Non-conventional Energy Resources

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Lecture – 26
Geothermal Energy

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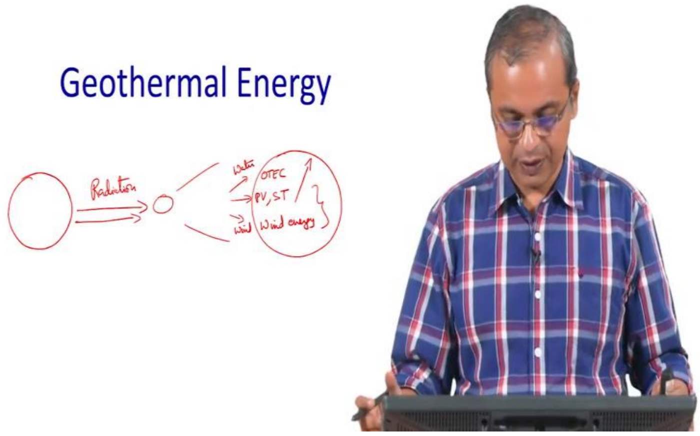

Hello, in this class we are going to look at geothermal energy. Interestingly much of the time that we have you know looked at the solar energy for example, and particularly let’s say solar energy and then how it related to say wind energy even ocean thermal energy, much of the time it was energy that was coming to us from outside ok. So, you are looking at the radiation from the sun reaching the earth those through some radiative process and from there we extracted that energy. So, various different things happened.

So, we had the sun, and then the earth. So, we have radiation here and then on the surface of the earth if you magnify this on the surface of the earth we had various weather phenomena. So, we have direct sunlight. So, that we had as photovoltaic or you know solar thermal and then this would affect the wind and then you have wind energy . So, you have all the windmills wind turbines etcetera this would affect the water and then you had OTEC. And really I mean as I discussed earlier really these two are the more significant ways in which renewable energy is being explored internationally and therefore, we also correspondingly spend more time on it, those technologies are much more mature there are many companies which you know actively work towards putting these products out.

Many of the other technologies we are looking at are not that mature at least ocean thermal energy conversion is not that commonly present, even though it is something that people are looking at you don't have many companies which are deploying it although that is increasingly being considered. Geothermal energy is an interesting concept in this context because unlike this situation where you had this radiation coming in which is what you know is the starting point for many of these other technologies here we are looking at something different you are looking at what is coming from inside earth ok, so what is coming from inside earth that is geothermal energy. So, that is already there that is energy that is sitting inside earth.

So, if you see if you look at this you know the spectrum of renewable energy sources people are really considering a wide range of ideas looking at a lot of different possibilities and, so there is no real restriction you if you can think of some other interesting way of utilizing energy that is around which we may not have recognized as something that we can tap then this is definitely something that we can look at. So, this is energy geothermal energy that comes from within earth and it is interesting to see what is the possibility of us capturing it and utilizing it in a manner that is useful for us ok.

So, and in terms of it being renewable I mean we will soon see that you know for all practical purposes it is infinite I mean from the perspective of you know lifetimes of human beings and the you know age of the planet etcetera its significantly I mean it's it's not something that we are going to run out of in you know pretty much the entire years that lye ahead of us.

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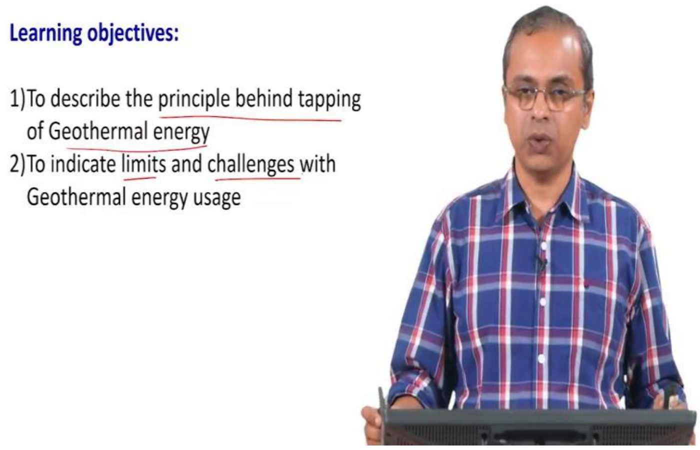

So, it is in this context that we look at geothermal energy. So, we will begin by first describing the principle behind tapping the geothermal energy so that's the basic idea that is being utilized here to extract this geothermal energy and put it to some use. And also in that context look at any limits and it is particularly challenges associated with geothermal energy usage. So, these are the two that we will focus on two objectives that we will focus on as we look through the content of this class, ok.

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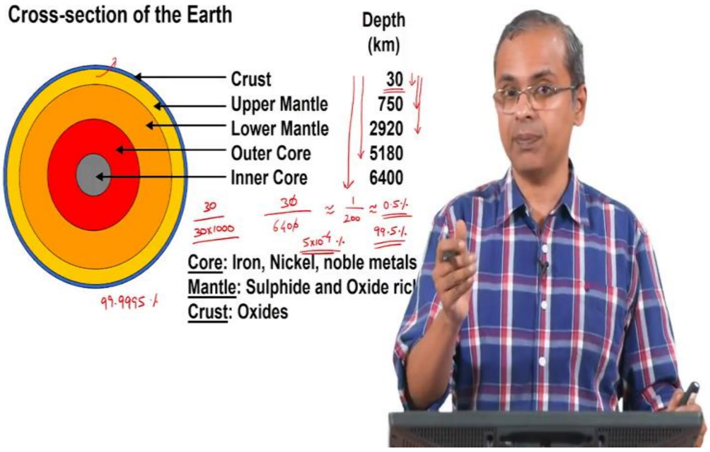

So, if you look at the cross section of the earth and this is where I think you get a sense of how more or less unlimited it is right. So, on this cross section we have not shown the atmosphere the atmosphere actually if you look at you know it is it is also a very thin layer around this planet the effective atmosphere that we use.

Ah. So, wind energy etcetera would fall within that thin layer, but the land area that we live one is essentially part of the crust ok. So, the crust is in general some thickness of the order of about 30 kilometers. So, that's the thickness of the crust. So, and it is also not completely stationary, the crust you know essentially consists of different plates which are sort of moving against each other and that is how you have all these you know for example, the Everest is still growing, that is how we get earthquakes. So, many things happen.

So, in a fairly long scale of time it looks I mean at least a human lifetime scale the movement is not dramatic, but it is there I mean it is there and that is what leads to like I said earthquakes when it when there is an earthquake of course, it is dramatic at that point and significantly effects a human life, but in general even though you know you may say that say the Everest is growing by so many centimeter every year or so, many millimeters every year whatever it is.

That's not something that is dramatic in our scale of time. I mean you don't look down and then you look up and then you suddenly see Everest as grown it does not work that way it is a relatively slow process. So, for all practical purposes the crust is relatively stable relatively stationary in from that perspective although there is some movement that is going on. Below the crust we have the upper mantle.

So, the crust is really the only part that is I mean truly solid. So, to speak then up below that you have different different layers below it and so the thickness of the upper mantle is about 720 kilometer. So, thickness would be this then. So, you are looking at a crust being just this thick and the upper mantle would be this thickness. So, that's the upper mantle thickness 720 kilometers then below that is the lower mantle 2170 kilometers. So, that is quite significant. So, from here to here you cannot see that there, upto that.

So, we will just select something else here, from here to here that's the lower mantle. And then the outer core which comes from here to here that's the thickness of, the outer core is about 2260 kilometers thick that's the thickness and then the inner core. So, it is from center to here. So, I will just a , so the inner core is from here to here . So, that’s the thickness of the inner core which is about 1220 kilometers thick. So, if you total up all of these that’s the thickness of the earth from the surface up to the center essentially the radius of the earth. So, if you total this up you will get roughly about 6400 kilometers that’s the radius of the earth ok.

So, the core basically contains iron, nickel, some noble metals are are present in the core mantle consists of sulphide and oxide has is has is both sulfide and oxide rich and the crust is mostly oxides. So, you have all this silica and everything that’s all in the crust. So, this is how we get this is how the earth is, so this is what we are looking at ok. So, if you actually look in terms of depth this is what we are looking at you are looking at about 30 kilometers depth for the crust and then from there the upper mantle will I mean all the way down if you go to the end of the upper mantle you are looking at a 750 kilo meter depth then you can go further down nearly 3000 kilometer depth is where the lower mantle would end and there your outer core would start and then from there to the end of the outer core is about 5180 kilometers and then from the surface all the way deep into the center of the earth is about 6400 kilometers .

So, this is what we have in terms of the structure of the planet and incidentally. So, so we will also get an idea of the temperatures that we are looking at here in terms of what is expected at different locations in this in the planet. So, we will just look at that we will revisit this information in a few moments.

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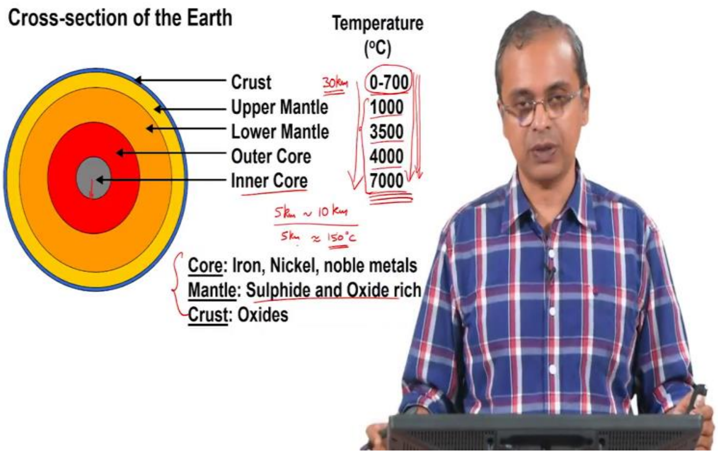

So, this is the kind of temperatures we are looking at the crust is anywhere from 0 to 700 degrees centigrade in temperature ok. So, you start at the topmost layer of the surface of the earth which is where we are you know essentially standing. So, based on which part of the world you are sitting in it could vary you know it could be 10 degrees, 15 degrees, 20 degrees, 30 degrees, something like that it can go down to about 0 degree centigrade can actually can even go negative based on which part of the world you are and so an approximate number we are looking at. So, for giving ouselves a range, so we are looking at about say 0 degree centigrade as the starting point of the temperature here and then it continues you can go warmer and warmer and then as you go deeper and deeper into the crust you could reach about 700 degree centigrade is what you can expect in the crust.

The upper mantle will have temperatures of the range of about a 1000 degree centigrade then you go to the lower mantle that's about 3500 degree centigrade. The outer core is about 4000 degree centigrade and the inner core is about 7000 degree centigrade. So, like I said we will look at these numbers again in in just a few moments. This is just to give you an idea of the kind of numbers we are looking at when we discuss the planet. So, the question is actually how do we arrive at all of this information ok. So, how do we arrive at all of this information? So, although you may have read science fiction you know books along the nature of journey to the center of the earth and so on.

If you actually look at the temperatures here right these temperatures they are so high that basically we have no technology that can do this we have no technology you cannot just dig a hole and arrive at the center of the planet of the of the earth and there is no way any human being is going to survive that, there is no technology that we know that is going to survive that. So, in fact, in the foreseeable future we have no means of actually reaching the center of the earth and finding out what exactly is happening there. So in fact, almost everything I have shown you in this slide in in terms of depth in terms of thickness depth and temperature and even this information that you have down here.

Very little of this is actually available to us as as an experiment that you can conduct physically conduct you know you take a sample you put it and put it in for some analysis and come up with all this information saying that as per the sample which was picked up from the core this is the composition of the core this is the composition of the mantle and so on. So, we are actually not in a position to do any of this stuff. So, in fact, the situation is that using a lot of incidental information about the planet we have theories which predict what is inside the planet, interestingly.

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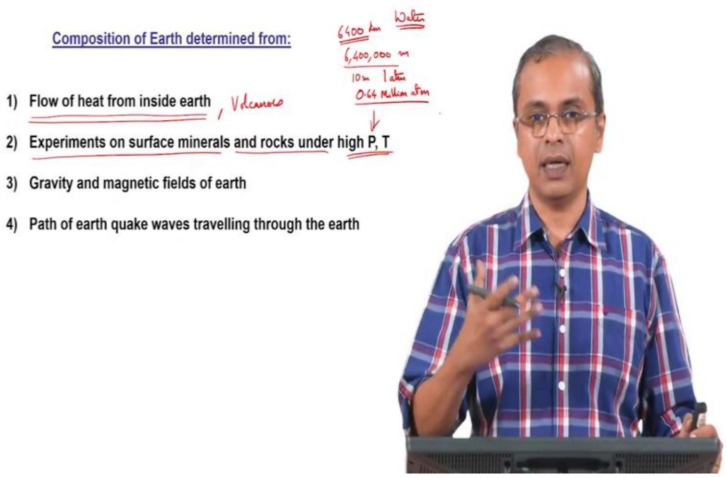

So, for example, if you look at what you see here we look at what is the flow of heat from inside the earth. So, based on let's say just the temperature of the earth as you go deeper and deeper into the let's say even the crust. So, where is that heat coming from? That heat is not coming from the sun here it is already heat inside the planet. So, there is an expectation that you understand that something inside deep inside the planet is hot. So, we do understand that you do have volcanoes which are you know sending out material from under the ground. So, we know that below the crust there is something that is molten that is hot that is able to come out. So, we can you know look at those temperatures you can look at the composition of what is coming out. So, you have some idea of what is underneath right. So, that that is that is another piece of information we have.

So, flow of heat from inside earth we also have a volcanoes that give us a lot of information of what is at least just below the crust. So, that gives us a lot of direct information. So, that is again a place where you can actually see a sample where you can actually do something with the sample , we can also do experiments on surface minerals and rocks right, both surface minerals and rocks under high pressure and temperature ok. So, you can do experiments under high pressure and temperature, but this is actually little bit tricky because temperature you can actually heat up if you want to reach you know a range of temperatures. So, for example, if you look at this temperature that we are seeing here 7000 degree centigrade okay even though 7000 seems like a large number technically getting 7000 degree centigrade is not an impossible task is a very doable task there are many places in the in the world where we have experimental setup which is crossing 7000 degrees centigrade.

So, any place there is a nuclear reactor for example, some nuclear power plant is there. You are actually crossing 7000 by a long margin you are you know right now you are running fission reaction or something like that. So, you are looking at temperature which may be approaching even a million degree centigrade. So, a very high kind of temperature is not unusual to accomplish reaching about 1000-2000 degree centigrade occurs in labs routinely. So, 7000 degree centigrade that will be ways to reach if you run a plasma arc for example, you are looking at 4000 degree centigrade, so you are getting temperatures closer to 7000 degrees centigrade and. So, that is not very impossible you can easily physically get those the kinds of temperatures. The challenge therefore, is the pressure.

So, we saw actually even with the ocean you know thermal OTEC kind of analysis that if you go even 11 kilometers down into the sea, this is just seawater right sea water is just above you 11 kilometers of sea water you have 1000 atmosphere, 1100 atmospheres of pressure sitting on top of you and so maybe you can access that experimentally by you can put 1100 atmospheres on top of an experimental setup by just sinking it into the sea and get yourself that kind of a pressure. But generally speaking even that is going to be insignificant in this case because that is just 11 kilometers you are now looking at about 6400 kilometers of material sitting on top of some things. So, even if you look at say water for example, so 6400 kilometers so that is 6400 kilo , so this many meters. So, you are basically looking at if you divide this by 10, you are looking at more than half a million atmospheres right.

So, if for every 10 meters if you have one atmosphere if you just take water I am only taking water okay, I am not taking any other material just water. If you had an ocean that was 6400 kilometers deep we don't have that right we don't have that we only have you know some 11 kilometer deep portion I am just hypothetically saying if you had a notion that extended all the way to the center of the earth right. So, that I am just considering that as a hypothetical situation.

So, in that would be this many meters and every 10 meters is one atmosphere. So, if you, so this is nearly 6 and a half million meters. So, you are really looking at about 0.64 million atmospheres ok. So, more than a more than half a million atmospheres that is if it were only water. now, we do not even have water we have a much denser material that is under us we have molten metal's, we have various other materials that are all you know sitting at very high temperatures you have iron, you have nickel, that is in the core you have sulfides and oxides in the mantle. So, you have something that is distinctly heavier and denser than water.

So, what is just you know half a million atmospheres if it were water is going to be many orders of magnitude more if you have all these materials. So, the possibility that you can actually generate this kind of a pressure in your lab is actually very difficult. So, there are people who focus on high pressure studies and. So, they they have specialized ways of trying to generate at least in extremely confined regions they cannot do a large sample, but in extremely confined regions they can generate at least for a short brief instances of time they can generate high pressure. So, they do these kinds of studies. So, they study what happens to minerals that are present on the surface and rocks that are present on the surface under extremely high pressure and temperature.

So, this gives them an idea if the same material were heading down further and further down if this were sinking into the core then what would happen. If we were sinking below the earth's crust if it fell through the earth's crust and kept slowly sinking deeper and deeper inside what would happen, what in what condition will it exist. So, this is something that people need an idea for right.

Then we also have information about earth's gravity and about the magnetic fields of earth. So, again you had this. So, this is obviously, going to you know all this information has to be pulled together. So, you have magnetic field. So, you can sort of figure out what kind of material should be there. So, we need something that will be able to generate and sustain magnetic fields being present inside the earth. So, that is how you figure out that now what kind of materials we narrowed down what kind of materials may be present.

Another very important parameter or a very important information that people use to figure out what is sitting where on the earth because if you can see here we have come up with nice layers right, we have so many different layers saying this layer is this material that layer is the other material etcetera how do we ever know this they mean it is impossible for you to I mean figure this out without even doing a sample. So, one major you know data point for this comes from earthquakes ok. So, that's a very important data point in this analysis. So, what happens is every time there is an earthquake there are seismographs these are instruments that are recording the earthquake intensity they are recording the time that the earthquake took place etcetera.

These are located all over the world ok. So, now, they have it present all over the world. So, you can figure out the you know based on the data picked up by all these seismographs you can sort of try to figure out what was the path that the earthquake wave took for it to reach that location. So, therefore, you can use this information collectively spread across all these places where this was recorded to figure out what sort of materials it must have gone through to have arrived here at this point in time with this kind of intensity or attenuation etcetera.

So, that kind of analysis they do and on that basis they figure out what might be they say you know kinds of materials that may exist in this path between here and where that earthquake took place. So, this is another very important piece of information. So, you see that all of these are sort of indirect pieces of information maybe except for the what comes from the volcanoes what is the heat present inside the earth and some experiments that we do on the surface minerals which is, so these two are direct what is on the surface, what analysis you do on the surface is direct. What analysis you do on the volcanoes is direct those two are perhaps only to direct pieces of information you have. Everything else is an experiment that you do and you make conjecture that this is possibly what is going on etcetera.

But these are all diverse experiments they are you know experiments from different, totally different starting points and so, if you have a model that puts all of this together and shows you that if you had a certain composition for earth and if that composition was distributed in a certain way in different locations on the planet different depths in the planet. Then the property that the planet would demonstrate would be consistent with all of the data that you are getting here ok.

So, its density its gravitational field, everything a magnetic field, temperature, everything would become consistent if all of those parameters were right. So, this kind you know consolidated analysis is what enables you to come up with this kind of information. And even there, there is no it is not that it is without any controversy. So, for example, different models it is not I will not say controversy different models predict different values for what is the exact temperature of the core for example.

So, there are models which predict about 7000 degree C there are other models which predict about 5000 degree C, 5500 degree C. So, a range of temperatures are there, but at least in in general they agree with this idea that you know you are starting off at around 0 degree C and as you go deeper and deeper into the earth you are looking at several 1000 degrees centigrade increase in temperature. So, this is come into the planet from the time that the planet was formed.

So, it is inherent and in internal to our planet and it exists. So, you can see here we are actually occupying only 30 kilometers we are not even occupying 30 kilo we are just occupying the surface of this 30 kilometers right. So, we are not really occupying anything actually. So, we are basically you know the the crust itself if you see is 30 by whatever 6400. So, if you remove that. So, you are looking at roughly 1 by 2, 1 by 200.

So, it's only 0.5 percent of the thickness of the earth right. So, so it just in terms of thickness 99.5 percent is everything, but the crust ok. So, everything else is 99.5 percent related to the crust. And we are as human beings we are using not even this 30 kilometers we are forget 30 kilometersm forget 20 forget 10 we are barely using the top you know I would say literally we are we are using the top 20 meters maybe top 20 meters top on average across the planet across the planet if you look at all our agricultural activity, all other activities we are probably using only the like the top 10 meters of this crust across the board.

If you look at you know you know foundation of our buildings and average it out because there will be people who will be using just the surface alone there will be people who will be digging a little deeper, if you average everything out we are probably using only about 10-20 meters of the crust.

The rest of it we are actually not using at all. So, we are actually using much less than this. So, if you see even, even if even if you consider the crust as a whole I am saying that we are you the crust that is only 99 that's only 0.5 percent. So, and in reality we are probably using. So, this is 30 kilometers. So, even if you say 30 meters. So, that would be another what is it another two or three orders of magnitude let's say three orders of,magnitude. So, let's just see that 30 yeah. So, you are looking at 3, 3 orders of magnitude less in terms of actual space that we use. So, we are looking at instead of 5 into 10 power minus 1 you are looking at 5 into 10 power minus 4 percent.

So, this is the actual volume that we use actual thickness of the planet that we use 5 into 10 power minus 4 percent is the thickness of the planet that we use. So, something like you know 99.9995 percent is unused. So, 99.9995 percent is unused by us of the planet. So, therefore, if there is energy in this planet that is distributed into this 99.9995 percent of the material of the planet for all practical purposes it is infinite for us, its infinite energy that is available for us we are using such a mean we are not using it. In fact, at the moment we are basically not using it, it is all available there its almost infinite energy for us and we can potentially tap it indefinitely.

And in foreseeable future I mean even if we I mean extensively use this energy the chances that we are going to run out of this is just impossible I mean is nonexistent in any grand sense of the word. So, this is for some information that we should at least you know keep in mind as we sort of look at this activity. So, we are basically using a very small percentage of the crust this information this amount of material and therefore, any heat that it contains it's a huge thermal mass right there is a massive thermal mass that is sitting under us which we can tap heat is energy and if we can tap this energy we are in excellent condition.

So, the geothermal energy is essentially that we are tapping the energy that is available under us and it is already there. So, you don't have to burn anything, you don't have to again burn coal or any such thing you simply have to reach that hot spot that is it you have to reach the hot spot and essentially ascend let's say water get the water hot and bring it back up and then utilize it. So, this is essentially all we have to do.

So, clearly if you have some volcanic activity already something from inside is coming out ok. So, if you have some volcanic activity something from inside is coming out. So, if you get to regions that are closer to volcanic activity region so; obviously, you cannot work very close to a volcano that's very unpredictable and you have no idea what might happen, so little bit away from it, closer to those fault lines where there is a chance of this volcanic activity being present you have more access.

So, this crust even though I say 30 kilometers, is not uniformly 30 kilometers. So, based on where it is you may have slightly thinner region slightly thicker regions based on non uniformity etcetera. So, if you can access those regions you can actually get to higher temperatures sooner. So, that is the basic idea.

So, as I said this temperature range is something that you know people have done a lot of theories on and they have got this value. So, if you actually see, the temperature gradient is off the order of about 25 degree C to 30 degree C per kilometer ok, so 25 degree C to 30 degree C per kilometer.

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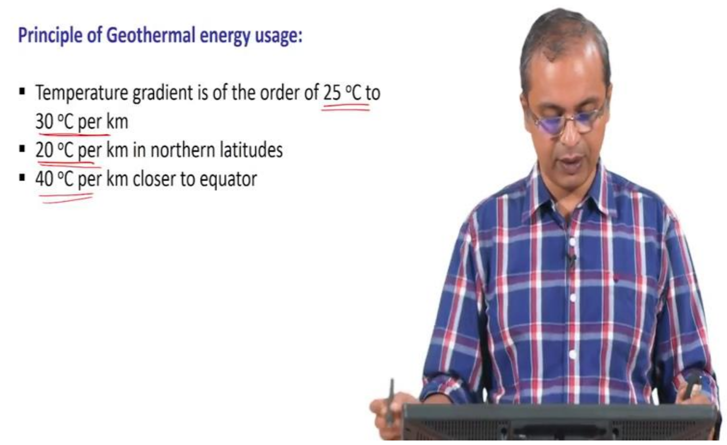

And it is actually a little less if you go to the northern latitudes 20 degree C per kilometer in the northern latitudes and 40 degree C per kilometer in the closer to the equator. So, these are the kinds of temperature we are looking at we will get to this in a in just a moment.

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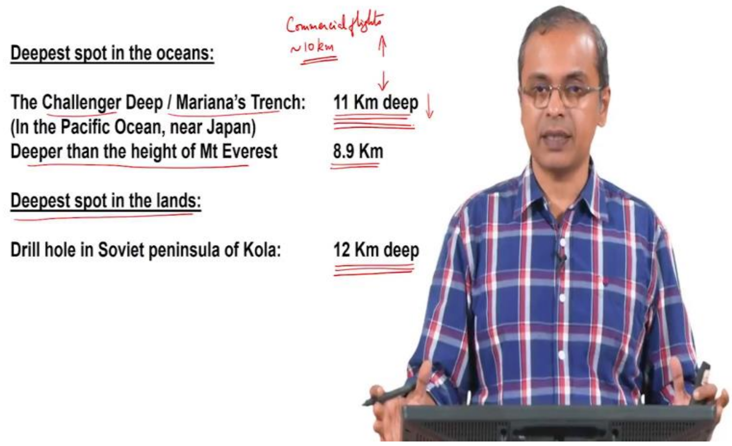

I also wanted to add this information we discussed this when we spoke about even the OTEC ocean thermal energy conversion process, where I spoke about this location called the challenger deep or Mariana's trench and that is about 11 kilometer deep. So, that is why I pointed to point out that in the crust is 30 kilometers thick, we are not even accessing most of the crust this is you know a rare occasion that somebody has even come to this depth. And deeper it is actually deeper than the height of Mount Everest which is about just around 9 kilometers. So, that point is deeper than the height of the Mount Everest.

And this itself like I said is quite difficult to get. So, interestingly if you go the other way around we spoke about an exotic situation of you know comparing this with going to space reaching the moon etcetera and discussed at how easy it is to reach the moon relative to going down 11 kilometer deep, but forget about something that exotic about going to the moon if you just go 11 kilometer about an equal to equal distance up into the air that is actually very accessible.

So, if you took at all commercial airlines, commercial flights. So, commercial flights especially long distance flights not short flights which are you know going from you know neighboring cities etcetera like they will not go to that greater height because they need to again start descending. But if you take long distance flights transatlantic flights, flights headed off from say India to Europe or something like that or India to Australia some longer distance flights they are all on average around 10 kilometers in height. So, they are all about 10 kilometers above the sea level traveling about you know 1000 kilometers an hour roughly roughly those are the kinds of numbers we need to remember.

So, at any given instant I mean there. So, there are 1000s of people who are routinely at this height right at 1000s of people are routinely traveling at this condition and any given day 10s of 1000s of people are traveling at this height any given day. So, even at any given instant right now there could easily be a few 1000 people who are 10 kilometers above the sea level at this instant. So, that is so commonly being accomplished by us human beings at this instant there is 0 people at 11 kilometer below this sea level. So, that’s the point that we just have to keep in mind about how difficult it is if you want to go down, this is in the sea ok.

On the other hand in the land we do have regions which are considerably deep not very often many times this is done for let’s say mining purposes many times they start drilling holes into the ground for mining purposes and various other purposes also they drill down. Mining could be for you know minerals they could also be you know drilling holes to reach oil rich regions, so we will look at that, but the point is people are drilling holes. So, technology is there that's my point right. So, it is difficult for you to do this in the sea this 11 kilometer going down in the sea which is basically a particular kind of you know small submarine kind of a structure which will not collapse under the 1000 atmospheres it is not so easy to do. In fact, most military or naval submarines are not going to this depth they are much more shallow relative to this which is where they at least officially are expected to operate perhaps they can go deeper and it is not known.

But generally officially they don't go anywhere close to this kind of depth. But in the land you can actually dig kind of deep and people have done it for various reasons. So, 12 kilometer deep is known. So, we are looking at this kind of a gradient, 40 kilometers, 40 degree centigrade per kilometer closer to the equator and 20 degrees centigrade per kilometer closer to the northern latitude.

So, this is the extent to which the temperature climbs as you go deeper and deeper into the earth in the crust ok. So, we are only looking at the crust. So, if you see and that is the reason if you go back here you have a crust which is about 30 you know 30 kilometers deep and that gives you about 700 degree centigrade right. So, that's the kind of temperature. So, you are looking at little over say around 23 degrees centigrade per kilometer. So, roughly around that will get you this 700 degree centigrade.

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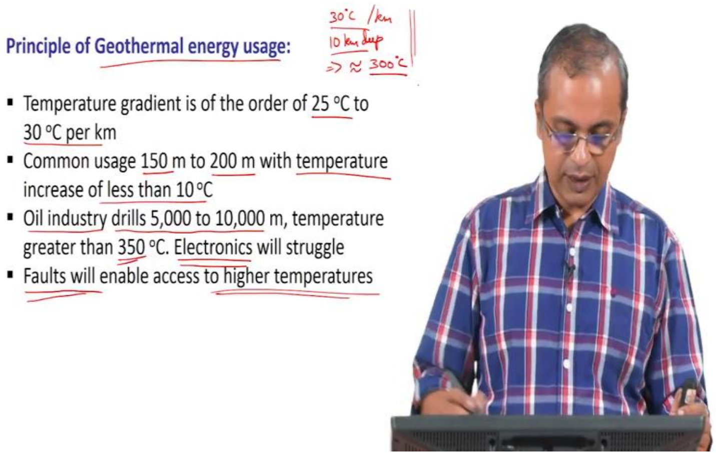

So, if you therefore start digging into the earth you can get these kinds of temperatures. So, common usage of the geothermal energy given that you have these 25 degrees to 30 degree C per kilometer common usage of geothermal energy is in the 150 meters to 200 meters depth ok. So, lot of people have demonstrated at least 150 to 200 meter depth I mean something some that you can go that deep and you can get this kind of temperature and then utilize it for some purpose, but at that point the temperature increase is less than 10 degree centigrade ok. So, that is not that effective or that useful. So, 10 degree centigrade is not particularly great.

On the other hand if you look at say the oil industry ok. So, the oil industry again because there is a commercial activity here and there is a significant profit margin involved in this. So, if they managed to find you know an oil field at some depth and they are able to get do some non destructive evaluation and they figure out that there is an oil field down there and they get an idea of the extent of the oil field let’s say they figure this out. Once they figure this out they know what is the profit margin? That is available in that oil field given that that huge oil field is there. So, they do not mind investing in a drilling process which will get them down there which may be difficult and even expensive, but overall in the grand scheme of things it will be a small fraction of the cost.

But for us more importantly what this has done the indirect benefit for I think the general environmental community is that the technology now exists to drill 5000 to 10000 meters ok. So, technology exists people have that kind of capability to drill those kinds of holes we are going to see. In fact, a couple of examples of it where they can actually drill this kind of hole. So, you can see here if you are looking at 30 degrees centigrade per kilometer. So, even if you go, so if you go about 10 kilometers deep, so 30 degree C per kilometer. So, 10 kilometers deep implies about 300 degree centigrade ok.

So, 300 degree centigrade is going to be the temperature 300-350 you can get some temperatures like this. So, what is the consequence of it? Typically at this kind of temperature electronics any electronics that you put in will struggle. So, why would you put in electronics? You are sending some machinery down there which is digging you may need to control it in some way you may need to send instructions to it, you it may have to make decisions based on what it is encountering there what I mean how much torque to put how to do it etcetera all those kinds of decisions might have to be made. So, there will be some electronics there which has to continue to function as the machine operates. So, many times if you are reaching about 350 degrees kind of temperature that might be an issue. So, that has to be addressed ok. So, that is an issue that we will keep in mind.

And generally as I mentioned if you have faults that will enable access to higher temperatures, so if you have, if there are you know geographical faults that are present that will enable access to higher temperatures. So, now, if you see 350 degree C you know it is a very nice number so to speak in the sense that at that point you basically well past the boiling point of water right. So, you are actually, so even if you go to let’s say 4 kilometers deep at 4 kilometers deep you are already past the boiling point of water 4 kilometers depth.

So, boy you would have crossed the boiling point of water. So, you can get steam you can get steam at if you just cross 4 kilometers depth. And the nice thing is, this is there is no great I mean although like I said you know faults will enable you to access these higher temperatures the reality is I mean since you have this general thing that you know every 30 degrees every kilometer you will not have this 30 degree C increase in temperature, you can actually do this there is no great restriction on the location there is no great restriction you can actually do it at other locations just the exact gradient may be different and at what depth you will get a particular temperature will be different.

But in principle you can do it and you can easily cross the temperature of the boiling point of water because water is a fluid that is easily available there is no environmental concern with respect to it, it is part of our environment two thirds of the world is water we are you know significantly filled with water. So, water is not an issue. So, if you just send water in and you don’t even have to waste water you send the pump water in it will just go it will heat up past the boiling point and you will have steam pull the steam out, run a generator cool the steam send the condense it back to water and send it right back into the hole.

So, you can keep this in some kind of a closed loop. So, you don’t even have to waste water. So, there is no wastage of water except some miniscule amount and you can keep this running and essentially this can run indefinitely I mean you as long as the heat is reaching that spot you can keep running it.

So, this is a very environmentally extremely friendly kind of technology like some many of the other technologies we are looking at. Here there is no, I mean we are not even really looking at any kind of a polymer or any there is no chemicals involved nothing the only environment issue perhaps is that when you drip when you dig, these deep drill holes there is a possibility that you will also release some gases which may be trapped in those areas ok. So, you may have other gases which are trapped well beneath the earth which otherwise would not have been able to come out, but because you have made a hole, you are actually punctured through some part of the crust and you have enabled some of those gases to escape.

So, that may vary from location to location and you have to make a judgment on the relative benefit that you know you have dug some distance into the crust, you are going to get heat, you are going to get energy over such a long period of time, but is the you know any other release that you are creating in that situation is that having any environmental impact that is over and beyond what is acceptable. So, that is the one environmental concern you have that. But beyond that this is a very nice straightforward technology you just dig a hole send water in convert it to steam, bring it out and then run the turbines. But more than more than that actually as we will see going ahead we may not even need to convert it to steam ok. So, as we saw that with respect to the you know OTEC system we are basically looking at temperature difference there of only about 25 degree centigrade right.

So, we have about surface temperatures in their 25-30 degrees centigrade and then you have water there at the floor of the ocean or 1 kilometer below the surface which is at about you know 3 degrees centigrade or something.

So, even with a difference of about 20 degrees centigrade in temperature you can actually run the plant and you can run the plant and you have a closed loop version of running the plant, you have an open loop version of running the plant, we can you know you can you can put low pressure run it in theclosed in a in an open loop kind of a situation where basically the water is being released or you can have a different working fluid which would then be a lower boiling point material in that case it was ammonia and you could use that to run the turbine where you would take the warm water and create this evaporator you take the cold water and you do the condenser.

So, so you have those options available even at temperature difference of 25 degree centigrade and we as we saw here that you can get 25 degree centigrade in the ground by just going 1, 1 kilometer deep right.

So, in fact, therefore, what we have learned from OTEC is the fact that you don't even need really need to go to you know 100 degree C, 200 degree C, 300 degree C etcetera even without that you can actually run this and still run get some energy. But clearly if it is the higher the temperature your efficiencies are going to be much better and with a single plant you can actually do much more therefore, if at all you are going to sink a hole in the ground to set up a geothermal plant it makes sense to see if your technology will permit you to go deep enough that you have a high enough temperature that you know the efficiencies are strong I mean very high and therefore, you can actually you know serve a significantly higher energy demand.

So, that is therefore, of interest, we saw that even 10 kilometer deep would get you 300 degree C which is which is very significant. So, your efficiency would go up dramatically if you instead of 30 degree C a difference you went to a 300 degree C difference right. So, this is something that we will keep in mind.

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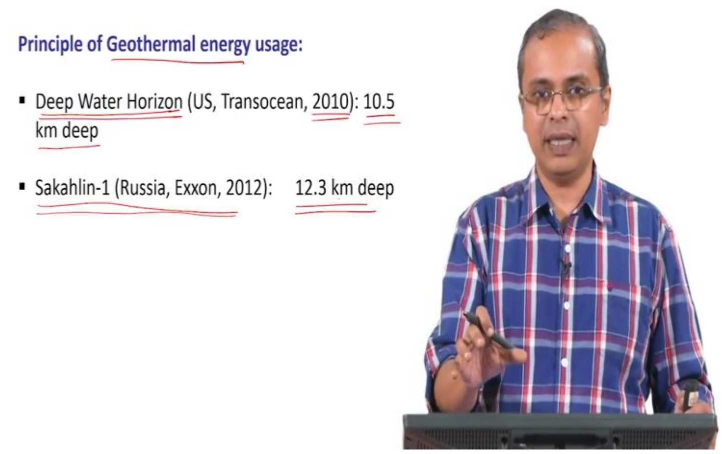

So, just for example, just to give you an idea of I mentioned that you know the oil industry already does this relatively successfully, just to give you some idea. These are actually two different oil platforms. So, these are actually in the sea in fact, deep sea deepwater horizon was one of them and Sakahlin is another one this is the second one is somewhere is basically controlled by Russia the first one is in the US, and they have actually gone 10 and half kilometers deep.

So, this is out in the ocean then they hit the floor of the, so of the ocean and then they continue digging deeper ok. So, they continue digging deeper and therefore, they have gone that far deep into the ocean and in this case for example, they have gone 12.3 kilometers deep into the ocean to reach into through the crust they have dug deep in through the crust and reach that point.

So, therefore, that's that that was the point I wish to make that the oil industry actually has this technology to get to this kind of depth. So, therefore, it is not something that is dramatically different for us to do. In fact, it is actually in some ways easier for us because if you are talking of geothermal energy because when we set trying to set up a geothermal plant we are not actually, not prospecting for oil.

So, we are not particularly concerned about you know we have going to dig this deep are we going to find oil we are not interested. In fact, we are not interested in finding oil we just want you it's absolutely fine to go to a location whether is no oil and dig a hole this deep. So, that's absolutely acceptable to us and therefore, in fact, we would perhaps prefer not to have some pressurized liquid or water in there or any other thing in there because it might come gushing out and it may actually damage everything that we have.

So in fact, I am if you go and look up in the in any online search you please search for deepwater horizon this was a huge environmental disaster in the united states where they had set up a big oil platform which went this far deep into the underground to reach an oil you know oil field.

And then just as they got the whole process started and running it was fairly recent 2010 if you go and take a look at it, as the oil came out they lost control they lost control of that process and it just blew up many of their you know control systems that were there in the pipeline and then the oil rig itself caught fire. It caught fire several people died in that accident it was a very you know severe and you know devastating accident, they died the entire oil rig collapsed and it sank into the sea.

There were several you know I think more than a 100 people were there on the place when this accident happened most people were evacuated, but some people were they couldn’t evacuate and they died . And the accident itself was bad in terms of you know the fatalities and we you know damage it had done to all those families and so on, but more than that I mean or at least you know that being one part the other major part was that there was a huge oil leak. They had already drilled a hole to reach one oil field and they had lost control of that hole there is a they have to keep proper control on it.

So, that they get this out in a controlled manner they lost control of it and so this oil began spilling out. So, it cost one of the worst oil spill disasters in history it is you know massive amount of oil that got spilled and it took several weeks, several weeks before they could. In fact, in the order of months before they could actually find a way to plug that hole they struggled. So, hard to plug that hole to stop that they tried various things they kept on if you actually read the history of this event incident you will find that they tried several things to try stopping that leak they couldn’t they struggled. So, and only then they could you know manage it after several months.

So, it is a complicated thing. But the point is you know far from our perspective if you are looking for geothermal energy this is not an issue, we are not really looking for something underground we just want to make a hole to just access the temperature that is there and therefore, this is a very clean energy. And so not only we avoid you know burning of fuel which was taken up by that hole if it were a oil drill. We actually do not even have the problem of a leak from an oil drill because there is no oil there and therefore, this is not an issue for us.

So, you can go look this up there is a lot of information on it, there is I think this is even a movie based on it called a deepwater horizon. So, you can take a look at. As I said that is not the end of it this is Exxon is a big company. So, they have also actually worked I think in Russia and they have got a hole that is 12.3 kilometer deep. So, this is routinely being done by the I may not may not be routine, but at least the capability is there to make these kinds of holes and the nice thing is there is it is not a finite quantity that is there you get there, you get that temperature and you can keep working on it .

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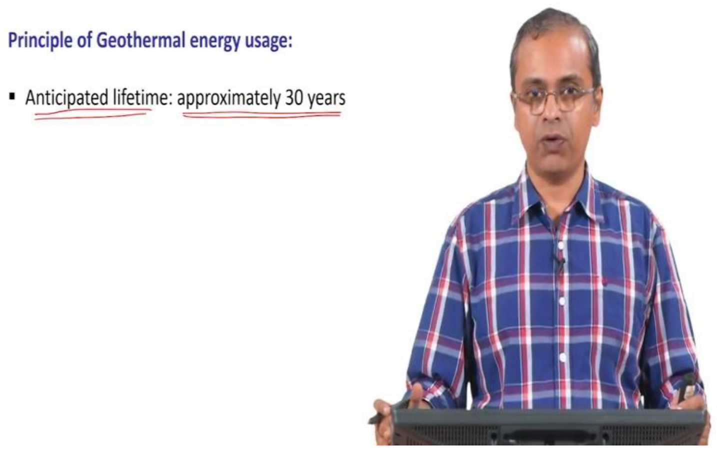

Generally the anticipated lifetime for geothermal energy usage is about 30 years. This is again you know some estimate that is there based on you know how much heat is arriving at that location and how much heat we are extracting. So, this is actually not that the place becomes unusable after 30 years it may temporarily not be as effectively usable.

But it really depends a lot on the you know the thermal moment, so the moment of heat from well within the earth to that location. So, so that is actually got a lot of thermal mass. So, you as we saw you know 99.99995 percent of the land is below that. So, if you are 99.5 at least is below that of the planet. So, that much thermal mass is there at much higher temperature. So, you are not going to run out of heat that easily. But this is the expectation is that if you use a spot for about 30 years it may be that locally it may cool a little bit if you give it some time it will recover and then you can continue using it.

So, this is one thing. But even in even economically perhaps that that gives you some idea of how long this unit can be used. So, this is the kind of you know an energy phenomenon and you know the kind of concept that is involved in a geothermal energy and as I said here if you go back to what we looked at in terms of temperature you have this huge temperature range.

So, clearly all of this we are not going to be able to access, this is much much deeper we believe it is there, but we cannot really access it. So, we are really looking at this 0 to

700 degree C temperature and there also we may not go the whole 30 kilometers because we also do not want to you know create a situation where we have punctured through and we are actually having you know leaking lava coming out of that location.

So, it is more than adequate for us to do anything of the order of 5 kilometer to roughly 10 kilometer. And if you are able to get to this kind of depth we have already you know got enough heat there that we can actually utilize it very effectively in terms of running a steam turbine and then capturing electricity. So, this brings together many nice phenomena. So, like we saw in the OTEC thing, OTEC technology the heat is the energy is already there in the system we are now really burning anything to create this energy, there also we were not burning anything to create the energy here also we are not burning anything to create energy.

There is no you know effluent coming out of this, there is no carbon dioxide coming out of this there is no methane coming out of this nothing is coming out of this except as I said if you heat a spot where there is some other gas that was trapped under the earth and you end up releasing that gas.

So, this is a bit difficult to actually predict because you have to really have a good idea of the geology of the location etcetera. So, that is something that more analysis is required to do. So, that way we do not have an issue the third thing is we are not using any even the fluid that we use is quite clean both even, even in the OTEC condition we are just using water except we take seawater and we put it right back into the sea.

So, we are all really doing nothing. Here also you are just taking water you are sending it down, a deep hole converting it to steam bring it, bringing it back running a turbine and then cooling the water and sending it back into the hole. So, this is a simple process that way again. So, there is no effluent even coming out of this location and therefore, is another reason why it is a very clean technology.

So, for example, 5 kilometer depth. So, we sat about 30 degree C. So, 5 kilometers would actually get you about 150 degree C is that right yeah 150 degrees C of temperature. So, that is I mean already above the you know boiling point of water so that we can do and as we said we can even use a evacuated system or a or a low pressure system in which case you do not even need 150 degree C even at 30-40 degree C temperature difference you can run a turbine or you can use ammonia or something in turn a turbine. So, multiple things can be done in the geothermal energy sector and there are people who are trying to set up plants based on this and trying to run this system ok.

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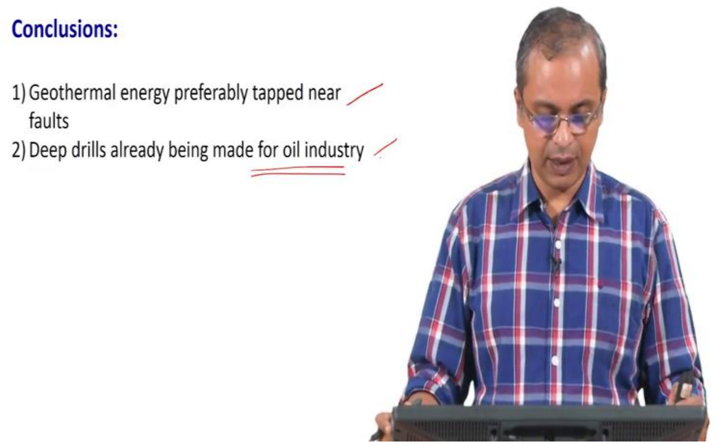

So, in conclusion the geothermal energy is a very clean form of energy and it can be tapped at almost at more or less any location around the world, but preferably is tapped near faults because then without having to go that deep into the you know into the ground you can actually get a considerable amount of heat which you can utilize for some purpose.

I also said that deep drills are already being made for the oil industry. So, this is again something that is available. So, the technology is available and therefore, nothings dramatically new needs to be made to enable this industry. So, where they are setting up complicated plants you know, so once the oil industry is set up you have to dig you don't what comes out is just crude oil. So, you cannot directly use the crude oil. So, you need actually a massive plant and in that plant you have to do all this kind of you know distillation to separate out all these fractions then transport all of these fractions to various locations and use it. All of that is not necessary here nothing has to be cleaned you are just getting electricity straight directly you get electricity and you can release the electricity.

So, the plant is actually very simple you simply have to have this turbine and access steam off the turbine that is really all it is. So, there is some piping plumbing involved to get it to happen and you have a turbine which generates your electricity for you a generator that will get you the electricity. So, very very clean process no complication, no you know fractions that have to be separated, no ways to be thrown out etcetera. So, you can take advantage of the good parts of the oil industry without worrying about any bad parts of the oil industry. So, that is a very nice thing and it is already it is still supporting the industry. So, the industry is also not threatened because some parts of the industry can get used for this.

So, those are our major conclusions for this class. We will halt here; we would look at some more details in our next class.

Thank you.

KEYWORDS:

Geothermal Energy; Crust; Upper Mantle; Lower Mantle; Inner Core; Outer Core; Radius of Earth; Sesmographs; Oil Platforms

LECTURE:

Geothermal energy is one form of Clean energy, which can be directly tapped from earth directly without the need of sophisticated technologies nor purification. An insight into Geothermal energy is provided in this lecture.