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Study of ocean thermal energy resources in Para'baya, West Sulawesi

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Abstract: Ocean thermal is one of the renewable energy resources. In 1981, a design of Ocean Thermal Energy Conversion (OTEC) pilot power plant was proven could produce electricity. The performance of OTEC depends on the possible temperature differences of the warm and cold seawater, at least 20°C. In the coastal of Para'baya, this requirement can be satisfied since the distance to reach the 1000 m depth is less than 10,000 m from the shore. The result of ocean thermal power calculation in Makassar Strait shows that Para'baya could produce higher power than any other place in west coast of Sulawesi, with an average power output of 120.35 kW. This ocean thermal study, in the coast of Para'baya, used sea surface temperatures (SST) data from the result of Long-term Indonesian Throughflow Model Simulation (LITHMOS) over 24 years (1982 – 2006), and sea temperature data at 1000 m depth from the World Ocean Atlas (WOA) 2009. The result shows that ocean thermal energy distributions in the Makassar Strait were affected by the combination of gust, wind direction, and sun position which varies in each season. Maximum ocean thermal power is reached during the first transitional season (March, April, May) with output power of 128 kW, and the minimum power is achieved during the dry season (June, July, August) with an output power of 114 kW.

1. Introduction

The ocean is a vast resource of energy. Ocean thermal is one of energy source that can be harvested from the ocean. This energy comes from the absorbed solar energy by the ocean. Nowadays, a method to utilize thermal energy from the ocean to produce electricity has been invented, namely Ocean Thermal Energy Conversion (OTEC). This system uses warm sea surface water and cold deep sea water with minimum 20°C of temperature different [1–3]. In the tropical area, the 20°C temperature differences mostly can be acquired from sea surface water and 1000 m depth deep water [1].

Para'baya is a coastal region in West Sulawesi Province, Indonesia, located in coordinate 3.16°S; 118.82°E (Figure 1.a). It is one of the potential areas for ocean thermal energy exploration. It is located on



the equator where the sea surface temperature (SST) is always higher than 27.5°C. Another reason is the steepness of the bathymetry. A thousand meters depth can be reached within 9,300 m from the shoreline (Figure 1.b).

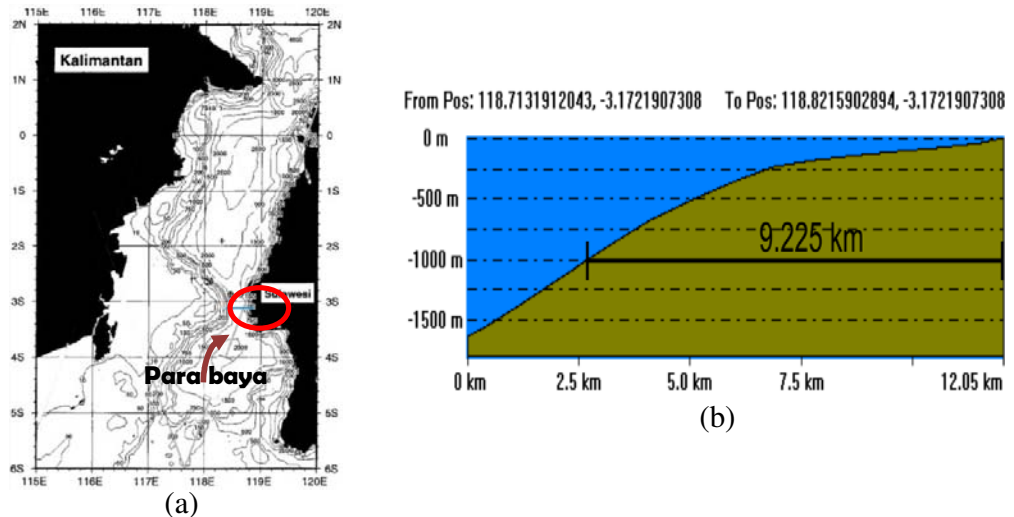


Figure 1. (a) Bathymetry Map of Para'baya [4], (b) Section View of Para'baya Coastal Area

This study calculates the ocean thermal energy potential of Para'baya, by simulating an OTEC design and calculate the heat exchange within the system. The simulation of the OTEC design use the SST output of Long-term Indonesia Throughflow Model Simulation (LITHMOS) from 1982 to 2006 [5], and World Ocean Atlas 2009 [6] water temperature of 1000 m depth as the input variable. The purpose of this study is to analyze the monthly variation of ocean thermal energy in Para'baya coastal area.

2. Literature Review

Since the early development of OTEC system, several variations of method had been proposed. The most common varieties are classified based on its thermodynamic cycle; closed cycle, open cycle, and hybrid cycle [1].

In 1981, an OTEC pilot power plant was built in the Republic of Nauru. This power plant applied the OTEC closed cycle system [7]. This OTEC system works by evaporating the working fluid into the steam and let it flow through the turbine to move the turbine. As the turbine running, it generates electricity. After the working fluid pass through the turbine, it is condensed back to the liquid state in the condenser and pumped back to the evaporator for the next cycle. The heat source to evaporate working fluid is extracted from the warm sea surface, and the heat is dumped into the cold deep water to condense the working fluid [1]. Table.1 shows the specification of the Nauru's OTEC pilot power plant. The average sea surface temperature in Nauru is around 29.8°C, while the temperature in 600-meter depth is 8.1°C. The pilot power plant project in Nauru, on average could produce 100.5 kW electricity with a maximum power output of 120 kW electricity [7].

Table 1. Specification of OTEC Pilot Power Plant, Republic of Nauru [1]

| | Evaporator | Kondensor |
|---|-------------------------|------------------------|
| Shell ID (Inner Diameter) (m) | 1.9 | 1.5 |
| Length of Shell (m) | 8 | 9.1 |
| Number of Tube | 870 (<i>enhanced</i>) | 914 (<i>grooved</i>) |
| Tube OD (Outer Diameter) (mm) | 25.4 | 25.4 |
| Thickness of Tube (mm) | 0.7 | 0.6 |
| Length of Tube (m) | 5.35 | 6 |
| Seawater Flow Rate (kg/s) | 402.8 | 391.7 |
| Seawater Flow Velocity (m/s) | 2 | 1.97 |
| Pressure drop (m) | 2.9 | 3.71 |
| Freon Flow Rate (kg/s) | 20.6 | 20.6 |
| Effective Area Heat exchanger (m ²) | 371.4 | 437.6 |
| Overall U (Watt/m ² K) | 3000 | 2560 |

Note: Rankine Closed Cycle; Working Fluid: Freon R-22;

Heat Exchanger Type: Shell & Tube HXs; Tube Material: Titanium;

Horizontal Evaporator; Vertical Condenser

Figure 1 shows the location of Parabaya, and the section view of the steep bathymetry of Para'baya's coast. It makes this area suitable for OTEC system application, where it needs the least energy to pump up the cold deep sea water compared to any other location on the west coast of Sulawesi. The proposed coordinate is also close to residential area. Therefore, the generated electricity can be used to supply the electricity demand load of this region.

3. Power Calculation of OTEC Closed Cycle

OTEC works by utilizing warm sea surface water and cold deep layer water. Therefore, Sea surface temperature and deep sea water temperature data are needed to calculate the produced energy. The type of OTEC design also determines the process within the system, hence influences the system power generation. LITHMOS temperature output at the surface is used as the sea surface temperature in the data, and WOA 2009 temperature data of Makassar Strait at 1000 m depth is used as the deep-water temperature data in the calculation. The power generation system is OTEC closed cycle as specified in Table 1. The schematic of the OTEC closed cycle is illustrated in Figure 2.

The power calculated in this study is only gross power, without taking account of power required for the pump and any other parasitic power demand. The power produced by the turbine is assumed to be the heat rate difference between evaporator and condenser. The power generation by the OTEC system is formulated in equation (1) [1,8]:

$$\dot{W}_t = \dot{Q}_e - \dot{Q}_k \quad (1)$$

Where \dot{W}_t is the power produced by the Turbine, \dot{Q}_e is the heat extracted from the sea surface water in evaporator, and \dot{Q}_k is the heat absorbed by the cold deep water in the condenser.

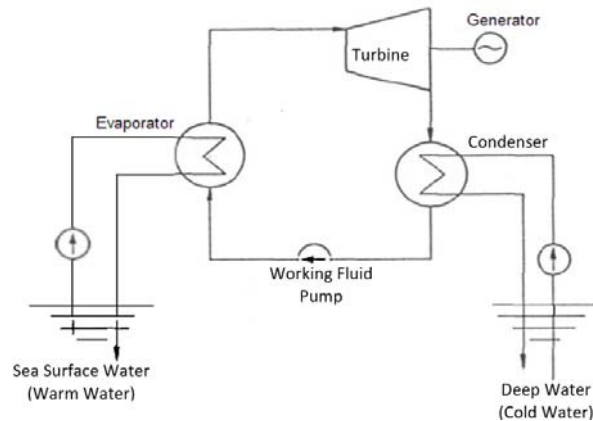


Figure 2. OTEC Closed Cycle schematic [7]

The heat rate, \dot{Q}_e and \dot{Q}_k are calculated with equation (2):

$$\dot{Q} = \Delta T_m U A = \frac{U A (\Delta T_i - \Delta T_o)}{\ln(\Delta T_i / \Delta T_o)} \quad (2)$$

Where \dot{Q} is the heat rate between sea water and working fluid in each heat exchanger, U is the thermal conductance of the heat exchanger, A is the effective area of the heat exchanger, ΔT_i is the temperature differences between incoming seawater and incoming working fluid in each heat exchanger, ΔT_o is the temperature differences between outgoing seawater and outgoing working fluid in each Heat Exchanger.

The outlet temperature of sea water and working fluid temperature influenced by the heat flow rate in each heat exchanger. Hence, the outlet temperature should be calculated using the derivation of heat transfer formula (3):

$$T_{out} = \frac{\dot{m}_1 C_H T_{in1} + \dot{m}_2 C_2 T_{in2}}{\dot{m}_1 C_H + \dot{m}_2 C_2} \quad (3)$$

For the evaporator part, the index 1 indicates the reference fluid, while index 2 indicates the target fluid. For the condenser part, the index 1 indicates the target fluid, while index 2 indicates the reference fluid. And index H show the heat exchanger material. Where \dot{m} is the flow rate of the fluid, T_{in} is the incoming fluid temperature, C_2 is the fluid specific heat, either sea water or working fluid, and C_H is the heat exchanger specific heat.

The working fluid of this study is Freon R-22. The specific heat of Freon is 1.22 kJ/kgK, and the specific heat of seawater is 3.93 kJ/kgK. The heat exchanger material is titanium, and its specific heat is 0.47 kJ/kgK.

To solve \dot{Q}_e and \dot{Q}_k using equation (2), ΔT_i and ΔT_o need to be solved first using equation (3). However, the incoming working fluid from evaporator is the outward working fluid from condenser, and the incoming working fluid of condenser is the outward working fluid from evaporator. Hence, for this system, equation (3) is an implicit equation and need to be solved using iterative method.

4. OTEC Power Output

The average power output of the OTEC simulation at Makassar Strait is shown in Figure 3. The simulation shows different power output between southern and northern part of Makassar Strait. The southern part has higher potential compared to the north of Makassar Strait (Figure.3a). However, the region with the highest ocean thermal energy potential is quite far from the shore. The Capital Expenditure (CapEx) to build the

floating platform for the OTEC system in that area is expected to be more expensive compare to the onshore OTEC platform, due to the technological complexity.

Para'baya is the closest shore with the most exceptional ocean thermal energy potential along the West Sulawesi Coast (Figure 3.a). The average power output is 120.39 kW. However, the power output is seasonally varied in a year basis (Figure 3.b). During the wet season (December, January, February) and dry season (June, July, August) the average power output decreased. While during first transitional season (March, April, May) and second transitional season (September, October, November), the average power output increased.

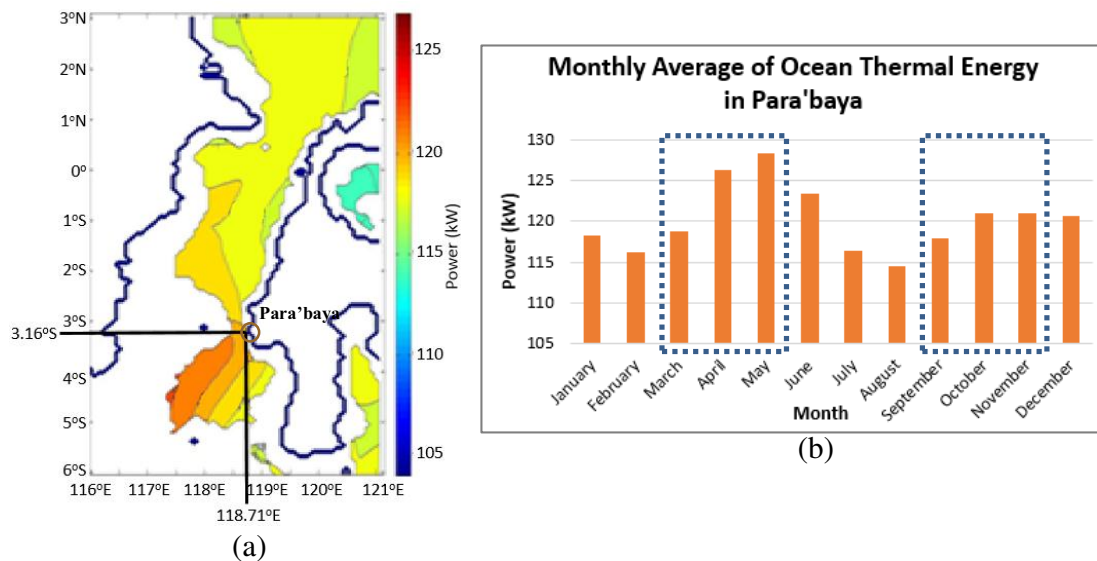


Figure 3. (a) Average Ocean Thermal Energy Distribution Map in Makassar Strait, **(b)** Monthly Average of Ocean Thermal Energy in Para'baya

In the wet season, the maximum ocean thermal power is 120.91 kW, which is acquired in December, while the lowest output is in February with a power output of 116.33 kW. The maximum power output during the first transitional season is in May with a power output of 128.36 kW, and the minimum output is in March with 118.83 kW. During the dry season, the highest ocean thermal output is around 123.29 kW which is acquired in June, and the lowest ocean thermal output is in August with 114.7 kW power output. In the second transitional season, the power output does not have high variation. The highest ocean thermal is in November with power output of 120.16 kW, and the smallest is in September with 118.27 kW output.

5. Sea Surface Temperature (SST) Variability

The SST variability is the primary cause of the ocean thermal energy variation. The correlation between sea surface temperature and the ocean thermal energy in Para'baya is very high, 0.86. The ocean thermal power increases when the SST jumped and it decreases when the SST dropped. SST varies, as the weather changing. Meanwhile, the deep layer water below 1,000 m depth temperature is hardly had direct influenced from the weather. Hence, the temperature variation is low and doesn't give significant impact to the ocean thermal power. Figure 4 shows the vertical variation of temperature over the time in Para'baya based on the output of LITHMOS for 1st of January 1982 to 31st of December 1983. The temperature in the surface is fluctuative, while the temperature below 900 m is relatively uniform.

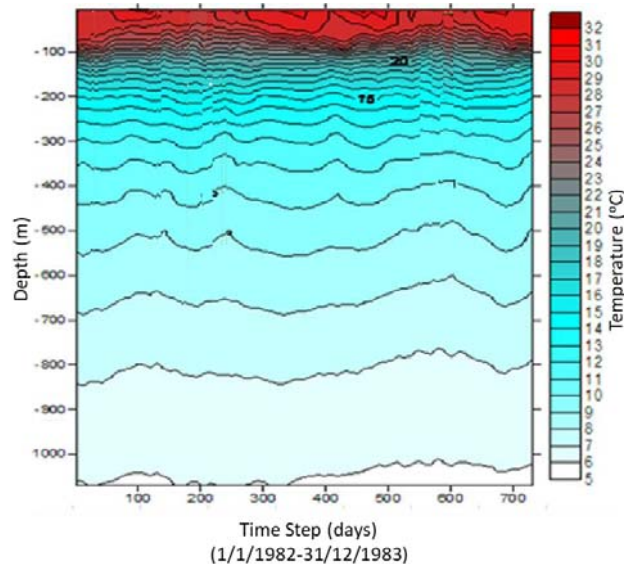


Figure 4. Para'baya Vertical Variation of Temperature from 1st of January 1982 to 31st of December 1983 of LITHMOS output.

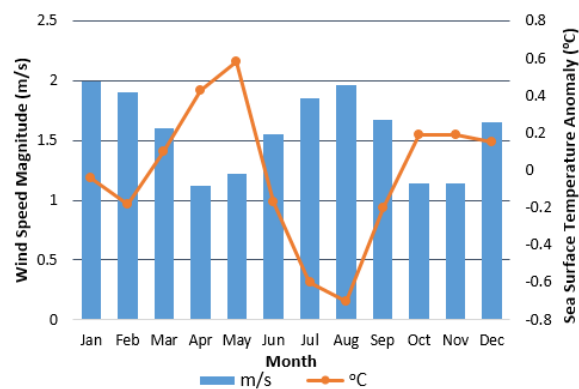


Figure 5. Monthly Average of Wind Speed at Coordinate 2.5°S;117.5°E [9] and Sea Surface Temperature Anomaly at Para'baya.

The intensity of solar radiation and the wind speed influence the SST. The higher solar irradiation received by the ocean then, the higher sea surface temperature would be. The water particle absorbs more heat if the solar irradiation is greater. However, the SST decreases when the gust of wind is greater. Figure 5 shows the monthly average wind gust in the southern part of Makassar Strait and the monthly average of SST variation. When the wind blows hard, it causes turbulent in the sea water. The turbulence mixes the water and distributes the heat evenly. However, the turbulence also blocks the solar ray; hence, the surface temperature is low when the wind is strong. And vice versa, the sea surface temperature is high when the wind is weak.

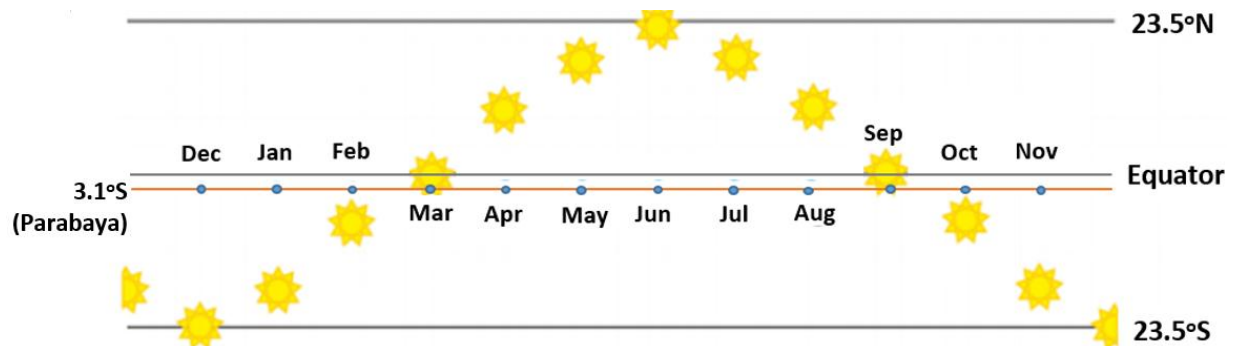


Figure 6. Relative sun position over Para'baya's latitude (3.1°S)

Figure 6 shows the relative position of the sun to the latitude of Para'baya. The sun is above Para'baya around March; thus, the solar irradiation reached the maximum point. However, the lowest wind speed in Makassar Strait is around April – May; hence the sea surface temperature in May is the highest. On average, the temperature anomaly in May is 0.6°C above average. In July, the sun position is in the farthest north from Para'baya. The sea surface temperature is low, and it gets even lower in August due to the strengthening of the wind. The strong wind to the north during August is causing an upwelling effect on the west coast of Sulawesi, and it also contributes to the sea surface temperature drop. On average, the sea surface temperature in August drops by -0.74°C compare to the average temperature.

In December, the sun reaches the farthest south from Para'baya, the wind speed also relatively high, but the wind is blowing to the south and doesn't cause an upwelling effect on the west coast of Sulawesi. Therefore, the temperature drop is not as much as in August. The average sea surface temperature in December is still 0.17°C higher than overall average sea surface temperature.

Meanwhile, in January – February, the sun is getting closer to Para'baya. But the wind is stronger than the wind magnitude in December. Therefore, the sea surface temperature keeps getting lower until February. The average sea surface temperature of Para'baya water is -0.17°C lower than the overall average temperature.

6. Conclusion

Para'baya is one of the potential locations for the ocean thermal energy utilization. The ocean thermal power simulation shows Para'baya coast could produce quite significant power compared to others region in the west coast of Sulawesi. Another reason is the bathymetry of Para'baya is steep enough to reach the 1000 m depth. The water intake from the deep layer would not be very far from the shoreline. Therefore, it would minimize the power requirement of the pump; hence decrease parasitic power demand and increase the net power output.

The ocean thermal power in Para'baya varies over the time as the SST changes. The SST has strong influence on the OTEC closed cycle power generation. Meanwhile, the SST is varied in season. The combination of seasonal solar radiation intensity and wind magnitude determine the SST variation. The highest ocean thermal power in Para'baya is in May when the wind magnitude is at the lowest, and the sun is not in its farthest position to Para'baya. The average gross ocean thermal power in May is 128.36 kW. The smallest ocean thermal power is in August when the wind magnitude is high, and there is an indication of upwelling effect in the west coast of Sulawesi. The average gross ocean thermal power in August is 114.7 kW.

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