Design and Simulation of Axial Turbine for Ocean Thermal Energy Conversion (OTEC)

Irfan Syarif Arief [1], Tony Bambang Musriyadi[2], Desta Rifky Aldara[3]

***Abstract*— decreasing in fossil energy reserves about 3% every year and has not been matched by the discovery of new energy reserves. Therefore, it is necessary to increase the use of renewable Energy to meet energy needs. Renewable energy is energy derived from sustainable natural processes. Indonesia located in the tropical area, it has a lot of potential ocean energy. OTEC (Ocean Thermal Energy Conversion) is one of many renewable energy sources from the ocean. OTEC or Ocean Thermal Energy Conversion is one of the latest technologies that used the temperature difference between deep and shallow seawater. OTEC system generally used ammonia (NH_3) as working fluid. Ammonia is used because it has a relatively low boiling point compared to water. OTEC system consists of evaporators, turbines, generators, condensers, and pumps. In this research, the authors focused on the design of lab-scale OTEC turbines. 2 stage turbine will be varied the tilt which is 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 degree. The computational fluid dynamics (CFD) method is used in this research to simulate the OTEC Turbine. Based on the simulation results, the highest efficiency and net power is a 2 stage 40 degree turbine with 57.45% of efficiency and 287.25 kW of generated power.**

Keywords— CFD, ocean thermal, OTEC, renewable energy, turbine,

I. Introduction

Energy has an important role in the achievement of social, economic and environmental goals for sustainable development, and national economic activities. Energy use in Indonesia is increasing rapidly in line with economic growth and population growth. Indonesia faces a decreasing in fossil energy reserves about 3% every year [1], and has not been matched by the discovery of new energy reserves. Therefore, it is necessary to increase the use of renewable Energy to meet energy needs. Renewable energy is energy derived from sustainable natural processes.

Studies and projects on renewable energy sources have been actively conducted around the world to solve the challenge of energy supply and concomitant environmental issues. OTEC (Ocean Thermal Energy Conversion) is one of many renewable energy sources from the ocean.

OTEC or Ocean Thermal Energy Conversion is one of the latest technologies that used the temperature difference between deep and shallow seawater that drive generators to produce electrical energy. In the tropical oceans between approximately 15° north and 15° south latitude, the heat absorbed from the sun warms the water in the mixed layer to a value near 28°C that is nearly constant day and night and from month to month. The annual average temperature of the mixed layer throughout the region varies from about 27°C to about 29°C. Beneath the mixed layer, the water becomes colder as depth increases until at 800 to 1000 m (2500 to 3300 ft), a temperature of 4.4°C [2]. This temperature does not change dramatically throughout the year, with varying degrees due to weather and seasonal changes, and the temperature difference between day and night turns only has an effect of about 1°C [3].

OTEC cycle generally used ammonia (NH3) as working fluid. Ammonia is used because it has a relatively low boiling point compared to water. OTEC system consists of evaporators, turbines, generators, condensers, and pumps. In this research, the authors focused on the design of lab-scale OTEC turbines to get the highest efficiency and net power.

II. METHOD

The turbine modelling used Auto blade. The blades angle designed based on the enthalpy difference between the inlet and outlet condition in turbine. Figure 1. shown the 2D drawing of turbine blades, and Table 1 shown the number of blades. After the modelling finished, it simulated by using FINE Turbo with the parameter as shown in Table 2. Simulation started to know the torque, mass flow and efficiency of turbine.

A. Preliminary

Indonesia has a lot of energy resources, both in the fossil resources, and renewable natural resources. In renewable natural resources, Indonesia has excellent potential, one of them is the ocean thermal sector. National Energy Council has mapped the potential of Ocean Thermal Energy Conversion. Theoretical resource: 4.676.689 MW, Technical resource: 216.609 MW, practical resource: 60.985 MW [1][10] [11].

B. Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) used the temperature difference between deep and shallow seawater that drive generators to produce electrical energy. The cycles are based on a Rankine cycle of heat energy stored in the seawater into electrical energy [2].

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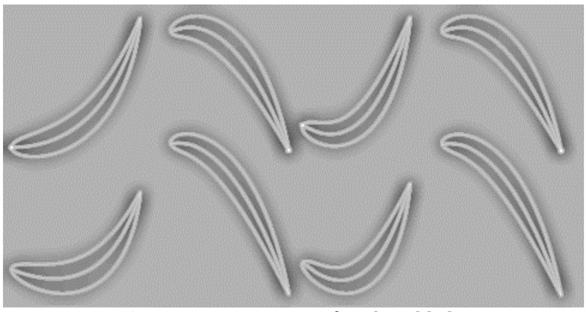

Figure. 1. 2D Drawing of Turbine blades

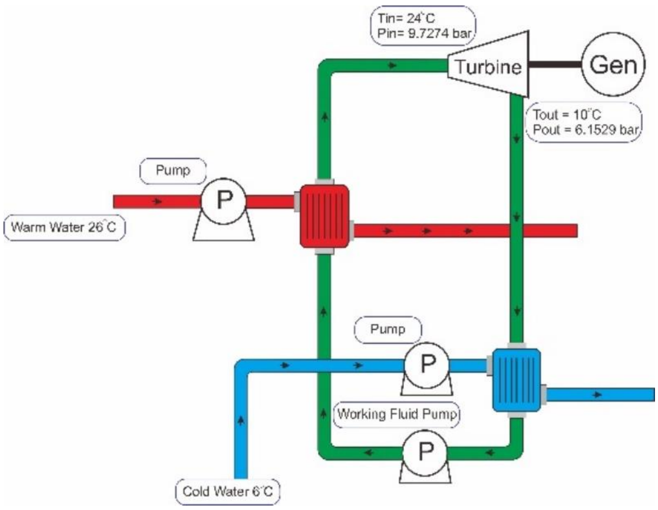

Figure. 2. OTEC Cycle**.**

TABLE 1.
NUMBER OF BLADES

Number of Blades	
Row	**Value**
1	10
2	15
3	15
4	20

TABLE 2.
PARAMETERS OF SIMULATION

Parameters		
Name	**Value**	**Unit**
Temperature Inlet	297	K
Pressure Inlet	972740	Pa
Temperature Outlet	283	K
Pressure Outlet	615290	Pa

In OTEC operation, the working fluid is pumped back to the evaporator after condensation (conserved), as shown in Fig 2. Ammonia is commonly used in this cycle because it has a relatively low boiling point with seawater as a fluid to evaporate and condense.

C. Rankine Cycle

The Rankine cycle closely describes the process by which steam-operated heat engines commonly found in thermal power plants. This cycle used two phases of working fluid, there are liquid and vapor. in a simple Rankine cycle consists of 4 main components namely condenser, pump, boiler, and turbine [4]. The difference of OTEC power plant and thermal power plant is the boiler replaced by evaporator and the boiling point of OTEC cycle is lower so that water is not suitable for working fluid in OTEC system. Fig. 3. Shown the diagram of Rankine cycle.

The ideal states of turbine's outlet can be found by using equation:

$$s_{2s} = s_f + x_{2s}(s_g - s_f) \quad (1)$$

$$h_{2s} = h_f + x_{2s} . h_{fg} \quad (2)$$

$$x_{2s} = \frac{s_1 - s_f}{s_g - s_f} \quad (3)$$

And the real condition can be found by using equation:

$$h_2 = h_1 - \eta_t(h_1 - h_{2s}) \quad (4)$$

$$x_2 = \frac{h_2 - h_f}{h_{fg}} \quad (5)$$

$$s_2 = s_f + x(s_g - s_f) \quad (6)$$

Where:
S_{2s} = Entropi ideal state (kj/kg.K)
S_2 = Entropi real state (kj/kg.K)
S_f = Entropi saturated liquid (kj/kg.K)
S_g = Entropi saturated gas (kj/kg.K)
h_{2s} = Entalpi ideal state (kj/kg)
h_2 = Entalpi real state (kj/kg)
h_f = Entalpi saturated liquid (kj/kg)
h_g = Entalpi saturated gas (kj/kg)
x = Gas quality
η_t = Isentropic efficiency

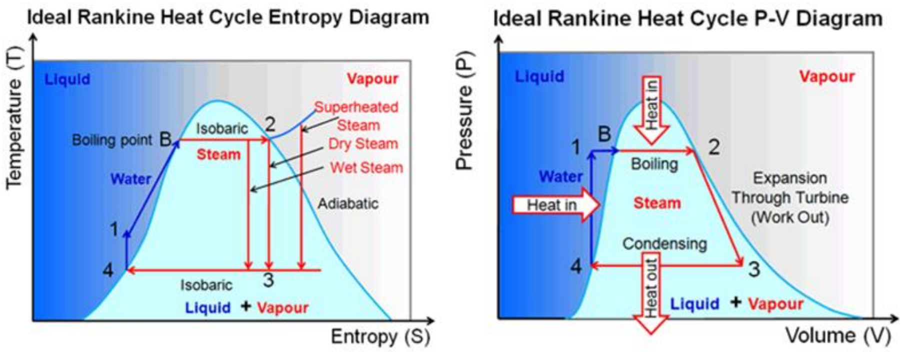

Figure. 3. Diagram of Rankine Cycle

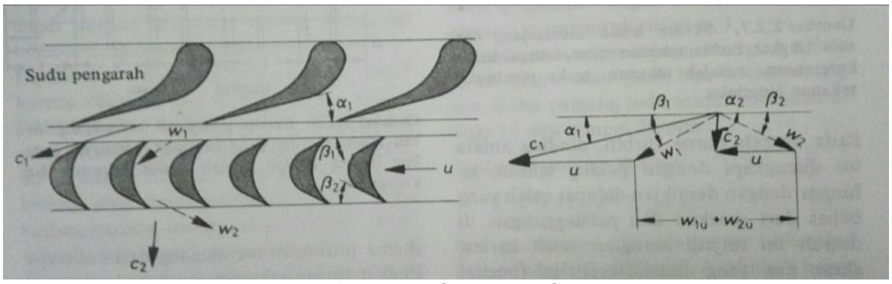

Figure. 4. Velocity Triangle

D. Steam Turbine

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The rotating part is the rotor, while the non-rotating part is the stator or turbine housing. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. The work produced by a turbine can be used for drive the load (i.e. electrical generator, pump, compressor, propeller, etc.). The working fluid may be water, steam, or gas [5].

Steam turbine is a driving force that converts steam potential energy into kinetic energy and then converted into mechanical energy in the form of turbine rotation. Turbine axle, directly or with reduction gear, connected with the mechanism to be driven. If the torque and RPM of turbine are known, then turbine power can be calculated using the equation [6]:

$$P = T \times 2\pi \times RPM/60000 \quad (7)$$

P = Power (kW)
T = Torque (Nm)
RPM = Revolution per minutes

In the steam turbine, vapor is expanded in the nozzle so, obtained the vapor velocity (c1) that will enter to the rotor on turbine. The rotor rotates with the velocity (u). It needs c1 and u ratio with a certain value so that the steam flow out of the nozzle works optimally. Thus, can be obtained inlet and outlet angle [6]. Velocity triangle can be seen in Fig. 4.

Angle α1 and β1 shall be made in such a way, according to the vapor velocity. Value of α1 is free to determined, but should be as small as possible. The optimum value of α1 is between 14°-20°[7]. From α1 can be found:

$$w_1 = \sqrt{C_1^{\,2} + u^2 - 2.C_1.u.\cos\alpha_1} \quad (8)$$

$$\beta_1 = \frac{c_1}{w_1} \times \alpha_1 \quad (9)$$

$$\beta_2 = \beta_1 - (3° - 5°) \quad (10)$$

$$w_2 = \Psi \times w_1 \quad (11)$$

$$C_2 = \sqrt{w_2^{\,2} + u^2 - 2.w_2.u.\cos\beta_2} \quad (12)$$

$$Sin\ \alpha_2 = \frac{w_2}{c_2} \quad (13)$$

Where:
c1 and c2 : absolute velocity of steam inlet and outlet from the nozzle

w1 and w2 : relative velocity of steam inlet and outlet from the rotating blades
u : circumference velocity of the rotating blade
α1 and α2 : angle of the nozzle
β1 and β2 : angle of the rotating blades
Ψ : speed coefficient

E. Heat Exchanger

Heat exchanger used to transfer heat between two or more fluids. The fluids separated by a solid wall to prevent mixing or they may be in direct contact. In OTEC system used heat exchanger that is evaporator and condenser. evaporator replace the boiler function in the steam power plant. An evaporator used to turn the liquid form of a chemical substance such as water into its gaseous-form/vapor. A condenser used to condense a substance from its gaseous to its liquid state, by cooling it. The design calculation for heat exchange means is essentially determining the heat transfer coefficient and heat transfer area (A) of the following equations [8]:

$$A = \frac{Q}{U \times LMTD \times F} \tag{14}$$

$$Q = \dot{m}_{warm} \times C_{p\,warm} \times \Delta T \tag{15}$$

$$LMTD = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln\left[\frac{(T_{h,in} - T_{c,out})}{(T_{h,out} - T_{c,in})}\right]} \tag{16}$$

A = Area (m^2)
Q = Heat transfer rate (Watt)
U = Overall heat transfer coefficient ($W/m^2.^oC$)
LMTD = Logarithmic mean temperature difference (^oC)
F = LMTD correction factor

F. Pump

A pump is a device that moves fluids by mechanical action. Pumps operate by some mechanism, usually reciprocating or rotary, and consume energy to perform mechanical work for moving the fluid. The characteristics of the pump are determined by the volume of the pumped fluid (V), Head losses (H), Condition on each side of suction. One of the important factors in sizing a pump is total head requirements. a pump head is maximum height that the pump can achieve pumping against gravity [12]. Total head is the sum of Head static, Head Pressure, Head Velocity, Head Loss.

1. Head Static
   Head static is the maximum height reached by the pipe after the pump. Head static pump is calculated from the pump inlet till the end of discharge.
2. Head Pressure
   Head Pressure is the diference of pressure on the suction and discharge.
3. Head Velocity
   Head Velocity is difference velocity of fluid between in suction and discharge of pump.
4. Head Loss
   Head loss is energy loss per unit weight of the fluid in the drainage of fluid in the piping system. Head Losses including head major and head minor in suction and discharge.

- Head Major
  Major losses are associated with frictional energy loss per length of pipe depends on the flow velocity, pipe length, pipe diameter, and a friction factor based on the roughness of the pipe, and whether the flow is laminar or turbulent. Head Major can be calculated with the equation:

$$Major\ losses = \frac{f \times L \times v^2}{d \times 2g} \tag{17}$$

Where:
f = the Darcy friction factor (unitless)
L = the pipe length (m)
d = the hydraulic diameter of the pipe D (m)
g = the gravitational constant (m/s^2)
v = the mean flow velocity V (m/s)

- Head Minor
  Minor loss is a pressure loss in components like valves, bends, tees and similar. Head minor can be calculated with the equation:

$$Minor\ Losses = \frac{\Sigma nk \times v^2}{2g} \tag{18}$$

Where:
Σnk = Minor loss coefficient

$$Minor\ Losses = \frac{\Sigma nk \times v^2}{2g} \tag{19}$$

Pump power can be calculated by using equation:

$$P = \rho \times Q \times g \times H_{total} \tag{20}$$

Where:
P = Power (Watt)
ρ = Density (kg/m^3)
Q = Volume flow rate (m^3/s)
g = the gravitational constant (m/s^2)
H_{total} = Total head (m)

III. RESULT AND DISCUSSION

OTEC system consists of turbines, generators, evaporators, condensers, and pumps as shown on Fig. 5. In this chapter will explain how to design Ocean Thermal Energy Conversion (OTEC) turbine, simulation of turbine design, heat exchanger calculation, pump calculation, and net power calculation to be delivered to the consumer.

A. Design and Drawing of OTEC Turbine

In this sub-chapter will be explaining the design process using Autoblade software and simulation process using Fine Turbo. The first process is to determine the working fluid state at the inlet and outlet of OTEC's turbine, then, determining the angle of the turbine blades, and the last is the drawing of OTEC's turbines by using Autoblade software.

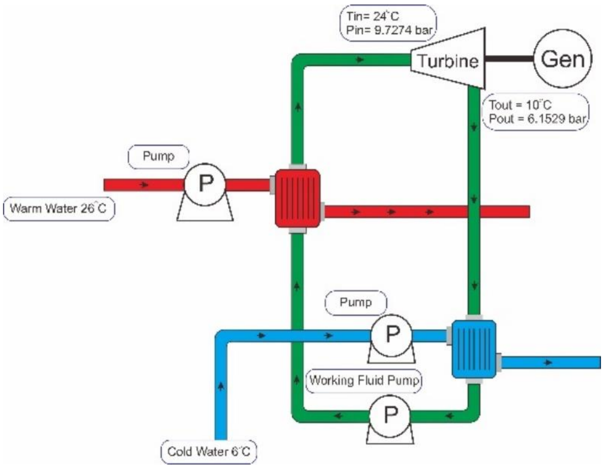

Figure. 5. OTEC System

1. Calculation of Turbine Sates

Data obtained from research conducted by Syamsuddin et al on "OTEC Potential in The Indonesian Seas" the average temperature of shallow and deep water temperature are 28.68°C and 6°C with the difference reaching 22.68°C at a depth 500 – 700m [9]. From the data assumed the inlet and outlet of temperature and pressure of turbine are:

T_{in} : 24°C
P_{in} : 9.7274 bar
T_{out} : 10°C
P_{out} : 6.1529 bar

Then, State 1 is found after the working fluid exits the evaporator. From the ammonia table properties we get:

P_1 : 9.7274 bar
T_1 : 24°C
h_1 : 1462.61 kJ/kg
s_1 : 5.0394 kJ/kg.K

State 2 is found after the working fluid flow through the turbine, can be calculate by equation 1 to 6:

P_2 : 6.1529 bar
T_2 : 10°C
h_2 : 1433.997 kJ/kg
s_2 : 5.1404 kJ/kg.K

2. Drawing OTEC Turbine

The angle of the turbine blades is designed so as to produce optimum work on the turbine. Value of α1 is free to determined, but should be as small as possible. The optimum value of α1 is between 14°-20° [7]. In this research, the value of α1 = 15 °. Following is the result of blade's angle calculation by using equation 8 to 13:

$\alpha_1 =$ 15°
$\alpha_2 =$ 31.78°
$\beta_1 =$ 24.1°
$\beta_2 =$ 21.1°

Drawing process is done by using Autoblade, the 3D model of OTEC turbine can bee seen on Fig. 6. After modelling process, next step is processing by using FINE Turbo.

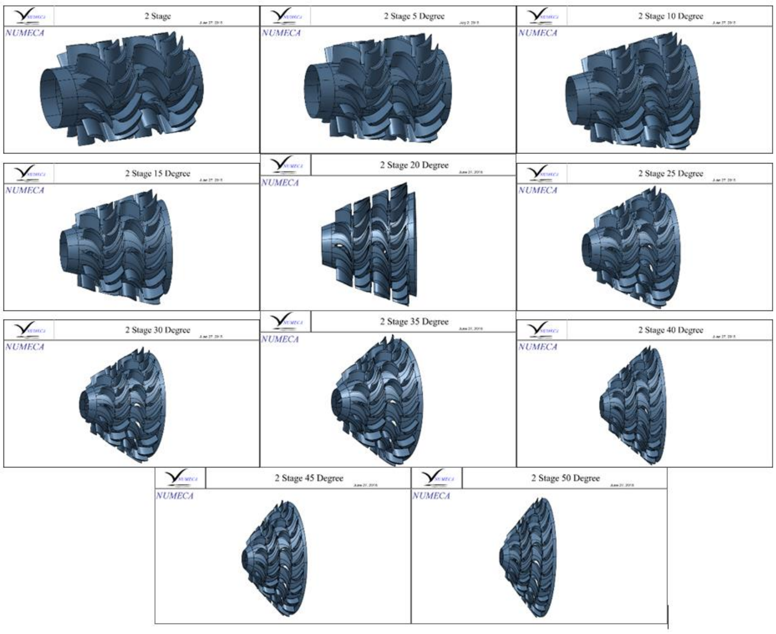

Figure. 6. 3D Model of OTEC Turbin

B. Performance of OTEC Turbine

After simulating process. The performance results of each turbine model will be compared to obtain the best OTEC turbine for laboratory scale. Simulation using Numeca Fine Turbo obtained numerical data, such as mass flow balance (inlet and outlet), efficiency, and torque. The result of simulation can be seen on Table 3.

TABLE 3.
SIMULATION RESULT

No.	Name	RPM	Mass Flow In (kg/s)	Mass Flow Out (kg/s)	Efficiency (%)	Torque	Power (kW)
1	2 Stage 0 Degree	3000	6.17	6.175	41.17	316.9	99.59714
2	2 Stage 5 Degree	3000	8.21	8.19	42.3	500	157.1429
3	2 Stage 10 Degree	3000	8.9	8.898	46.75	620.58	195.0394
4	2 Stage 15 Degree	3000	12.37	12.38	45.33	958	301.0857
5	2 Stage 20 Degree	3000	12.97	13.02	55.05	1177	369.9143
6	2 Stage 25 Degree	3000	14.52	14.56	55.04	1396	438.7429
7	2 Stage 30 Degree	3000	15.83	15.85	53.97	1584	497.8286
8	2 Stage 35 Degree	3000	16.8	16.82	54.89	1744	548.1143
9	2 Stage 40 Degree	3000	17.86	17.94	57.45	1943	610.6571
10	2 Stage 45 Degree	3000	17.77	17.82	53.89	1852	582.0571
11	2 Stage 50 Degree	3000	17.32	17.35	49.87	1632	512.9143

TABLE 4.
VOLUME FLOW RATES

No.	Name	Mass Flow Rate (kg/s)			Volume Flow Rate (m3/h)		
		Ammonia	Warm Seawater	Cold Seawater	Ammonia	Warm Seawater	Cold Seawater
1	2 Stage o Degree	6,17	12,64	3,62	35,56	44,38	12,71
2	2 Stage 5 Degree	8,21	16,81	4,81	47,31	59,05	16,91
3	2 Stage 10 Degree	8,9	18,23	5,22	51,29	64,02	18,33
4	2 Stage 15 Degree	12,37	25,33	7,25	71,29	88,98	25,48
5	2 Stage 20 Degree	12,97	26,56	7,61	74,74	93,29	26,71
6	2 Stage 25 Degree	14,52	29,74	8,51	83,68	104,44	29,9
7	2 Stage 30 Degree	15,83	32,42	9,28	91,23	113,86	32,6
8	2 Stage 35 Degree	16,8	34,41	9,85	96,82	120,84	34,6
9	2 Stage 40 Degree	17,86	36,58	10,47	102,93	128,47	36,78
10	2 Stage 45 Degree	17,77	36,39	10,42	102,41	127,82	36,6
11	2 Stage 50 Degree	17,32	35,47	10,16	99,81	124,58	35,67

Based on Table 3. Can be seen that the highest efficiency and OTEC turbine power is 2 stage 40 Degree with 610.6571 kW and 57.45% of efficiency, and the lowest is 2 stages 0 degree turbine with 99.59 kW and 41.17% of efficiency. From 2 stage 0 degree until 2 stage 40 degree the power of OTEC turbine increased and going down on 2 stage 45 degree OTEC turbine.

1. Calculation of Volume Flow Rates

In order to an Ocean Thermal Energy Conversion (OTEC) system to work, it needs ammonia as a working fluid, warm seawater used to change the ammonia phase from liquid to vapor, and cold seawater used to change the vapor phase to liquid. The volume flow rates can be calculated by using equation 15. Table 4 shown the result of volume flow rates calculation.

2. Calculation of Pump

Ocean Thermal Energy Conversion (OTEC) system use about 3 pumps are used to pump the working fluid ie ammonia, warm seawater, and cold seawater. In this sub-chapter will be explained about the calculation of the pump, including the calculation of head and power.

- Working Fluid Pump
  Fig. 7 is a pipeline of the working fluid. The pump's total head should be provided for the planned amount of seawater. Total head can be calculated by using equation 17 to 19, and the power gained by the fluid can be calculated by equation20. Table 5 is the result of working fluid pump calculation.

- Evaporator Pump
  Fig. 8 is a pipeline of the evaporator. The pump's total head should be provided for the planned amount of seawater. Total head can be calculated by using equation 17 to 19, and the power gained by the fluid can be calculated by equation 20. Table 6 is the result of evaporator pump calculation.

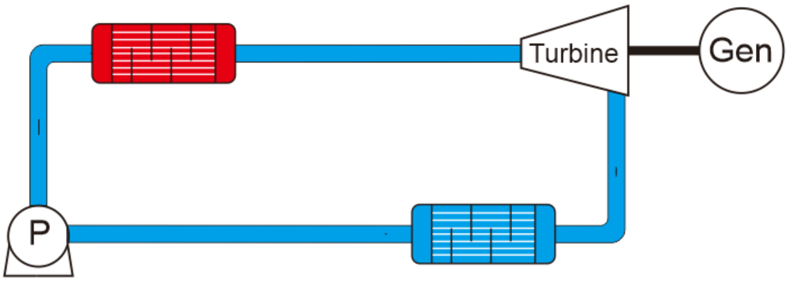

Figure. 7. Working Fluid Pipeline

TABLE 5.
WORKING FLUID PUMP

No.	Name	Total Head (m)	Power (kW)
1	2 Stage 0 Degree	2.005624	0.16
2	2 Stage 5 Degree	2.009958	0.22
3	2 Stage 10 Degree	2.011702	0.23
4	2 Stage 15 Degree	2.022607	0.33
5	2 Stage 20 Degree	2.024853	0.34
6	2 Stage 25 Degree	2.031148	0.39
7	2 Stage 30 Degree	2.037022	0.42
8	2 Stage 35 Degree	2.041698	0.45
9	2 Stage 40 Degree	2.047126	0.48
10	2 Stage 45 Degree	2.046652	0.48
11	2 Stage 50 Degree	2.044319	0.46

TABLE 6.
EVAPORATOR PUMP POWER

No.	Name	Total Head (m)	Power (kW)
1	2 Stage 0 Degree	15,0017	2,48
2	2 Stage 5 Degree	15,003	3,30
3	2 Stage 10 Degree	15,0035	3,58
4	2 Stage 15 Degree	15,0068	4,97
5	2 Stage 20 Degree	15,0075	5,21
6	2 Stage 25 Degree	15,0094	5,84
7	2 Stage 30 Degree	15,0112	6,37
8	2 Stage 35 Degree	15,0126	6,76
9	2 Stage 40 Degree	15,0143	7,18
10	2 Stage 45 Degree	15,0141	7,15
11	2 Stage 50 Degree	15,0134	6,97

- Condenser Pump

Fig. 9 is a pipeline of the condenser. The pump's total head should be provided for the planned amount of seawater. Total head can be calculated by using equation 17 to 19, and the power gained by the fluid can be calculated by equation 20. Table 7 is the result of evaporator pump calculation.

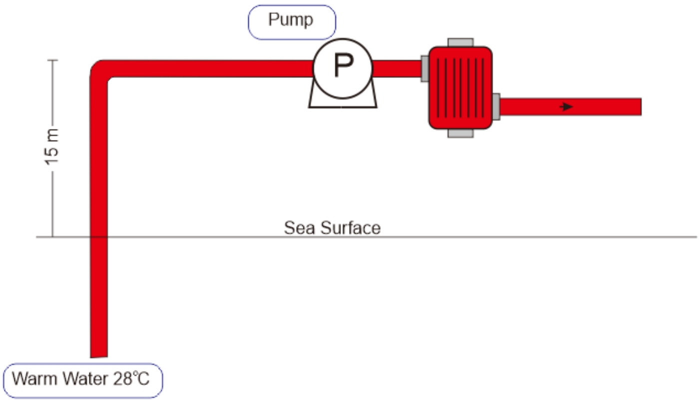

Figure. 8. Evaporator Pump Pipeline

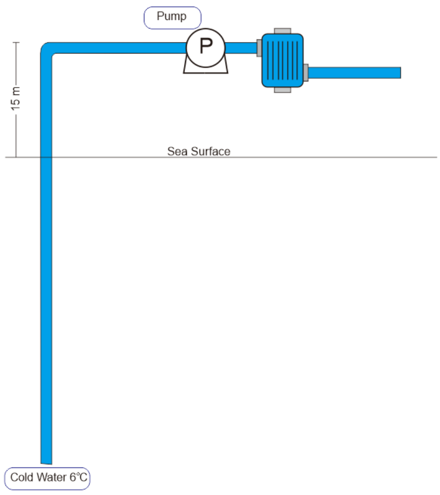

Figure. 9. Condenser Pump Pipeline

TABLE 7.
CONDENSER PUMP POWER

No.	Name	Head Total (m)	Power (kW)
1	2 Stage 0 Degree	15.0005	0.71
2	2 Stage 5 Degree	15.0009	0.94
3	2 Stage 10 Degree	15.0011	1.02
4	2 Stage 15 Degree	15.0021	1.42
5	2 Stage 20 Degree	15.0024	1.49
6	2 Stage 25 Degree	15.003	1.67
7	2 Stage 30 Degree	15.0035	1.82
8	2 Stage 35 Degree	15.004	1.93
9	2 Stage 40 Degree	15.0045	2.06
10	2 Stage 45 Degree	15.0044	2.05
11	2 Stage 50 Degree	15.0042	1.99

3. Calculation of Nett Power

Nett power is the power that distributed to the consumer. Generator is needed to generate power that will be distributed to the consumer. In this research, generator efficiency is assumed to be 85%. Table 8. shown the power generated by generator.

After knowing the power generated by the generator, the pump calculation needs to be done to know the nett power to be distributed to the consumer. Table 9. shown nett power to be delivered to the consumers.

TABLE 8.
POWER GENERATED BY GENERATOR

No.	Name	Efficiency (%)	Turbine Power (kW)		Generator (kW)	
			Simulation	Nett	Efficiency	Power
1	2 Stage 0 Degree	41,17	99,60	41,00	85	34,85
2	2 Stage 5 Degree	42,30	157,14	66,47	85	56,50
3	2 Stage 10 Degree	46,75	195,04	91,18	85	77,50
4	2 Stage 15 Degree	45,33	301,09	136,48	85	116,01
5	2 Stage 20 Degree	55,05	369,91	203,64	85	173,09
6	2 Stage 25 Degree	55,04	438,74	241,48	85	205,26
7	2 Stage 30 Degree	53,97	497,83	268,68	85	228,38
8	2 Stage 35 Degree	54,89	548,11	300,86	85	255,73
9	2 Stage 40 Degree	57,45	610,66	350,82	85	298,20
10	2 Stage 45 Degree	53,89	582,06	313,67	85	266,62
11	2 Stage 50 Degree	49,87	512,91	255,79	85	217,42

TABLE 9.
NETT POWER

No.	Name	Power by Generator (kW)	Pump Power (kW)			Nett Power (kW)
			Evap	Cond	NH3	
1	2 Stage 0 Degree	34.85	2.48	0.76	0.16	31.45
2	2 Stage 5 Degree	56.50	3.30	1.07	0.22	51.91
3	2 Stage 10 Degree	77.50	3.58	1.23	0.23	72.46
4	2 Stage 15 Degree	116.01	4.97	1.80	0.33	108.91
5	2 Stage 20 Degree	173.09	5.21	1.99	0.34	165.54
6	2 Stage 25 Degree	205.26	5.84	2.34	0.39	196.70
7	2 Stage 30 Degree	228.38	6.37	2.67	0.42	218.92
8	2 Stage 35 Degree	255.73	6.76	2.96	0.45	245.56
9	2 Stage 40 Degree	298.20	7.18	3.29	0.48	287.25
10	2 Stage 45 Degree	266.62	7.15	3.41	0.48	255.59
11	2 Stage 50 Degree	217.42	6.97	3.45	0.46	206.54

Fig. 10. Can be seen that a single-stage OTEC turbine produces nett power of 31.09 kW. For the 2 stage OTEC turbine, the lowest power is a straight turbine model with a nett power of 31.62 kW, while the highest is generated by a 40 degree turbine with a nett power of 287.73 kW. For 3 stage OTEC turbines producing the highest power among all models, the resulting nett power is 351.37 kW.

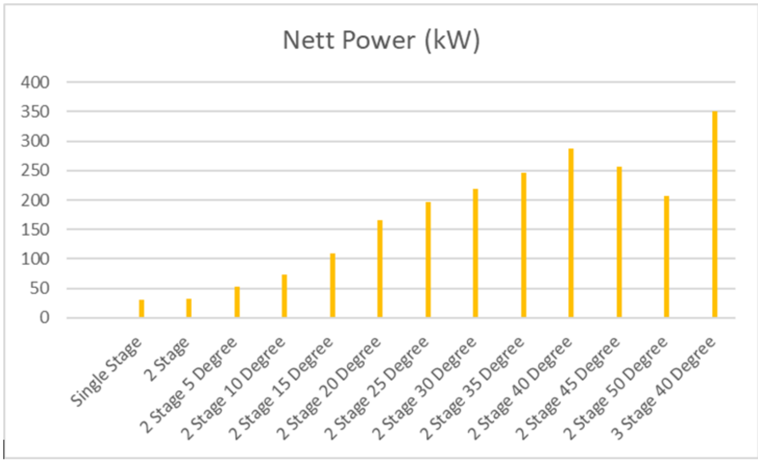

Figure. 10. Net Power

IV. CONCLUSION

Based on the results of design and simulation that has been done, it can be concluded as follows:

1. Design of the OTEC turbine conducted based on thermodynamic conditions on a region. Turbine with Tin = 24 ° C, Pin = 9.7274 bar, and Tout = 10 ° C, Pout = 6,1529 bar, have an enthalpy difference of 28.6 kJ / kg using ammonia as working fluid. Result of calculation turbine blades angle with $\alpha 1 = 15°$ are: $\alpha 2 = 31.78°$, $\beta 1 = 24.1°$, $\beta 2 = 21.1°$.

2. Adding the number of stages can improve the efficiency and power generated by the turbine. The highest efficiency and net power is a 3 stage 40 degree turbine with 351.37 kW generated power, and 65.02% efficiency. Lowest is single stage turbine with nett power 31.09 kW, and efficiency 45.85%.

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