the first steps that we need. Crushing and grinding also has to be followed by a process called sizing, you simply cannot undergo comminution, crush, grind or leave it at that.

You have to define to what degree you have reduced the size, and for that we need screening. Now, you may have seen, the way the house wife you know screens an Atta, they have a circular device of perforated base and they will put the atta, and if when they do that the finer things goes and the coarser things stay on the top and they rejected.

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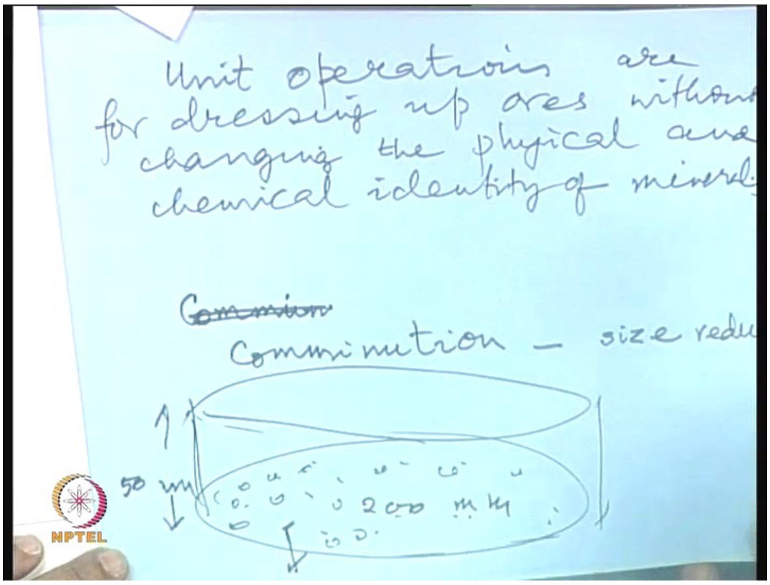

Something similar is done for the industry also, that we have a perforated base, see this could be say about diameter about 200 millimeter and about 50 millimeter high, very usually in the laboratories they are made of brass and in this there are screens and they have standard openings. So, if we do this sort of thing, then the finer particles go through and coarser particles are remained on down, but this is what we what we do in the laboratory in small scale, in the industry this will not happen, what we can do? We can have a stack of such screens, the coarser ones will be on the top, and the finer ones will be at the bottom.

See, if there is a series of screens like that, and they are vibrated in a stack, so the finer and finer particles keep going towards finer and finer screens, and the coarser ones on top. So, we have now, we do a size classification that between this size to this size in this screen, this size to this size in that screen etcetera, etcetera.

We have to have the size reduction within certain limits because, industrial processes define that, we do not want the input materials to be in this size range; now in the industry of course, they do not want this vibrating screens like that.

There are other processes like for example, they may have an incline with rods at certain spacing and the ore goes above them, the whole thing is vibrated, that the finer the openings between the rods will go down, and the coarser works will be on top. There could be a series of such things, so in the process there is also similar and other methods, this parallel rod device is called the greasily, these greasily are used for size reduction, there are also other devices. So, essentially we always want the input material in an industrial process of a particular size and that is done by mineral beneficiation technique, a comminution.

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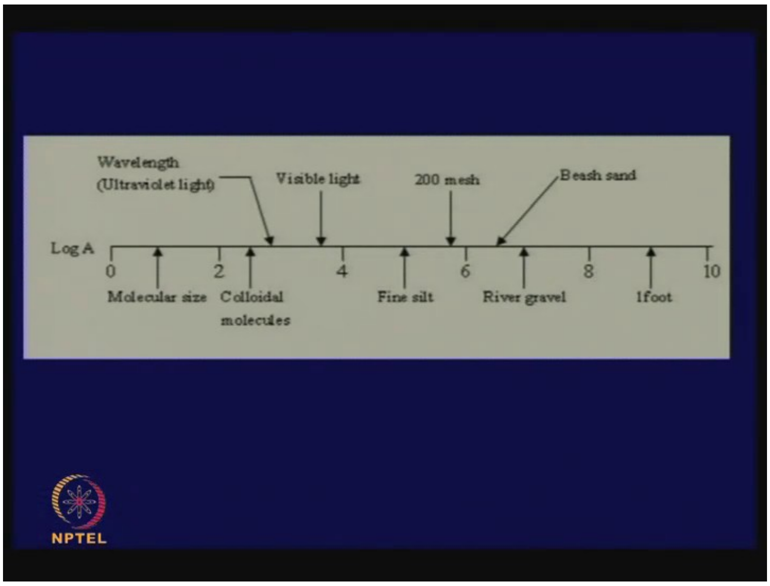

To give you an example, why, what happens in a size reduction, here is a simple to give you an idea as to what we mean by size reduction. This is a typical size ranges for various materials, it is in angstrom unit.

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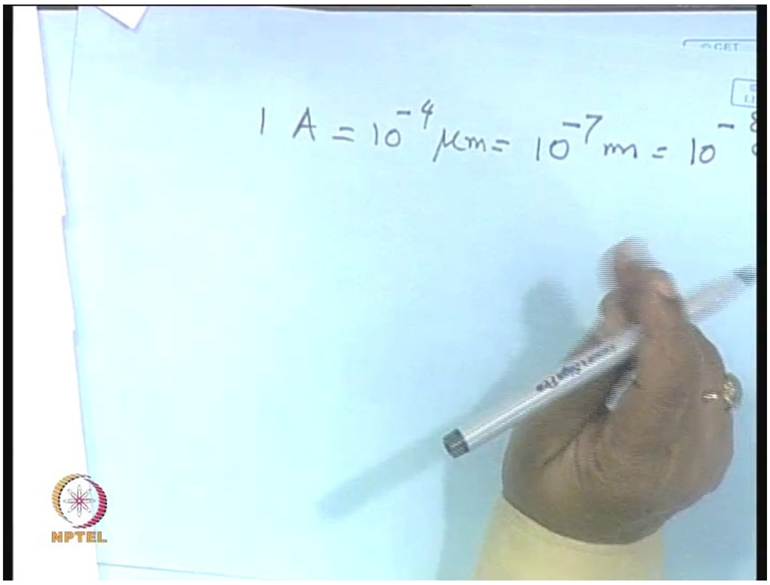

You know that, we mean by 1 angstrom is 10 to the power minus 4 micrometer, that is 10 to the power minus 7 millimeter, that is 10 to the power minus 8 centimeter, and you get an idea here, that the fine silt would be here, the river gravel means the smaller particles are here, beach sand is here, this is a log scale. Now very often, we will be actually operate in in this kind of range in most of the industrial processes, 200 mesh, mesh is a unit defined in most book say that, what is a mesh? 10 mesh is about 2 millimeters, 200 mesh is about 0.075 millimeter and they are many standard conversion things are available, so in most of the industrial processes will operate in this range.

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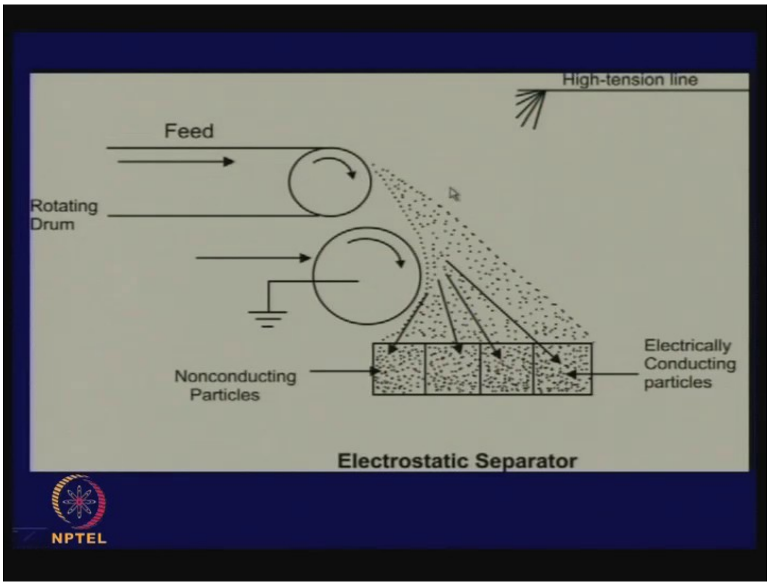

To give you a simple example, why we need to do this kind of sizing? Say, here is the schematic diagram of an electrostatic separator, which can be used for electrically conducting mineral particles. Suppose, we have an ore body in which there are particles of minerals, which are electrically conducting and others are not electrically conducting. Now, as such if you let that go under an electric field, everything will pass through, there will be no separation, but if you do comminution, if you reduce the size, if you have liberated the electrically conducting particles from other kinds of things.

Then, we can use a device like this, while the feed will come on a belt, conveyer belt and these are the particles of ore, where all kinds of grains, all kinds of minerals with different electrical conductivity properties and we will have a separation here. Because, those that are electrically conducting will fly off, because this is the rotating drum that will attract, so none conducting will go in some places, electrically conducting particles will go in another places, so we can have a separation based on electrostatic charges.

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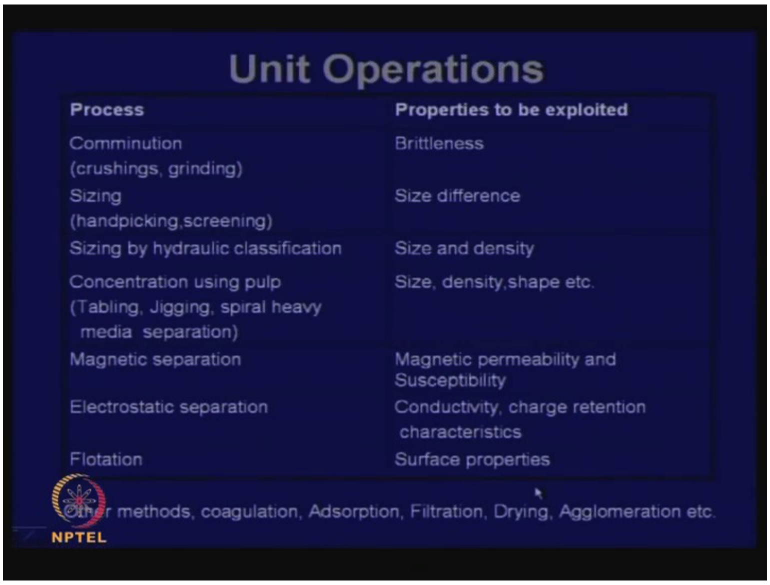

Now, all processes of mineral beneficiation exploit one or more properties of ore particles, and here is a list of unit operations to indicate, what is being exploited where? what I describe this as, comminution or size reduction, obviously exploit the property of brittleness because, the ore particles are brittle does not mean that any force will break it, but some force or other will break it, some need more force and some need less force but they are brittle, in the sense that it will not get deformed.

So, we have the grain aggregates of different particles, they will break into smaller fraction, so we are exploiting the property of brittleness, then we are doing sizing; we showing to screening using various devices, so there is greasily or other things and we are creating different fractions, we are exploiting size difference amongst particles.

This can be done in various ways; in the earlier days, it is to be done by handpicking, and handpicking was also get quite advanced and it is still done in some places, that on a conveyer belt whatever has been mind is going and there are skilled labors, labors on both sides. Men and women will pickup particles of a certain size they have been trained to do that and coarser particles in one side, finer particles in one side, they can also do something more, they can be trained to pickup particles rich in certain kind of minerals that can also be done, this is called handpicking, but then big industries handpicking will no longer do.

Then there are hydraulic classifications, there are many kinds of devices and I will not go into that, mineral beneficiation techniques comprise a full course in many undergraduate curriculums. Then there is concentration using a pulp, we will discuss an example of this in detail. Sizing by hydraulic classification means, that you have devices where it can be air or it can be fluid and the entire body of ore is sentinel and the whole thing circulate like this, and there is a separation between some which go up and some particle which sink they all are make use of the properties or size in density differences. Now, the concentration using a pulp is a very important method of separating different kinds of minerals, by a pulp we mean the solids that have been quest and ground and then its mixed with water, so we have solids say 10 percent, 15 percent, 20 percent solids in water, it is called a pulp; it can be agitated, it can be made to flow, so we will say a pulp is flowing.

Now, when we have a pulp, there are many devices that can be used to separate different minerals from one another, exploiting the properties of size, density and shape. Size, density and shape, all defined the way particles move in a pulp and I will give an example that will perhaps make things more clear. Then there are magnetic separation devices, which make use of magnetic permeability and susceptibility, so if you have in an ore, lot of mineral particles which have been liberated and if that are magnetic minerals, using magnetic devices we can separate them from the nonmagnetic ones.

In fact, we will come to some examples, where there can be a series of minerals of gradually changing magnetic property they can be separated using magnetic separation, same as with electrostatic separation I give you an example. And floatation is very important for sulphides because, the sulphide particles attach themselves to soap bubbles and so if you have a finer finely ground sulphide particles, they can be separated from the gangue simply by the floatation technique. And we will see that in the case of some sulphides like, copper sulphide, the ore may contain only 1 percent copper sulphide.

But, after crushing and grinding if they are sent through floatation device, we get a concentrate on the surface which is about 25 to 30 percent copper sulphide, the gangue materials do not float, they sink at the bottom, but the Sulphur come to the top. There also other methods like coagulation, adsorption, filtration, drying, agglomeration, etcetera, and etcetera. We are not going to discuss these things, because there will be other times we will see that.

Let me discuss here one example, which actually is very relevant for indeed, it is the beneficiation of beach sands, what do we mean by beach sands? I do not have it here, but it is here, in a coastal area of India there are certain areas all along our southern course way up to the also eastern course, our eastern side whether in some areas with the sand is actually almost black, and it is black because it contains ilmenite, ilmenite some of you know is written as FeO TiO_2 or FeO TiO_3 is the source of titanium.

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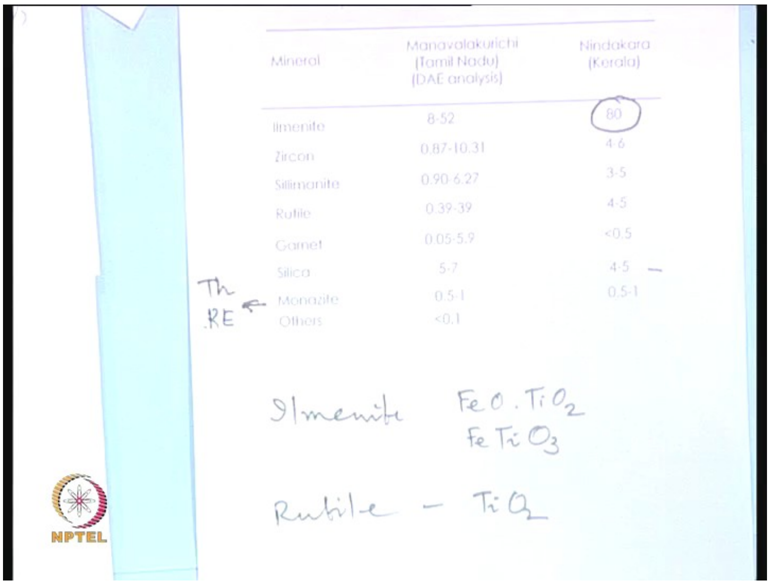

Now, in the beach sands in the Tamilnadu coast, this is an analysis given in one source, it may contain from 8 to 52 percent ilmenite, zircon 0.87 to 10, sillimanite, rutile is TiO_2, then garnet, silica, monazite this is important, this is important because it is a source of thorium and rare earths and there are some others.

In a Kerala beaches also you find some beach sands containing as high as 80 percent ilmenite, there is also zircons, sillimanite, rutile, garnet and monazite. There are beach sands of Orissa also, which they contain all these things. Now, these are all very valuable minerals, from ilmenite we get not only titanium, we also produce TiO_2 which goes into the paint industry. TiO_2 is very white, from zircon we get zirconium, and from monazite we get thorium, rare earths and many other elements.

Actually its very interesting that, there is an interesting theory as to why the olive ridley turtles come for to deposit their eggs in certain area in Orissa called Gahirmatha, you may have heard about Gahirmatha around the month of February thousands of turtles come to lay their eggs in the beaches and which hatch and then and the hatchlings will going to the sea.

One of the reason they say why the olive ridley turtles come to Gahirmatha is because, we have the beach sand with ilmenite very dark, they observe sun's rise and they are very worm, so the sand bed beach sand bed is very wormed there just right for the turtles they have found the spot, where the eggs will hatch because they drop their eggs they cover them and they go away into the sea.

Anyway, what I am trying to say is, we have a very valuable resource in beach sands in many locations along our course line from Gujarat, Tamilnadu, Kerala and this is a very valuable mineral that needs to be processed to extract different minerals out of that, and the different compounds and different metals.

How do you treat a complex mixture like this? The treatment of such ore bodies, which have so many different kinds of minerals, all with different properties has actually have evolved over hundreds of years, may be thousands of years, and people have found different ways of doing things by trial and error.

And now only the science is trying to understand, exactly how these things work? There are similar techniques in our household things also like, if you have you may have seen our housewife, if when they take, there is a there is a dirt in the wheat, they have a pan they keep doing that and they keep blowing that, so the lighter ones, the dust particles and they and their coverings they flown, they fly away and they get something; this is a kind of technique is also adopted in in the mineral industry.

Now, I use to be fascinated by the techniques that are adopted in the in the mineral industries and I worked in regional research laboratory in Bhubaneswar, very near that there is Indian rare earths, which process beach sands primarily for production of TiO_2, and also to get the other fractions like, monazite, garnet, sillimanite, etcetera, which will go into other industries.

Now, then in a in a place like that, there are whole a series of mineral beneficiation techniques are adopted, unit operations, electrostatic separation, magnetic separators, etcetera, etcetera, etcetera. I will describe only one operator, which is called the spiral, which is ever useful equipment for separation of different minerals based on size, density and shape. Now, if you see the principle of one, you will see how similar principles have been employed elsewhere.

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Now, in the beach sands I have just described, there are actually some minerals we call very heavy minerals; this very heavy minerals means ilmenite, zircon, and monazite these are very heavy minerals. Then we have heavy minerals, this is not o this is bracket closed, heavy minerals which are garnet and sillimanite, and then we have lighter minerals like silica, this may be around 2, this will go up to 7, 8, 9, 10 that kind of density.

Now, we want to find ways of not only separating very heavy minerals and heavy minerals from lighter minerals, but again VHM from HM, and then also ilmenite from rutile, zircon and monazite, we want to get different fractions.

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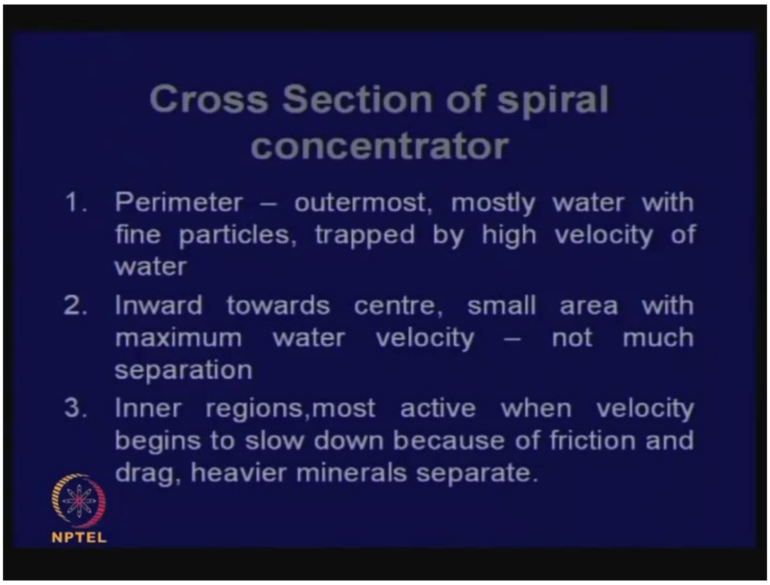

Now, this device that I am going to describe called spiral concentrator, achieves this remarkable well.

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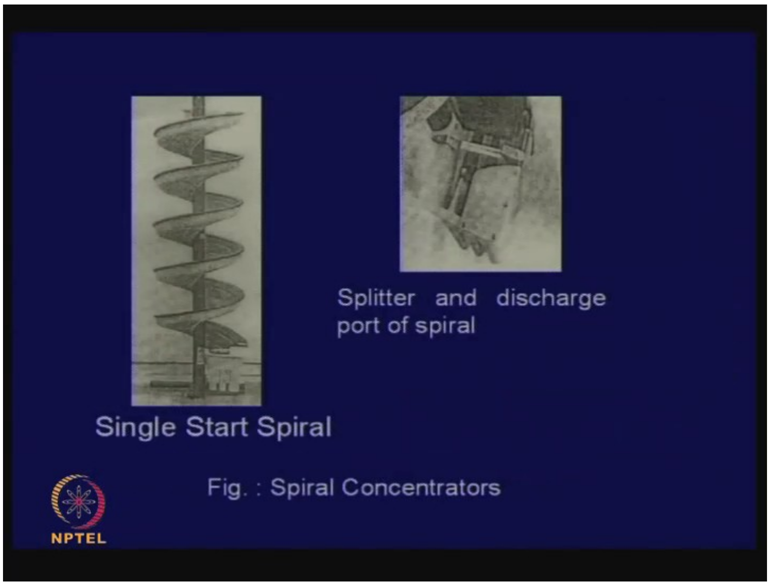

Now, first of all, let us see what is a spiral concentrator, this is called a single start spiral. The total height would be say something like 3 meters or 4 meters may be little more, see as I as many halls.

A single start means one spiral, there can be multiple start spirals, which mean that at one place, you have more than one spiral, like this spiral is going to occupy say, as a diameter about say 6 feet or 2 meters, so if you want another spiral there has to be another space than another space, but people have found that, they will put one more spiral in between these spaces to go through that, then there will be another one through so. There are there are spirals with three starts, three spirals are at one place, forget about that, look at just one spiral. The idea here is, that a slurry which means certain amount of solids particles above in in water will be pumped from the top and it will flow through this vessel, so it will go round and round and round and round and come out at the bottom.

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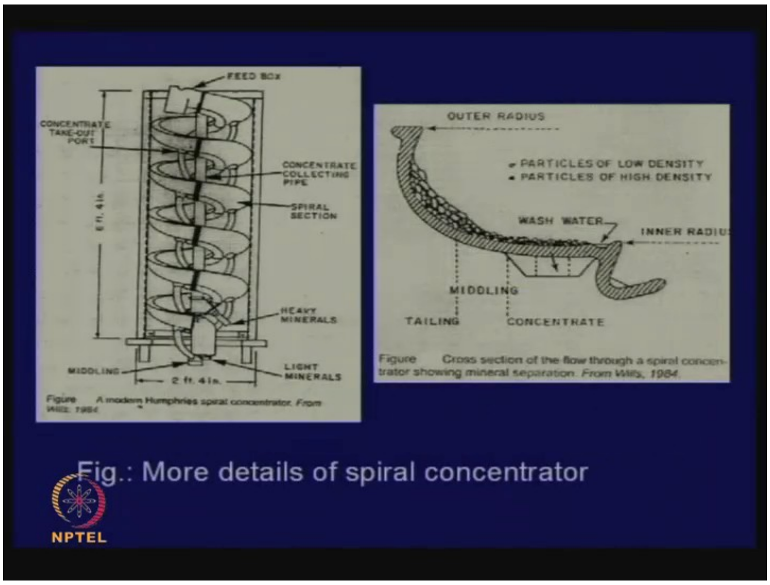

When that is happening if you see, it is a trough which goes with a slope downwards. How will the water flow in water? We will have 0 velocity in contact with the perimeter, it will have a 0 velocity at the center, so there is a velocity gradient from the center to the side at any place, at any place here from center to the perimeter, there is a velocity gradient.

Now, the water will be flowing at a much higher velocity towards the perimeter, it will be it will be, it will slow down towards the center and we say that in the perimeter, in the outer most area mostly water with fine particles will flow, because trapped by the high velocity of water, water is flowing pretty high velocity all the fine particles will go at this side.

As you go we go inward towards the center, there is a small area where the water velocity is maximum, because as I mentioned at the perimeter it is 0, velocity is also 0 and the center, somewhere in the center the velocity is maximum and when it is flowing so fast, not much separation of minerals take place. But, as we come closer to the center, the inner regions most active when velocity begins to slow down, why is begins to slow down? Because of friction, drag and heavier mineral begin to separate; look at this diagram, which is little more makes it little clearer.

The slurry is going through this device, flowing through this device and at every stage, from the outer sections we are tapping out some water, we are tapping out some water from the middle part from the middle part and we will we will take out something from the central part. Now, this is the cross section of one place here, now you see not only there is a gradiate in water velocity as you go from this center to the side, there will be gradiate in water velocity in the vertical direction also (Refer Slide Time: 44:44). Because, the heavier particles are beginning to come towards the center, so the water will find it difficult to go through, so there are all kinds of things happening in this device.

Someone substances very light particles will fly towards the periphery, they will get separated and the heavier minerals depending on not only the density by size also begin to aggregate towards the center, but there are also fractionation amongst them and there are there are devices to tap them from different places.

So that, at the end we get three products, one the lighter products are the periphery are taken out, the heavy minerals will come at the bottom, in between we will have the middlings. This kind of device separates the minerals and the separation will depend on a large number of factors, but again go through what is happening there, outer most mostly water with fine particles tapped by high velocity water means, silica we will get eliminated. Then, where there is maximum water velocity not match is happening, it is only the inner regions where the they will get minerals are begin to separate depending on their density and size.

How do you study this? Now, some of my friends and I looked at only one spiral, where they were trying to separate these minerals, and they have add operation going on for some 20 years because, there is lot of trial and error involved in knowing how you separate the minerals and the general wisdom said that, there are three factors which are mostly important. And these are what we say, first of all through put, how much you are sending through the spiral per hour and the other is the concentration of the particular mineral in the mass in the mass of minerals, and the third one is the pulp density.

What is the fraction of solids in the water? There are some other things we do not know, we need not consider. I do not know whether I am I am I am able to make it clear, but we have a device, which is going to separate the minerals depending on their density and the operators find through their trial and error, that they have to control three factors.

As to how much they pore from the top per hour, because if you put too much, too fast separation is not effective, if you send too little of that the slurry, separation not too effective, you need to have a certain concentration of the solids in in water, if it is too high it does not work very well, it is too low does not work very well. And also it depends on how much of a particular mineral do you have in the input mass for it to be recovered effectively. Now, we have looked at their data and there are some statistical techniques, which is called statistical design of experiments.

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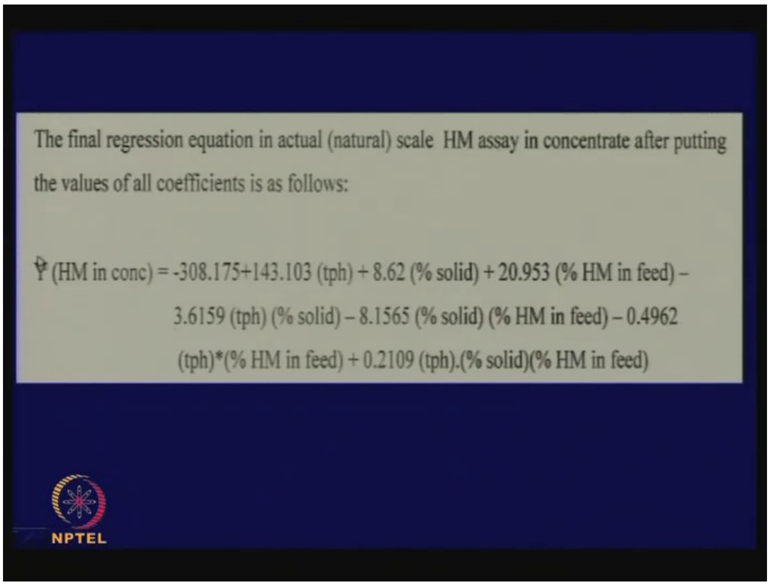

We developed an equation like this, that in the product we said first of all, let us consider the entire hot metal, several minerals at a time, amount in the concentrate depend on tons per hour. What is the feed rate? It will depend on percentage solid; it will depend on percentage hot metal in the feed and so on and so forth. So, we were able to quantitatively develop an equation that, if we want 3 or 4 heavy metals together the total yield will be defined by these parameters like this, tons per hour, feed rate, percentage solid and also the how much of that heavy metals is in their total world.

Subsequently, we have done it for every single mineral and such equations have been developed, so an operation which was basically developed by trial and error, we try to put science into it looking at their own data; their own data over say 10 years, 5 years, we picked up certain selected some data, develop some equations and when you have an equation like that, which expresses the yield of the total heavy metals or yield of a particular mineral in terms of factors like, the tonnage that you are sending through a percentage of total solid, percentage of metal or hot metal in the mass you can develop an equation.

Once you have an equation, you can go through an optimization technique to maximize that, under what conditions of throughput solid concentration and hot metal in feed of the particular metal in feed you get the maximum yield, we have done that, and computers do that if you feed right kind of data.

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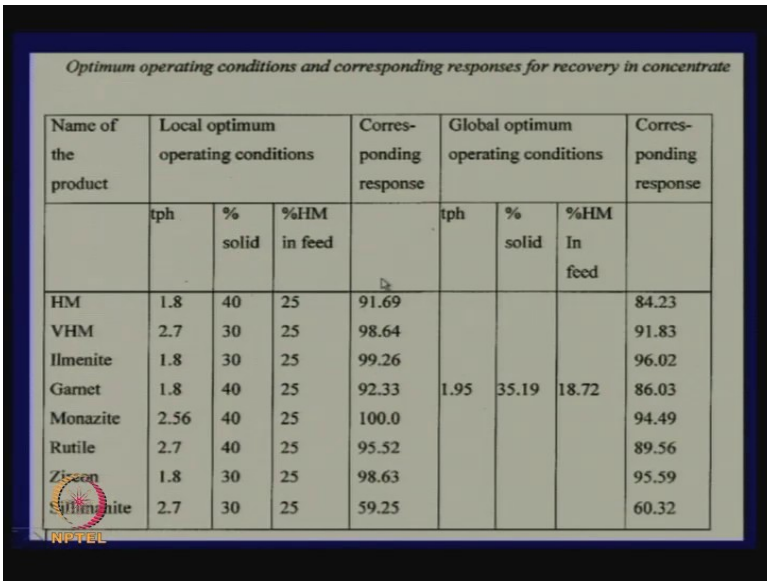

Optimum operating conditions and corresponding responses for recovery in concentrate

Name of the product	Local optimum operating conditions			Corres-ponding response	Global optimum operating conditions			Corres-ponding response
	tph	% solid	%HM in feed		tph	% solid	%HM In feed	
HM	1.8	40	25	91.69				84.23
VHM	2.7	30	25	98.64				91.83
Ilmenite	1.8	30	25	99.26				96.02
Garnet	1.8	40	25	92.33	1.95	35.19	18.72	86.03
Monazite	2.56	40	25	100.0				94.49
Rutile	2.7	40	25	95.52				89.56
Zircon	1.8	30	25	98.63				95.59
Sillimanite	2.7	30	25	59.25				60.32

And we had this kind of information, we have found equations for heavy metals, heavy minerals, very heavy minerals, and then individually for ilmenite, garnet, monazite, rutile, zircon, sillimanite, everything has been done, so the beauty now is that, we found what will be the optimum conditions. That we found mathematically, and these are the once we predicted, that under this kind of conditions this is what will happen and their 15 or 20 years experience they said, these are the kind of data they had; and it was very interesting what they have done over 15 to 20 years, you can do that in two months if you pick up the right kind of data, and then you say these are the optimum conditions for getting maximum yield of this mineral.

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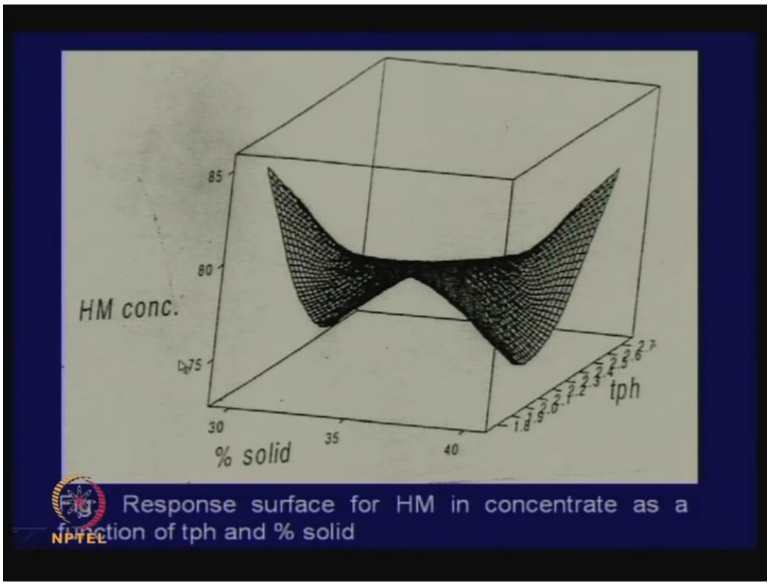

Well, this can be done put in terms of the computer camera also, print that for heavy metal in this case, it is heavy mineral, it can be for very heavy minerals all together or single minerals, we can plot them heavy mineral in the concentrate as a function of percentage solid and tonnage per hour, we did something like that for very heavy minerals also.

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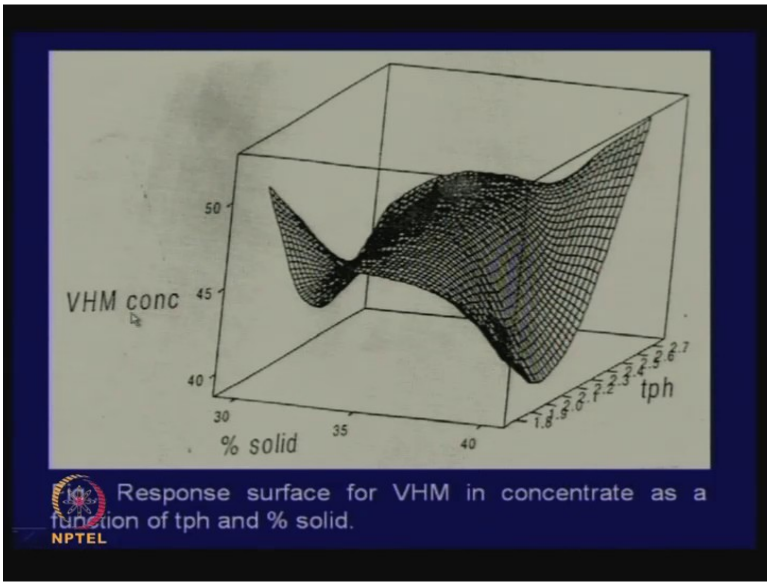

And then the computer gives a software also, that for any particular concentration, if you want this much of concentration in the product, you have to, you can cut it through this, you can get a horizontal thing surface, that for different concentrations of very heavy mineral, 42, 44, 46, 48, 50 these are there are different combinations of solids and tonnage per hour will give you that.

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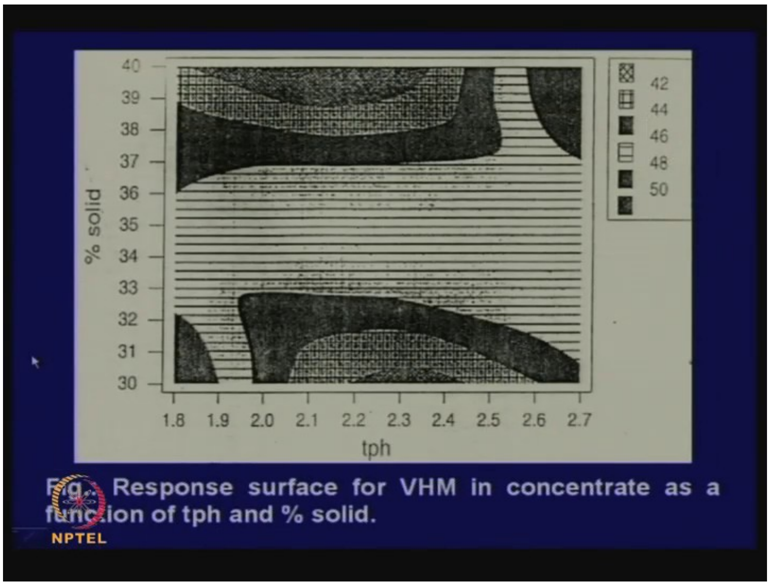

Fig. Response surface for VHM in concentrate as a function of tph and % solid.

I will stop it here now, and I will simply say that I am sorry I do not want to go into the details of this topic, but mineral beneficiation technique is actually it depends very heavily on trial and error over centuries.

And now this equipment have been standardized, but we can play around with this equipment to do lot of scientific research, bringing lot of science, lot of mathematics and gives them optimization techniques which will minimize the labour that they have to put into find what are the best conditions. So to summarize, mineral beneficiation means mineral dressing and there effort to unit operations, which will make an ore body more suitable for an industrial extraction process and all unit operations exploit certain property of the minerals.

To start with communition, which is size reduction, it will make use of their brittleness and there are other properties. Rarely would a unit operation change the physical and chemical nature of minerals, but there can be some exceptions as I have mentioned.

I will not discuss this subject anymore, but everywhere subsequently, whenever you talk about an extraction process, you will see there will be a reference to someone or more mineral beneficiation technique, and if necessary I will give you little more detail. I have give a I have a particular example of use of a spiral, if you are interested you can you can read that of in internet or in any book, thank you very much.