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Potential of Ocean Thermal Energy Conversion in 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 the potential areas of OTEC to be applied in Indonesia. The paper proposed six regions that very high application of OTEC. They are West Sumatera, North Sulawesi, North and South Maluku and North Papua.

KEY WORDS: *Indonesia, Ocean Thermal Conversion Energy.*

NOMENCLATURE

OTEC	Ocean Thermal Energy Conversion
MW	Mega Watt
KRISO	Korea Research Institute of Ships and Ocean Engineering

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 OPEC 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.

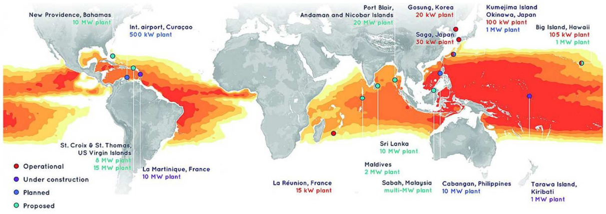

Figure 1: Distribution of the OTEC potential around the world [OTEC Foundation]

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 potential OTEC in 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

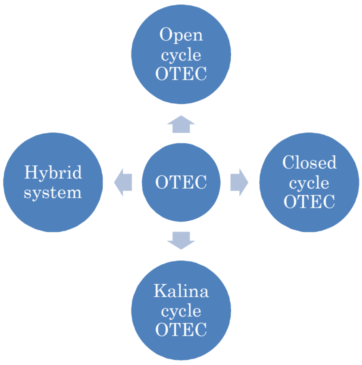

Figure 2: Types of OTEC

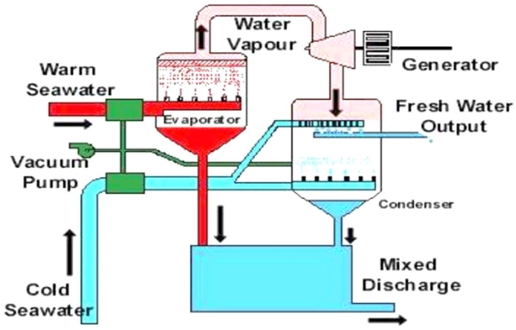

Figure 3: Open cycle OTEC

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).

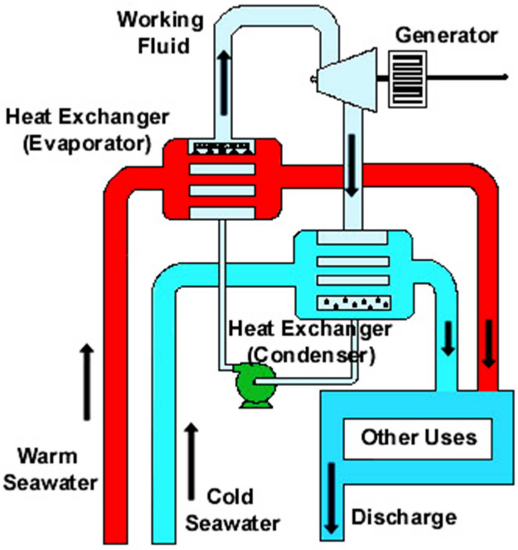

Figure 4: Closed cycle OTEC

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.

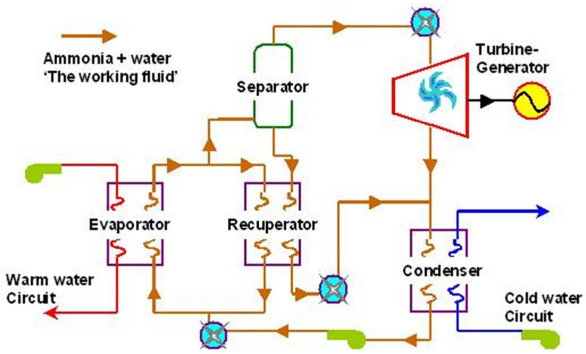

Figure 5: Kalina cycle OTEC

2.1.4 Hybrid OTEC

Hybrid systems combine both the open and closed cycles 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.

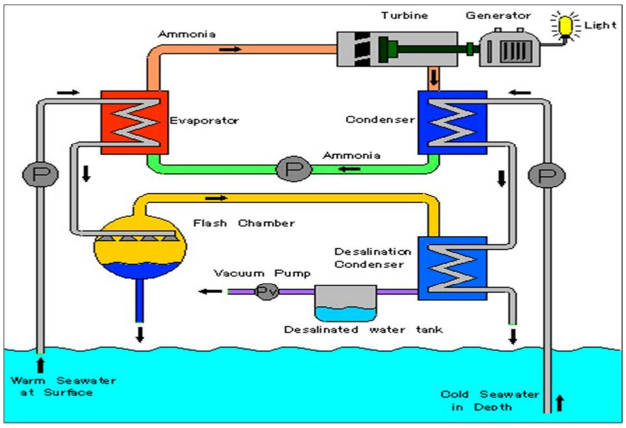

Figure 6: Hybrid OTEC

2.2 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.

$$\eta = \frac{T_{max}-T_{min}}{T_{max}} \qquad (1)$$

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.

2.3 Multi Functionality of OTEC

Besides electricity production, OTEC plants Figure 7 can be used to support air-conditioning, seawater district cooling (SDC), or aquaculture purposes. OTEC plants can also produce fresh water.1 In Open-Cycle OTEC plants, fresh water can be obtained from the evaporated warm seawater after it has passed through the turbine, and in Hybrid-Cycle OTEC plants it can be obtained from the discharged seawater used to condense the vapour fluid.

Another option is to combine power generation with the production of desalinated water. In this case, OTEC power production may be used to provide electricity for a reverse osmosis desalination plant. It is nearly 2.28 million litres of desalinated water can be obtained every day for every megawatt of power generated by a hybrid OTEC system [Magesh, 2010].

The production of fresh water alongside electricity production is particularly relevant for countries with water scarcity and where water is produced by the desalination process. For island nations with a tourism industry, fresh water is also important to support water consumption in the hotels. Based on a case study in the Bahamas, Muralidharan (2012) calculated that an OTEC plant could produce freshwater at a costs of around USD 0.89/kgallon. In comparison, the costs for large scale seawater desalination technologies range from USD 2.6/k gallon to 4.0/ k gallon.

Given that deep seawater is typically free of pathogens and contaminants, whilst being rich in nutrients (nitrogen, phosphates, etc.), land-based systems could further benefit from the possibility of using the deep seawater for parallel applications, such as cooling for buildings and infrastructure, chilled soil, or seawater cooled greenhouses for agriculture, and enhanced aquaculture among other synergetic uses.

Using deep seawater to cool buildings in district cooling configurations can provide a large and efficient possibility for overall electricity reduction in coastal areas, helping to balance the peak demands in electricity as well as the overall energy demand.

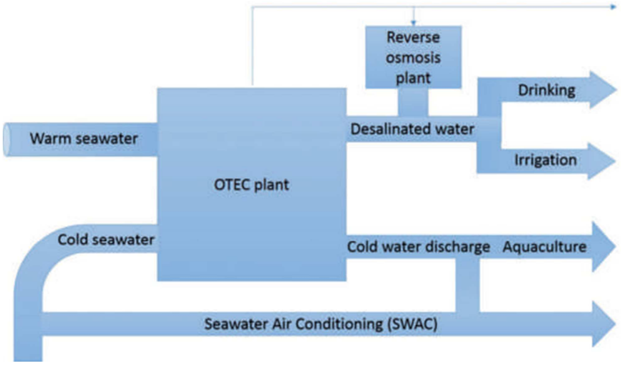

Figure 7: Multi functionality of an OTEC plant

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2.3 Costs and performance

There is limited actual project cost data available for OTEC. Instead, most cost references are based on feasibility studies from a limited number of sources (Lockheed Martin and L.A. Vega). Figure 8 provides an overview of the latest cost projections for a range of OTEC plants.

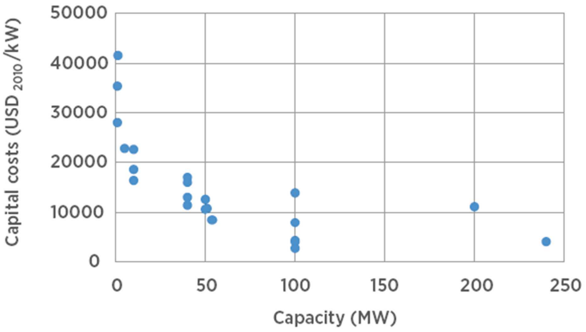

Figure 8: Capital cost estimates for OTEC plants.

The capital costs projections are a function of four parameters. First, the scale of the project has an important impact on the cost projections. Due to the large overhead costs, small scale OTEC plants in the range of 1-10 MW have relatively high installation costs of around USD 16 400–35 400/kW. However, combined with the production of fresh water they become economically viable for small island states or isolated communities (up to 100 000 residents), especially if OTEC resources are within 10 km of the shore (Muralidharan, 2012). OTEC plants in the 10-100 MW range are estimated to cost between USD 15 000/kW and USD 5 000/kW when installed [Muralidharan, 2012; Vega, 2012]. Larger OTEC plants built on moored ships could have costs as low as USD 2 650/kW.

The other parameter is the choice between open and closed cycle designs. Closed cycle designs are estimated to be slightly cheaper than open cycle designs. For example, a comparable feasibility study of a 50 MW OTEC plant design, estimates installation costs of USD 8 430/kW for the closed cycle, and USD 10 751/kW for the open cycle design. However, the open cycle design could produce 120 000 m3 of water per day, which is equivalent to 240 litres per capita for a population of 500 000 residents (Vega, 2010).

A third parameter is the production of by-products. Water can be produced as a by-product, which increases the initial installation costs, but improves the overall economics for regions where fresh drinking water is valued. Also, large scale OTEC plants can be combined with the production of energy-intensive products or energy carriers, like hydrogen, ammonia or methanol. Interestingly, technologies to increase the temperature difference may reduce overall investment costs by reducing the size of the evaporators, condenser units, and heat exchangers [Straatman and Sark, 2008; Lewis, et al., 2011].

A fourth parameter is the environmental conditions at the location where the cold water is extracted. On the one hand, the surface temperature gradient may be more beneficial off the coast, but would require either longer pipes (for an onshore plant) or longer subsea cables (for an offshore plant). According to estimates by Magesh (2010), a 100 MW OTEC plant located 10 km offshore would have capital costs of USD 4 000/kW. Increasing the offshore distance to 100 km or 400 km would increase the capital costs to USD 6 000/kW and USD 12 300/ kW, respectively. On the other hand, extracting cold water closer to the coast could lead to disturbances in the environment for other ocean activities, like tourism and fishing. Other factors to consider are the nature of the seabed, which has an impact on anchor and mooring costs, and the weather conditions that impact the designs of the platform.

The capital costs of an OTEC plant can be broken down into six categories [Muralidharan, 2012]:

1) Platforms,
2) Power generation system,
3) Heat exchangers,
4) Electricity cables,
5) Water ducting systems including the cold water pipes,
6) Deployment and installation processes.

3.0 POTENTIAL OTEC IN 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 and Nias Islands, 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 °C, Figure 10 shows profile temperatures at different water depths in West Sumatera retrieved from NOAA as shown in Figures 11-12.

Table 1: Surface and seabed (700 m) temperatures on several locations in Indonesia.

Location	T_{Max}, (°C)	T_{Min} (°C)	Efficiency (η)
Siberut, West Sumatera	29	8.00	6.9%
North Sulawesi	29	6.00	7.6%
West Papua	29	6.00	7.6%
Morotai Sea	29	6.00	7.6%
South of Maluku	29	7.00	7.3%

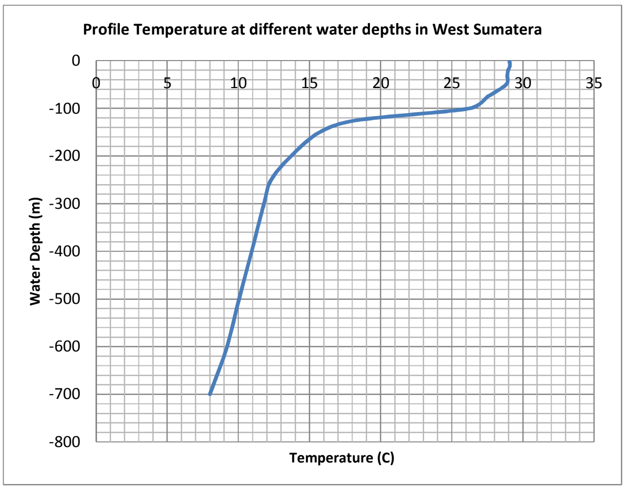

Figure 10: Profile temperature at different water depths in West Sumatera

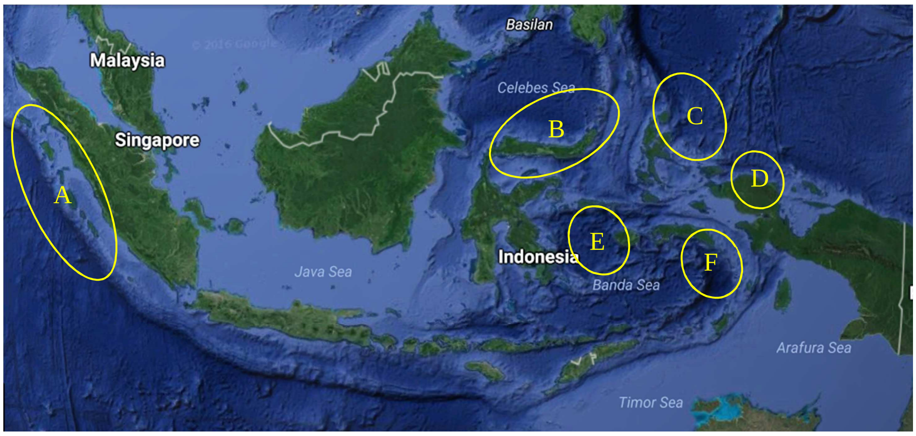

Figure 9: Schematic of the OTEC potential in Indonesia [Google Map].

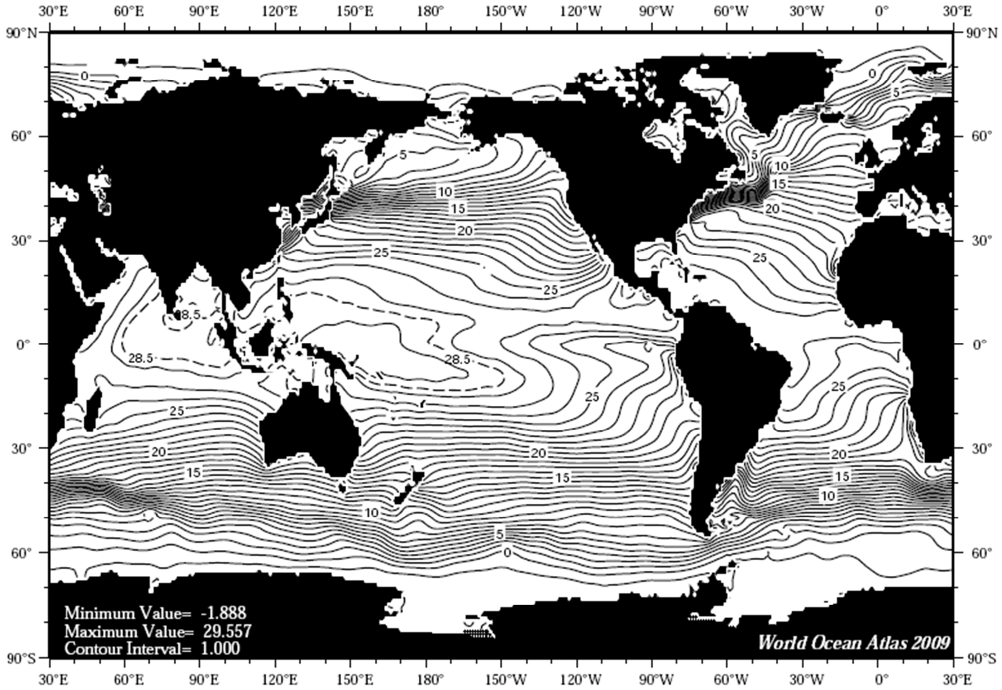

Figure 11: Annual temperature [^{o}C] at the surface [NOAA].

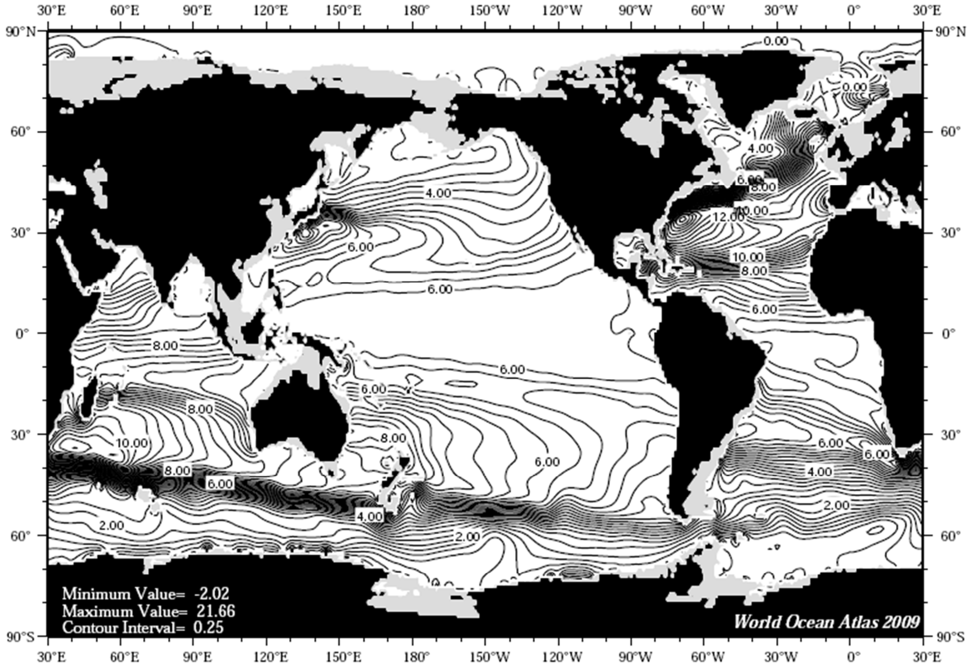

Figure 12: Annual temperature [^{o}C] at 700 m. depth [NOAA].

4.0 CONCLUSION

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

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