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Preliminary Study on Ocean Thermal Energy Conversion in Siberut Island, West Sumatera, Indonesia

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ABSTRACT

Ocean Thermal Energy Conversion (OTEC) is a clean marine renewable energy using temperature difference between the sea surface and the deep ocean to rotate a generator to produce electrical energy. As Indonesia is an equatorial country located at latitudes less than 20 degrees covered by 77 % ocean, thousand islands, strain and many difference of topography, OTEC is very compatible build in Indonesian. This paper discussed on performance of closed cycle of OTEC in Siberut Island, West Sumatera-Indonesia. Siberut Island has a hot and humid tropical rainforest climate, with an annual rainfall of 4,000 mm with temperatures range 22 - 31 ^{0}C and humidity averages 81-85%. The study founded that the Siberut island has potential OTEC due to the gradient temperature more than 20 ^{0}C.

KEY WORDS: *Siberut Island, West Sumatera, Indonesia, Ocean Thermal Conversion Energy.*

NOMENCLATURE

OTEC Ocean Thermal Energy Conversion

1.0 INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) is a clean and friendly renewable energy with zero-emission. OTEC uses temperature difference between the sea surface and the deep ocean to rotate a generator to produce electrical energy. The sea surface is heated continuously by sunlight from surface up to 100 m. OTEC is capable of generating electricity day and night, throughout the year, providing a reliable source of electricity.

OTEC is one of the world's largest renewable energy resources and is available to around the tropical countries as shown in Figure.1. OTEC have installed in certain countries as follows. Saga, Japan produces 30 kW which was operated since 1980 with the purpose of research and development. Gosung, Korea, KRISO produces 20 kW which was operated since 2012 with the purpose of research and development. Réunion Island, France - DCNS produces 15 kW whicich was operated since 2012 with the purpose of research and development. Kumejima, Japan produces 100 KW with grid connected operated since 2013 with the purpose of research and development and for electricity production. Hawaii, US under Makai Ocean Engineering produces 105 kW with grid connected operated since 2015 with the purpose of electricity production.

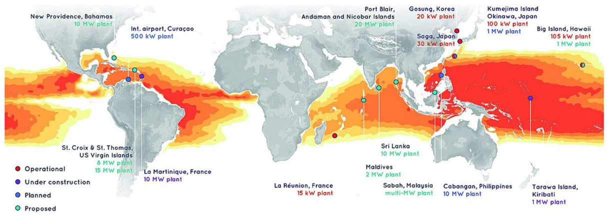

Figure 1: Distribution of the OTEC potential around the world [OTEC Foundation]

Many OTEC plants are under development such as Andaman and Nicobar Islands, India -DCNS- 20 MW, Bahamas, USA -

cean Thermal Energy Corporation (OTE)- 10 MW, Cabangan, Philippines -Bell Pirie Power Corp- 10 MW, Curaçao, Kingdom of the Netherlands -Bluerise- 0.5 MW, Hawaii, USA -Makai Ocean Engineering- 1 MW, Kumejima, Japan -Xenesys and Saga University- 1 MW, Maldives -Bardot Ocean- 2 MW, Martinique, France -Akuoa Energy and DCNS- 10,7 MW, Sri Lanka -Bluerise- 10 MW, Tarawa Island, Kiribati -1 MW and US Virgin Islands

Indonesia is the tropical oceans country, approximately defined by latitudes less than 20 degrees, may be thought of as enormous passive solar collectors. As the Indonesia has 77 % of total area covered by the ocean, OTEC can be done effectively and on a large scale to provide a source of renewable energy that is needed to cover a wide range of energy issues. This paper discusses performance of closed cycle OTEC applied in Siberut island, West Sumatera, Indonesia.

2.0 OCEAN THERMAL ENERGY CONVERSION

2.1 OTEC Process System

Ocean Thermal Energy Conversion (OTEC) is a marine renewable energy technologies that harness the sun's energy is absorbed by the oceans to produce electricity. hot sun warms the surface water a lot more than sea water, which creates a natural temperature gradient provided the sea, or thermal energy.

OTEC is an extremely clean and sustainable technology and in some cases will even produce desalinized water as a byproduct. Like any alternative form of energy generation OTEC has its advantages and disadvantages, but it nonetheless a feasible means to achieve a future of sustainable power.

OTEC uses warm water at sea level with temperatures around 25 °C to vaporize a working fluid, which has a low boiling point, such as ammonia. Steam expands and rotating turbine coupled to a generator to produce electricity. The vapour is then cooled by seawater pumped from deeper ocean layers, where temperatures around 5 °C. The working fluid that condenses is back into a liquid, so it can be reused. It is a continuous cycle power plant. These power plants face many engineering challenges. They require deep-water sources so are only useful around coastal regions and islands. Additionally, the pumping of ocean water from up to 300 meter deep requires a large diameter pipeline. Dealing with ocean conditions is also often difficult in executing an OTEC power plant. The offshore location of these plants means they must be located on floating barges, fixed platforms, or deep beneath the sea.

There are four main types of OTEC as shown in Figure.2. All four types of OTEC can be land-based, sea-based, or based on floating platforms. The former has greater installation costs for both piping and land-use. The floating platform installation has comparatively lower land use and impact, but requires grid cables to be installed to land and has higher construction and maintenance costs. Finally, hybrid constructions combine OTEC plants with an additional construction that increases the temperature of the warm ocean water.

2.1.1 Open Cycle OTEC

Warmer surface water is introduced through a valve in a low pressure compartment and flash evaporated. The vapour drives a generator and is condensed by the cold seawater pumped up from below. The condensed water can be collected and because it is fresh water, used for various purposes as shown in Figure.3. Additionally, the cold seawater pumped up from below, after being used to facilitate condensation, can be introduced in an air-conditioning system. As such, systems can produce power, fresh water and air-conditioning. Furthermore, the cold water can potentially be used for aquaculture purposes, as the seawater from the deeper regions close to the seabed contains various nutrients, like nitrogen and phosphates

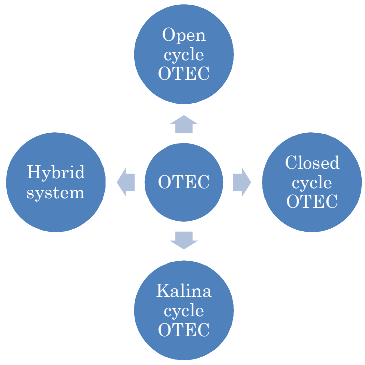

Figure 2: Types of OTEC

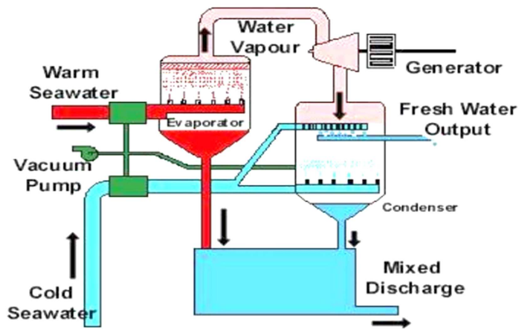

Figure 3: Open cycle OTEC

2.1.2 Closed Cycle OTEC

Surface water, with higher temperatures, is used to provide heat to a working fluid with a low boiling temperature, hence providing higher vapour pressure. Most commonly ammonia is used as a working fluid, although propylene and refrigerants have also been studied [Bharathan, 2011]. The vapour drives a generator that produces electricity; the working fluid vapour is then condensed by the cold water from the deep ocean and pumped back in a closed system. The major difference between open and closed cycle systems is the much smaller duct size and smaller turbines diameters for closed cycle, as well as the surface area required by heat exchangers for effective heat transfer. Closed conversion cycles offer a more efficient use of the thermal resource (Lewis, et al., 2011).

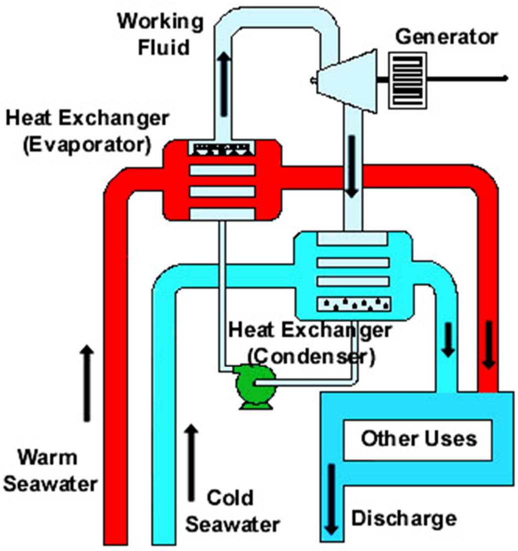

Figure 4: Closed cycle OTEC

2.1.3 Kalina Cycle OTEC

The Kalina cycle is a variation of a closed cycle OTEC, whereby instead of pure ammonia, a mixture of water and ammonia is used as the working fluid. Such a mixture lacks a boiling point, but instead has a boiling point trajectory as shown in Figure.5. More of the provided heat is taken into the working fluid during evaporation and therefore, more heat can be converted and efficiencies are enhanced.

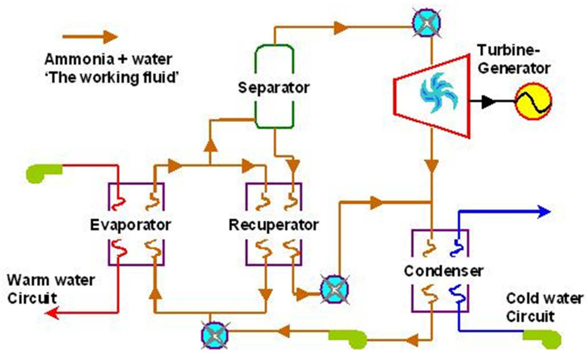

Figure 5: Kalina cycle OTEC

2.1.4 Hybrid OTEC

Hybrid systems combine both the open and closed cyc les where the steam generated by flash evaporation is then used as heat to drive a closed cycle as shown in Figure.6. First, electricity is generated in a closed cycle system as described above. Subsequently, the warm seawater discharges from the closed-cycled OTEC is flash evaporated similar to an open-cycle OTEC system, and cooled with the cold water discharge. This produces fresh water.

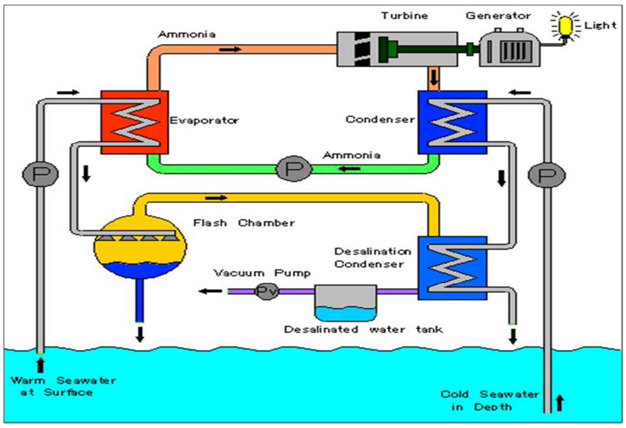

Figure 6: Hybrid OTEC

2.2 Closed Cycle OTEC Theory

Ocean thermal between water surface and water depth must be converted to reach maximum output from its thermal. The OTEC efficiency value can be calculated using the equation of Carnot efficiency.

$$\eta_{Carnot} = \frac{T_{max} - T_{min}}{T_{max}} \quad (1)$$

Where; η is Carnot efficiency, T_{max} is an absolute temperature of the surface water, T_{min} is an absolute temperature of the deep water

The efficiency of the cycle is determined by the temperature difference. The greater the temperature difference, the higher the efficiency. This technology is therefore worth especially in equatorial regions where differential temperatures throughout the year are at least 20 ^{0}C.

Figure 7 shows diagram temperature (T) versus entropy (S) used to analyze performance of the cycle in Ocean Thermal Energy Conversion. Figure.8 shows closed cycle Ocean Thermal Energy Conversion Schematic.

Figure 7: Diagram of temperature (T) versus entropy (S) of the cycle in OTEC.

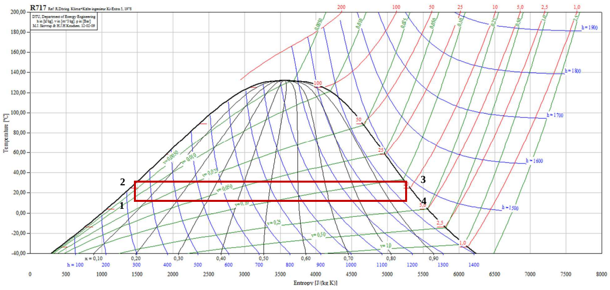

Figure 7: Diagram of temperature (T) versus entropy (s).

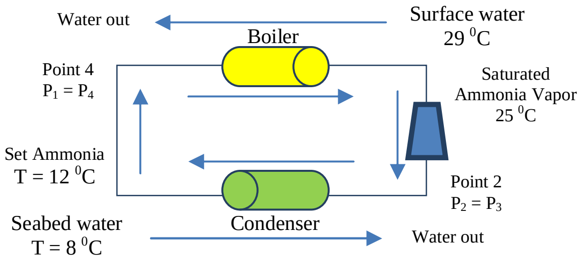

Figure 8: Closed Cycle Ocean Thermal Energy Conversion Schematic.

According to figure.8, turbine work can be calculated using the following equation:

$$W_{Turbine} = h_3 - h_4 \quad (2)$$

Where; $h_{1,2,3,4}$ is enthalpy at points 1,2,3 and 4.

The pump work (W_{Pump}) can be calculated using the following equation:

$$W_{Pump} = v \cdot (P_2 - P_1) \quad (3)$$

Where; v is specific volume of the ammonia, P_2 is pressure at the boiler and P_1 is pressure at the condenser.

The work output (W_{net}) can be calculated using the following equation:

$$W_{net} = W_{Turbine} - W_{Pump} \quad (4)$$

Cycle Efficiency can be written as:

$$\eta_{Cycle} = \frac{W_T - W_P}{Q_H} \quad (5)$$

The enthalpy at point 2 can be written as:

$$h_2 = h_f + x_2 h_{fg} \quad (6)$$

Where; h_f is the saturated liquid enthalpy, h_{fg} is the enthalpy of vaporization and x_2 is the isentropic quality.

The isentropic quality can be written as:

$$x_2 = \frac{s - s_f}{s_{fg}} \quad (7)$$

Where; s_f is the saturated liquid entropy and s_{fg} is the entropy of vaporization.

The power output of the turbine can be calculated using the following equation

$$W_T = \dot{m}\,(h_1 - h_2) \quad (8)$$

Where; $\dot{m}$ is mass flow rate of the working fluid.

The pump power input (W_p) will be calculated along with the enthalpy at Point 4.

$$W_p = -v \cdot (P_4 - P_3) \quad (9)$$

Where; v is specific volume (m^3/kg), $P_{3,4}$ is pressure at point 3 and 4.

Total pump power input ($W_{Pump-Total}$) will be calculated along with the enthalpy at Point 4.

$$W_{Pump-Total} = -\dot{m}\, W_p \quad (10)$$

The heat supplied to the heat exchanger (q_h) can be written as:

$$q_h = h_1 - h_4 \quad (11)$$

Where; h_1 is enthalpy at point 1.

$$h_4 = h_3 - W_p$$

The specific heat to the heat exchanger (Q_h) can be written as:

$$Q_h = \dot{m}\, q_h \quad (12)$$

The efficiency of the cycle can be calculated

$$\eta_{Cycle} = \frac{W_{net}}{Q_H} \quad (13)$$

2.3 Carnot Theory

Ocean thermal between water surface and water depth must be converted to reach maximum output from its thermal. The OTEC efficiency value can be calculated using the equation of Carnot efficiency.

$$\eta = \frac{T_{max} - T_{min}}{T_{max}} \quad (14)$$

Where; η is Carnot efficiency, T_{max} is an absolute temperature of the surface water, T_{min} is an absolute temperature of the deep water

The efficiency of the cycle is determined by the temperature difference. The greater the temperature difference, the higher the efficiency. This technology is therefore worth especially in equatorial regions where differential temperatures throughout the year are at least 20 ^{0}C.

3.0 PERFORMANCE ANALYSIS OF OTEC IN SIBERUT ISLAND, WEST SUMATERA, INDONESIA

Indonesia is an archipelago island nation along the equator and tropical areas, lies between the Indian Ocean and the Pacific Ocean. With Indonesia's climate tends to be relatively even throughout the year, therefore Indonesia has OTEC energy source is provided plentiful and constantly replenished during the sun was shining and the ocean currents naturally present.

OTEC obviously can have huge application in tropical areas, where the required water temperatures occur, providing power, fresh water, air conditioning and more. Figure 9 shows the schematic of OTEC potential in Indonesia. There are six potential areas for OTEC application, they are south of Sumatera (A) such as Siberut Island, North of Sulawesi (B), North of Maluku (C) such as Morotai Island, South of Maluku (E) such as Taliabu, Buru and Seram islands (F). Table 1 shows surface temperature and seabed temperature on several locations in Indonesia which found temperature difference more than 20 ^oC.

Siberut Island has a hot and humid tropical rainforest climate, with an annual rainfall of 4,000 mm with temperatures range 22 - 31 ^0C and humidity averages 81-85%. Siberut is the largest and northernmost of the Mentawai Islands, lying 150 kilometres west of Sumatra in the Indian Ocean. A part of Indonesia, the island is the most important home for the Mentawai people. Siberut Island has area 4,030 km^2 with population 35,091 people.

Figure 10 shows profile temperatures at different water depths in West Sumatera retrieved from NOAA as shown in Figures 11-12.

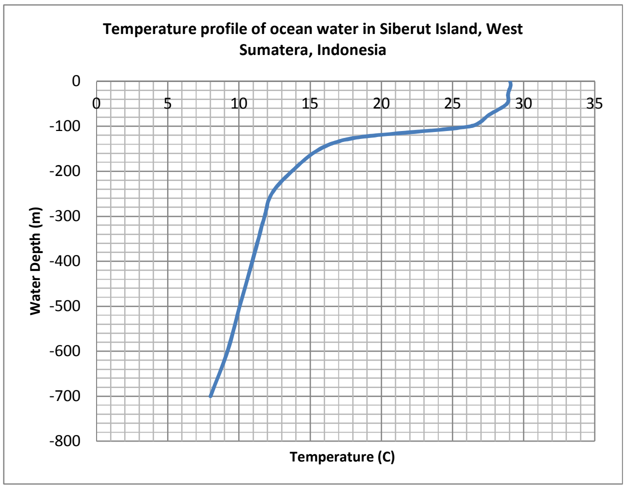

Figure 10: Temperature profile of ocean water in Siberut Island in West Sumatera Indonesia.

Tables 1 - 3 show temperatures on surface and seabed at 700 m water depth, properties ammonia and Carnot efficiency in Siberut Island, West Sumatera, Indonesia.

Table 1: Temperatures on surface and seabed at 700 m water depth in Siberut Island, West Sumatera-Indonesia.

Location	T_{Max}, (^0C)	T_{Min} (^0C)
Siberut island, West Sumatera	29	8.00

Table 2: Properties ammonia in Siberut Island, West Sumatera-Indonesia,

Location	h_1, (kj/kg)	h_2, (kj/kg)	h_3, (kj/kg)	h_4, (kj/kg)
Enthalpy of Ammonia	240	242	1468.2	1400

Table 3: Carnot efficiency of Ideal Rankine Cycle in Siberut Island, West Sumatera-Indonesia.

Parameter	Valus	Unit
Turbine Work (1) W_T	68.2192	(kj/kg)
P_1 (Pressure at the condenser) at T = 8	571.92	kPa
P_2 (Pressure at the boiler) at T = 29	1137.87	kPa
v (specific volume) at T=8	0.001625	m^3/kg
Pump Work (1) W_p	0.919827	(kj/kg)
Q_H (h_3 -h_2)	1226.219	(kj/kg)
Q_L (h_4 -h_1)	1160	(kj/kg)
W_{net} (W_T - W_p)	67.29937	(kj/kg)
$\eta_{thermal}$ (Cycle Efficiency)	5.488	%
η_{carnot} (Carnot Efficiency)	6.950	%

Table 4: Enthalpy and entropy of ammonia saturation.

Parameter	Point 2	Point 4	Unit
Temperature	25	12	°C
Enthalpy (h_f and h_g)	1465.8	237.2	kj/kg
Entropy (s_f)	5.0395	0.9130	kj/kg
P_1 (Pressure at point 1)	1007.63	657.28	kPa
P_4 (Pressure at point 4)	1007.63	657.28	kPa
v specific volume		0.001639	m^3/kg
Enthalpy of vaporization (h_{fg})		1218.005	kj/kg
Entropy (s_g)		5.18926	kj/kg
Entropy of vaporization (s_{fg})		4.2762	kj/kg

Table 5: Efficiency of ammonia saturation in OTEC cycle

Parameter	Values	Unit
mass flow rate of the working fluid	1000	kg/s
The isentropic quality	96.5	%
Enthalpy at point 2.	1412.51	kj/kg
Power output of the turbine (W_T)	53331.87	kW
Power output of the turbine (W_P)	-0.574182	kW
$W_{pump-total}$ (Total pump power input)	574.1816	kW
Enthalpy (h_4)	237.7334	kj/kg
q_h (heat supplied to the heat exchanger)	1228.107	kj/kg
Q_h (specific heat to the heat exchanger)	1228	MW

W_{net} (work output)	51.9	MW
η_{cycle} (Cycle efficiency of amonia saturation)	4.23	%
η_{carnot} (Carnot efficiency of amonia saturation)	4.36	%

Figure 9: Schematic of the OTEC potential in Siberut Island, West Sumatera-Indonesia [Google Map].

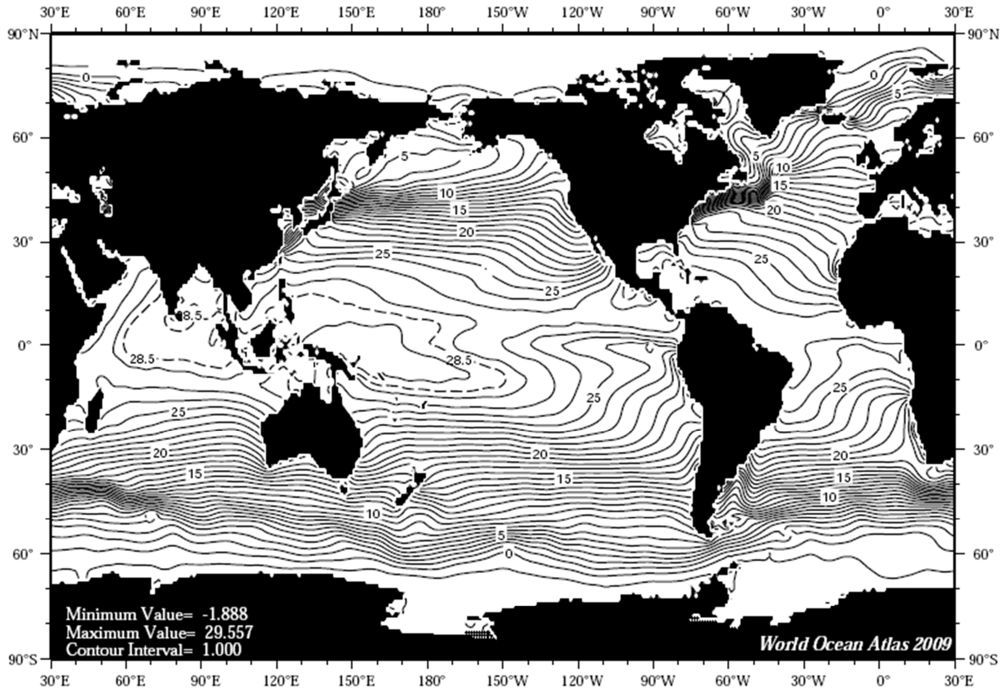

Figure 11: Annual temperature [^{o}C] at the surface [NOAA].

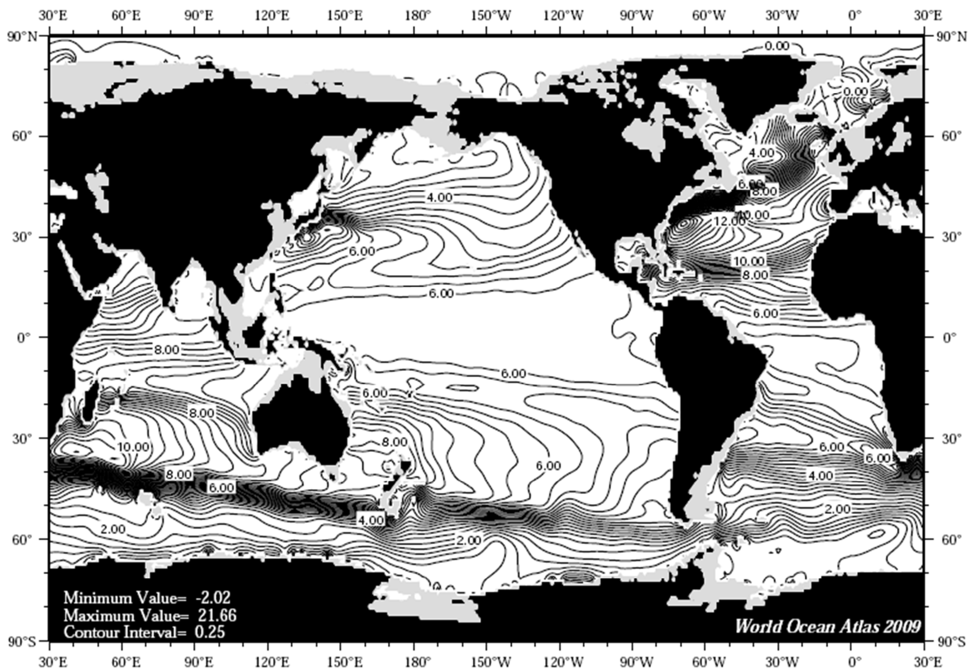

Figure 12: Annual temperature [^{o}C] at 700 m. depth [NOAA].

4.0 CONCLUSION

In conclusion, this paper discussed potential of OTEC in West Sumatera, Indonesia. The results founded that Siberut island, West Sumatera, Indonesia has gradient temperature more than 20 ^{0}C. It means they are suitable to install OTEC.

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REFERENCES

1. A. Fanny Octaviani, B. Muswar Muslim, C. Danny Faturachman, D. Ayom Buwono, 2016, *Study of Ocean Thermal Energy Conversion (OTEC) Generation as Project of Power Plant in West Sumatera-Indonesia*, Vol.10, pp.65-69, International Journal of Systems Applications, Engineering & Development.
2. Bharathan, D, 2011, Staging Rankine Cycles Using Ammonia for OTEC Power Production, *Technical Report, National Renewable Energy Laboratory*, NREL/TP-5500-49121, March 2011, www.nrel.gov/docs/fy11osti/49121.pdf.
3. Jaswar, C. L. Siow, A. Maimun, C. Guedes Soares, 2013, *Estimation of Electrical-Wave Power in Merang Shore, Terengganu, Malaysia*, Jurnal Teknologi, Vol 66, No 2
4. Lewis, A., et al, 2011, *Ocean Energy*, In O. Edenhofer et al. (Eds.) IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, Cambridge, and New York
5. Lockeed Martin (2013), Covenant Lockeed Martin, Reignwood Group, signed on 13April 2013, www.lockheedmartin.co.uk/us/news/press-eleases/2013/october/131030-mst-otec-lockheed-martin-nd-reignwood-group-sign-contract-to-develop-ceanthermal-energy-conversion-power-plant.html.
6. Magesh R, 2010, *OTEC Technology -A World of Clean Energy and Water-*. Proceedings of the World Congress on Engineering 2010, World of Clean Energy and Water, London.
7. Muralidharan, S, 2012, *Assessment of Ocean Thermal Energy Conversion*, MSc thesis System Design and Management Program, Massachusetts Institute of Technology, February.
8. NOAA Atlas NESDIS, *World Ocean Atlas 2009*, Volume 1: Temperature, 2010.
9. OTEC Foundation, http://www.otecfoundation.org/
10. Straatman, P.J.T., and W.G.J.H.M. van Stark, 2008, *A new hybrid ocean thermal energy conversion – Offshore solar pond (OTEC-OSP) design: A cost Optimisation Approach*, Solar Energy, Vol. 82, pp. 520-527.
11. Vega, L.A., 2007, *OTEC Economics*, Offshore Infrastructure Associations, 22 August.