Non-conventional Energy Resources
Prof. Prathap Haridoss
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Madras

Lecture – 25
Ocean Thermal Energy Conversion (OTEC)

Hello, in the last several classes we have looked at you know solar energy and wind energy. We focused a lot on those two because they have you know considerable promise and it's something that you can install easily relatively easily and you also see it considerably in you know its required visibly there in many places around the world. And here people also consider you know those two to be quite promising in terms of the ease with which they can be deployed, the number of places they can be deployed, the flexibility of these technologies and so on. So, that's the reason why there was so much focus on it and there is so much information also available on it and so on.

Today we will look at another of our renewable energy technologies that people have worked on two different degrees of success and that is the ocean thermal energy conversion or OTEC it is as it is called ocean thermal energy conversion. As you know two-thirds of the planet is covered by water and clearly if you have energy there which you can tap that is significant amount of energy that you can get access to. So, that's the context in which we are looking at the ocean thermal energy conversion or OTEC.

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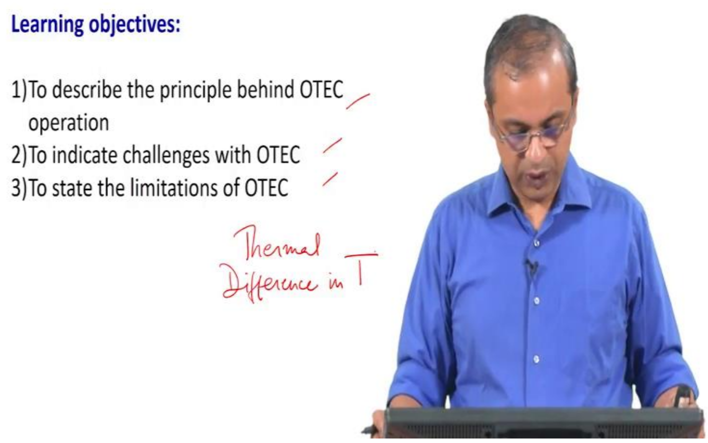

So, in this class for example, are learning objectives are to describe the principle behind the OTEC operation what is the basic idea behind it, because actually from the energy that is available in the sea you can actually tap it in multiple different ways. So, this is one of the ways in which you can sort of get energy out from the sea and put it to use where you would like it to be put to use.

And in the context of how it is done we will also look at what are the challenges associated with this OTEC technology and also try to understand I mean therefore, related to those challenges what are may be some limits associated with it or even some theoretical limits associated with it. So, this is the general context in which we will look at today's discussion. As I said two thirds is covered by water there is lot of energy that's available in the water and at some fundamental level just the way you talk of you know energy available in the wind system. The energy that's available in the water system is also at some fundamental level coming from the solar energy.

So, sun beats down on the earth and then heats up the land, heats up the water, heats up the atmosphere and because earth is a sphere we have you know one one side facing the sun, one side not facing the sun. So, in any you know at any given instant of time. So, clearly there are locations which are receiving a lot of heat there are locations which are not receiving a lot of heat this is simply based on the time of the day. On top of it based on the latitude and the season you will have you know some regions receiving less sun and sunlight and more sunlight, during winter and summer and so on and as a result there is a lot of variation of thermal energy across the planet and there is lot of variation of the thermal energy that is held in the water across the planet.

This therefore, results you know differences in density in the water. So, you can have water moving up. Moving down you have lot of water currents that are existing and on top of it. So, you can actually potentially you know capture energy from just these water currents if there is a way in which you can do that. And then on top of it there is also the temperature difference issue. So, if there is a way in which you can utilize the temperature difference between the region that is heated and between water that is heated and water that is not heated and that if that's energy that you can tap then that is something that you can utilize.

So, the ocean thermal energy conversion as the term indicates you have the word thermal there. So, we are primarily looking at temperature difference. So, temperature difference is what we are trying to capture here. So, difference in T in what I just discussed with you there is a difference in temperature based on region that we have, but we don't have the ability to pick up the heat from the you know dark side of the planet and the bright side of the planet and then capture the heat to generate a run a heat engine. So, that is not something we are not talking about today. So, there is another way in which there is a difference in heat that is held in the water. So, that is what we are going to look at.

In technically if you are out in a satellite you could do that in a satellite you could have dark side of the satellite and the side of the satellite facing away from the sun and side that is facing the sun, potentially you could run a heat engine there and generate electricity. So, there you could just tap the you know hot side and the cold side, but there you won't have convective heat transfer, you only have radiative heat transfer. So, within whatever is possible there you can actually do that. So, this is something that can be done. But in the planet that's too big you know location for us to pull that off. So, we are looking at a thermal difference that is present in in a much more local geography local location region, but there is still a difference due to some other parameters. So, we will look at that and on that basis the temperature difference is being utilized to generate electricity to do bunch of other things and that energy is being taped. So, this is the OTEC idea.

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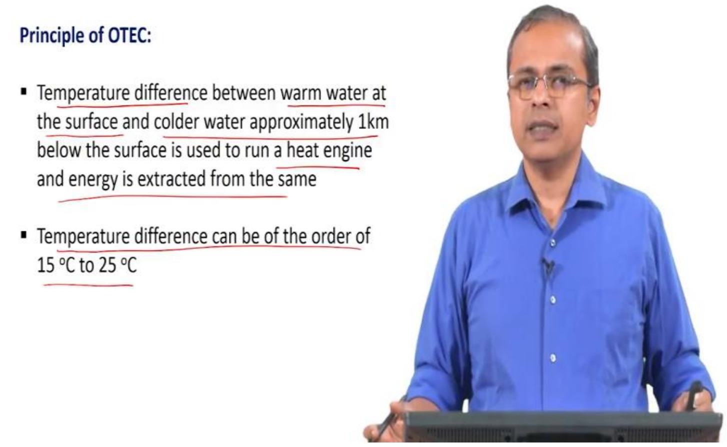

So, what’s the idea here? As I said it’s not region difference it is basically the difference in temperature between warm water at the surface. So, sunlight comes and we will see that detail there. So, at the surface there is warm water and much colder water that is approximately, 1 kilometer below the surface ok. So, 1 kilometer is really not that large a distance, but in the context of water that may be significant, look at that in just a moment, but basically if you look at sea water you have water at the surface and that is warm and then there is significantly colder water about one kilometer deeper into the ocean.

And so if you can pull that water, so you don’t have to put some other geographical location you are in exactly the same location in that same location if you can pull the water from about 1 kilometer. So, you basically have to put a pipe down about 1 kilometer long pipe and then pull the water up once you pull the water up you have cold water available with you, and you also have warm water from the surface of the sea and you can use those two to run a heat engine and in that process if you generate electricity you know extract the heat engine heat extract energy from that heat difference in temperature that is what this OTEC is all about, so ocean thermal energy conversions.

So this temperature difference between what is at the surface and what is much below the surface about a kilometer below is of the order of 15 to 25 degree centigrade ok. So, this varies from region to region and there, there may be other factors contributing to it, but we are looking at a temperature difference of somewhere between 15 and 25 degrees difference ok. So, this may not be much I mean doesn’t seem like much and. In fact, it is not much we will see some numbers relative to this. So, as suppose to the kinds of temperature difference that let’s say you know engines in our car or trying to utilize etcetera, this is not much, this is a much smaller temperature difference much more modest temperature difference ah.

Even relative to say the temperature difference say thermal power plant is trying to use this is not of that order at all it is just that it is abundantly available. I mean it is just you know potentially just there infinitely available and therefore, it can be taped. It’s of course, renewable because you know it is happening in the time scales of in long these are temperatures that are equilibrated in a very large body of material over a long period of time and they will continue to keep getting equilibrated at those temperatures with passage of time.

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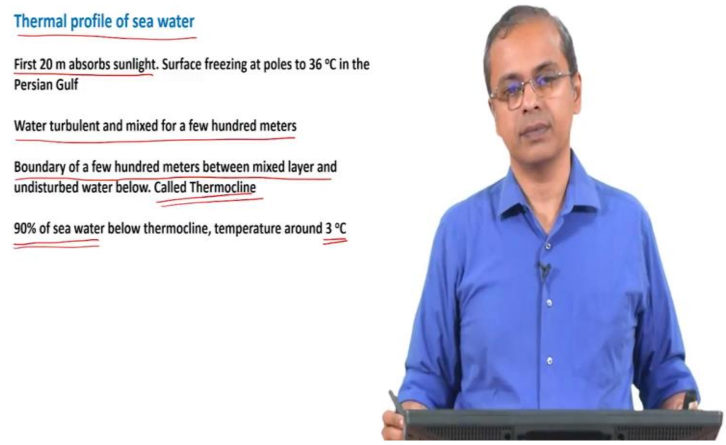

So, what is the thermal profile of sea water? So, the this is of interest to see because you understand what is actually happening in the system and therefore, understand the context within which we can you know tap this energy for example.

So, when sunlight arrives at the sea surface of the sea water mostly it is a first 20 meters that absorbs sunlight so in fact, even when you look down into the sea I mean you only find a few places where water. So, clear that you can actually see few meters down and you will see the sand below right invariably it is kind of dark after some few meters it is very dark. You don’t really see anything if you just stand at the beach and you see the water in front of you will see it light I mean based on which part of the world or how deep the water is and of course, depending on how clean the water is, what you know turbidity is a whatever other factors are there in involved in it you will see a certain level of clarity in the water, but beyond that it becomes dark right. So, it also means the light just penetrates that far and at that point it just its all absorb.

So, the sunlight more or less in first about 20 meters of depth which is you know not a whole lot it is like say the depth of say two rooms that you may typically be using . So, in about 20 meters of depth the sunlight gets absorbed ok. So, the this gives this surface some temperature. So, this temperature varies from region to region. So, at the extreme when you go closer to the poles you have a temperature, the surface temperature of the water of the sea water that is there could be very close to freezing conditions you may even be frozen or very close to freezing conditions at the polls. But if you go to some warmer region, so Persian Gulf is considered some one amongst the warmer regions where the sea water is quite hot you can see temperatures of the order 36 degree centigrade at the surface of the water, so in the sea water.

So, at the surface itself based on the region you have a lot of variation and this is primarily got to do with how much sunlight is arriving at what rate it is arriving there in the sense basically what is the power it is delivering there and if it is more obliquely inclined the at the polls that the power being delivered it is a lot less and you may even get it delivered for 6 months of the year and therefore, it becomes very cold there. So, but then you have hot places at about 36 degree C.

So, now, if you start in that 20 meters whatever is there that heat energy that has been captured there then as a result of you know both the turbulence caused due to the you know mixing of that water because you have now, hot water and you have slightly colder water below it. So, there some density variation you starts seeing some mixing going on. You also have a lot of when you go and stand in this sea when you go and stand in the beaches, you see all the waves coming to you that is got to do with the interaction of the wind that is blowing and the surface of the water. So, that surface keeps getting churned up quite a bit by the wind that is blowing across.

So, generally the you know water both due to all the activity that is happening at the surface and all the you know to what degree that energy transfers downwards variation in density etcetera, you have a lot of mixing going on for a few 100 meters ok, of depth depth of a few 100 meters. Significant amount of mixing is going on, starting both due to this energy that is coming from the sun also due to the action of the wind on the surface of the water etcetera, considerable amount of churning around and mixing and what on is going on for the first 100 meters. So, first few 100 meters this happens.

And then you have below that a boundary. So, this top layer is called the mixed layer and from there you have a boundary that boundary itself extends for a few 100 meters ok, it’s not a very sharp boundary, but it relatively sharp in the grand scheme of things, but few 100 meters of boundary is there in which there is you know this the level of you know disturbance comes down and then below this boundary there is a relatively undisturbed water ok. So, so we have first 100 meters also which is very turbulent and then few 100 meters you continue you come through a boundary below that you have a boundary and that boundary itself lasts a few 100 meters across which this you know disturbance steadily cuts out and then you are at one point it comes completely undisturbed. So, there is water below the boundary that is undisturbed. This boundary is called the thermocline.

So this boundary is called the thermocline and below that you have water that is largely undisturbed and has been you know at certainly not disturbed with relative to whatever water action is going on top. So, this thermocline it turns out that you know more than 90 percent of the sea water, more than 90 percent of the sea water exists below this thermocline.

So, the volume of water below the thermocline is significant so the surface water which is disturbed and you know mixed up and having higher temperatures etcetera is actually a very small fraction of the total water that's available in the sea. So, in fact, that is only 10 percent of the water that is available in the sea right and all the 90 percent of that water that is a is now below the thermocline where the temperatures are very low and of the order of 3 degree centigrade ok.

So, that temperature is there. So, very close to freezing temperatures significantly below the depth of you know from the surface. So, if you go, so may be about kilometer or so, below you go and then it becomes this cold. So, this thermocline is also quite important from various other you know if you read you know books related to say submarine and how submarines operate and so on.

This is also considered kind of important from that perspective in terms of how you know sonar behaves there, how calm the water is or how disturbed the water is all these things are related to the thermocline and so, this is also relevant from military aspects so to speak. We are not really looking at it and that is not really focus here, but for us the idea is that that this layer below which the water is undisturbed and this layer is called the thermocline.

And more specifically we have a temperature of know at depending on where your above the thermocline close to the surface you have a temperature of 36 degree C, below the thermocline you have a temperature of 3 degree C. So, in this case we are looking at about nearly 30 degrees, 33 degrees C difference, but this is like and extreme case as I pointed out mostly it is somewhere between 25 and 15 degree C. On average in fact, it's about 17-18 degree C across the water that you are going to see at various places various coasted areas, but you can have anywhere from 25, 15 to 25 degree C difference.

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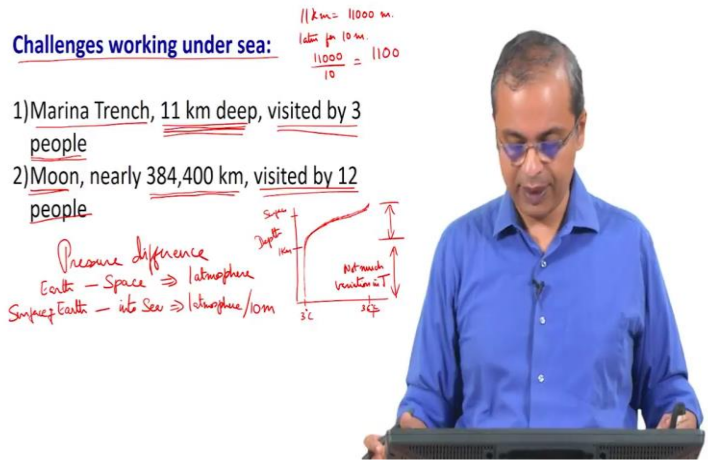

Okay so this is clearly work that we have to do with respect to the sea right. So, this is a this technology by definition is something that is associated with the sea with how you can operate something in the sea. So, what are the challenges there, right?

So, and we are also looking at as I said we are trying to get water that is cold and you know find a way to interact with water that is warm that is on the on the surface and process generate energy. So, you have to get that cold water and that cold water is about a kilometer plus deep you have to go further down and then it you get that temperature. So, so, in fact, if you plot temperature right and depth, so if you are on surface and let’s say this is 1 kilometer and this is further down. So, you are looking at say let’s say this is 36 degree C, this is say 3 degree C. So, you looking at something that is like this. Some profile like that this is just a schematic of a profile.

The point being it’s not very linear it’s not a very linear profile and you are going to see significant variation of temperature in this region and then virtually no variation of the temperature below ok. So, here there is the lower region not much in this region right. So, in the lower region there is not much variation in T on top there is significant variation in T. So, it is certainly a non-linear behavior coming from top to bottom.

So now, we have to work with water that is at the surface and work with water with that significantly below the surface which is about a kilometer below. So, just to give you an idea of how complicated it gets working with the sea water and especially water that is deep in the sea. If you look at what is you know people have explored the surface of this you know bottom of the sea the sea bed across the earth some kind of a mapping has been done to understand what at what depth you have the sea bed etcetera . So, the deepest point that they have seen in the sea bed is the marina trench ok. So, the marina trench.

This is about 11 kilometers deep. So, you have to go 11 kilometers deep into the sea to reach this point it is somewhere near japan somewhere in that area it is it is called the marina trench. And people got know about this quite some time back that they were, they knew they were aware that this place existed.

So, in the if you take the last you know say 100 years, where people have tried to do various things you know in terms of exploration, trying to reach places that others have not gone to etcetera and try to push boundaries of what human people have humans have achieved over the period of time. Then if you look at the marina trench which is 11 kilometers deep in all this time that people have worked on trying to get there with all the technology that has existed and so on till very recently it has been visited by total of 3 people ok.

And these 3 people, in fact, did not even step out at this location they were inside a particular kind of vessel which and stayed inside that vessel and that vessel basically reach this point, this marina trench it reach the base of this location and they were able to come to this point. So, they sat inside this vessel and this vessel went deeper and deeper and deeper into the ocean went 11 kilometer deep, reached the bottom of this place a called the marina trench and they were essentially there.

So, 3 people did this, 3 people managed to visit this place it includes one of these you know film directors of the movie titanic is visited this place James Cameron he is one of the people was visited this place and so that’s it there are 3 people gone to this place .

Now, if you contrast that with the moon if you contrast that with the moon that is 384,000 kilometers away 384,000 kilometers away ok. So, not really half a million, but approaching that you know approaching half a million kilometers that kind of a distance okay. This has been visited by 12 people. There are 12 humans who have landed on the moon ok. So, 12 humans have landed on the moon and not just landed on the moon, they were able to come out of that spacecraft of course, they were wearing a special space suit they were not you know wearing our kind of clothes they has a special space suit which you know moderated, their temperature and atmosphere that they could breath normally etcetera because there is no air there.

But they were able to step out of the spacecraft wearing that suit walk around on the moon ok. So, 12 people, 12 human beings have set foot on an object that is outside earth these are the only 12 people who have ever done that ok. So, we have only explored the planet these are the only 12 people who have 12 human beings who have ever stepped on any object outside of earth, any you know any other celestial object other than the earth. So, only 12 people have done that. But 12 people have done that, they have been able to landed on the moon, they may able to get out, walk around, even drive vehicles they have had some lunar modules something rovers they had they drove those vehicles on the moon. They did various things various activities that humans could do on earth they try to mimic doing all those activities there. So, this is 384,000 kilometers away.

And you know the amount of difficulty it is you mean every time there is a rocket launch people are. So, anxious that everything has to go right. So, many technical challenges are there it’s by no means easy. Even to spend an unmanned you know satellite to space it is a extremely technically challenging activity there are only a few countries, even today there are only a few handful of countries that are able to regularly send unmanned satellites India is of course, proudly one of those countries that is able to do so quite regularly, but still that is only handful of countries that can do that. In that the man machine has literally been done only by 3 3 countries in which only 2 have really prominently done it only 1 the china has just started doing it.

But really only the Soviets and the they Russian people of the Soviet Union and the Americans have been able to do manned machines on a regular basis and in that only the Americans have managed landed on the moon. So, has been quite a complicated set of activities that are there and that is very complex ,very difficult, very challenging and lot of danger there. People have died in the process of trying to land on the moon. So, the very first Apollo we are actually blew up, I mean the very first such rocket. So, which was on a test mode basically blew up I mean or the people were trapped in a fire they got killed. So, it is quite a dangerous activity, it is hardly a safe activity, with despite all those challenges, despite that challenges of you know what is required to get out of the gravity of earth to pull out do so many complicated things have to be done before you reach the moon. Despite all those challenges 12 people landed on the moon okay.

So, that is the phenomenon accomplishment. But contrast that with the marina trench that's just 11 kilometers, 11 kilometers is nothing. I mean 11 kilometers if you if you if you were on a you know road outside 11 kilometers would take you no point I mean if you and if the traffic were flowing you would probably cover 11 kilometers you know if you were doing say 60 kilometers on earth, then every 6 minutes you would be doing 10 kilometers right. So, 6 7 minutes is what you are looking at to do 11 kilometers , I mean something like that you know in under 10 minutes on a road in about 10 minutes time on a road you would cover 11 kilometers based on the traffic conditions.

So, 11 kilometers is not at all a significant distance in the context of human activities. In the context of human activities 384,000 kilometer is a significant amount of distance it will take you forever to travel this distance if you had do so, still 12 people managed to reach the moon step out, walk around, do various activities only 3 people managed to reach the bottom of the marina trench and nobody stepped out, nobody stepped they just sat inside that vessel looked out through whatever port was available in the vessel and they can right back up ok. So, they just took picture some inside the vessel, they saw through the port, they flash the light around and then came right back. So, this is all they were.

So, what is the challenge there? The challenge is the pressure or the pressure difference ok, the pressure difference that is the challenge. So, what is a challenge? When you go from the earth to the moon even though it's such a complicated activity so many dangers and so many difficult things involved that difference in pressure when you got from the surface of the earth into space is one atmosphere ok.

So, difference in pressure, so earth to space. So, one difference in pressure meaning, when you are on the earth you have one atmosphere of pressure that you are experiencing that when you stand you experience one atmosphere of pressure. If you just lift off from earth and come out into space there is essentially vacuum out there. So, there is the pressure has dropped to 0.

So, your are used to one atmosphere pressure, pressure outside is 0. So, whatever you know vessel that you create whatever space ship you create should, should maintain one atmosphere pressure inside the space ship while facing 0 atmosphere on the outside of the space ship. So, the wall of the space ship we will see one atmosphere inside it will see 0 atmosphere on the outside right. So, that's the difference. So, difference in pressure across the wall of that space ship is one atmosphere. It has to see one atmosphere inside 0 atmosphere outside.

So, that is the difference and that space ship should stay in tact in that difference it should not break up, it should not explore you know you blow air into a balloon, why it is expanding its expanding because the pressure inside is more than the pressure outside or at least it is initially it if you just maintain it like that pressure is higher. So, it expands still the air pressure outside as well as the you know the elastic properties of that balloon together counteract the pressure inside. So, that's how it takes some shape, but if the balloon is weak it will explore right. So, that is because there is a pressure difference between inside and outside.

Same thing, if the space ship which is a manned machine should enable people inside to lift. So, it has to have oxygen it has to have if it is just air it has to have a mix of oxygen and nitrogen and the pressure should be one atmosphere if the pressure is too low you will be struggling to breath. So, pressure should be one atmosphere because our bodies used to that pressure outside is 1 0. So, that pressure difference across the wall of the vessel is 1 atmosphere.

Now, from surface of earth into sea one atmosphere pair 10 meters ok. So, remember it is not just one atmosphere pressure difference it is difference of pressure is one atmosphere for every 10 meters that you go into the sea ok. So, you started the surface of the sea and you go down 10 meters depth you go the difference in pressure is one atmosphere. So, your body is now, used to one atmosphere, but the pressure outside is two atmospheres ok.

So now, if you want to compare spaceship that has landed on the moon with something that is underwater and you want to create a situation that is very similar, similar to a spaceship sitting in the moon and is and underwater vessel. So, what is the situation ah? The pressure difference across this one atmosphere and pressure inside one atmosphere.

So, in the moon pressure difference is one atmosphere between inside and outside and pressure inside is one atmosphere. In the sea if you go down just 10 meters you have recreated the same situation except that the pressure outside is excess there the pressure outside is 0, in the sea you just go down 10 meters or anywhere even you know in a deep enough swimming pool if you go down 10 meters the your body is feeling a pressure of one atmosphere of air and 10 meters of water the 10 meters of water is equal to 1 atmosphere of air. So, two atmospheres you are facing right.

So, just 10 meters down the vessel already faces the same situation that vessel that is landed on the moon faces. So, you can now, imagine if you got on 11 kilometers ok. So, 11 kilometers is 11000 meters and it is one atmosphere for every 10 meters. Therefore, pressure differences total pressure differences 11000 divided by 10 more than 1000 atmospheres the difference in pressure between the inside and outside of that vessel is more than 1000 atmospheres. So, that is why even though this is only 11 kilometers and technically you know on a straight road you will reach this in about 10 minutes time, you would never do it in 10 minutes if you are going under the sea and the pressure difference you faces 11000, I mean 1000 100 atmospheres that is 1000 times more difficult from just the pressure of perspective of pressure this is 1000 times more difficult to handle than the than landing on the moon.

If do not look at any other technology other technology change the scenario completely I am just saying with respect to pressure going 11 kilometers under the sea is 1000 times more difficult than reaching the moon ok. So, that’s the point and that’s that’s a reason why this is problem.

And the OTEC technology requires you to deal with water that is at least 1 kilometer down. So, therefore, you have to send a pipe down there, 1 kilometer down you have to send a pipe you have to work with the fact that there is water is moving the top water is moving there may be some currents of water below.

So, you have to work with all that ok. So so, there is a lot of challenge associated with dealing with water pressure is major challenge, depth is a challenge, water currents are a challenge. So, these are all extremely difficult to deal with and therefore, OTEC even though people have been working on successful demonstration that has lasted a period of time have been very few where they have managed actually work with it.

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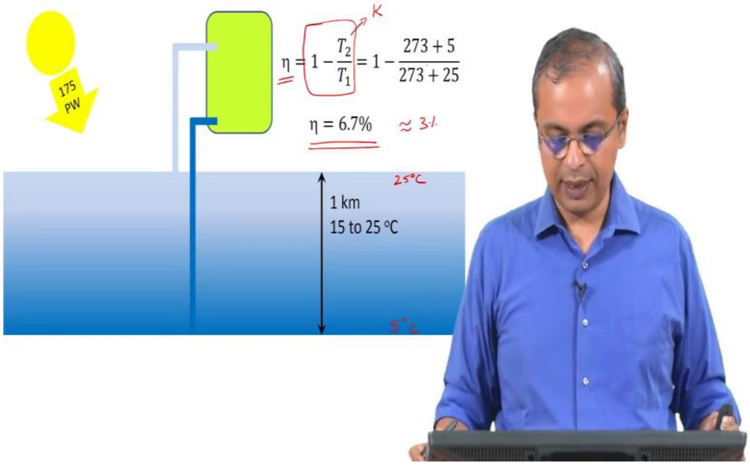

So what is happening here? So, you have as you as you recall 175 peta watts of energy coming from the sun. So, that arrives into the sea and then it heats up the top surface of the sea. So, we said you know say let's say this is the top 20 meter. So, this is one kilometer. So, top 20 meters is very thin layer. So, in this context this is a very thin layer.

So, we are looking at this is 1000 meters. So, this is 1000 meters. So, basically it 10 percent of this would be 100 meter. So, you are looking at 20 meters we should just be this much ok. So, to the first 20 meters is where you are having much of the heating that is going on and then below that you have actually you know several 100 meters over which things are cooling down quietening down and then when you go down, 1 kilometer down everything is quiet. So, this is 1 kilometer and that is where you have this temperature difference of 15 to 25 degree centigrade.

So, what are we doing? In principle this OTEC system which is what we have here simply takes water from the surface of the sea and water from deep below and both of them arrive here and with this we generate electricity. So, this is the basic idea of the OTEC. So, you have picked up water. So, you have readily got this and this is in large supply that is the whole the attraction to OTEC is that is if you go to any coastal area this is available to in large supply. You can keep pulling up this water I mean you just have to put two pipes you in that sense is a very simple technology. You have two pipes, one pipe will be at the surface of the sea another pipe has to go deep down that's it and then you have a pump to pull up the water from deep below and that will get you the cold water. Pump to pull up the water from the top that is a warm water that's it.

You already have all this you don't have to put in any thermal energy, you don't have to you know burn coal or do any such thing to generate your energy. So, it will clean in that sense a very clean you don't have to do any major thing. So, this is the two things that you have got, but having picked up this cold water there is actually bunch of different things that we can do. So, it is not you should not see the OTEC plant in isolation because actually many things can be done once you pick up this cold water cold seawater that is coming from about kilometer down. So, in a sense when you look at the OTEC process you should look at it in totality you should try to actually do all of the things that are possible at the OTEC system and then you can fully benefit from it ok.

So, but now, for example, we this is what at the top level this is what we are doing we have picked up cold water from the bottom we have picked up hot water from the top . So, now, let's look at efficiency. So, it tells us that you know if you want Carnot cycle efficiency you have 1 minus T 2 by T 1 is the efficiency that we can get is the best efficiency that we can get. So, that is we have you know let's say 5 degree centigrade that is down here, let's say its 5 degree centigrade below and let's say this is 25 degree centigrade on top ok. So, 5 degree centigrade in the cold water that is significantly below and 25 degree centigrade on top those are numbers that as told you know roughly similar to numbers that I just mentioned to you in this context.

So, we have to this T 2 and T 1 have to absolute temperature, so in Kelvin. So, that is 278 Kelvin and 298 Kelvin respectively right, so 1 minus 278 by 298. So, if you do the calculation you will arrive at about 6 and half percent roughly ok. So, that's like the best that we can get.

So, in fact, mostly we are not even doing this we are read actually looking at you know values of the order of 3 percent of something like that that's more the practical kind of efficiency that you get out of a OTEC plan. So, that seems like remarkably low I mean even, even if you look at our worst case scenario of solar energy that you will be a looking at 5 percent deficiency that is like our worst case this is the best case or typical cases you know 3 percent. In solar energy you can looking at 20 percent and then you say that that is also not good enough you want to do better than that.

So, lot of things we are trying to do that and we are looking at a hypothetical case where you can even get 80 percent efficiency or something like that right. So, you are you are considering all those options here you are looking at 3 percent. So, this seems like a complete you know waste of our time to do this. But the advantage as I said is that this is very easy to do and there is abundance of this available and it's a very you know not at all complicated to set this up in a in a grand in the relative send of the you know activity there are lot of side benefits to it and so on. So, therefore, people feel that even if it is only 3 percent if you just like they are going to give get it, I mean if you just going to get it without much effort and you just going steadily add to the energy stream then let's added everywhere.

Because in general what you are going to see is if you look at the entire energy scenario internationally it is unlikely that any one solution we are oursleves seeing a whole bunch of solutions, here it is unlikely that any one solution is going to completely take over from everything else. It is very likely on the other hand to have multiple different solutions which will serve various needs locally will also add to the global pool of energy that is there and so on and many of them have side benefits many of them have side disadvantages.

So, we have to keep all of that in context when you look at any one technology. So, nothing is going to be an all concurring technology. So, in that context this is also okay this 3 percent is that all I mean pretty much any course line anywhere you can try and capture this a something that is great plus right. So, therefore, this is so, efficiencies is about 6 and half percent at best and then you are actually looking at about 3 percent more likely.

So, what can we do? I mean having picked up the cold water one thing that you can actually do very easily straightforwardly is air conditioning ok. So, in fact, if you look at the air conditioning plants if you look at you know AC plants at various building. So, when they do centralized air conditioning when they do air conditioning of you know multiple buildings using one plant which are which are distributed buildings. Many times what they are doing is you know cold water is being sent off to different places. So, one place only the plant operates and creates cold water then that gets sent into different places from there the local you know heat exchanger will then eventually you make that building cold etcetera.

So, will, so things like that are being done you know, so you transport cold liquid to different locations and then work on it. So, here you have already got the cold liquid you have got 5 degree centigrade or 3 degree centigrade liquid you just pulled it out from the bottom of the sea here sitting there you just pulled it from there. So, it is there.

So, if you are you know if you set up a network ahead of time. So, imagine you know coastal city let’s say in Tamilnadu in Tamilnadu for example, I mean Chennai, Chennai is very hot in summer it is very hot a lot of people struggle with the heat it is very hot and humid and so there is a great need I mean lot of people really feel the need for air conditioning it would be extremely uncomfortable to operate and function doing the middle of the day with without air conditioning many places in Chennai, so that that feeling will be there. So, we are putting air conditioners, but now, if you have cold water from the sea for. So, far that lot of electricity is being used. So, the electricity usage in Tamilnadu or in Chennai at least we will go up significantly in summer because of the number of air conditioners that will switch off during summer.

So, significant use of electricity, so significant use of energy. So, now, in the process of generating electricity or generating electricity you just pulled out cold water from the bottom of the sea and if you actually had a network of pipes which could transport this cold water to various places in the city. You can actually technically do air conditioning using this water without having to put you know air conditioners in the conventional sense of the word where you have a compressor a lot of different things, that are going on in lot of electricity being used you already have this cold water that’s available with which you can appropriated design your air conditioner to deliver this cold air to various places in city.

So, technically at various buildings in the city for example. So, technically we can have air conditioning that is significantly dependent on this 3 degree centigrade water that were getting off the you know 3 or 5 degree centigrade what are the getting from the bottom of the sea where essentially you are main energy in usage is that pump that is pulling that water out right. So, that’s a major thing that you can do associated with this OTEC plant.

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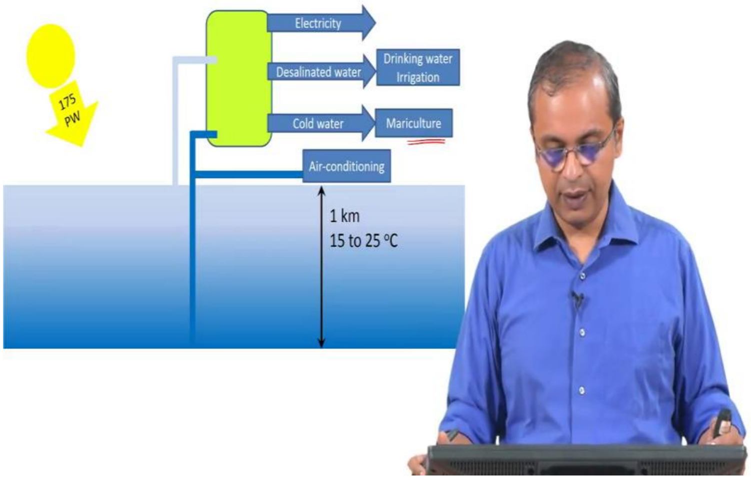

Of course the purpose of it is electricity. So, that is one major activity that we will anyway do. So, there essentially what you are doing we will we will talk how the electricity is generated in just a momentum. So, that is one major output from this OTEC plant.

So, air conditioning would be like a sort of a byproduct of this plant because you can do it and then electricity is your primary product. Desalinated water. So, in the process of doing this electricity generation one of the ways in which we do it there will be couple of different ways in which we can do it I am going to talk about that, but one way in which you will do this desalination would do this electricity generation would result in desalinated water being available to you that of course, can be used both for drinking as well as irrigation.

I mean again if you look at Chennai situation water is also major issue like with any major city like with major cities increasingly now, in the news you here about cities which are which have either out of water or just on the verge of running out of water and for example, they say in Bangalore is one of the cities which is likely to run out of water.

So, the scarcity of water is significant issue in many cities have that problem. So, Chennai also has a problem with scarcity of water and depending on where you are in India you have differing levels of water scarcity issues through the year or even internationally many cities have this issue. Because populations have grown and they are concentrated in some area and you have to have water available to them. So, if I mean of course, you may depend on rain or you may depend rivers you may depend on some perennial rivers you may depend on glaciers etcetera this is one way in which you can get the water where you getting electricity at the same time we are also getting drinking water by doing there because the process of getting the electricity is creating desalinated water for you right. So, you can get that.

So, you can get drinking water you can use it for irrigation and to some degree whatever cold water remains you can actually do mariculture. So, where it's sort of you know running you know forms where you allow you know sea animals to grow and you can use them for various purposes depending on what you are interested in. So, as you can see there is a wide range of things that you can do with this associated with this OTEC process and they are all associated with activities that where anyway already doing, air conditioning we are already doing some amount of you know usage of sea you know related products we already doing, water we need, irrigation we need. So, all these things I already have electricity we need. So, all these things come together with OTEC plant and therefore, this OTEC plant is a good thing to have despite the challenge of you know having to deal with the depth of water and you know getting the pipe to stay together.

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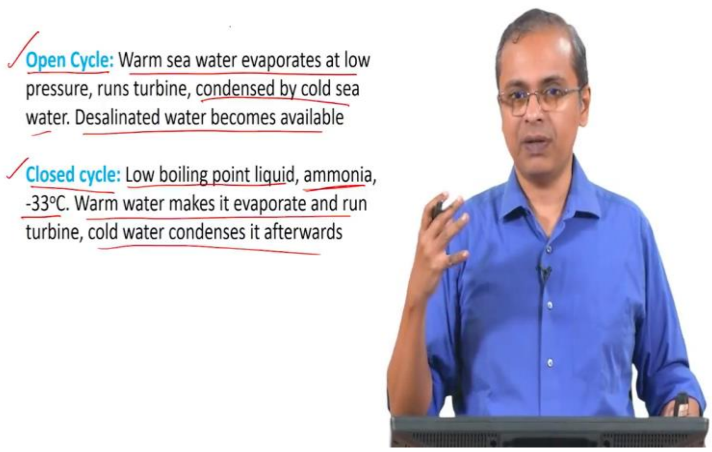

So, once you get all this cold water and the warm water what you do. So, there is one way there are two different ways in which you get this electricity out of it at the end of the day you have to run a turbine.

So, if you just have water sitting at 36 degree C that's just flowing I am you cannot really run much of a turbine with water sitting at the temperature you need you know basically vapor pushing through the turbine and getting the turbine to run. So, normally what is done is if you can be set up a low pressure situation. So, that the water you know now, become comes out in vapor form and then is able to run the turbine.

So, so warm see water will evaporate at low pressure and it will run the turbine and then will be condensed by the cold sea water and you will have some water you can eject. So, this warm water which first come you know which evaporated is now, clean a because it is an vapor form. So, it the salt is not there in it and then when you again condense it you can actually have desalinated water. So, you remove the salt separately and then you can this desalinated water and so that desalinated water becomes available as a byproduct. So, when you do this open cycle method of getting electricity out of this OTEC plant are you get desalinated water as a byproduct .

Another way in which you can do it is to run this closed cycle operation where basically what to do if you take you do not use the water directly to run the turbine instead you have a closed system where you actually have low boiling point liquid typically ammonia is used any other refrigerant could also be used, but with refrigerant we have already had this issue of you know how the refrigerant creates this hole in the ozone layer. So, many refrigerants are now, banded.

So, there are only specific refrigerants that are permitted to be used and so and that contact should be careful what you use. For example, ammonia would be something that boils at minus 33 degree C and so you can use that in the context of this you know system and then that would be the liquid that would evaporate, that would run the turbine and then be you know condensed and etcetera. So, again warm water will make it evaporate it will run the turbine and then cold water will condense it. So, this kind of an operation we can think of.

So, we have an open cycle and we have closed a cycle. We will also keep in mind that you know your pumping in large amounts of water. So, everything that comes with it.

So, it's not going to be like clean water you going to have you know you may even have some small sea creatures that show up and you know various things that are available in the sea will show up. So, in some sense yes you may do some disruption to the marine you know environment that is there and the water that you are ejecting, is ejected back into the sea. So, you are doing some little bit of churning of the sea water in this process, but the general calculation shows that you know at least with respect to the water you you I mean the quantity of water we are going to use is so minuscule relative to the amount of water that's available in the sea and we are basically just putting it back.

So, whatever churning that we are doing it so tiny that it would more or less have no impact at even if you did large scale deployment of this OTEC technology. Okay so, if you did large scale deployment also we would not have much of an impact on the behavior of the water and just because of our interfere incident. But we have to always be cautious because this is how we thought about the atmosphere and we should know what can we do we are not going to do anything on earth that can disrupt the atmosphere, but we are currently doing that with respect to the CO, CO_2 emissions.

But in this case it seems like the calculations shows that you can use significant amount of OTEC technology across the word not really make a big difference to the water itself. However, we may impact the marine life that exists there because they are accustomed to certain temperature at various regions and if you keep on pumping in pulling out water your probably disrupting the creatures that all are at the depth and you are pushing back water at some other level which has a different temperature. So, you are effecting creatures are that depth.

Again that is close to the shore. So, if you go away from the shore this is not going to be an issue you can even have offshore platforms which basically like a ship. So, in the ship some of the even right the early days people tried all of this they put a ship out there and from the ship that we are pipe going for deep down pulling of the cold water and then doing all the electricity generation. But all of these have been challenging many of those ships have been destroyed in the you know ocean. So, that has happened even in India one of the plants that was put up in 2002, in Tamilnadu it was put up it had issues with the cold water pipe lines. So, it was partially successful, but not you know they couldn't sustain it over a period of time that they have some issues dealing with the cold water pipeline.

So, even in the coastal area there is a problem even off shore when you when the set up is made there, there can be challenges. So, it is not an easy technology to work with because you are not on solid ground I mean you are dealing with liquid that is and dealing with depths liquid, flowing and large quantities that we do not have enough control on. So, that is something that we have to worry about.

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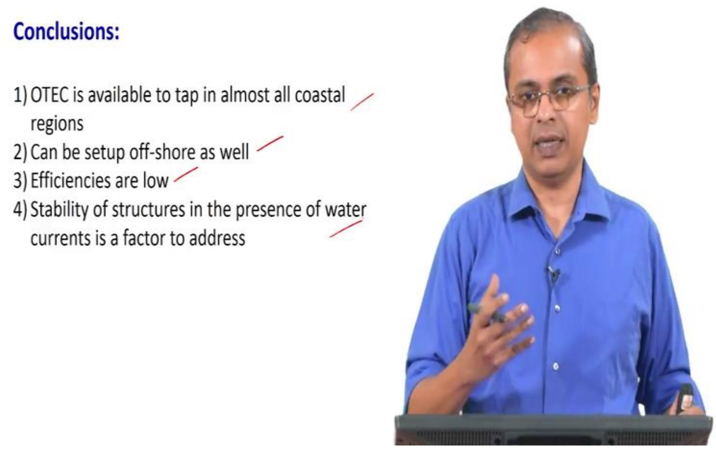

So, in conclusion you know OTEC is available to tap in most all coastal regions. So, except if you go to extremely cold regions then you may not have big difference between the surface temperature and the temperature of the water much further down. So, that's something that we can think off, but most other coastal regions this can be done and as I said you can do in large scale it doesn't make a big difference. It can set up in an offshore mode as well just the way you have offshore oil ricks right you have off shore oil ricks which are sitting floating platforms sitting out in the sea . So, they would have to figure out at what location they are able to access the depth of water easily.

So, lot depends on how the you know sea shelf is, you know what is the topology there because there are places in the if you if you examine the coast depending on where you are the water will sometimes drop off the depth will suddenly increase a dramatically. There are other places where the you know the ocean floor is quite shallow from the you know say the coast. So, you stand at the coast you can actually walk quite some distance into the water and you will still be only you know knee deep or you know waist high and you can still see you know it even for further distance the water is just maintaining that kind of depth. So, many many of those you know popular resorts that are there with you see beautiful photos of our all places where this kind of a situation is there that the depth is very shallow for a long distance.

So, you can get into the water, but you are not in any deep water for a quite some distance very visible distance we can see. But many other places for example, in Chennai, in and around Chennai lot of people say that the water floor falls off quite dramatically even if you go a little distance into the water therefore, it is not safe to go unless you know what you are doing it is not at all safe to just you know way into the water beyond some very short distance. Lot of people do not realize the risk there, but that is the safety issue that is there.

So, the point being the depth from the coast, from the surface can change significantly from location to location. So, in some places you can have an on shore setup which can be which is the typical way in which you would probably think of an OTEC plant because you can have the whole plant sitting on the shore and just a pipe that goes out into the water because in a short distance the pipe can just drop down in great depth it can go down and then from there you can pull up the cold water.

There may be other places where you have to go quite a bit away from the coast before the depth in water is significant enough right. So, then it doesn’t make sense to start at the coast and send a pipe which goes long distance at the floor and then eventually goes down. So, it helps there to actually have offshore platform where like an oil rig you are just sitting you know this whole platform is sitting out in the sea and you just have a pipe going vertically down then that will be an easier pipe to you know put together and manage. So, it goes straight down vertically down to that location which is you know as deep as it can get about a kilometer deep and then from there you can pick up the cold water and then the warm waters is on top.

As I said the efficiencies are low it is only about you know 3 4 percent functionally your only getting about 3 4 percent, but that is adequate because you can actually do I mean you are just more or less getting it for free there is nothing of any great significance there. And its clean your, you know except for the fact that you are churning up the ocean and you are getting lot of marine creatures or marine organisms out which could be significant if you doing this in large scale over a period of time there is no emissions as such it's basically clean kind of energy and that therefore, that is fine.

And then the big challenge there is the stability of the structures in the presence of waters, water and water currents is a fact that you have to address. Even be you know you know all the piping and what not you are you are using salty water. So, you have to make sure that you know corrosion is not an issue. It's not just the salty water it is flowing salty water you are pulling up you know water pumping up water. So, it is going to flow. So, you also could have some abrasion of the surfaces and so the material should be such that they are abrasive resistant and they don't corrode even if there is abrasion and you have this salty water conditions. So, these are all some of the challenges.

So, that is the overview of the OTEC technology. As I said it has been deployed some few places in the world has been tried in India and I think more attempts are going to be made because it adds an interesting mix to the energy scenario. Some places it will make a lot of sense to have may not be in every location and to the degree that it makes sense its worth time ok. So, this is what we want, we I would like to discuss on this topic and gives you a reasonable overview of this technology.

Thank you.

KEYWORDS:

Ocean Thermal Energy Conversion; OTEC; Thermal Profile; Thermocline; Challenges of OTEC; Air Conditioning; Desalinated Water; Open Cycle Method; Closed Cycle Method

LECTURE:

An overview on Ocean Thermal Energy Conversion (OTEC) and its principle is explained. Challenges encountered in tapping such an energy and the byproducts of tapping energy from OTEC are discussed.