POWER PLANT SYSTEM ENGINEERING

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Module 4

Lec 5: Energy From Oceans: Part-I

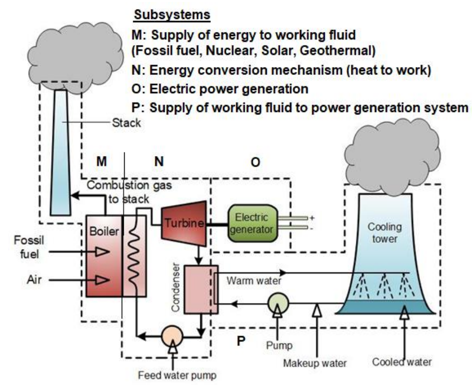
Dear learners greetings from IIT, Guwahati. We are in the MOOCs course Power Plant System Engineering module 4. The title of this module is Hydro and Renewable Energy Power Generation System. In our previous discussions, we elaborately discussed about hydro energy, wind energy. Now in today's lecture, we will focus our attention to harness energy from ocean.

So, in this lecture, we are going to touch upon the following topics. What is the concept behind this ocean energy? Because ocean & seas are characterized with its wave pattern as well as the temperature difference that occurs on the surface of water and the deep water. So, this particular concept is called as ocean temperature difference that normally happens throughout this world or earth. Now by virtue of this ocean temperature difference, one can think of the concept of heat engines to harness power from the ocean waves. And that particular segment is called as energy harnessing from oceans.

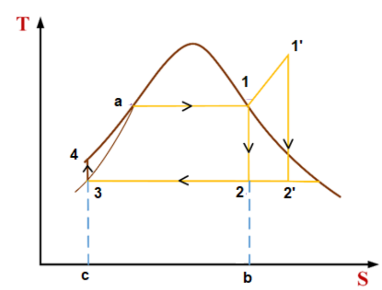
But there are thermodynamic viewpoints to this. When we are using specifically working fluid, we can think of two ways for harnessing the energy. And because this ocean temperature difference is typically low, so based on this, we have proposed two thermodynamic cycles and they are called as open cycle OTEC system means ocean temperature energy conversion systems and closed cycle OTEC systems. And they have been given names, we call this open OTEC system as a cloud cycle, & closed OTEC system as Anderson cycle. In fact, both the cycles are modified form of ideal Rankine cycles. When you deal with these cycles, effectively they are called as low temperature cycles because the temperature difference, which is available to us, between the ocean surface and deep water is less. So, we will touch upon these two cycles briefly, but main intention is to see the concept behind this ocean wave energy.

Now previously in our syllabus, we have covered mostly steam power systems. Now if you look at this particular figure which we have shown in our module 2 in the beginning of the lecture, that figure talks about three major part; one is this region M and that is nothing, but the supply of energy from the working fluid, which can be fossil fuel, nuclear, solar and geothermal.

When we dealt with steam power system, our main target was the use of fossil fuels, so we never bothered about any other resources. Now time has come when you say we want to harness energy from ocean wave, then we have to think about the other sources and mainly this concept of ocean waves energy is a kind of passive mode of solar heating. Then other parts like we have region N which is the energy conversion mechanism that is heat to work this is nothing, but your heat engine concept. Then next part is your electric power generation that is we need to couple with electric generator and last part is supply of working fluid to this power generation systems. So, the choice of working fluid is also equally important when you dealt with the low temperature cycles.



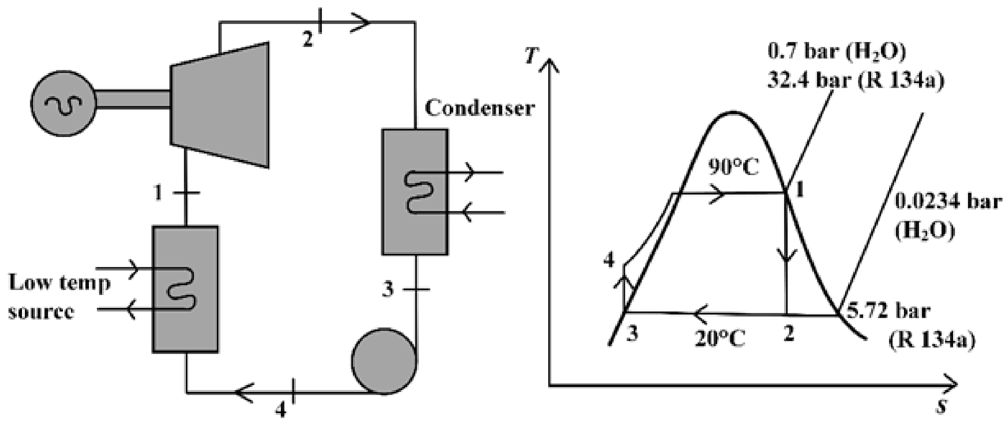
So, we will see their importance. Now if you refer this temperature entropy diagram, for a conventional fossil fuel based steam power system, our working fluid was mainly water. And to get the advantage of water, we bring this water to the maximum possible heated location that is towards the superheated region. Then only the steam has maximum potential to be expanded in the steam turbine. So, point 1’ is normally for fossil fuel based power generation system that is steam power systems. We start this turbine process or expansion of steam much above this saturation line or saturation dome. So, that means, turbine inlet condition mostly falls in the superheated region and we try to expand the steam to the best possible extent.



So this dome region that is 1’-2’ used for steam power generation. Now when you dealt with low temperature system, then we do not have option to go to the superheated region, so somewhere inlet for turbines you start from point 1 and that is nothing, but it falls exactly in the saturated vapor region and we try to expand the steam in the turbines. This is one part. Second part when you dealt with the steam power system, this temperature difference ΔT that is at the stream generator pressure and condenser pressure is very high. Here, very high means, we can keep it at maximum ΔT possible for a fossil fuel based plant. So, that we can typically go to the superheated region in an easier manner. But the in case of low temperature power generation system, we do not have the flexibility of this ΔT to be much higher. So, typically this ΔT is lower and that is the reason, we call this as a low temperature cycle. But both of them fall under the common roof that is called as Rankine cycle.

Now when you deal with the low temperature cycle, then we call this as ideal Rankine cycle because it says that you should start the turbine process ideally when we have the inlet condition of the steam almost exactly at the saturated vapor region. So, this is all about the low temperature cycle, and the advantage of low temperature cycle is that fuel resources is free. The fossil fuel based plant requires infrastructures and there is an investment of money. Whereas, when you say low temperature cycles like in case of oceans, the energy from the ocean is free. So, for that reason, to some extent the low temperature cycle becomes a lucrative option. So, if you look at a low temperature cycle essentially speaking we are looking for an expansion process in the turbine, when the steam is exactly at saturated vapor region and it expands to turbine. That is one aspect.

Second aspect is the ΔT difference is less. That means, in this case shown in the diagram, if your saturation temperature is 90℃ and condensation occurs at 20℃ then ΔT is close to 70℃, but still this difference could be possibly lower than that. So, there are two possibilities to take into account. One way is the working fluid can be same as that of the fluid which is available in the ocean, that is water or the other way is the working fluid can be considered as a different one.



So, based on that, in this dome, this particular low temperature source could be an ocean and in this secondary cycle, we can have different working fluid. That means, we have a heat exchanger that taps the energy from the ocean which is typically available at certain temperature difference and use that temperature difference to power the turbines. In other words we can say that, heat which is getting released from this ocean water to the working fluid is utilized to heat it to a conditions which goes in the into the turbines. So, for example, if your ocean condition is saline water, then the working fluid may be ammonia as it is a low temperature refrigerant which can use this and this refrigerant only will give you the conditions in the low temperature cycle. So, this is all about the concept behind the ocean waves. Now, let us try to understand this ocean waves & where it comes from.

Typically, the solar energy is the major source of energy which is available in plenty and we call this as a renewable form of energy. Now, under this single roof we have multiple ways of passive energies available in our mother earth. One way is the wind energy and this wind energy comes due to uneven solar heating of earth surface which we have seen in the in our previous two lectures. So, to harness wind energy, you have to incorporate the concept of wind turbines. Second part is that when the energy of the Sun falls on the surface of water, the water on the surface gets evaporated and goes to higher altitudes and in turn it comes as a rain at a particular location. When there is rain we can store that energy in a dam and through this process, we can convert this energy from the water and we call this as hydroelectric energy. So, we have wind energy, we have hydroelectric energy, which we get by evaporation of surface water by solar heating. So, one way the solar heating causes the formation of wind or motion of air and we call this as wind. Second way, the solar heating also causes the rain and this rain water can be utilized by storing it in a dam and through the conversion we get hydroelectric energy.

Now, rest two parts that we have are like these. One is ocean temperature energy conversion, we call this as OTEC plant. So, here what happens is there is an absorption of solar radiations causing ocean currents. So, basically when the solar radiation falls on the surface of the ocean the energy gets absorbed at every places in the ocean and thereby the surface water gets heated whereas, the deep water does not feel the sense of heat. So, through this process the energy gets absorbed by this surface water, but since the oceans are very deep, it cannot go much into the depth. It means that the effect of solar radiation is only felt at certain depth in the oceans that is close to 1km or 1000m. So, within this depth, we feel a temperature difference and we call that as ocean current, because top surface has lower density and below the depth of 1000m we have a different temperature. So, that way we can see the ocean currents only within the depth of 1 km, but below that the water is still at lower temperature. So, we can conclude here that if you go below 1000m depth, we have temperature of water which is much lesser than the surface of the water and that difference could be in the range of 15℃ to 20℃. So, that is the concept of temperature difference availability between the surface of the water and the deep water. And this concept is typically used as a heat engine concept. So, when the solar energy falls on the water surface, it follows an equation called as Lambert's law of absorption which says that there is a decay or the intensity of the radiation varies with the depth which is in the form of exponential nature.

Lambert's law of absorption, $-\frac{dI(y)}{dy} = \mu I; I(y) = I_0 e^{-\mu y}$

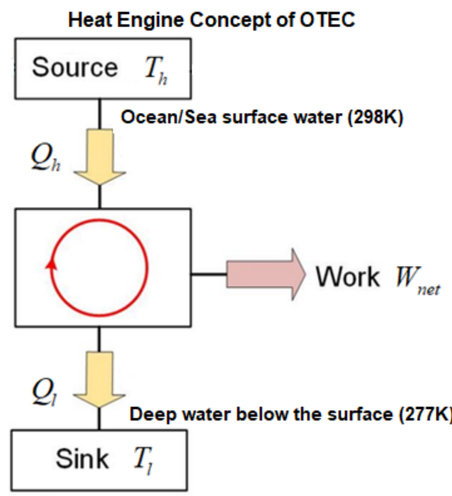
I_0&$I(y)$:Intensities of radiation at $y = 0$ & at distance y below the surface

That means, intensity of radiation falls down with depth exponentially with the maximum being on the surface of the water. And this μ value depends on the nature of water.

μ: Absorption coefficient / Extinction coefficient

Freshwater, $\mu = 0.05\text{m}^{-1}$; Turbid fresh water, $\mu = 0.27\text{m}^{-1}$; Salty water, $\mu = 0.5\text{m}^{-1}$

So, the higher value of μ means less penetration. So, of course, these are the some ways or methods, in which we can say how the intensity of radiation varies on the surface to the depth.

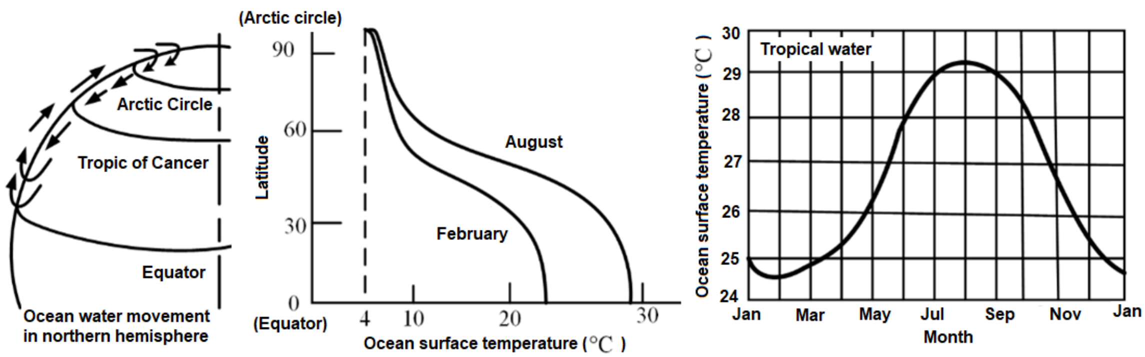


Now let us see the concept of ocean temperature difference. As I mentioned that if you say this is the ocean surface and we are looking at depth much below that is y and typically if $y \approx 1000\text{m}$, then we will get a temperature difference. Now often what happens is that ocean surface is typically at $T_s = 25°\text{C}$ and if you go below 1000m depth then we call this as deep water. And availability of deep water is close to $T_d \approx 10°\text{C}$. So, below this there is no further temperature reduction possible because the sun's radiation cannot penetrate. So, the ocean currents is available within the depth of 1000m. So, it means that we can imagine the surface to be a reservoir and we call this as a source and the deep water can be called as another reservoir, which is called as sink. Now same concept if we introduce here in a heat engine then we can say that your source temperature is close to 25°C and sink temperature is close to 10°C and in between we are using a heat engine by extracting heat from the source and rejecting heat to the sink. So, this is called as ocean temperature energy conversion. That means, the temperature difference is getting utilized as energy conversion which is in the form of work. So, heat energy gets converted to work. So, this is the concept.

Now here we have two choices. So, when you say heat engines, we have choice of working fluids. One possible choice is that same water can be circulated continuously to produce work that is the ocean or sea water. And second category is that we use a different working fluid. We are using different working fluid for better performance. So, it can be either ammonia (NH_3) or Freon (F_{12}). This kind of refrigerant fluid can be used for operational viewpoints. So, considering these two things together, entire things falls under two fundamental aspects, one is low temperature cycle and second is binary vapour cycle.

So, in the binary vapour cycle what happens is that we are restricting the power generation using the specific working fluid which is typically ammonia (NH_3) or Freon (F_{12}), but the heat exchange takes place between QH and QL, high temperature source and low temperature by virtue of this temperature difference. So, this is all about the concept behind the ocean temperature difference for harnessing power or energy from the oceans.

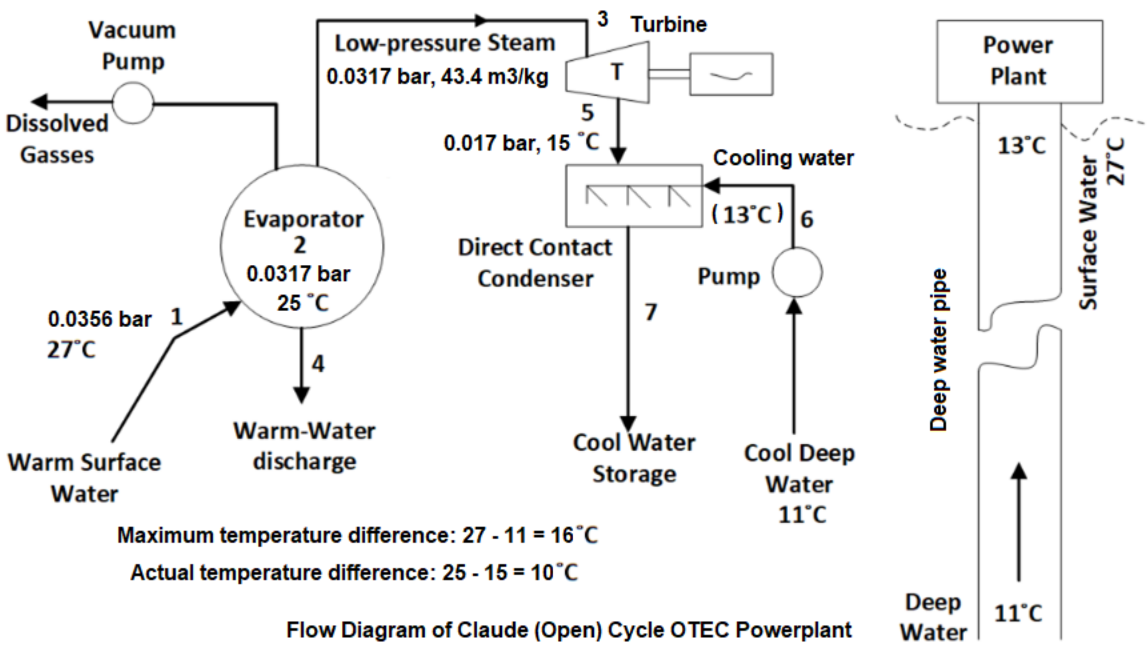
So, based on that we have two cycles, one is called Claude cycle which is open cycle, where same working fluid is being used and other one is Anderson cycle or closed cycle in which we are using different working fluids like one for tapping the energy from the ocean water or sea water, and other is using that tapped energy and transferring it to the secondary fluid which normally expands in the turbine. And the possible limitation for this ocean temperature difference concept is the geographical map of ocean water movement on the earth surface. This particular figure shows different locations on the earth surface. We have Equator, Tropic of cancer, Arctic Circle along the latitude.



Now, moving along the latitudes, we see that ocean surface temperature is less at Arctic Circle and higher close to equator. And this temperature also varies across the months. So, in February and August, we can typically get maximum temperatures difference. That means, if you are at equator closely, then we will have this much temperature difference in the month of February and August as shown in the graph. Now, on a tropical water which is somewhere at the tropic of cancer which is at 60° latitude, the variation typically looks like in the range as shown in the graph.

So, that means, the temperature availability is more during certain duration that is from the May to November. At a given location if you take month wise data, then higher temperature is felt in the month close to August. So, that means, in the month of August, we have highest temperature which happens in tropical water and the temperature is lowest in the month of January. So, basically this is the temperature difference that we are going to achieve, which is presented in the graph month wise. So, with this concept we are now going to propose the first cycle which is called as open OTEC systems.

So, open OTEC system means ocean temperature energy conversion system. We have temperature difference on the surface of ocean and the deep water, which is called as ocean temperature difference. Now, why you call this as open cycle, because we are using only a single working fluid and cycle is open because the fluid that enters into this system and exit out of the system is same and in this case it is nothing, but your ocean water. In one case we have warm water inlet other case it is the deep water outlet.

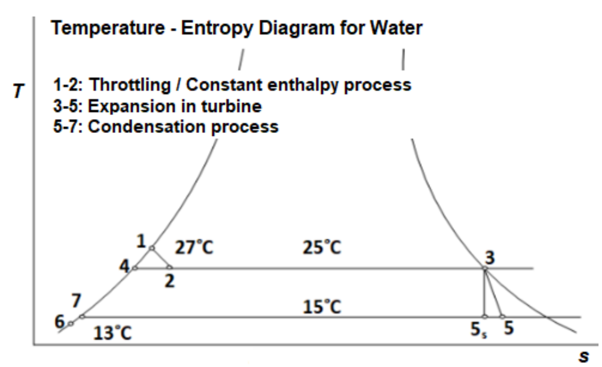


Flow Diagram of Claude (Open) Cycle OTEC Powerplant

Now, in this figure, we have shown that just for a gaining geographical location, the surface of ocean water is available at 27℃ and we are putting a deep water pipe whereas, deep water is close to 11℃ and the depth could be approximately 1km. So, across this depth we have put a pipe which we call as a deep water pipe. So, this temperature availability at this deep water and surface water is different. Now, we are having this power plant here & this power plant constitutes of an evaporator, a turbine generator assembly, a direct surface condenser and a cooling water circulation for the condenser. Now, how we are going to feed the water into turbine? So, first thing you need to see is the available temperature difference for us. First is warm surface temperature which is available somewhere in these locations.

So, you take this as inlet that is state 1 and it is available at 27℃. Corresponding to this, the saturation pressure from steam table will be 0.0356 bar. Now, when it goes in, then it enters into an evaporator. Now, what does this evaporator do? This evaporator is normally operated at a low temperature much lesser than this that means, it is 0.0317 bar. So, the corresponding synonymous part in the steam plant is a boiler, but here we are using evaporator because our dealing of working fluid is at low temperature, so the evaporator is the most appropriate word. But evaporator and boiler both perform the similar operation. Now, what happens after that? Then after removing some dissolved gases that low pressure steam, with very high specific volume enters to the turbine at state 3 and remaining water gets discharged. So, basically speaking we are separating the vapour part and liquid part in this evaporator and all this liquid part goes as a discharge, the vapour part enters as a low pressure steam with very high specific volume and it enters and expands in the turbine. It can expand close to maximum 15℃. So, from 25℃ to 15℃ it expands.

Now, after it expands, it enters into condenser. So, basically the condenser gets circulating cooling water like the cool deep water, which is available at 11℃, through a pump and then it cools that and finally, it discharges the cool water. So, through this process this cycle operates and we call this as a Claude plant or Claude cycle. So, typically based on the water availability on the surface of ocean and deep water the Claude cycle is defined.



Now, coming back to this thermodynamic viewpoint, we see this particular temperature entropy diagram. So, here the process 1-2 is throttling that means, from warm surface water to evaporator condition, it goes in the throttling manner. And from 2-3, it is evaporation process, 3 -5s is an isentropic expansion in the turbine, but actual process becomes 3-5. Then 5-7 is a condensation process and again 6-5 the cycle continues. So, essentially speaking this is nothing, but a typical Rankine cycle. Since this Rankine cycle was implemented in a low temperature system by Claude, so we call this as a Claude cycle. So, we will discuss more into this in later part of this.

So, I have already mentioned about the explanation for this cycle arrangement. Most importantly what we see is that, 1-2 is a throttling process, but at this point 2 what happens is that, this evaporator sends the vapour part to point 3 and liquid part to point 4. That means, liquid vapour separation takes place. At point 3, we have this low pressure steam which expands till point 5 and then enters into the condenser at 15℃. So, essentially speaking we have 10℃ temperature difference availability for running this cycle. So, this is all about this open cycle plant.

Now, let's move on to the closed cycle OTEC systems. So, here the concept remains same as it is, but only difference what we see is that with respect to this heat engine perspectives, here we are using this working fluid in 3 parts like ammonia, propane or Freon. So, these are called as low temperature cycles that uses typical working fluids like ammonia, propane and Freon for their operations. Why we are saying it? Because if you compare steam to this part we can see here that saturation pressure for steam is 0.85 kPa at 4℃ and 3.5 kPa at 27℃. So, if you use the steam as working fluid, then we must operate that evaporator at this low pressure. But when you choose other working fluids then we have a preferred choice that we can operate them at much higher pressure. So, when you operate them at much higher pressure, losses will be minimal and there is a probability of harnessing maximum potential of energy.

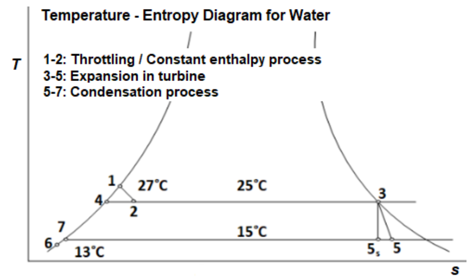
Now, if you compare this low temperature cycle with respect to superheated steam, you can imagine that, when you use a steam power plant then, we are looking at operation of the plant about 16.5 MPa, 540℃ & specific volume close to 0.02 m^3 per kg, as compared to very high specific volume value for low temperature cycles. So, these are some of the advantages and one more important point which I need to emphasize is that, whether we are using Claude cycle or Anderson cycle, under no circumstances, we will have efficiency more than 25%. That is because if you look at the flow diagram of OTEC plant, at any location, let us say from warm surface water to evaporator we have hardly 2℃ temperature difference. Let us say we are looking at this exhaust from the turbine and cooling water, here also we have 2℃ temperature difference. Then between deep water and cooling water entry to the condenser, we have only 2℃ temperature difference. Now, within the 2℃ temperature difference, there is issue like irreversibility. And although we have maximum possible temperature difference that could be 16℃ based on the availability of water, yet the only possible way for exchanging heat availability is 2℃. But one advantage is that with that 2℃, we can use large volume of water. Now, using that large volume of water for small temperature difference requires huge infrastructure cost.

So, till this point of time, harnessing power from ocean temperature energy conversion is yet to be justified because it requires a huge infrastructure and different technology. Although theoretically it is possible, but in fact, due to its less efficiency at higher infrastructure cost, till this point of time OTEC system has not gained many attention. So, this is all I need to speak about this ocean temperature plant concepts Claude and Anderson cycle. Now, just to give a feeling of the Claude cycle and its applications, let me solve a numerical problem. Of course, this numerical problem will give you some emphasis on how you are using the similar concept of steam power systems in a Claude cycle and essentially we are looking for a low temperature vapor cycle.

Q1. An OTEC plant produces 100 kW gross power while operating on Claude cycle as shown in the figure. The turbine has a polytropic efficiency 0.8 and the combined efficiency of turbine-generator unit is 0.9. Calculate, (a) surface & deep-water flow rates; (b) gross cycle efficiency; (c) plant efficiency.

So, here I have taken the same figure, in which the system operates. Already I have told you that maximum available temperature difference between warm surface water and deep water is 16℃, but actual temperature which is available between this evaporator and turbine exit is 10℃. So, through this process, there is irreversibility associated with it. And due to this irreversibility, we have polytropic efficiency for the turbine which is defined as 0.8 and turbine generator unit has a combined efficiency of 0.9. So, typically an OTEC systems produces 100 kW gross power while operating on Claude cycle. So, when I say Claude cycle, we know that there is no change in the working fluid that means, same ocean water is being used as working fluid, and there is no separate working fluid. And we have all the numbers that denotes the available temperatures and through this process when you try to incorporate in this T-s diagram, so the T-s diagram looks like this.

Process 1- 2 is throttling, 2-3 is evaporation process, 3-5 is your turbine process, and 5-7 is condensation process. And this is nothing, but typical ideal Rankine cycle analysis. Similar to ideal Rankine cycle, we are using the properties of water at different temperatures. And why I am taking only this temperatures, because there we do not have any other possibilities to go any other temperatures.



So, this table has the data for corresponding saturation pressure, specific volume, enthalpy and entropy. This data will be used to calculate to solve this problem. So, first thing let us try to solve one by one component.

We are looking at evaporator unit. So, evaporator unit we starts from the process 1-2 -3.

T (°C)	P (bar)	Specific volume (m³/kg)		Enthalpy (kJ/kg)			Entropy (kJ/kg.K)		
		v_f	v_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
13	0.015	0.001	88.2	54.6	2470	2525	0.1952	8.6324	8.8276
15	0.017	0.001	78.0	63.0	2465	2528	0.2244	8.5562	8.7806
25	0.032	0.001	43.4	104.8	2442	2547	0.3672	8.1898	8.5570
27	0.036	0.001	38.8	113.2	2437	2550	0.3951	8.1196	8.5147

So, that means, from 1 it comes to 2, from 2 the separation starts, liquid component moves to 4 as a discharge, vapor component moves to 3 towards turbine. Since process 1-2 is a throttling process, so

$$h_1 = h_2; \text{and } h_1 = (h_f + x_2 h_{fg})_{27°\mathrm{C}}$$

So, from the data table, we can write (data taken at 25degrec)

$$h_f = 104.8\frac{\mathrm{kJ}}{\mathrm{kg}};\ \ h_{fg} = 2442\frac{\mathrm{kJ}}{\mathrm{kg}};\ \ h_1 \text{ at } 27°\mathrm{C} = 113.2\ \frac{\mathrm{kJ}}{\mathrm{kg}}$$

$$\Rightarrow 113.2 = 104.8 + x_2(2442)\ \Rightarrow x_2 = 0.00344$$

So, dryness fraction at location 2, x_2 = 0.00344.

So, from this point you take the vapor out towards 3 and bring the discharge water towards 4.

Then it was asked to find the surface and deep water flow rate. So, for the time being we will assume that unit turbine flow rate is

Let us say, unit turbine flow rate $= 1$ kg/s

Warm water mass flow rate, $\dot{m}_{\text{w}} = \frac{\dot{m}_1}{\dot{m}_3} = \frac{\dot{m}_2}{\dot{m}_3} = \frac{1}{x_2};$ as $\dot{m}_1 = \dot{m}_2$

$\Rightarrow \dot{m}_{\text{w}} = 290.7$

So, this is for evaporator. Now, from evaporator we have moved to turbine. So, turbine process is typically reversible adiabatic or isentropic.

$h_3 = (h_g)_{25°\text{C}} = 2550 \, \frac{\text{kJ}}{\text{kg}}$; as it is saturated vapor at 25°C

At this point, $s_3 = 8.5147 \frac{\text{kJ}}{\text{kg. K}}$

Process $3 - 5s$; $s_{5s} = s_3$

$\Rightarrow (s_f + x_{5s} s_{fg})_{15°\text{C}} = 8.5147$

So, taking the data from the table for 15°C, we get

$x_{5s} = 0.9739$

$h_{5s} = (h_f + x_{5s} h_{fg})_{15°\text{C}} \Rightarrow h_{5s} = 2463.5$ kJ/kg

So, Isentropic work, $\dot{W}_{is} = h_3 - h_{5s} = 2550 - 2463.5 = 86.4$ kJ/kg

Then turbine work, $W_T = \eta_{is} \times \dot{W}_{is} = 0.8 \times 86.4 = 69.1 \frac{\text{kJ}}{\text{kg}}$; as Efficiency of turbine $= 0.8$

So, we have now turbine work and this turbine work can also be interpreted as

$$W_T = h_3 - h_5$$

$$\Rightarrow h_5 = 2550 - 69.1 = 2480.9\frac{\text{kJ}}{\text{kg}}$$

So, this we get from the turbine output. Now, we have this turbine generator unit. So, already for turbine $W_T = 69.1\frac{\text{kJ}}{\text{kg}}$. Now, efficiency of turbine generator is 0.9.

$$W_T = 69.1\frac{\text{kJ}}{\text{kg}}; \eta_{tg} = 0.9$$

$$\text{Actual Power}, W_{ac} = 0.9 \times 69.1 = 62.2\ \frac{\text{kJ}}{\text{kg}}$$

Now this particular power is linked to the gross power. So, basically speaking, we need to correlate this power with the gross power to find the mass flow rate. But before we do that we also need to do analysis for the condenser. So, condenser process is from 5-6-7 that is condenser and cooling water systems.

Now, this temperature is known, cooling water state 6 is known. So, we can say

$$h_6 = (h_f)_{13°\text{C}} = 54.6\ \text{kJ/kg}$$

Then at this point, specific volume $v_6 = 0.001\ \text{m}^3/\text{kg}$.

$$h_7 = (h_f)_{15°\text{C}} = 63\ \text{kJ/kg}$$

So, we can find out the cold water mass flow rate/ unit mass flow of turbine = $\dot{m}_c$

$$\dot{m}_c = \frac{h_5 - h_7}{h_7 - h_6} = \frac{2480.9 - 63}{63 - 54.6} = 288.9$$

So, remember this number, which we are going to use further. Then let's move to complete cycle. So, for complete cycle we have information that total power or gross power is 100kW and we need to find out the turbine mass flow rate $\dot{m}_T$. Previously we calculated $W_T = 69.1$

Turbine mass flow rate $\dot{m}_T = \frac{100}{69.1} = 1.447\,\frac{\text{kg}}{\text{s}}$

Then we have already calculated, $\dot{m}_{\text{w}} = 290.7;\ \dot{m}_c = 288.9$ and this is based on unit flow rate of turbine. So, already we have found that the mass flow rate in the turbine is 1.447 kg/s to generate 100kW of gross power.

So Surface water flow rate, $\dot{m}_s = \dot{m}_T \times \dot{m}_{\text{w}} = 420\,\frac{\text{kg}}{\text{s}}$

Then Deep water flow rate, $\dot{m}_d = \dot{m}_T \times \dot{m}_{\text{c}} = 418\ \frac{\text{kg}}{\text{s}}$

So, roughly we say that we deal with this above calculated flow rate of water, but effectively to produce a gross power of 100 kW which is quite less with respect to this flow rate.

Cycle Efficiency, $\eta_{cycle} = \frac{\dot{W}_T}{q_A}; q_A = h_3 - h_7$

$$\eta_{cycle} = \frac{69.1}{2550 - 63} = 0.028$$

So, it means is that by virtue of this temperature difference at location 3 and 7 that is the maximum available enthalpy and within this 10 °C temperature difference your cycle efficiency is approximately 2.8%. And for power requirement and mass flow rate this efficiency is quite less. So, this clearly indicates that OTEC plants have very less efficiency & it involves very high infrastructure cost. So, this is a glimpse of an OTEC plant and its cycle analysis. So, with this I conclude this lecture. Thank you for your attention.