MARINE ENGINEERING

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Lecture53

Binary cycle/Rankine-Brayton cycle

good morning everybody. we are continuing this gas turbine cycle. So, this is the last part of gas turbine system. So, we will discuss about binary and anchor cycle. Before that, let us recap the gas turbine cycle.

It is having one compressor, one turbine, one combustion chamber, then gas is going out, air input and exhaust gas is going out. Now Rankine cycle I am saying. Rankine cycle means it is having one boiler. Then it goes to turbine. From turbine, we have one condenser.

Then from condenser again it will be going to boiler but through pump. in Rankine this is Brayton cycle so in Brayton cycle exhaust bond gas is going to turbine and turbine blade is getting energy but in Rankine cycle your water is giving steam so that steam is driving turbine so basic difference is that in Brayton cycle the burnt gas is driving turbine so there is no water here but in Rankine cycle we have your burning fuel but that fuel directly is not going to turbine the other water what steam is going to turbine now in previous lecture we have seen like reheat cycle for Brayton cycle so compressor is here turbine is here then again another turbine combustion chamber here entry entry entry then again before going to second stage of turbine you are reheating again so you will have combustion chamber here again or the heating source so that temperature will be going up here you take fluid it put here again from here like this one two 3, 4, 5, 6.

This is reheat cycle. So you can see this reheat cycle. This is reheat cycle.Now if I say intercooler with intercooler. So again you draw the gas turbine system. So again you draw the gas turbine system. first stage is taking air, then here heat exchange will be happening. So, heat will be going out, heat out or cooling before going to second stage of compressor.

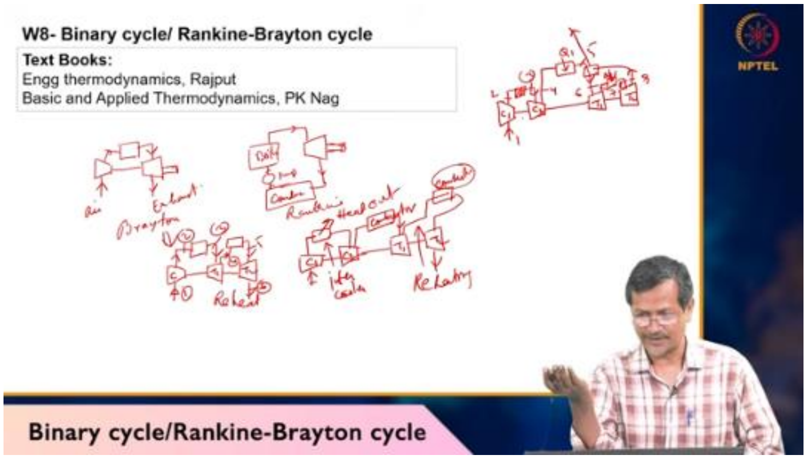
compressor 1, compressor 2, turbine 1, turbine 2. In this case, only one compressor was there. In the first case, compressor, turbine 1, turbine 2. So, this is again from C2, we are sending it to heat source or combustor from combustor turbine turbine 1 to again is going to some heat source combustor or some heat source from heat source to turbine 2 turbine 2 going out okay so this is this is intercooler this is reheating

in previous lectures, for example, in pump section or turbine section, we have discussed that if you have one single stage compressor and that will be taking more energy to compress same amount of air. But if you have intercooler, then compressor performance will be increasing. That is why we do intercooling application or we reduce some heat between every stage of compressor system. In turbine, again, we can increase performance if we reheat the system. So, that is why one turbine system can have multiple intercooler, multiple reheating system.

Now, if we have intercooler reheating and regenerator also. So, what is happening? In intercooler, you have compressor 1, compressor 2. Then in between there is heat rejection process. Then it is run by one turbine system.

Maybe multiple turbine is also possible. Now C2 to your heat addition is happening is going to turbine 1 turbine 2. So what is happening? Turbine 1 turbine 2 whenever heat is getting rejected so that heat will be given to here okay and in between there will be an intercooler also uh let's say q 1 maybe q 1 dash 1 2 3 4 5 6 7 8 9

from there again it go out or it can be directed to 1. Now, you can see process 1 to 2 compression happening. 2 to 3 you are releasing certain amount of heat and you are putting into compressor 2. So, that total compressor performance will be increased. Now, from C2 the compressed air it is going to a combustion chamber.

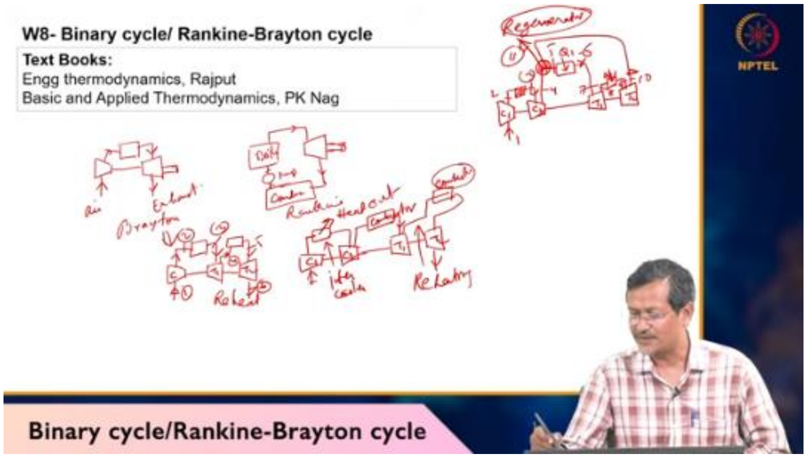


So, 4 to 5 4 to 5 here So, 4 to 5 your combustion chamber. So, combustion chamber is adding lots of heat. Now, here I have done one mistake. I have to correct it.

It will not be here. Rather turbine 2 will be giving heat here. This is your heat exchanger. So, 9 may be this one 10. So, 4

to 5 instead of 4 to 5 I have to put 5 here I have to put 6 here you have to change the numbers 7 8 9 10 11 so 1 2 2 compression happening 2 to 3 intercooling happening 3 to 4 again compression happening 4 to 5 actually heat exchanging happening what is happening T2 rejecting lots of heat exhaust gas is going out from T2 that high temperature fluid, high temperature exhaust gas will be used to increase temperature of compressed air. Because compressed air, C2 to combustion temperature is going. If you can increase certain amount of temperature, it will be beneficial for us. we can recover some amount of heat from exhaust gas.

So, that is called a regeneration. Generative just to increase whole system performance so exhaust gas temperature or heat will be used to increase temperature of my compressed air so that compressed air will go to combustion chamber so five to six combustion happening six to seven seven not equal actually so six to eight you can say six to eight turbine is taking power eight to nine you are reheating you are giving extra heat and okay just to increase whole system performance so exhaust gas temperature or heat will be used to increase temperature of my compressed air so that compressed air will go to combustion chamber so five to six combustion happening six to seven seven not equal actually so six to eight you can say six to eight turbine is taking power eight to nine you are reheating you are giving extra heat and 9 to 10 the turbine is taking power 10 you see 10 is exhaust actually turbine exhaust so turbine exhaust is heating your compressed air then this is going out okay so this this system is having all this intercooler plus reheat plus your intercooler reheat and regeneration all these techniques and mechanism used to increase whole system performance now uh actual system will be more complex this is this is a we are showing line diagram that there will be lots of control valves and fittings and other arrangement uh insulation many things are there we are not showing here uh these are the basic cycle how the fluid will be flowing and how you are getting power okay now binary cycle



So naval ships are submarines powered by nuclear fuel pressurized water reactor. Normally there will be one energy source reactor. reactor in a steam turbine system is a boiler. But it is having very high temperature. Temperature will be so high so directly normally we do not put water here.

Rather we will have one secondary fluid. Let us say fluid 1 will be taking heat. So, let us say this is taking heat and now this fluid is having very high temperature. Because reactor, nuclear reaction is giving very high amount of energy and temperature is very high. So, that high temperature and radioactive environment will not be putting any water or any other fluid or working fluid.

So, one working fluid will be there just to circulate or take heat from the reactor to my actual system. So, now let us say we have one heat exchanger here. And now we will have boiler system. Condenser, then pump, 1 or A and B. So cycle A may or may not be producing power. Cycle B actually my Rankine cycle.

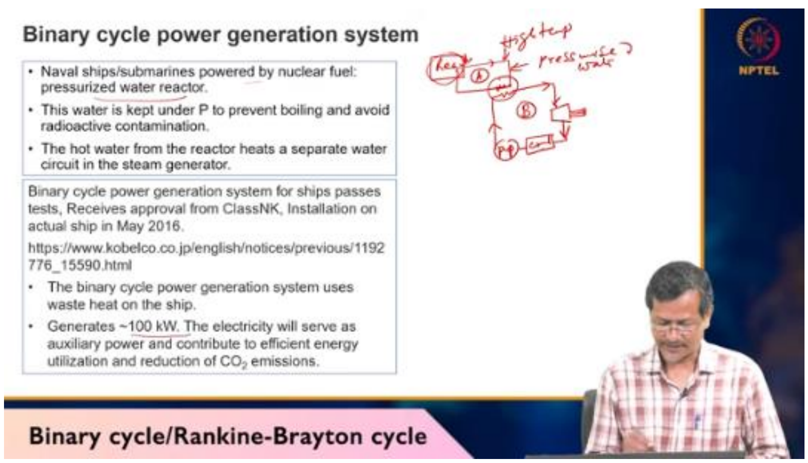
So normally nuclear power plant will have one dummy cycle and one Rankine cycle. So Rankine cycle will be extracting energy. So your naval system especially for passengers ships will not have this nuclear system because of reaction radioactive things. But naval system, aircraft carrier and submarines, many applications, nuclear fuel will be there. So, there will be nuclear engine because there will be no emission or like say carbon dioxide or any other fluid will be going out from here.

So, no one can detect it also. So, naval ship submarines powered by nuclear fuel, pressurized water reactor. So, these are pressurized water. Pressurized water. And this water is kept under control.

Pressure to prevent boiling and avoid. So pressure will be very high so that no boiling will be there in loop A. The hot water from the reactor hits a separate water circuit in the steam generator. So you have two circuits. One circuit A and another circuit B. Binary cycle power generation system for ship process test.

So, I got from one news item. So, they have used binary power cycle for their marine vehicle. Class NK, this classification type ship. Binary cycle power generation system uses water waste heat on ships. So, wherever waste heat is there, for example, you have any boiler system, you have extra exhaust gas or ice engine.

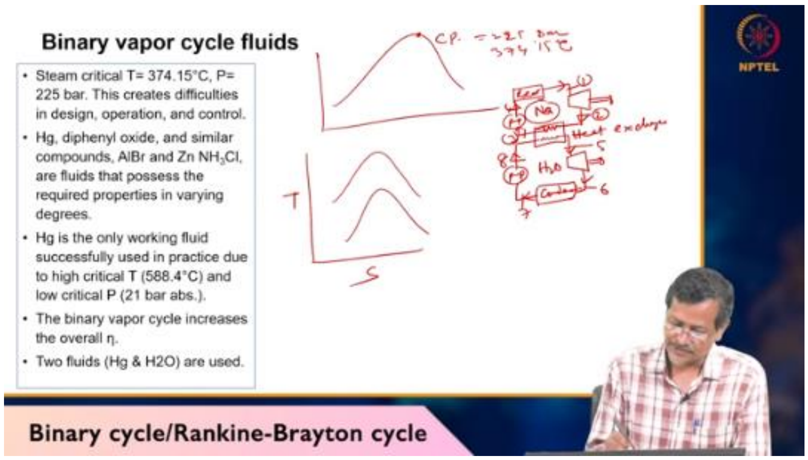
So that exhaust heat or waste heat can be used to run another steam turbine system where you can generate certain amount of energy. So it generates 100 kilowatt power. The electricity will be serving as auxiliary power to contribute efficient energy utilization and reduce carbon dioxide emission. normally that waste heat can be utilized to drive a turbine system and you can utilize for your shipping in many other purposes. binary vapor cycle fluid.



Steam normally will have critical temperature 374 degree. This critical temperature, critical pressure is 225 bar and 374.15 bar. centigrade because this create difficulty in design operation control so mercury diphenyl oxide similar compound aluminum provide zinc ammonium chloride these are fluid can be used for the one fluid another fluid can be water okay so this binary cycle means i will have two vapor envelope one is here another is here t s okay uh because you have seen like one i'll draw the cycle also let's say this is my reactor okay it will be driving one turbine then it will have one condenser simple rankine cycle i am assuming pump okay and this can be like say sodium sodium cycle possible because very high temperature sodium can be liquid like water okay now i have one heat exchanger so this this heat exchanger This is heat.

This heat exchanger temperature is also very high. So this will be used to increase your water temperature. Pump condenser So, I can put some name also, right, 1 before turbine, then 2, then 3, then 4 for my sodium cycle and for my water cycle, I can put similar nomenclature, 4, then 5, 6, 7, 8, okay. Now, sodium cycle temperature higher, so T-S diagram, my cycle will be up, right.

So, let us say my sodium cycle is here. Maybe some separate also we are assuming. Then turbine is taking power. Then condenser will be condensing. Okay.



Then where is my pump? So, where is my one? One is here. This is sodium cycle. 1, 2, turbine, 3.

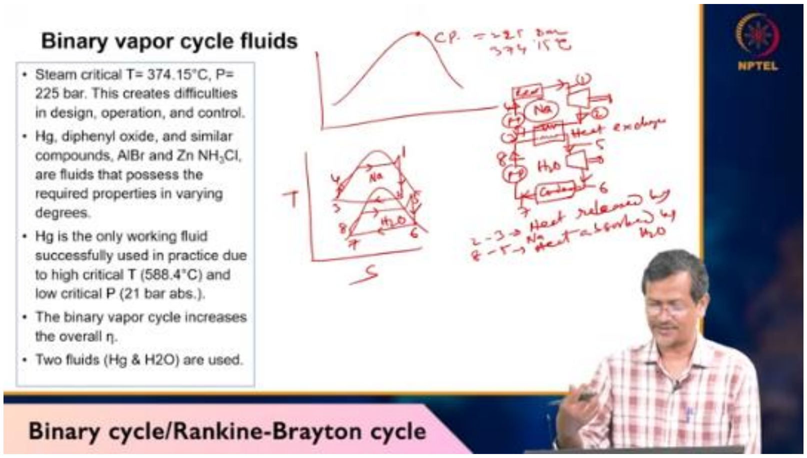
2 to 3, my condensation happening. 3 to 4, pump working. 4 to 1, again your heating happening. This is happening inside reactor. Now, 2 to 3, the top cycle is releasing heat.

So, bottom cycle will be absorbing heat. So, bottom cycle will be absorbing. So, 5, 8, 8 to 5, right? So, 8 to 5.

I am assuming everything is ideal. 2, this is 5, this is 6, 7, 8. So, this is H2O cycle. So, two cycles together. So, first cycle may be it is harnessing some energy or extracting some energy from the fluid.

H2 also extracting certain amount of energy. Now, you can see that 2 to 3 heat released. L E A S E by N A loop. Right. So, 8 to 5.

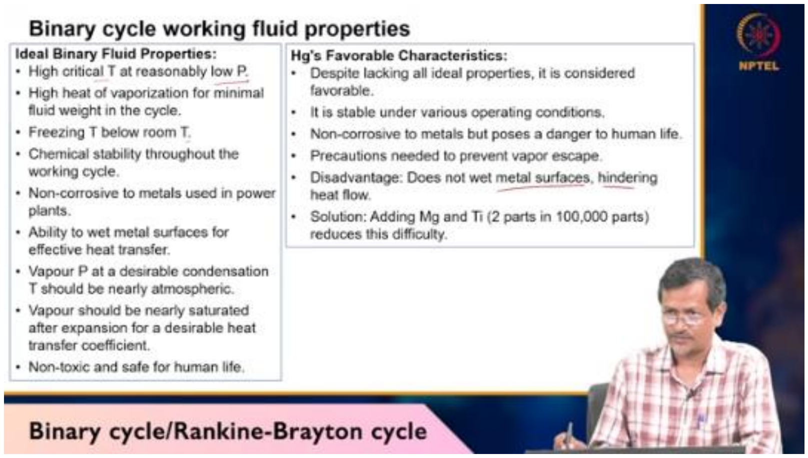
Heat absorbed by H2O. So, from reactor, water is not giving directly, taking directly energy. Rather, someone loop is taking energy. It is giving to another loop. Maybe several other loop also you can create based on your temperature.



Let us assume we have only two levels. Now, mercury can be possible, sodium can be possible. Mercury is the only working fluid successfully used practically due to high critical temperature 580 degree and lower critical pressure. Binary vapor cycle increase overall efficiency eta. Two fluid mercury and water are used. So, mercury also can be used. Binary cycle working fluid property.

This high critical temperature must be there, reasonable low pressure must be there, high heat of vaporization for minimal fluid weight, freezing temperature below room temperature, chemically stable. So, many other properties are there, just you can go through it. So, mercury favorable characteristics also there, like normally it will be liquid in normal temperature, but at high temperature, it can be evaporated also. So, So some disadvantages also there it does not weight metal surface so hinders heat flow rate. So some disadvantages also there it does not weight metal surface so hindering heat flow rate.

So because it is not weighting so heat transfer will be lower. Adding magnesium and titanium this very small part also will be helping to improve heat transfer rate. okay binary cycle overall efficiency so how to calculate overall efficiency for two cycles okay so first you draw the two cycles ds diagram d s okay so i am drawing the cycle again uh i will have one pump here okay so this uh yeah so the point 1 is here, 2 is here, 3 is here, 4 is here. Then the other cycle is 1 is here.



Then other cycle is 1 is here. Another cycle C, D, A, B. Okay. Now eta equals W by Q. work network output divided by heat input. So, eta this is say P cycle this is Q cycle we are assuming.

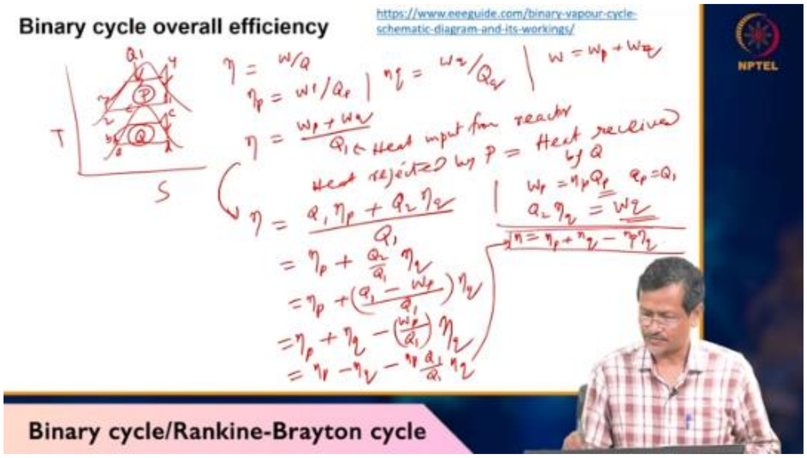
So, eta P equals W P by Q P input and eta Q equals W Q and Q Q. Now, total work output W equals W1 plus W2 or Wp and Wq we can add. Now, eta Wp plus Wq by Q1. Q1 means actually you are giving 3 to 4 heat energy. Total energy is coming from reactor only.

So, this is reactor any high energy source where very high amount of heat is there. So, you are not running only one cycle rather you are creating two cycles or three cycles for binary system ok. So, first cycle is giving you taking heat and other part automatically running one releasing another accepting one releasing. So, that way it is working ok and we are assuming this 2 1 q 2 to 1 equals q b to c. which is higher?

Higher is 1, right? Or I will write heat rejected by P equals heat received by Q cycle. So, both cycles are there. One is rejecting, another is receiving. Same amount we are assuming there is no losses.

eta equals Q1 eta p plus Q2 eta Q by Q1. You can see here, W, this coming like this, Wp equals eta p Qp. So, Qp actually Q1. Because upper cycle total energy input is happening here only and Q2 eta Q equals WQ. So, both we have given here and we are getting eta equals Q1 eta P Q2 eta Q. Now, eta P this is Q1.

plus Q2 by Q1 eta Q so eta P plus Q1 minus W1 means WP by Q1 eta Q so eta P plus eta Q you can see eta Q minus WP Q1 eta q so it is giving eta p minus eta q minus eta p q q 1 by q 1 eta q so after solving this one we are getting eta equals eta p plus eta q minus eta 1 eta p eta q this is your formula. If binary cycle is there and if efficiency given for cycle 1 and cycle 2, so combined cycle efficiency you can calculate from this formula. Again Brayton Rankine cycle.



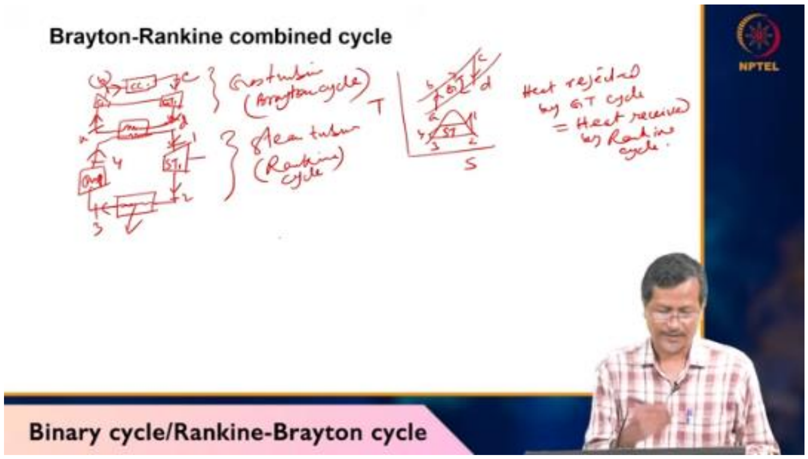
So in previous part you have seen Rankine Rankine. Now you have Brayton Rankine cycle. So you have some wastage and you want to run another cycle. So normally the Brayton cycle will be running at higher temperature. So higher temperature means I have one compressor.

I have turbine connected. I have combustion chamber. Compression chamber C1, T1 or GT1. And this is giving, let us say, heat rejection here. So, this is rejecting heat here.

Number is A, B, C, D. Now, I have another cycle here. steam turbine i'm writing st st1 maybe and in this case i have one pump then i have heat exchanger here so heat is getting rejected here okay numbering sir here one two three four now you can see this top one is gas turbine this is steam turbine if you have any high heat source steam turbine or it may be possible that the ice engine is there it is having lots of waste heat so that also can run one steam turbine system okay so anywhere if you find any waste heat is there you can boil it you can run one system which will give power so it will be normally it will be like Rankine type cycle now TS diagram if I draw Now, if I draw TS diagram, you can see this Rankine cycle will be running at lower temperature, but Brayton cycle will be running at higher temperature. So, first draw Rankine cycle envelope and it is like this, 1, 2, 3, 4 as per your cycle diagram.

Now where is gas turbine cycle or Brayton cycle? It is here. A, B, C, D. Now what is happening? Heat rejected by GT cycle or Brayton cycle equals heat received by Rankine cycle okay so this is GT this is steam turbine or Rankine okay so rank so you should not get confused steam turbine or Rankine cycle gas turbine or Brayton cycle

Now, overall efficiency also it will be follow same rule eta 1 plus eta 2 minus eta 1 eta 2. So, whatever you have derived from previous case like Rankine-Rankine here Brayton-Rankine also will have same formula. So, you can derive also. So, organic Rankine cycle means like you are using waste heat to run a Rankine cycle. So, they put the name organic Rankine cycle.



So, similar to Rankine cycle uses lower boiling point organic fluid suitable for lower temperature heat source. So, somewhere you have some small amount of heat source. So, you use lower boiling point system and you increase you boil certain fluid and you get energy from there. One good example is that we have OTEC system, Ocean Thermal Energy Converter. So, there what they do, they will have sea flow temperature about 4 degrees centigrade.

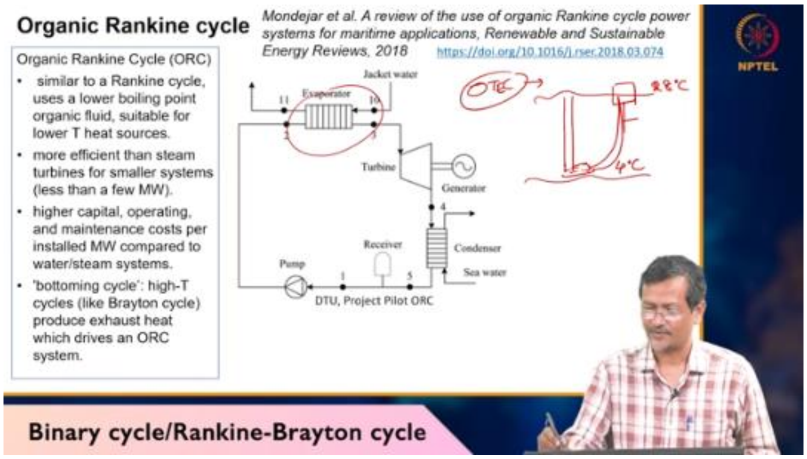
You know that because high density of water, water temperature will be 4 degree. But sea surface temperature will be like about 30 degree or 28 degree say. Now, this 4 degree and 20 degree, temperature difference is very low. But in gas turbine system or steam turbine system, your temperature difference was maybe 100, 200, 400 degree centigrade. But in OTEC system, Ocean Thermal Energy Converter system, your temperature difference only 2025 maximum.

So, NIOT, National Institute of Ocean Technology, they designed their OTEC Ocean Thermal Energy Converter to produce desalinated water for luxury island. And their system was running about 18 degree temperature difference. So, within 18 degree you cannot boil your mercury or sodium or you cannot boil your water. So, what they do? They will be using ammonia as a working fluid.

So, what they do? They will have one pipe at lower temperature. So, let us say any fluid you take ammonia or any refrigerant. Refrigerant I will be teaching later. Refrigerant means like

Those fluid will be creating vapor and liquid if you change pressure and temperature. So, low at normal temperature, it may be gas. If you reduce temperature further, let us say 4 degree, then it will be liquid. So, at 4 degree, it will be liquid. Pump it to the surface and there you put on turbine.

So, turbine, then what will happen? At surface, at high temperature, 28 degree temperature, that ammonia or other fluid, it will be gas. So, gas, when it is passing through turbine, turbine will be giving energy. Then, after turbine, you put the same one through another pipe to this seabed again. So, in your steel turbine, if you remember, you see this picture also.



Pump is here. condenser is here turbine is here okay so condenser where condenser will be there my condenser is a seabed okay you can link it okay turbine is on the surface and pump there must be pump somewhere here okay so pump can be somewhere here okay because pump will be delivering only liquid so four degree centigrade temperature make refrigerant or ammonia liquid then pump it to surface run your turbine then after the turbine again re-inject that fluid into seabed through one pipe pipeline So, that way the OTEC system will be working. So, NIOT, National Institute of Ocean Technology, if you visit sometime, you can see their system actually.

They have already deployed in Lakshadweep area. So, the temperature is very low. So, system performance is also very low. But people say like because it is free energy, you are not, once you install things, then after that things will be running automatically. You do not need to invest again.

So, that is why many people are interested to develop ocean thermal energy converter also like Japan, US, India, many other country also there. They are trying to develop or trying to harness ocean thermal energy through Rankine cycle. This is also Rankine cycle. Practically NIOT applying.