Energy Resources and Technology
Prof. S.Banerjee
Department of Electrical Engineering
Indian Institute of Technology - Kharagpur

Lecture - 33
Ocean Thermal Energy Conversion

Today we will be talking about OTEC, ocean thermal energy conversion.

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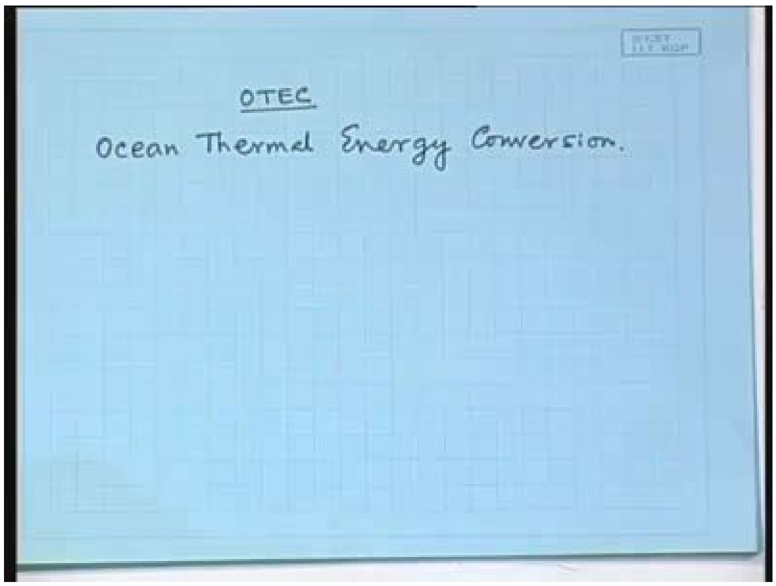

As you know, a greater part of the Earth's surface are the oceans and naturally, the solar energy that is absorbed, most of it is absorbed in the oceans and as it is absorbed, a huge amount of energy in fact far surpassing the energy that is available anywhere else in the world, is available in the oceans. But the problem is, that is available in such a diffused and difficult to utilize form that the development of the converters to tap that power, that energy has been somewhat recent. Not exactly recent, the initial steps to develop ocean thermal energy was in the mid of the last to last century. But, at that time it was only a concept. It was only a, somewhat at that time a wild idea, which came to fruition somewhere in the middle of the last century and people started designing actual plants and finally, today we have very working models available. Even India has one.

So, what is the exact concept? The concept is that as solar energy is absorbed in this, in the open ocean, the surface of the sea becomes heated and since the solar energy, most of the solar energy is absorbed close to the surface, so there is a layer close to the surface that is relatively hotter and as you go down deep into the sea, you have still cold water. So, we can have a temperature difference between the warm water of the sea surface and the cold water at the sea bottom and the question then is can we utilize that temperature difference in order to produce energy?

You might ask what can be the temperature difference like? What are the typical temperatures? Say, the typical temperature on the ocean surface may be something like 30 degrees, typical temperature at the ocean bottom can be something like 10 degrees. Can you calculate the ideal Carnot efficiency of that kind of a machine? Calculate. Ideally how much is achievable, what kind of efficiency is achievable?

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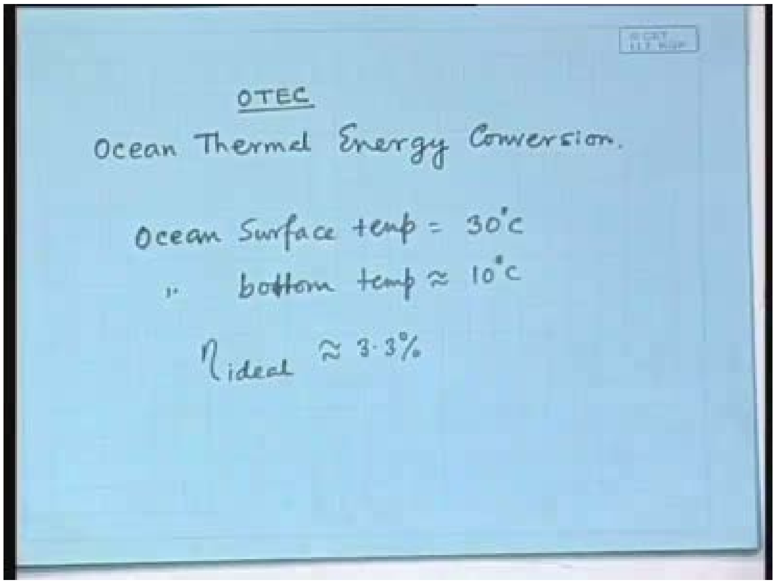

So, you have the ocean surface temperature and ocean bottom temperature is close to say, 10 degrees. What can be the efficiency like? 1 minus T 2 by T 1. What you do not have a calculator? You can simply press and tell me the result.

8%. How did you get it? How did you get it?

Student: 1- T 2 by T 1

1 minus T 2 by T 1 in absolute scale. So, this has to be converted into absolute scale, this has to be converted into absolute scale and then only you can talk about the value. So, how much is it?

Student: 3.6

Something like that. Is it right? Can you, can anybody check?

Student: …

So, around 3.3% would be the ideal thermal efficiency, ideal. So, you can see that the efficiency of a normal thermal power plant would be of the order of 40%, while the ideal efficiency here is about 3%. So, naturally this is, even if you go very close to the ideal efficiency, this is very inefficient process. Nevertheless, the point is that here the energy that is available is vast, huge, huge amount of energy is available and all that is free and so, still it makes sense, even though the efficiency is low.

What really matters? Why were we were so much interested in the efficiency of a thermal power plant? Because, there the input was coal which is finite, so out of that finite resource, how much can be utilized that was the very important question, while here what is available is infinite almost and so, the efficiency is not all that an important question. What is more important is that how can we make the converter, the system relatively inexpensive, so that the initial investment is manageable. How can we make the whole thing such that it lasts for a longer time? So, these are the real concerns rather than the efficiency.

So, now let us come to the concept of how can we utilize this small temperature difference? Now, when we talked about the Rankine cycle that means the normal power plant, what was the idea? The idea was that we will heat up the water, the principle working fluid, to a temperature where it boils and it boils and then it goes to the superheated zone and then it is expanded through a turbine. So, all that part you have to put in a large amount of heat and in this case you are not really trying to put in additional amount of heat, you are trying to utilize the surface water which will be about this temperature.

Can you then produce steam at that temperature, 30 degrees? Everybody is shaking the head in this direction, wrong. You can produce steam at this temperature, simply by reducing the pressure. So, there would be a pressure at which, at this temperature it will be superheated steam. So, it is possible do that. So, all you need to do is to reduce the pressure, so that this water is converted into steam. So, then it is steam, but at a very low pressure. But, if at the other end of the turbine you can produce even lower pressure, then obviously the turbine can operate.

In the normal power plant, the concept is that you have a high pressure and here a moderately low pressure, but not very low. But here in this case, in case of the OTEC, you have the superheated steam at a low pressure, sub atmospheric pressure and at the other end it is even lower pressure, so that the turbine can operate. You might have a bit of ringing in your minds, is it feasible? Yes, it is feasible, has been demonstrated to be feasible. So, then the concept would be that we will take in the surface water, we will allow it to what is called flush, allow it to flush in the sense that we reduce the pressure by suction, by simply running a pump and that pump has an additional advantage that in the water that you take from the surface there will be dissolved gases which is not steam. So, if you have the pump running, the exhaust pump running, then obviously that gases are also taken away, so the pressure is brought down. At that pressure the steam is formed. Then, the steam goes to the turbine and the turbines end, other side what it should be there? What is there after the turbine?

A condenser; so, there has to be a condenser and the condensers exhaust would be simply again water, right. That water can again be discharged into the ocean. The question then is how to do the condensation. It has to be at a very low temperature, so that temperature is the ocean bottom temperature. So, somehow you have to pump water up from the ocean bottom to use it in the condenser, right. In that case, what becomes the T 1 and T 2? T 1 as you know is the temperature of the steam at the highest point. T 2 is the temperature of the water at the lowest point in the circulation of the principle fluid.

In that case, these two are the temperatures. So, you can reach efficiency somewhat close to this, 2% is more or less average. So, the concept then would be something like this. In fact, that is the concept by which it was first done.

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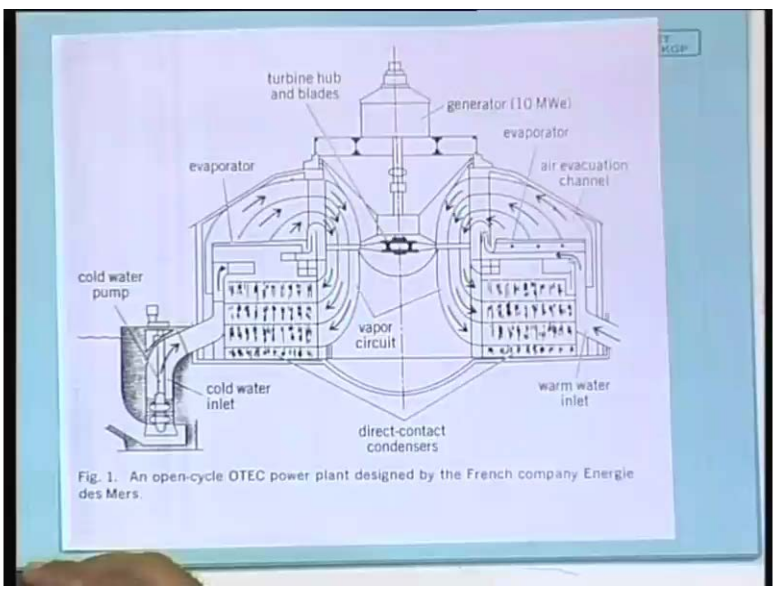

Instead of drawing, let me see if it can be projected. Can you see or should I have to draw? Seeable, so what is the concept? The first design, this is called an open cycle, because water that is taken from the sea is again discharged into the sea. The water that is taken from the sea bottom is again discharged into the sea bottom. So, it is a very open system. So, this is the place where the warm water is collected, is taken in. That warm water rises and it is here in this part you have the low pressure created. So, here is a place where the flushing takes place, where the water at 30 degrees start to boil and produce steam. So, here you have a low pressure steam. That steam is then, you might imagine the whole thing as a round shaped. So, this is all round, so here also you have the same thing going.

In this part, you have the steam that is generated. Here, you have the turbine. Turbine is vertical axis turbine and normal propeller type and you have the shaft going up and this is the place where the generator is housed, outside the casing. So, the steam goes like this and goes through the turbine blade, right. As it goes through the turbine blade, in this part then the pressure has to be even lower than this pressure. So, in this part the pressure has to be low, in this part it is relatively high and the turbine rotates because of that difference in temperature and it was in fact generated. You can see that 10 megawatt generator was actually designed, operated by this principle.

Then, you have the cold water that is taken in from the sea bottom, that rises and it is mixed with this water, the steam that is coming. As a result, the steam again condenses into water and this condensation, because of a huge reduction in the volume, you have the suction created here; you have the low pressure created here. So, this is the essential principle of the open cycle OTEC plant. Again notice, what are the different components? You have the component of the water inlet, hot water inlet, the flushing chamber, the space in which the evaporated, relatively high pressure steam is accumulated and in this part, you have the relatively low pressure. So, you have the flow of the steam like this and it comes to the condenser part and it is a direct contact condenser means this cold water is in direct contact with the steam, thereby condensing it fast.

The steam temperature in this part thereby becomes the, actually the temperature of the cold water. So, here you have the advantage that in the thermal power plant, though the cold temperature is much higher than the steam temperature, but we had to take the maximum temperature of the steam as the T 1. Here it is the same temperature, as it is, 30 degrees. T 2 was the temperature, to which the principle fluid could be cooled down in a heat exchanger. But here, they are mixed and therefore, you have same temperature of the ocean bottom as the T 2. So, that is one advantage here.

But, there were some disadvantages also. One disadvantage is called bio fouling means, the warm water that comes in, that contains planktons, algae and stuff like that. You might put away the fish, because you might put some screening somewhere here, so that fish do not get in. But nevertheless, the smaller microorganism would come in and that would foul the various components to which it comes in contact. Same thing happens with the condenser. So, periodically that needs to be cleaned and stuff like that.

The second main problem is that, because very low pressure is there, if you want to have certain amount of steam, if it is at a high pressure, then the, then the volume is small and the volume is small means the size of the turbine is also small. That is why in a normal power plant, when you have the high pressure turbine, intermediate pressure turbine, low pressure turbine and you know that after the high pressure turbine, the steam is bled out for the riveting and stuff, right. So, there are different stages of the turbine and the high pressure turbine is actually very small, the intermediate pressure turbine is relatively larger, the low pressure turbine is really large. The diameter will be of the size of this room in a normal power plant. But here, it is even lower temperature, even lower pressure and naturally, you would need huge surface area, huge size of turbine. That is another disadvantage. But nevertheless, such plants have been constructed and have worked. This is an open cycle process.

Now, one natural improvement over this would be where you use not water, but some other fluid as the principle fluid. What can be the some other fluid? Anything that becomes superheated at 30 degrees, at high pressure. Can you name any of them? Any fluid that becomes high pressure superheated fluid, superheated gas at say, 30 degrees, any idea, can you name any? All the substances used in the refrigerators are such things. Freons for example, ammonia is one such thing, propane is one such thing. So, there are various such materials which can be used as the principle fluid.

Initially freon was used, but nowadays freon is going out of favour, because it causes the greenhouse effect, it causes the ozone layer depletion and that is why people are no longer favouring the freon to be used as a principle fluid in such a vast quantity, large quantity. So, nowadays more or less people are going for ammonia as the principle fluid. So, in that case what would be the structure of the whole system like? The hot water inlet pipe will bring in the hot water, that would go into a heat exchanger, that would transfer the heat into the principle fluid, thereby making it superheated at high pressure.

That high pressure principle fluid, in this case possibly ammonia, would go into ammonia turbine and it will expand through the turbine, because it is at high pressure, thereby the turbine size is much lower, a normal turbine size as you would have in a normal power plant and then after the turbine, it goes to the condenser and in the condenser it is condensed in contact with the water that is pumped from the ocean floor and that is a cold water like 10 degrees and you have again the fluid, principle fluid, after it has turned into liquid, it is again pumped back to the boiler part. Same system, same idea as what you have in the normal power plant, only the principle fluid is different.

In that case, the systems schematic diagram would be something like this.

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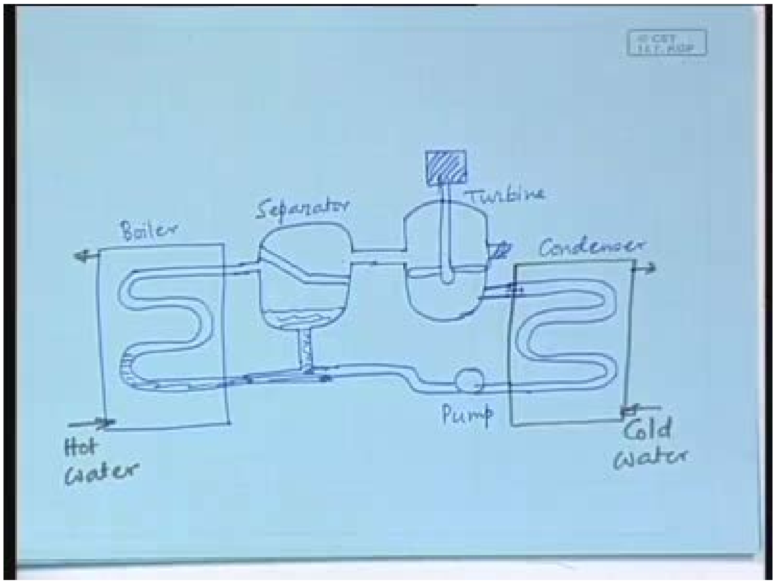

There would be one part; it is in this part you have hot water. So, this would be the boiler. Then, after the boiler it has to go, since at this stage what is produced is what? At this stage, what is produced is basically saturated, right, because it is in contact with the, with the liquid. Liquid may go up to this stage and as it goes up it becomes gas, but nevertheless saturated. So, there would be, like saturated steam there would be, it would be saturated ammonia vapour. So, saturated means there would be tiny droplets of liquid and so, that has to be separated out before it is fed into the turbine. So, it is, it is done by a chamber something like this. I will draw and here you have a separation where the liquid is collected and that is fed back to this line.

So, as it goes, it goes through the separator, essentially it goes through a baffle, so that as it goes, the liquid part is collected and drops down and the vapour parts go through. The pressure here is slightly reduced in comparison to the pressure here, as a result of which those tiny droplets also evaporate to produce superheated steam; it is not steam, ammonia. So, here you have, after this stage you will have to have the turbine. The turbine is, I am, I am drawing schematically, but normally these are axial flow turbines. That means as the vapour flows, the axis in same direction it rotates, so normally these are axial flow turbines. So, let me draw it like this, no, this will have to be at the bottom. This is where it goes out and here you have the generator. So, it goes like this and goes out and then, after this, what you should have?

You have to have a condenser again and at this stage, you have the cold water and here you have the cold water going out and after this, you only have to have a pump that pumps it back to that. This is called a separator. Is the concept understood now? So, can you see that, because the hot water is not directly in contact with the principle fluid, there is a heat exchanger. So, obviously the temperature of the principle fluid at its peak will not be the temperature of the hot water. That should be slightly below. Here also the cold water temperature can be 10 degrees, but the temperature to which it can be cooled will not be 10 degrees, somewhat higher. So, when we said 1 minus T 2 by T 1 that efficiency will also go down, right. So, this has a lower ideal Carnot efficiency, but nevertheless this cycle is often preferred, because the turbine size is manageable, mainly because the turbine size is manageable.

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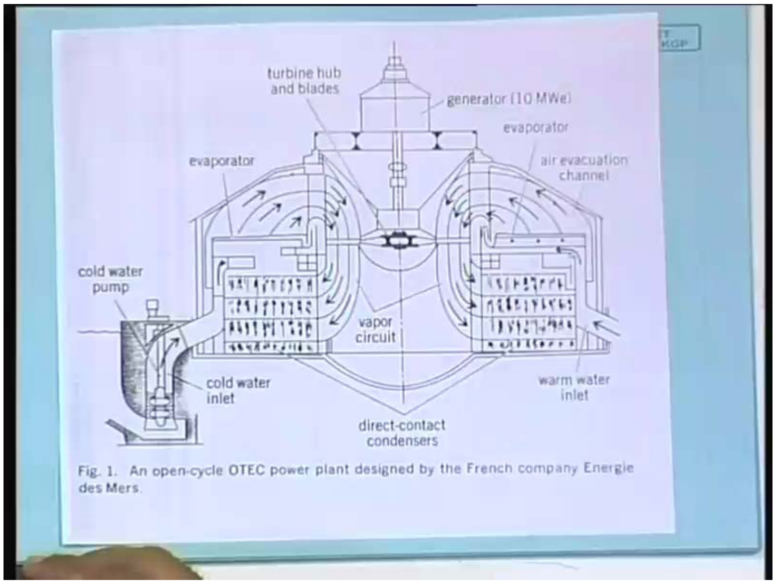

Now, one further idea that has been incorporated in some places is related to the cycle that I just earlier showed, the open cycle. There are many places in the world, which are deprived of normal water. Very few places are in India like that, but the whole of the Arab regions are like that, much of Sahara and Africa are like that and in those places, desalination is a big deal. One has to have desalinated water; water taken from the sea and that has to be desalinated in order to be potable. So, desalination is always a big industry in those countries. How is that done?

That is done mostly, that can be done by various means. Boiling the sea water, again distilling it, that can be one possibility. Even in many, in some of the Arab countries, I hear they simply burn oil and oil, as it burns produces carbon dioxide and water vapour and that is condensed. So, I do not know whether that is true, but that would be somewhat stupid way of doing it, in the face of the crisis that the world is facing. But nevertheless, the point is that desalination is the major requirement. Now, do you notice that here the water that is available is desalinated. Here, the saline water is coming that was evaporated and thereby the steam comes without any salt. So, here what is coming is already desalinated and here you are condensing it and finally you are producing again water.

In the cycle that I just described, we had mixed the cold water with the steam. But instead, if you simply have a heat exchanger, so that the cold water through a heat exchanger condenses the steam then you sacrifice a bit of efficiency, all right. Why because, the steam temperature as it cools down will not be the same as the cold water temperature, but nevertheless you have the advantage that what condenses is already desalinated steam. So, this can work both as a power generator as well a desalination plant. Do you see that? So, in those places where desalination is a major requirement, such plants can work together as a power generator as well as a desalination plant. But, here we do not have that facility, because here we are not flushing the steam, clear.

You might ask what do you do with that power. It is after all in the middle of the sea. So, what is the essential concept? There can be two types of concepts. One, you have the whole system located close to the sea, but on the land and then a pipeline goes to the bottom of the sea and that brings the hot water and the cold water. That is possible, in fact that system is there in a couple of places. But, close to the seashore, you normally do not have such depths which you require. How much depth do you require? Of the order of a kilometer; in order to reach a temperature something like 10 degrees, 9 degrees, you need to reach a depth something like a kilometer and obviously, close to the shore you do not have that kind of sites. There may be such sites, but normally you do not have. Where you have, you can have the actual plant located on shore with pipelines going down. But, where you do not have, you cannot afford to have very long such pipelines.

For example, in India the place where the present experimental facility is located that has to be about 40 kilometers away from the seashore that is in the Southern India, in TamilNadu, but that is about 40 kilometers away into the sea. 40 kilometers long pipeline is out of question, it becomes unmanageable, economically. But, 40 kilometers down there you can have a floating platform, housing the whole thing.

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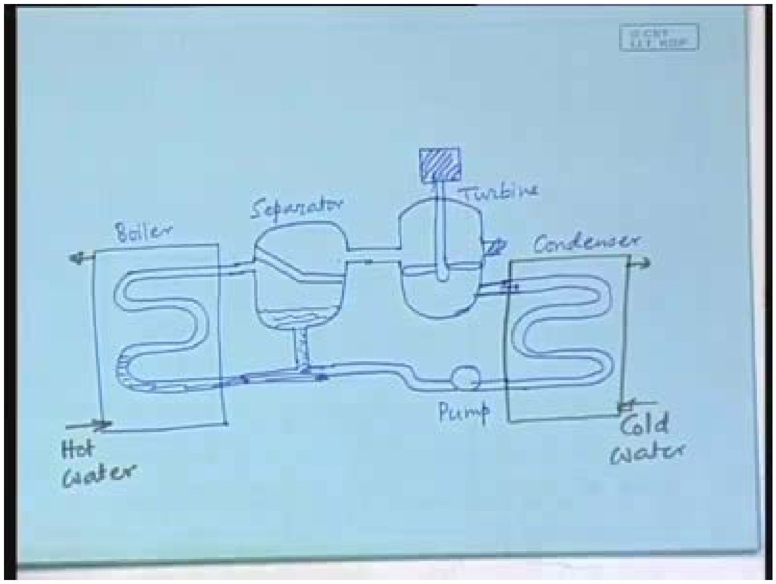

So, that is the concept that is being now incorporated in many places, a floating platform on which this whole system is. There is system to suck in the water from the surface and there is a big pipeline, big tube about a meter, diameter or so. For bigger plants, it would have to be even larger that goes down to the bottom of the sea. Mostly these things are moved, these things are you know anchored to a place where the whole thing operates and there would be a power cable going through the bottom of the sea from the ship to the shoreline. So, power cable of a large length is reasonably a feasible thing, but a big pipe going to such long distances is not feasible. So, that is one concept that you can have a floating platform with, it is stationed, it is stationed in a particular place and you have the system in place there.

There can be another concept. That concept is why do not you have a full industry right there where the power is being generated? Do you understand? So, if you are generating power in the middle of the sea, you do not always need to transport it to the, transport the power to the shore, because where would you, what would you do with that power on the shore? You will run some industry, making some industrial product. Will it not be more convenient to have the whole industry in the floating platform? Makes sense really, makes sense. What kind of industry can you think of? Obviously, it has to be something where the raw material is also available in the middle of the sea.

Students: Oil refinery.

Oil refinery; so, in that case the oil has to be available right there. For example, Bombay high is a place where you do not have 1 kilometer depth. So, if the oil availability place and the depth availability place are two different places, you cannot really use it. So, something that is available on sea.

Student: Fishing

Fish, so how much energy do you need to put a line and fish? No; fishing industry, you can have processing, but nevertheless let us think of something that is available on sea. Of course, sea water is available. What can you do with sea water?

Student: Salt

Produce salt; in order to do that you have to evaporate, evaporate the salt. You might think of taking the water, heating it up with that energy that is available and yes that is feasible. Anything else, anything else can be done with sea water?

Student: …

No, no; waves is a different issue. I am talking about the industry, not energy generation; energy generation is by this. What can you do with sea water? Of course there are two things that are available around there. One is water, another is air. What kind of industry can you run with water and air? Yes, there are industries that simply need water and air. For example, if you use this electrical energy to electrolyze water, you get oxygen and hydrogen. Oxygen is an industrial product. There are industries that produce oxygen for the hospitals. Oxygen is an industrial product. Hydrogen, what can you use hydrogen for?

Well, well, well, then hydrogen will have to be transported to the shore that will be a problem. Oxygen can be, can be transported, all right. Hydrogen would be a problem. So, what can we do with hydrogen? With the hydrogen what can be done is ammonia is an industrial product. Why, what is ammonia used for?

Producing, producing what? Ammonia is used for? Producing smelling salt is it? Yes, smelling salts does contain ammonia, all right. But, of course, that is not a huge requirement. So many people are not fainting all the time, so that you might need smelling salt. What is the industrial product that uses ammonia?

Student: Fertilizers.

Fertilizers, yes, fertilizers use ammonia. So, in order to produce those fertilizers you have to produce ammonia and ammonia can be liquefied and transported to the shore, small volume, no problem. How do you produce ammonia? You need nitrogen and hydrogen. Hydrogen can be produced in an electrolysis process. How can we produce nitrogen? From air. So, you see, water can be used for electrolysis to produce hydrogen, air can be used for producing nitrogen and oxygen.

How do you produce nitrogen and oxygen from air? Air is first liquefied and then it is fractionally distilled. So, liquefaction and fractional distillation is the process by which we produce nitrogen as well as oxygen that is used for hospitals and everything. That is the process. So, what is the requirement there? Only energy, electrical energy. So, you can have a whole floating platform that produces the energy, uses the energy, produces some industrial product and transport that to the shore as a liquid.

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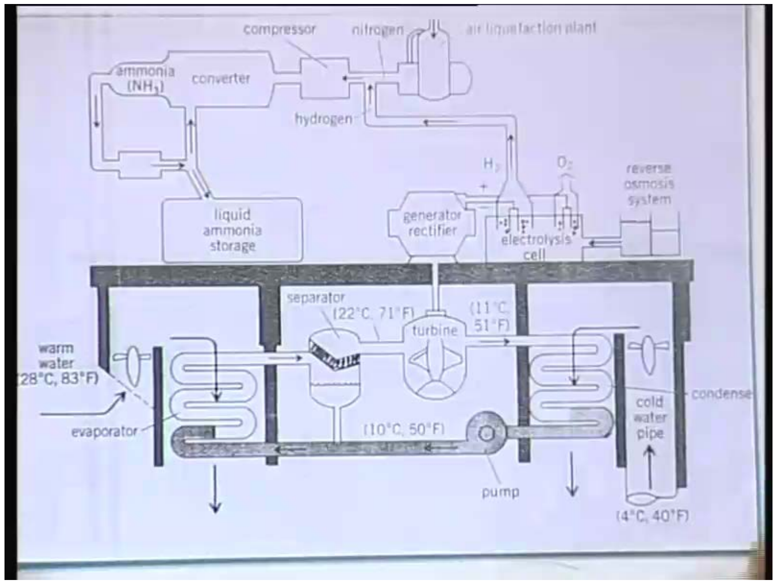

So, that is a feasible concept something that can be can be illustrated by this. Can you see? Yes, it is seeable. So, here you see, here is the platform. Here is the platform, below this you have the power generator and above this you have the industry and as I have just shown, this is the place where the warm water comes in. This is how the warm water goes out, again discharged into the sea. This is the boiler part. Up to this it is shown that it is liquid and then it becomes gas and here it is separated. It goes to the turbine. It goes to the, notice the temperatures. Here if the temperature will be something like 22 degrees, after it goes to the turbine the temperature comes down to 11 degrees and here it is, the energy is taken out and it is discharged something like 10 degrees. So, the temperature is not different very much. It is only the latent heat that is taken out by the cold water. So, the cold water is circulated like this and the principle fluid goes like this, good.

Electrical energy is generated in the generator. Now, this electrical energy can be first used. First, you put a rectifier here and put a electrolysis system here. So, the oxygen goes to the industrial product. Can you see that? Can you read, is it big enough? So, oxygen goes there. This has to be, the water has to be sea water, but from there a particular amount of conductivity has to be created, for that the reverse osmosis process is used. Now, the hydrogen goes here and here you have the air liquefaction plant, where it is a simple refrigerator. So, you have, by pressure you refrigerate the air and after the refrigeration, you have the nitrogen and oxygen. They are separated out by a fractional distillation. So, you have nitrogen here, oxygen nitrogen are mixed together that is compressed to a high pressure and then there has to be a catalytic converter which produces the ammonia and the ammonia is then liquefied and stored and finally, once a week, you can have a ship going to the shore taking the ammonia out. That can be used to produce urea and stuff like that. So, this is the concept that is highly feasible.

India has as yet incorporated only this part. It has made a 1 megawatt OTEC plant that works about, as I told you 40 kilometers off the South India shore, Tamil Nadu shore and there the surface temperature they get is something like 29 to 30 degrees, the bottom temperature they get about 1 kilometer down there is about 9 degrees and so, a large amount of water has to be pumped up and that is done by a flexible pipeline about 1 meter in diameter that goes down and that is anchored to the bottom of the sea. So, the flexible pipeline goes down, the whole thing is then anchored to that place.

There are also concepts where the ship itself is not anchored, rather that goes on moving in the sea. Only it has to ensure that it has that kind of depth available that means it should not drift to a place where the depth is less and the pipeline gets stuck somewhere, that should not be allowed. But then, the advantage of drifting is that it can then maximize the temperature difference. It can move to a place where the temperature difference is larger, so such systems are also in place. That means where this whole system is there, there is no electrical connection to the shore. The whole thing is self-contained that produces some industrial product and the ship itself is the whole industry. It goes on moving in the sea, trying to maximize the amount of energy that is available. Is that clear?

So, there are various concepts then. There are various concepts to put in place. As yet there are, there have been quite a few OTEC plants built all over the world. America has built a few to install them in the Panama coast. France has built, England has built. Mostly, these have to be situated not in the cold regions, because you do not have sufficient temperature difference. It has to be in the temperate regions within the 20 degrees belt from the equator. So, all the plants have been situated there, but the point is that such plants, as yet they are very expensive. Why? Because each and every component is custom made for this particular purpose. Do you see? There is nothing, there is no industrial product in the whole system. Each and every component is specific.

In this kind of a cycle, where it is closed cycle, the heat exchanger has to be very efficient, because a very, it has to work against a very small temperature difference and it has to give that heat to the principle fluid and that has to be, it has to be very efficient heat exchanger. In fact titanium heat exchanger, titanium pipes are used in the heat exchangers, which maximizes the heat transfer. This is expensive. You have to have the turbine which is again special, because it has to work with ammonia as the principle fluid. It has to be specially constructed, specially coated, so that it does not corrode.

You have the, again the condenser that also has to be very efficient in terms of heat transfer, again titanium pipes. So, these are all not industrial products, made for this particular purpose and that is why the expense goes up. Only when the first prototype that has been made, as I told you, 1 megawatt prototype, only when that becomes successful people gain experience, people gain confidence, then these individual components can be industrially produced, thereby bringing down the cost by a large extent.

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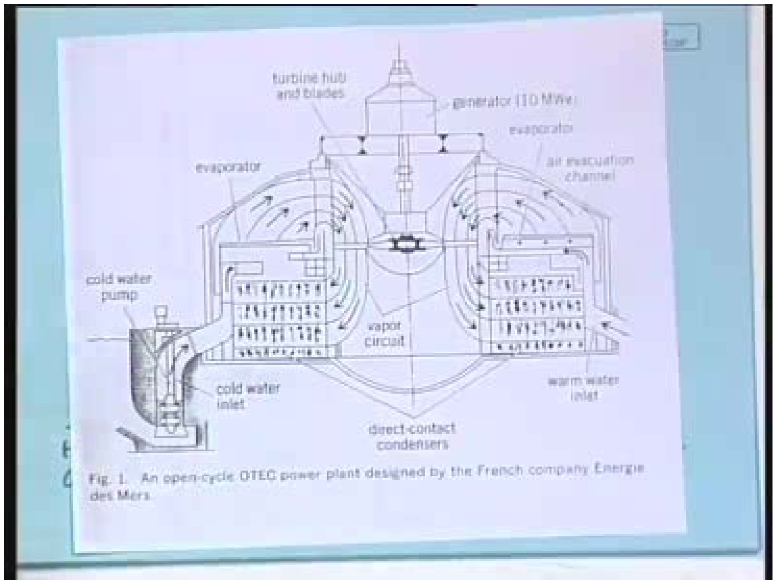

Fig. 1. An open-cycle OTEC power plant designed by the French company Energie des Mers.

In this kind of a cycle also you can see, open cycle, the turbine itself is a huge affair. The turbine blades would be of the size of this room, huge blades. That again are specially to be constructed for this specific purpose and that is why the cost is so high. So, unlike wind turbines, unlike photovoltaic, which have now become industrial products thereby bringing down the cost, thereby making them competitive, here the OTEC system is not yet competitive, because of this specific reason. The concept has been demonstrated, it works fine.

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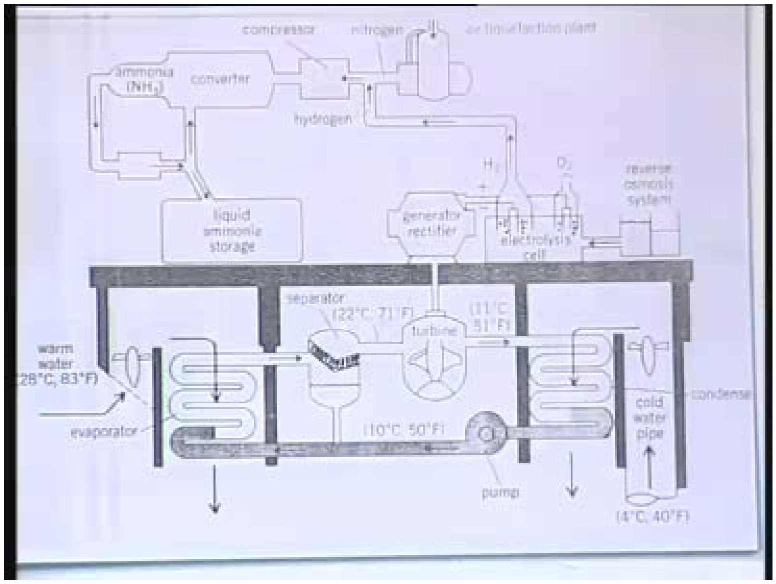

So, the right way to go forward would be to plan for a larger number of, at least 100 of OTEC plants all over the Indian coast and for that these components can be industrially produced.

What kind of powers can be generated? The experimental plant is 1 megawatt. There have been plants in the world that are 10, 15, 20 megawatts. There can also be, this can be scaled up. There can also be plants like 100 megawatts, but 100 megawatts is not a very big thing compared to the normal thermal power plants. A thermal power plant normally has for example, the Kolaghat thermal power plant the one that is installed by BHEL has 210 megawatt capacity in each unit. So, that is the standard size for thermal power plants. So, each one might not be produce more than something like a 100 megawatt. But, if you have a large number of ships, because a huge area is available, the area is almost infinite. So, if you have a large number of plants that can produce a large amount of energy though; there is no limit to it. While the thermal power is limited by the availability of coal, this is not limited by the availability of coal. So, that is the concept of OTEC.

So, in the next class then, we will go to another type of power generation; either we will take up wave energy or geothermal energy, which also have lot of promise in the Indian soil.

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The concept of the OTEC plant as a floating ship and the most visible part is that below the, at the bottom of the ship there is the pipe very wide pipe going down that goes to a depth of about a kilometer and this is the cold water pipe that has to bring the cold water from the bottom of the sea. Now, in this case, it is a very large ship that was designed for working in the United States, in the Southern coast, about 100 megawatt plant ship. The length is 750 feet.

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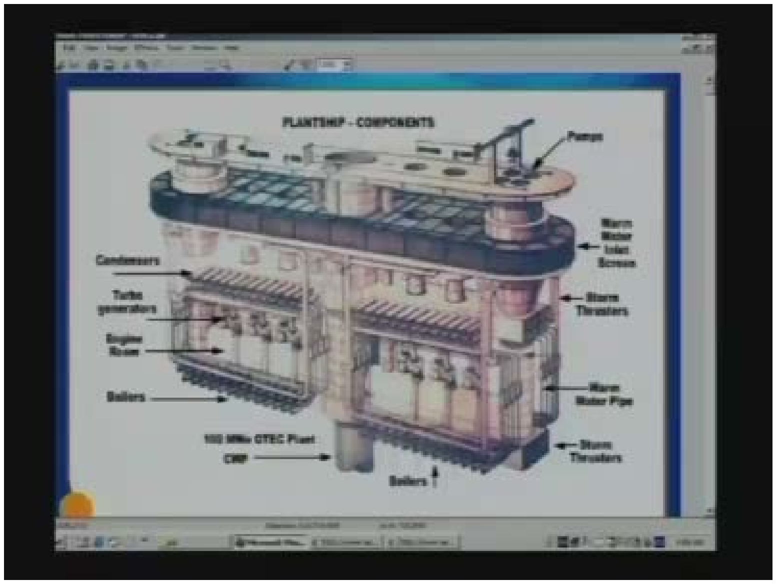

This is a big ship and its structure if you see, then it is it is something like this, where you have this cold water pipe and this is the place where you have the warm water coming in. These are the pumps that pump the warm water. Now, you have the, in fact the components when I drew on the sheet as a schematic diagram, these were very neat, clearly discernable components, but in this case it would be all mixed up. So, you need to understand how it works.

These are the condenser tubes. These are the condenser tubes and the warm water is actually going like this and you have the boiler part down there. So, warm water is taken in, goes in and here you have the boiler. After the boiler you have the turbines. These are the turbines in this case. In this particular case, you have the turbines not the usual kind of turbines and then the generator is housed there and the boiler is here and finally it goes up here and here is the condenser. So, that was the schematic diagram of the 100 megawatt plant that was designed to work.

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In India also we have plants, as I told already. This is the photograph of the plant. I suppose I can increase the slide, increase the size slightly. So, it was commissioned on an abandoned …. and you have the, the plant you can see here. Though in this case you cannot see the down pipe that goes to the bottom of the, bottom of the sea, but nevertheless this is the concept.

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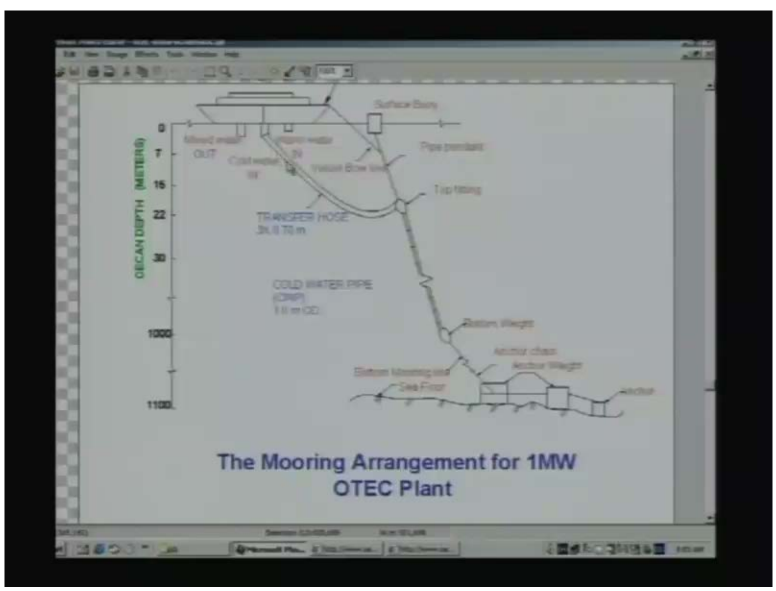

The schematic diagram is shown in this image. Here is the ship and here you have the depth. You can see, it starts from a depth of zero and goes to a depth of 1100 meters and the actual down pipe goes to a depth of about 1000 meters, 1 kilometer. Now, you can see that the ship is the usual construction within that what I discussed in the class. But, here the interesting part is that the cold water inlet pipe that goes and finally that goes into a fitting that hangs from a surface buoy by means of a wire, so that it is supported like this and from here also the cold water pipe goes down, further down to a depth of about a 1000 meters and this is again tied to the anchors. These are the anchor weights to which this end of the cold water pipe is tied, so that it cannot drift just like that.

So, the whole ship, the cold water pipe and the anchor, those things are stationed in the open sea. Though it can drift a bit, but not far, depending on the size of the line and then, you have the cold water going in and warm water is collected close to the sea and the mixed water that is discharged into the sea goes through this one and the rest of the system is as I discussed in the class. So, this is the arrangement for the 1 megawatt OTEC plant that has been commissioned in India.

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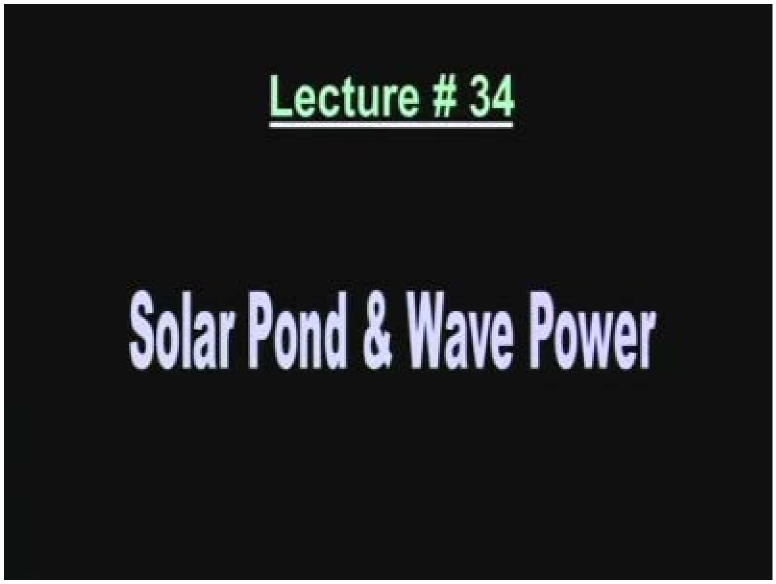

Today, we will cover two topics actually.

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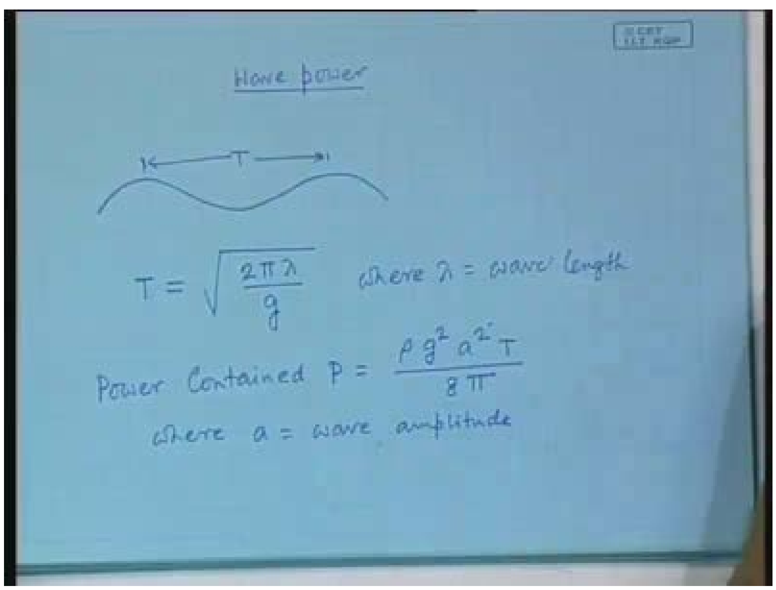

One is wave power and other is solar pond, I will come to that later. Now, as you know, there is a very large amount of energy that is available in the ocean waves and that is also solar energy in a different form, wind energy in a different form, but whatever it is, ultimately that is available in the form of the undulating motion of the ocean surface, because of the waves. You might ask how much is the energy available? It is actually very large. Often, we do not realize that when we go to say, the Puri coast, have you ever been there? Never, should go there; there is a reasonably large wave oscillation there and that you can easily feel that there is a large amount of energy available. But how large, how much is the energy available there? Well, you can do simple mathematics for that.

For example, if you have a wave going like this, then essentially the wave passes and so, if you look at a particular point, this crest will reach it at some point and the next crest will reach after some time. So, the time difference between the two may be called a T. That means T is the, assuming the wave is more or less sinusoidal in nature, T is the time period of that sinusoid. Now, the T can be expressed in this form where lambda is the wavelength. Now, T is necessary because the power contained in the wave is expressed as, where a is wave amplitude. So, you can see that it is, rho is the density constant, g is constant, a is the wave amplitude, how big are the waves, that appears here and T is the wavelength, T is the wave, the time period between the two crests and this is constant. So, essentially the whole thing depends on the a; so, the amount of oscillation that you experience at a particular point.

Do you know how this planet was created? Hi, you never asked that question to your teachers.

Students: Out of question.

Out of question? No, of course this is a very valid question. How was the Earth created and I think you have read that in geographic books in school, right. No, it was not there in geographic book, how the Earth was created. How?

Students: By the condensation of gases.

By the condensation of gases; that is what you have read.

Students: …

No, no. Is that what you have read about the creation of the Earth? Earth was not created as a big bang; come on, do not say that. So, it is definitely created in a different process. So, what is the process? Is he right? Is that what you read in school that it was created in the production of, in the condensation of gases? What kind of gases, from where?

Students: We do not know, Sir.

Do not know.

Students: It was already existing.

It was already existing? Since when? 1936, no. No, wrong, wrong. Earlier it was believed in fact when the Earth is there, the question is a valid question. How was it created? There were some people that believed that it is there, has been there. But, there are also some people who believe that there have must have been a process of creation, must have been a process by which it was created, a physical process, not the creation in the spiritual sense, a physical process must be responsible for that.

Now, initially there were two kinds of ideas. One said that it is created by means of, earlier the sun was there and either there was some kind of a disturbance, either initially the idea was that there was a comet that collided with the sun, as a result which some part got ripped off which went on rotating around the sun and that is what ultimately condensed into the planet. That is what you read. Later it was found that comets are so tiny; even though they look big, they are actually so tiny that they can have no impact if they fall on the surface of the sun. Do you remember sometime back a comet fell on the surface of Jupiter? Only, the scar remained only for a few days and after that everything vanished. No, no, I mean no visible change. So, the comets are really tiny.

Then, the idea was changed into, that it may have so happened that the sun was there and another star passed by. As a result of that, when it passes by, because of its attraction a part of the sun got ripped off again and that went on spinning around the sun, that condensed. Probably you have read something like that in school, right, from the part of the sun that condensed, you finally have the Earth created. Is that right? Today there is no time; we have got another class, so we will continue with that. First we will need to understand the process of creation of the Earth and then from there we need to understand where now the energy can be trapped, energy can be available. Everything is related. We will come to that in the next class.