Geoenvironmental Engineering (Environmental Geotechnology):
Landfills, Slurry Ponds & Contaminated Sites
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Lecture – 33
Geotechnical Properties of Coal Ash and Mine Tailings – Part 1

Good day to all of you and welcome to today's class on geotechnical properties of coal ash and mine tailings. Whenever we are dealing with the waste material which we call coal ash or mine tailings, the one thing which comes to our mind is and I have already talked to you about this that this is in the form of a fine powder which is having particles in the silt and sand range, but what we really want to know is it like soil is it different and how is it different and then we can look at the design aspects.

So, let us first take a ash and most of us would have seen coal ash, we must have burnt some coal in the house and if you have not, most of us must have seen the ash which comes from burning a wood or rice husk or something or the other. So, we all know it is a very fine material, but if I was to ask you to characterize ash in geotechnical terms, how would you go about it, how would you go about it, how you go about characterize in this material from a geotechnical perspective you know, the word ash does have a connotation, it is grey colored, it is something which came out of the burning process, but till I told you whether it was silt or clay or sand, you would not have told me; sir I would like to classify ash as follows . So, you have to discover it yourself.

So, the first step is always to look up green size distribution; what is this material and what are the particle sizes beyond that what is it that you would like to classify in ash other than grain size, how would you like to classify, how would you like to go about classifying ash in terms of geotechnical or geo environmental properties.

Student: Specific gravity.

Specific gravity is important because somebody suggested specific gravities is important, when you start identifying soils, what are 2 most important tests that you do if I bring soil from a particular site and give it to you? What are the 2 sets of tests that you do to be able to understand the soil.

Student: grain size distribution.

One is grain size distribution which I have already given you a rough idea, what is the next test that you do?

Student: Attergbergs.

Pardon;

Student: Atterbergs.

Yes, you do atterbergs limits, we want to know the plasticity of the material, what does plasticity of the material tell us, well first it will tell you whether it is plastic or non plastic and if it is plastic it tells you immediately, it has something which makes it interact with water in a particular way in soils, you get plasticity because there is a net negative charge on the clay particles and therefore, the colloidal behavior, the double layer that gives a soil affinity to water and that reflects itself as plasticity and if it is not plastic, then you know that it has no affinity to do water or do not have the capacity to hold water or it does not have the capacity to demonstrate a plastic state, right. So, sands will not have plasticity. So, you would do these 2 tests to classify the material that I gave you to begin with; then you would go on to other test like specific gravity; what are you trying to understand from specific gravity? Somebody said I like to do specific gravity; what are we trying to understand from specific gravity?

Student: How fast will settle.

How fast it will settle. So, we are trying to find the density of the solids. So, one of the test which we would like to do is specific gravity. What kind of specific gravity values do you anticipate? We have not done this test on ash, but we just trying to understand; what kind of specific gravities values do we anticipate? What are the range of specific gravity values that one encounters in nature on ground or on tera pharma or on mother earth.

Student: 2.6; 2.59.

2.6 is for soils is there; any other specific gravity that you have encounter.

Student: Organics to multiple.

Pardon; organics;

Student: Organics multiples.

I did not hear you, say louder.

Student: Sir, 1.5 to 2 organic.

So, the specific gravity of organics is defined and it is 1.5 to 2 or it can be lower. So, we expect this specific gravity to change with the material which is constitutes the solid grains. First as the solid grains change, what will give you higher densities; higher specific gravities; you said specific should be 2.65; whether it is soil in rocks; what is the specific gravity.

Student: 6, 6, 6.

6; which rock has got specific gravity of 6. 6 is a very high value. So, typically in all the soils and in the rocks, you are going to be around 2.6, you go higher only when metals starts to come in to the rock when you pick up an ore then the specific gravity will go higher because there is metal inside it, what is the specific gravity of metal; any metal anybody remembers iron, copper, zinc, lead, metal has very high specific gravity right and then you are going into the ranges of 5-6 plus that you are talking about and therefore, when you deal with rock which is got metal in it, then the specific gravity starts to increase from 2.65 to 3 in rocks when does the specific gravity go lower specific gravity begins to go lower than to 0.65; when the mineral is not quartz, it begins to change instead of quartz; both it is calcium carbonate, it might be 2.4 or 2.5 and as the organics come in to play, this specific gravity falls below that value. So, therefore, specific gravity is a good indicator of the fact that; what is your solid matrix, right. So, good test to do, do grain size division liquid limit than this specific gravity and in the end we are interested in the 3 engineering properties.

Student: Compressibility.

Compressibility;

Student: Strength.

Strength and permeability; to see whether it behaves like soil or not, we can also be bothered that it may be hazardous. So, we needs to the toxicity characteristically leaching procedure, we need to do the test which tells us whether the material that we are handling and I am; you are getting mine tailings, you are getting ash in your hand, you need to do a toxicity leaching procedure to see that will any toxic materials come out of the waste which is in your hand.

So, nothing comes out of it and nothing leaches out of it, no arsenic, no poison, no cyanide, then you will not die, I am; your health will not be affected. So, you are interested in knowing whether the material is hazardous or not; does it have any toxic materials inside it? You are interested in knowing whether the specific gravity similar to soil, you may want to find out loss on ignition, you want to know whether the material has got any still some pieces of wood and carbon which are not burnt. So, how much is the organic content of the material. So, you that is test which you do by loss of ignition; that means, you burn it and if there is still something which can burn it will go out of it.

So, in this manner, you get a holistic picture of the material that you are dealing with. So, let us try and demystify what is coal ash and what is mine tailings from a soils engineering point of you right every everybody looks at these things differently, the farmer looks at ash that if I put ash in my fields, productivity goes up, is that right, people burn, why do people burn the stubble? You ask anybody; they will typically add ash to the soil to improve the productivity of the soil, whether it changes the texture of the soil, whether it changes the water holding capacity of the soil, whatever it does, whether it has got in it, some elements which are able to help growth of plants, so many farmers will tell you that using of ash improves productivity of the ground and many a times, you will find a lot of burning of stubble one is of course, it is a easier way of not having to dig it up and throw it away the second is to put back into the soil whatever minerals where there which would not burn and it could go and mix with the soil once again.

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So, let us look at when we deal with ash; what are we; what is the material that we are dealing with. So, first we look at coal ash and this we will discuss in detail and then you will look at mine tailings which we will discuss not in that much detail. Both of them are powdery materials. So, the word coal ash is often also referred in the US; another countries as CCRs; coal combustion residuals.

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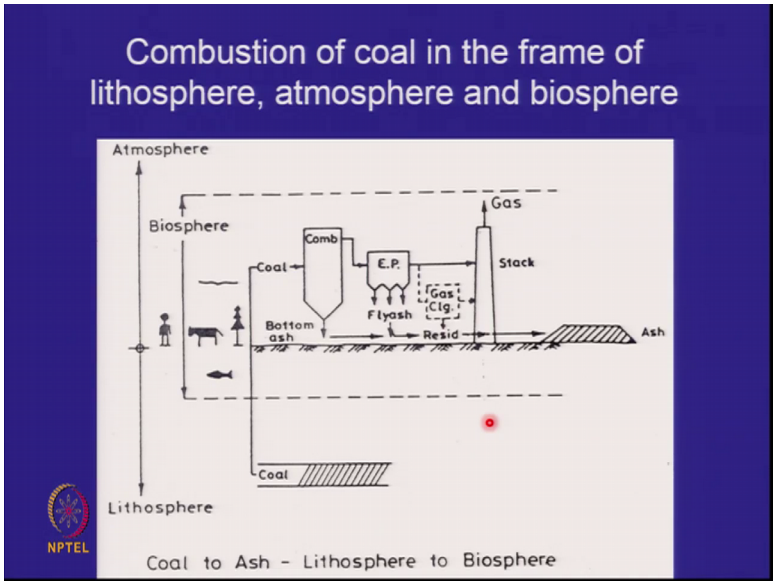

That means what remains after the combustion of coal and typically, what are we doing? Coal is available in mother earth deep below, it is available in the lithosphere, we all are

living in the biosphere, the birds, the plants, the animals, the fish; that means, on the ground surface and a little above it and a little below it.

So, we bring out the coal, we dig it out by the mining procedure, we transport it and then we send it to a thermal power station where the coal is burnt to generate electricity. Once it is burnt in a furnace or a boiler to generate electricity to make steam and then generate electricity, the residual of coal combustion falls down in the boiler or in the furnace and what comes here is called bottom ash, then the flue gases; that means, the hot gases which are formed; they move out into the chimney and they have a thick smoky look that is because fine particles are coming out of the chimney in the form of flying ash, flying ash or what they call fly ash.

So, you can have bottom ash which falls to the bottom of the boiler and you can have very fine particles going out is fly ash. To prevent this air pollution, we normally install what is called electro static precipitators. Now we will not go into; what are electro static precipitators, but these are nothing, but plates; very large sized plates which prevent these fine particles from going out with the hot gases, they attract these fine particles to their surface because of electro static charge and therefore, you get clean gases coming out, no smoky look and all this is collected on the plates which are occasionally vibrated and it falls down in to the bags below and comes out as fly ash.

So, there are 2 components of the products of coal burning bottom ash and fly ash; fly ash is collected in electrostatic precipitators, bottom ash is falling through this at the base and all these is placed in an ash pond or an ash mound. So, the Badarpur thermal power station in Delhi may be getting its coal from Bihar which is several 100s of kilometers away, but the ash does not go back. So, we do some impact on the environment at the mine and then when we are disposing of the ash that also is having an impact on the environment.

So, we are trying to understand; what is this ash; fly ash or bottom ash, sometimes the both of them are mixed together and sent the ash bound.

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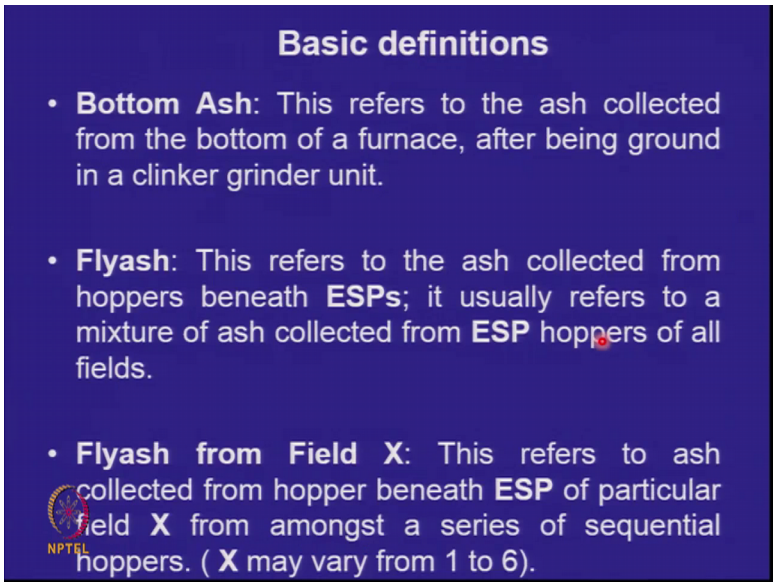

So, let us look at some terminologies bottom ash, these refers to the ash collected from the bottom of a furnace after being ground in a clinker grinder unit. So, at the bottom of the furnace or the boiler, you know large chunks of material fall, they may be coble sized, but there is a grinder at the bottom, you grind these and then there is a sieve. So, typically 1 to 2 an 1 to 2 inch is the mesh size of the sieve.

So, they will not allow the material to come out unless the grinder has ground this material into 1 or 2 inches in size. So, typically the particles falling through at the bottom through the sieve of the clinker grinder unit is bottom ash and its maximum particle size will depend on the sieve size use and typically will be 1 to 2 inches is the maximum particle size. Fly ash refers to the ash collected from the hoppers beneath the electro static precipitators. Now when this flue gases with this fine particles go through the flash precipitators, they meet a series of plates 1, 2, 3, 4, 5, 6; in each field, each plate is referred to as a each sets of plate are referred to as a field particles will settle down. So, as the flue gases go through in field; one the coarse particles of the flue gases will settle down then field 2; the finer particles, then field 3; the finer particles, the finest particles are caught in field 6. They are very small in percentage, but they are often very useful for some of the industry industrial application purposes like in ceramics and others.

So, flyers refer to the ash collected from the hoppers beneath the ESPs. It is the mixture of the ash collected from the hoppers. Now you have 5 fields, you will have 5 hoppers.

So, actually the ash which has been produced is in different sizes, some of them will overlap, but they are in different sizes going finer, finer, finer, finer, but when we take it out for sending it to a pond, we mix all of them together by we want; we can collect them individually we can collect them individually.

So, when you use the word fly ash from field X which X may be 1 to 6, this refers to the ash collected from the hopper beneath the electro static precipitator of a particular field X from amongst a series of sequential hoppers.

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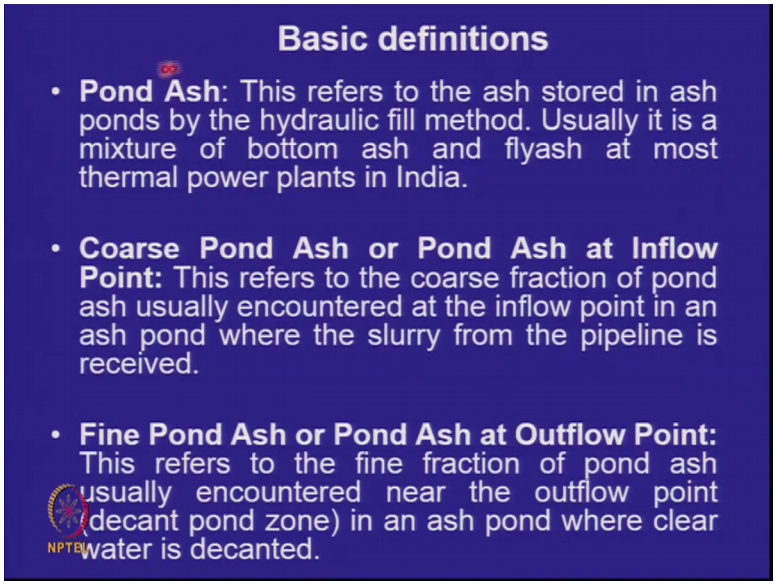

So, X may vary from 1 to 6 and the finest ash with the finer particles will come out in field 6, the word pond ash refers to the ash which is collected in the pond. Now depends on how a thermal power station is handling the ash, but normally because bottom ash is difficult to send in the form of the slurry, why its coarser fly ash is finer. So, the best way to send a slurry is to mix the 2, mix it with water and send it. So, coarser particles which will float in the finer particle matrix and will come out in the slurry pipelines.

So, pond ash refers to the ash showed in the ash pond by the hydraulic fill method usually it is a mixture of bottom ash and fly ash at most thermal power plants in India. Now more and more fly ash is being stored separately and bottom ash is being stored separately. So, when you go to a pond, they will say; sir, this is our fly ash. Firstly, any pond you go to the people will say, sir this is our fly ash, this is not fly ash, it is pond ash, it is a mixture of fly ash and bottom ash, but today in some of the thermal power stations,

the bottom ash being sand, like is being used for other purposes. So, they do not send it to the ash pond. So, what are you getting at the ash pond, actually you are getting fly ash. So, until you find out the processors of how the ash is being produced and how it is being sent, you will not know; what are the materials that you are dealing with. So, pond ash is what is available in the pond, it can be taken to fly ash.

Now, there will be sometimes, I will use the word coarse pond ash or pond ash at inflow point and fine pond ash or pond ash at out flow point when the slurry comes in a pipeline and it deposits itself on the base of the pond, the coarser particles separate out first and they settle first and the finer particles get washed away with the water, as the water goes further and further away, its velocity dissipates more and more. So, coarser a particles are near the inflow point, finer particles are near the outflow point or the outlet or the decant well.

So, coarse pond ash refers to the coarse fraction of the pond ash encountered at the inflow point where the slurry from the pipe line is received and fine pond ash is refers to the fine fraction of the pond ash usually encountered near the outflow point or the decant pond zone in an ash pond where clear water is decanted. So, the process of slurry in flow to the pond and then travelling and then outflow that is doing lateral sorting coarser portion at the inflow point finer portion at the outflow point.

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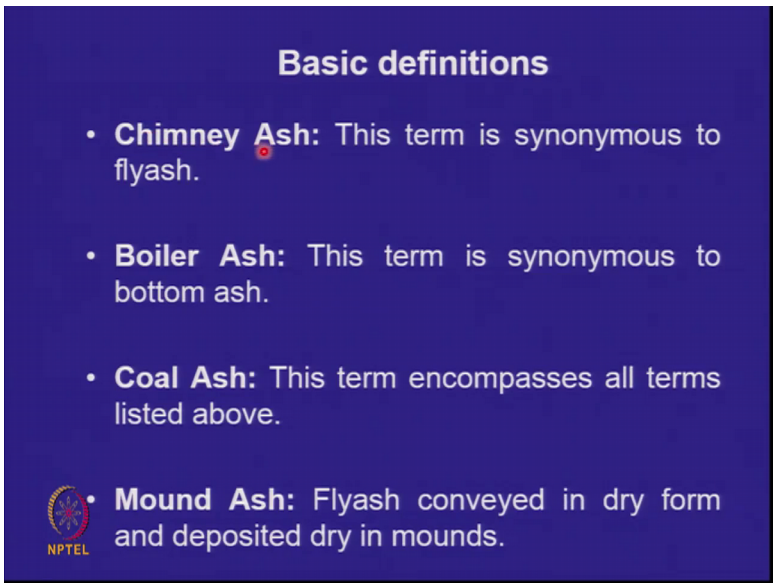

We will also come across the word chimney ash; the ash which settles down in a chimney; it is same as fly ash because this is what we; which came with the flue gases; boiler ash is a same thing as furnace ash, it is the same thing as bottom ash, it is what falls at the bottom of the boiler and comes out from beneath ,coal ash is a total term that is why we are using coal ash. So, that we are not confused is it flash, is it bottom ash, is it pond ash; that way is a subset of coal ash; mound ash is also like what is stored in a mound, but in encompasses it is like pond ash. The word mound ash and pond ash are similar; they only tell you that mound ash probably is ash deposited in the dry or moist state.

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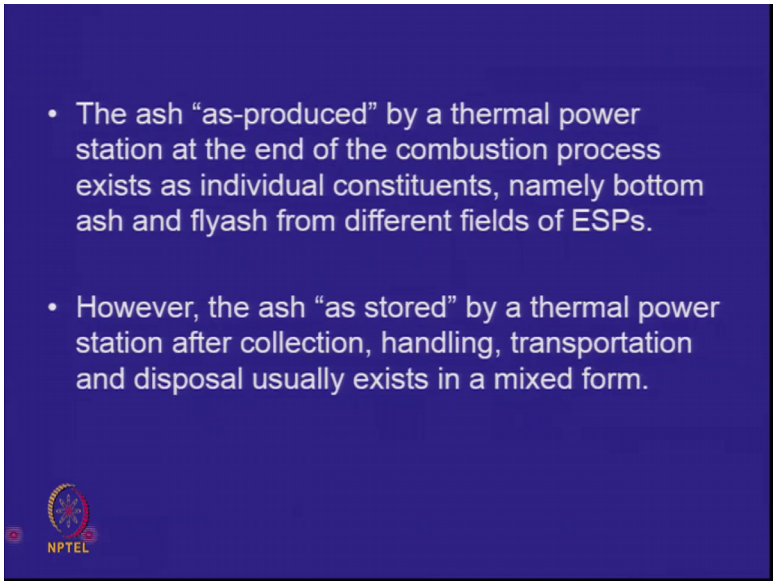

So, the ash as produced by a thermal power station at the end of the combustion process exists as individual constituents namely bottom ash and fly ash from different fields; however, the ash as stored by a thermal power station after collection handling transportation is usually in the mixed form. So, this we have to remember at the thermal power stations, we have ash in various component form field 1 to field 6 or bottom ash we can use it individually, but this is 24 by 7 electricity generation processes 24 by 7. So, the generation is on the boilers are functioning and this is coming out. So, there is a tendency that you mix it and dispose it in a pond.

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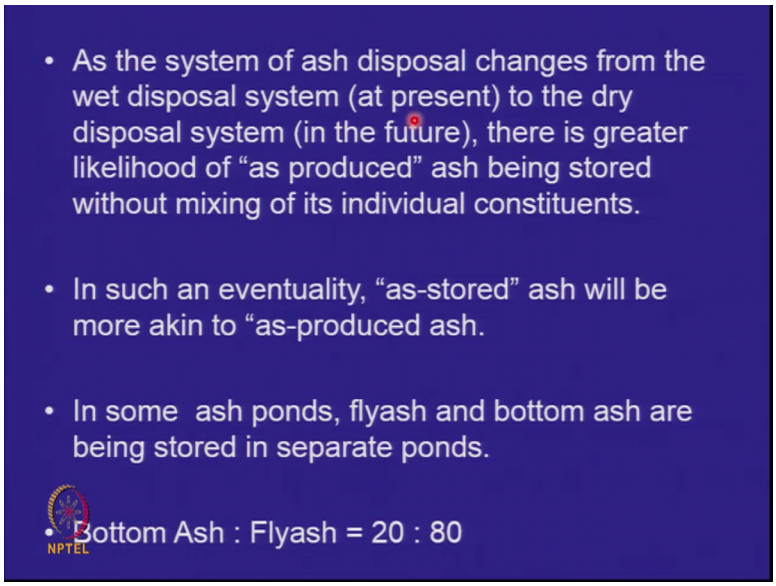

So, in the wet disposal system there is a tendency to mix the bottom ash to the fly ash because both can be sent through the slurry pipeline where as in the dry disposal system there is no requirement of mixing why both of them go can go on the conveyor belt or both of them can go in a truck. So, as the system of ash disposal changes from wet to the dry there is greatly likely hood of as produced ash being stored without mixing?

Now, dry disposal is more expensive than slurry disposal. So, it is not being adapted widely, but we can have a situation in the future where everything will be kept in its unmixed form. So, in such an eventuality as stored, ash will be more akin to as produced ash at the moment they are different. In fact, in some of the thermal power stations, now fly ash and bottom ash are being stored in separate ponds, fly ash and bottom ash are being stored; they are not being mixed; that means, you just make the slurry of the fly ash and send it in a pipeline, the bottom ash may come out in a conveyor belt and go to a separate pond in a separate holding area and typically please remember when coal is burnt 20 percent of the material is bottom ash 8 percent of the material is fly ash, the fines portion is 8 percent 20 percent is the bottom ash.

Now, in a coal, the ash content can vary depending on the type of coal that you get or I would love to have coal which has 100 percent coal and a 0 percent impurities, right and if I just go back to; how this coal was formed, it is nothing, but a lot of organic material which has fallen and have been buried and has converted itself to coal under high

pressure of the over years. So, if there is some soil which also got buried, with it the coal will have some impurities right; that when you burn the coal those impurities will come out in the form of ash. So, you can have coal which has 5 percent impurities and you can have coal which will have 55 percent impurities.

So, a thermal power station wants to get the best coal that it can, but it will only get that coal which is available nearby. So, understand this; Indian coal has got high ash content 35 to 45 percent; that means, high impurities imported coal from some of the countries has 3 to 6 percent ash. So, sometimes private thermal power stations will import coal from Australia because even after paying the cost of the transportation by sea, they will find that the residue which is there the colorific value is much better they get much more heat out of the same unit of coal used and in the end they have very little ash to dispose.

We have a lot of coal in India, but it is high ash content coal, our coal mines send the coal from the mine in the trains to the thermal power stations where this 35 to 45 percent material is remains and it goes to the ash pond, does not go back; one can spend more money on coal beneficiation; coal beneficiation is the process by which only the good coal comes to the thermal power station, but the bad coal remains, but that requires a lot of money and investment and at the movement we can have some beneficiation, but still a lot of ash comes to the thermal power plants.

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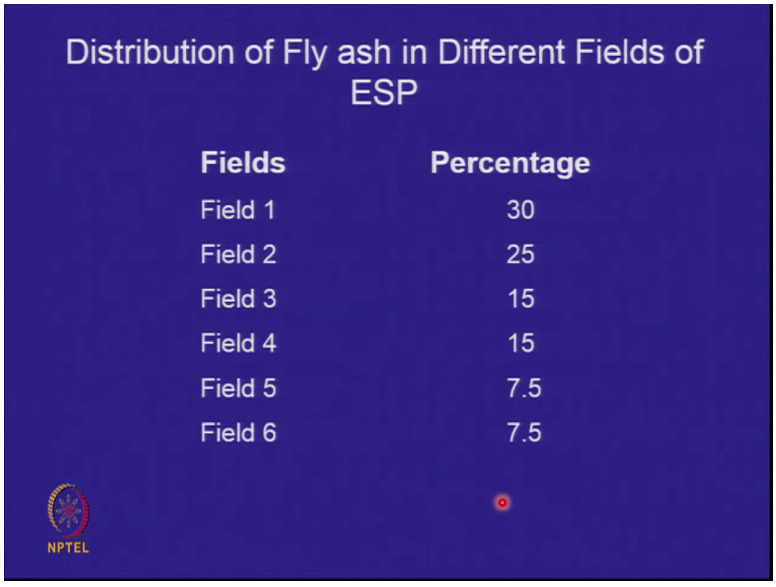

If I look at the distribution of the fly ash, you may like to see this; this is not a these are highly variable when I use the word 30, here it could be 28 to 35, these are just approximate ranges, but the first field; the first set of electrostatic precipitators capture 30 percent of the material. So, I said total ash is 120 is bottom ash 80 is fly ash, if I consider this 80 as 100, now then 30 would fall in field 125, in field 2 like that and the least would fall on field 6, it is the finest ash, but very very low value in terms of quantity that is collected; industry is very very keen to get these 3, 4, 5, 6, fields very keen because of the very fine nature, they have very good pozzolanic properties and other properties which are very useful to the industry, but as far as we are concerned everything is mixed and it is there as pond ash

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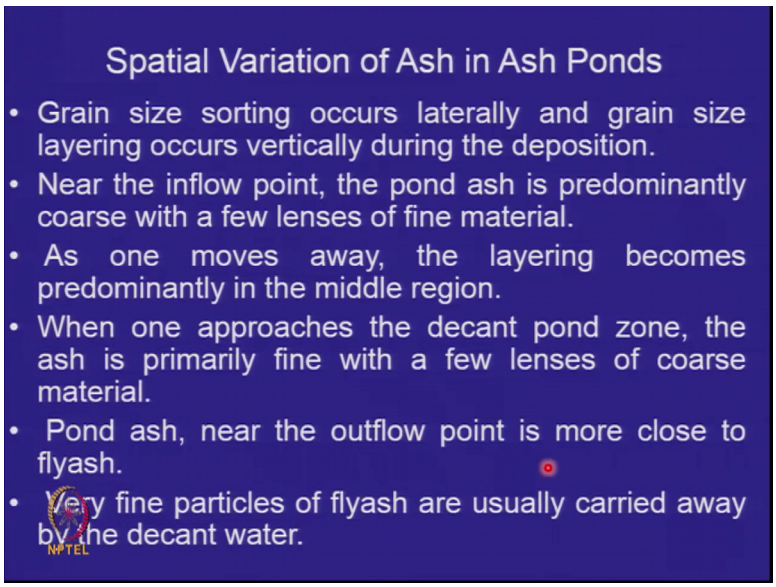

Now, as I said, there is spatial variation of ash in ash ponds, grain size sorting occurs laterally and grain size layering occurs vertically during the deposition, 2 things are happening, the slurry is coming in and it is moving in from the inflow point to the outflow point and I said coarser ones will get down here and finer, but now let us look at ourselves at one point when you do the hydrometer test, what happens at one point; the coarser a particle settle first at that point and the finer settle later.

So, while there is some lateral sorting there is also vertical layering. So, if you dig or excavate ash, you will find layers of coarse ash and fine ash because till the next load came first, the coarse settle then the fine settle. So, there is a kind of layering. So, grain

size sorting occurs laterally and grain size layering occurs vertically during the deposition, I already said this, near the inflow point pond, ash is predominantly coarse with a few lenses of fine material as one moves away layering becomes predominant in the middle region when one approaches is the decant pond zone the ash is primarily fine with the few lenses of coarse material.

So, pond ash near the outflow point is more close to fly ash and if you do not have enough space or area to allow retention time; then the very fine particles of fly ash; those 7.5 percent which we wanted to capture; they are usually carried away by the decant water because that is the muddy water that you are getting out at the end. So, when you deal it with it in the form of slurry; you are having a differences induced in the pond ash.

So, if that was pozzolanic or if the fines were active or pozzolanic or they had some kind of a like activity colloidal nature, they are gone or they are going. So, you are left with more and more inerts in the pond ash. Let us look at the shape of these particles, what do you think they would look like; ash is produced by a process of burning of coal and something gets volatilizes and then it sort of cools down. So, if you have something which is heated and then its allowed to cool rapidly do you think it will be crystalline in nature or do you think it will be amorphous in nature?

Student: Crystalline.

If I have rapid cooling versus slow cooling which is crystalline and which is amorphous.

Student: Rapid is crystalline.

Rapid means you particles did not have time to rearrange themselves in a efficient matrix. So, rapid would be amorphous and slow would be crystalline because slow meant that the particles would arrange themselves in to a crystal arrangement into a dense packing or a loose packing or whatever tacking that is efficient. So, when materials are quenched fast or cooled fast it tend to be amorphous. So, please do remember I am just introducing this because remember ash is created by the process of heating and cooling and what do you think would ash comprise of which mineral intuitively; I said that along with the coal soil also got buried.

So, soil was silica based. So, in a sense, silicon di-oxide SiO2 is going to be the predominant material, there will be other things. Now first let us look at the shape of the particles, we go into a micro scope and look at these particles and then we have to go to a scanning electron microscope to look at the very fine particles, if I look at a bottom ash particles, I just wanted to see this particle not a very clear shape and I can see some round particles because most of the particles which are large sized are not round.

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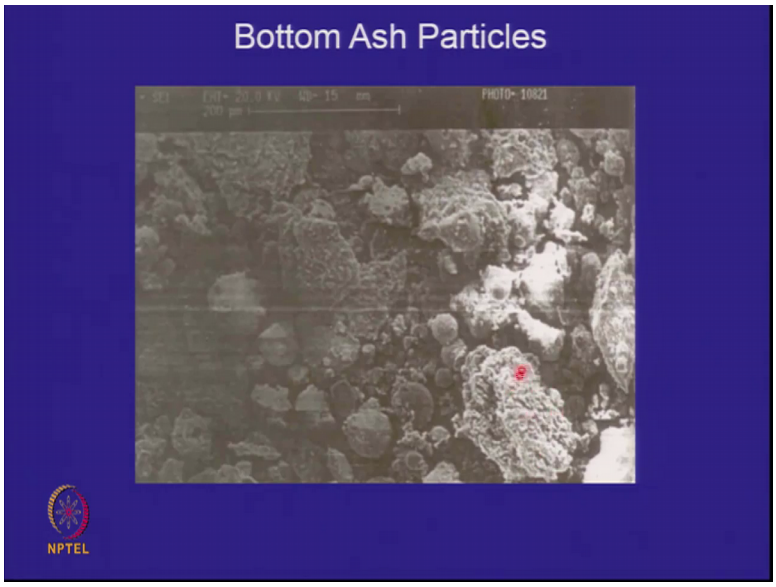

And if I go to pond ash that was bought a mash earlier, what do I start to see a lot more of rounded particles, I am looking at pond ash because it is predominantly fly ash, but a fly ash particles more several round particles are visible.

So, we will come across the word cenospheres, you will come across the word spherical particles, but in a sense these are these amorphous particles and I go back to this again you see very less of them in bottom ash bottom ash is all kind of clinker conglomerated material fuse together pond ash fly ash.

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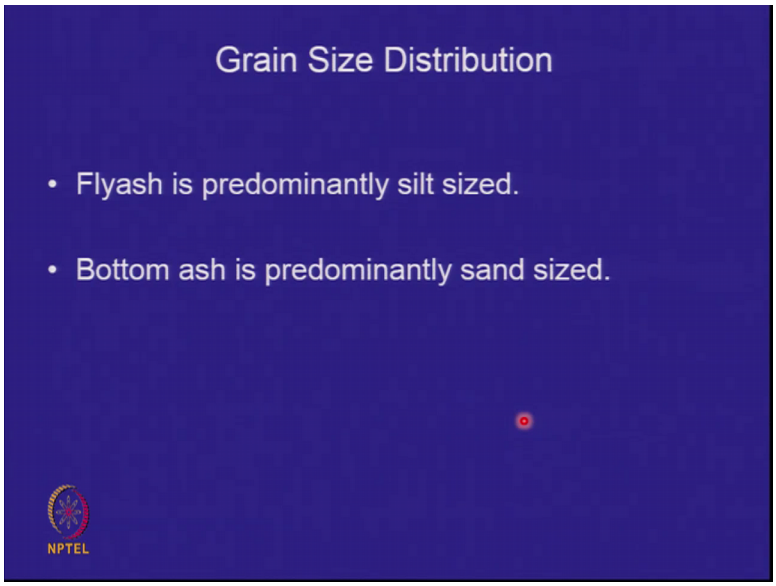

So, fly ash is predominantly silt sized, it will have some clay size materials bottom ash is predominantly sand sized and depending on the screens in which it is coming; it can be also have gravelly material.

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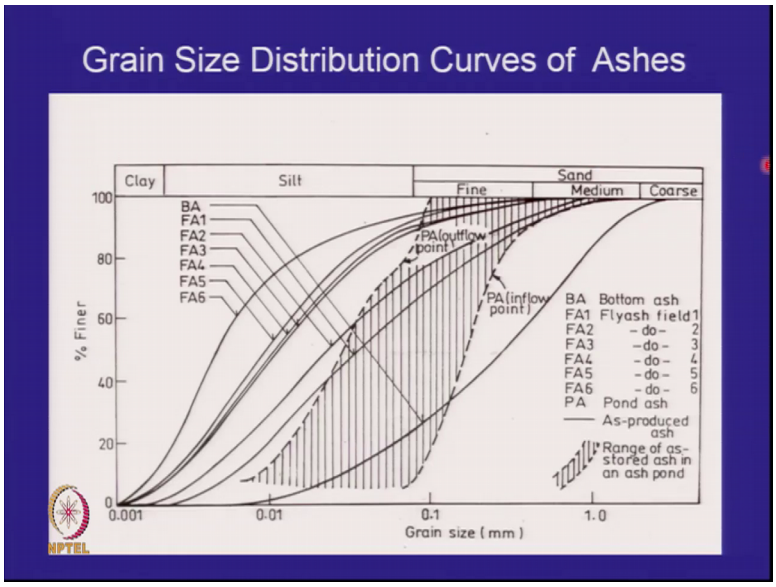

That means the screen or the sieve beneath the clinker grinding unit at the bottom of the boil and this is the grain size distribution curve of the various components from a particle thermal power plant.

If I take bottom ash; let us see; first go down this line, this is the coarse size particle bottom ash is the coarser material, it is less than still less than 1 millimeters, but it can be as high as depending on the screen size larger particles as well and then I do field 1, field 2, field 3, field 4, field 5, field 6. So, this is from the electrostatic precipitators, we picked up the material from the electrostatic precipitators, I mix all of that and I put; send this to the pond and this is the pond ash is results from the same thermal power station.

This is at the end of the production of the ash. So, we stood beneath the boilers and got this out furnaces and this was from the each hopper of the electrostatic precipitator in the pond ash is in this range. This is near the inflow point that is near the outflow point. So, please see if this is silt; if this line is the boundary between silt, all the fly ash is predominantly silt, if this is the silt line, all the bottom ash is predominantly sand, if this is the silt line, all the pond ash at the inflow point is predominantly sand sized and if this is the silt.

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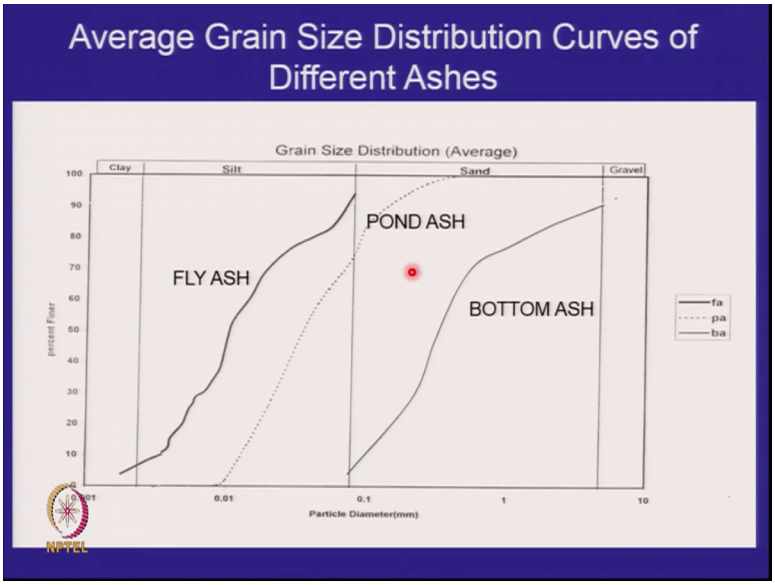

And sand boundary; all the or most of the material is silt sized still bottom ash is coarser then pond ash at inflow point and fields are final in a sense bottom ash can be like this fly ash can be like this and for this pond ash can be like this.

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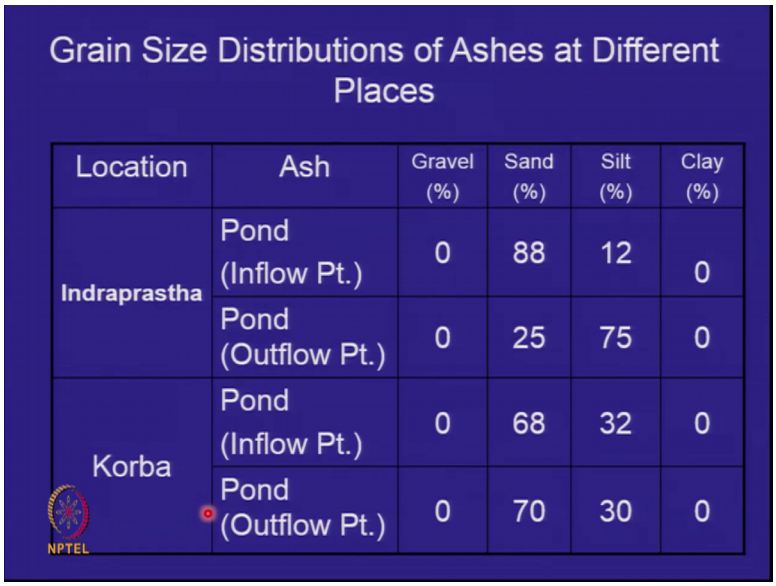

So, if I look at some of the data which is now available to us at different thermal power stations; inflow point sand 88 percent, 12 percent silt outflow point, 75 percent silt in flow points, 68 percent sand this is so surprising outflow point, 70 percent sand; that means, the outflow point had a pipeline which was depositing material very close to the outflow point, but in bulk of the other cases outflow point 20 to 75 bottom ash 18 point 2 inflow points 71; 24.

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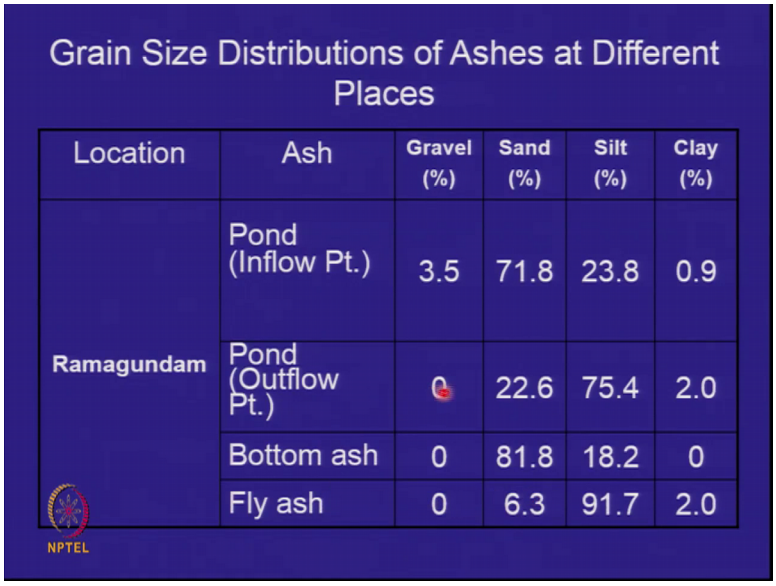

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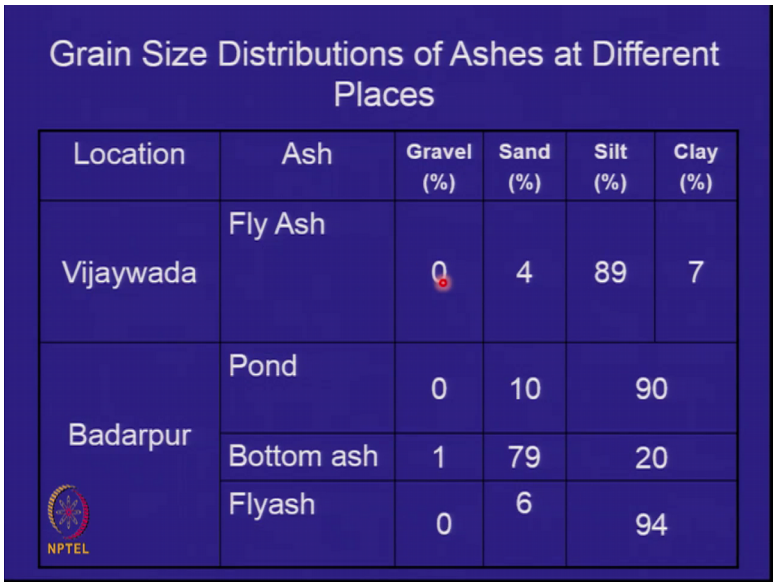

So, in bulk of the cases, the sand is near the inflow point always and we are getting some gravel; that means, their screen of the clinker grinder is slightly larger Vijayawada.

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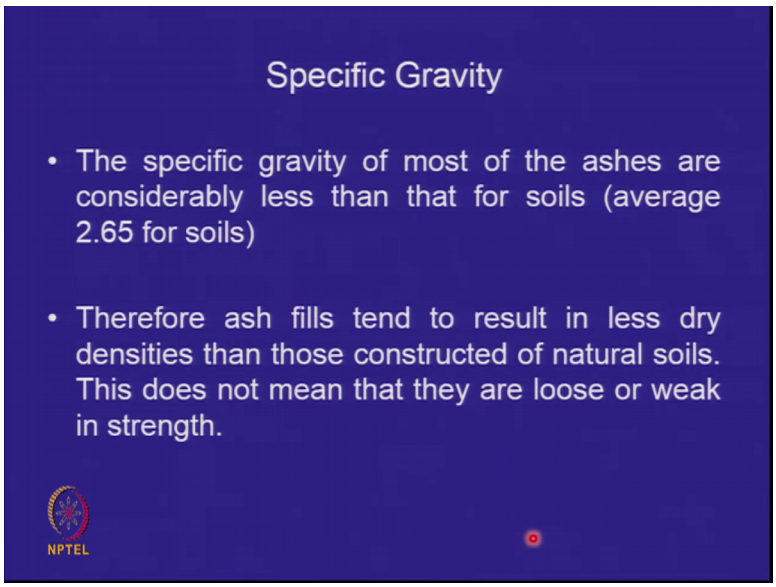

We wanted to talk about specific gravity and we will look at this specific gravity of most of the ashes are less than that for soils. So, that is the first observation, hello, we will see in the next table therefore, ash; if it is used as a soil results in lower dry density than natural soils this does not mean that they are lose or weak we will look at this later, but

these are some results of the specific gravity of ashes from different thermal power stations bottom ash fly ash pond ash pond ash and flow out flow.

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Specific Gravity of Ashes at Different Locations

Location	Specific Gravity			
	Bottom Ash	Flyash	Pond Ash (Inflow Point)	Pond Ash (Outflow Point)
Indraprastha	-	-	2.30-2.50	1.84-2.0
Korba	1.84	1.85	1.73	1.75
Ramagundam	2.28	1.85	2.22	2.13
Vijaywada	-	2.03	-	-
Badarpur	2.22	2.24	2.22	
CESC	2.09	2.16	-	-

So, see the lowest the highest value is about 2.2 here, ignore this 2.3 and 2. So, the highest is about 2.2 and the lowest is 1.7. So, the specific gravity of ash varies is from 1.72 to 0.2 typically.

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Plasticity

- Coal ash is non-plastic in nature.

And when I try and do the atterbergs limits, though it has got clay sized particles on it, let me go back and see if I can see; this is the clay to the silt boundary can you see this. So,

the flash does have clay sized particles in it, but it is non plastic we are not able to make the thin thread that we want to make from it yes you cannot make the thin thread you have an issue.

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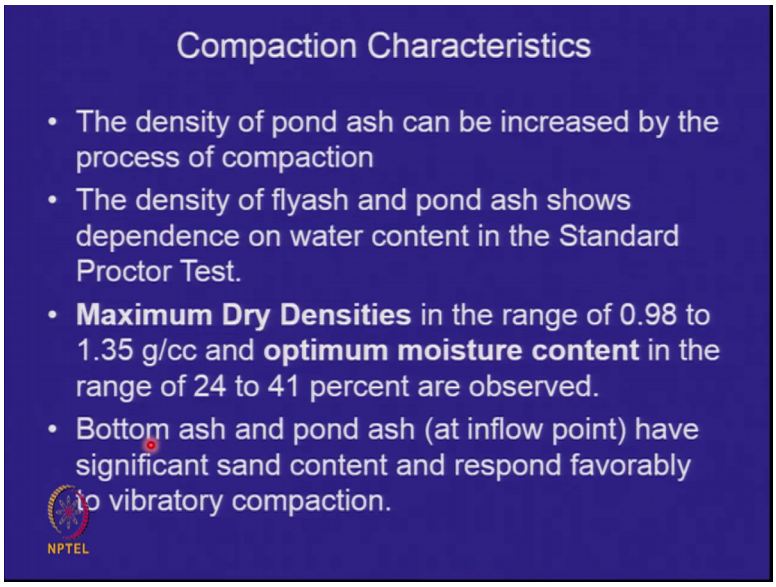

We will then now like to see the compaction characteristic of this material, but since you are almost towards the end of today's lecture, let us see what we have understood. Now we have understood that ash is made up of solid particles which have low specific gravity then soil ash is non plastic; what else did we understand, ash is made up of spherical particles which is not what you counter, if you were to look at Yamuna sand or Badarpur sand under the micro scope, will you see spherical particles, no, they all have silica mineral, they are either cuboidal or they are angular or they are sub angular or they are definitely not circular. So, and I also have talked about the concept of amorphous silica ash has silica which need not necessarily be in the form of crystals which is different from the quartz mineral that we talk about.

So, in the next class, with this one thing is clear, ash is a lighter material than soil. In the next class, we will look at the compaction characteristics and also we will look at strength compressibility and permeability and did not like to see; how different is it from soil and how it will influence; whatever we design with ash, after that; we look that at mine tailings, but I can give you a queue that the specific gravity of mine tailings is higher than soils because some of the metal still remains in the tailings and is not able to

be taken out by the mining process. So, we are going to see a material with lower specific gravity we will see materials with the similar specific gravity and we will see material with lightly heavier specific gravity in the next class. So, any questions would you like to something which bothers you. So, we will take it from here in the next class.

Have a good day.