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Potential of 100 kW of Ocean Thermal Energy Conversion in Karangkelong, Sulawesi Utara, 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 Karangkelong Sulawesi Utara in Indonesia. The paper found that Karangkelong was high potential for application of OTEC. Electricity and fresh water produced by OEC are cheaper than current price market.

KEY WORDS: *Ocean Thermal Conversion Energy, Karangkelong, Sulawesi Utara, Indonesia,.*

NOMENCLATURE

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

1.0 INTRODUCTION

1.1 Overview

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 turbine to produce electrical energy. The pumping can also be generated using solar and wind energy. This system is called Solar-Wind-Ocean Thermal Energy Conversion (SWOTEC). 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.

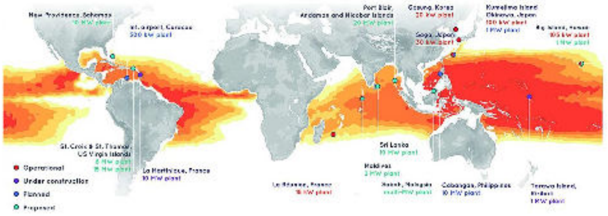


Figure 1: Distribution of the OTEC potential around the world [OTEC Foundation].

1.2 Multi Functionality of OTEC

Besides electricity production, OTEC plants Figure 2 can be used to support air-conditioning, seawater district cooling (SDC), or aquaculture purposes. OTEC plants can also produce fresh water. 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 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 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/ kgallon.

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.

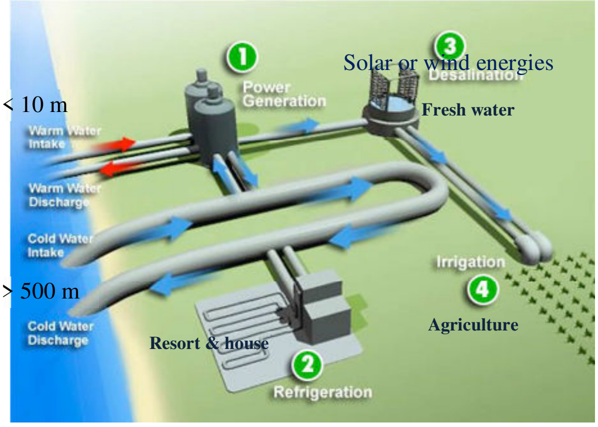


Figure 2: Several advantages of OTEC.

1.3 OTEC in the World

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 as shown in Figure 3. 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 which 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 as shown in Figure 4. Hawaii, US under Makai Ocean Engineering produces 105 kW with grid connected operated since 2015 with the purpose of electricity production as shown in Figure 5.

Figure 3: 30 kW OTEC and Desalination Room, Saga-Japan [IOES]

Figure 4: 100 kW Kumejima OTEC, Japan [Okinawa]

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

Figure 5: The Ocean Energy Research Center in Kailua-Kona, Hawaii [Makai]

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 6 [Jaswar]. 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.

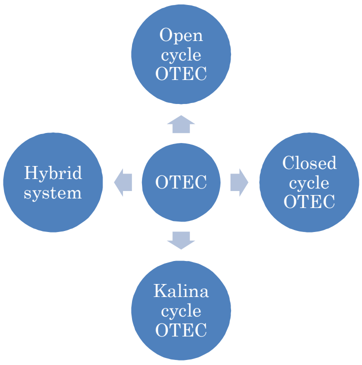


Figure 6: Types of OTEC

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. 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

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).

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. More of the provided heat is taken into the working fluid during evaporation and therefore, more heat can be converted and efficiencies are enhanced.

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. 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.

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 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 7 provides an overview of the latest cost projections for a range of 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.

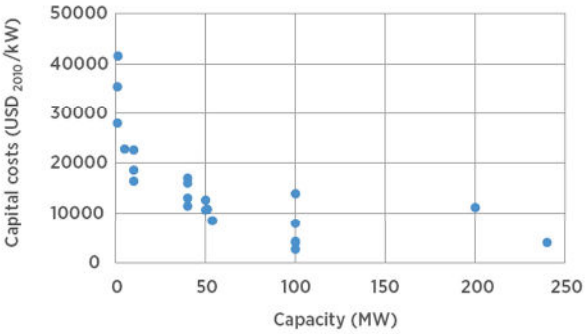


Figure 7: Capital cost estimates for OTEC plants.

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 OTEC IN KARANGKELONG, SULAWESI UTARA, INDONESIA

3.1 Potential OTEC in Indonesia

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 several locations in Indonesia such as Mentawai, Sumatera Barat, North of Sulawesi Utara, North of Maluku Utara and Banda, Maluku as shown in Figure 8.

3.2 Electricity and Clean Water Crisis in the Remote Island

Isolated islands or outermost islands have a variety of specific natural resources, limited, as well as the environmental carrying capacity is limited. In small or outermost islands, both in the West and the East, Indonesia, supplying fresh water in the dry or rainy season and supply of electricity is still a problem difficult and must be addressed by the government. The problem is more complex if the supply of water and electricity associated with integrated regional development plan that includes residential areas, industry, trade, transportation, Hankamnas, and others as shown in Figure 9. Strategic management of remote islands and outermost should be sought so that the water and electricity resources available will not be used beyond the limits of carrying capacity.

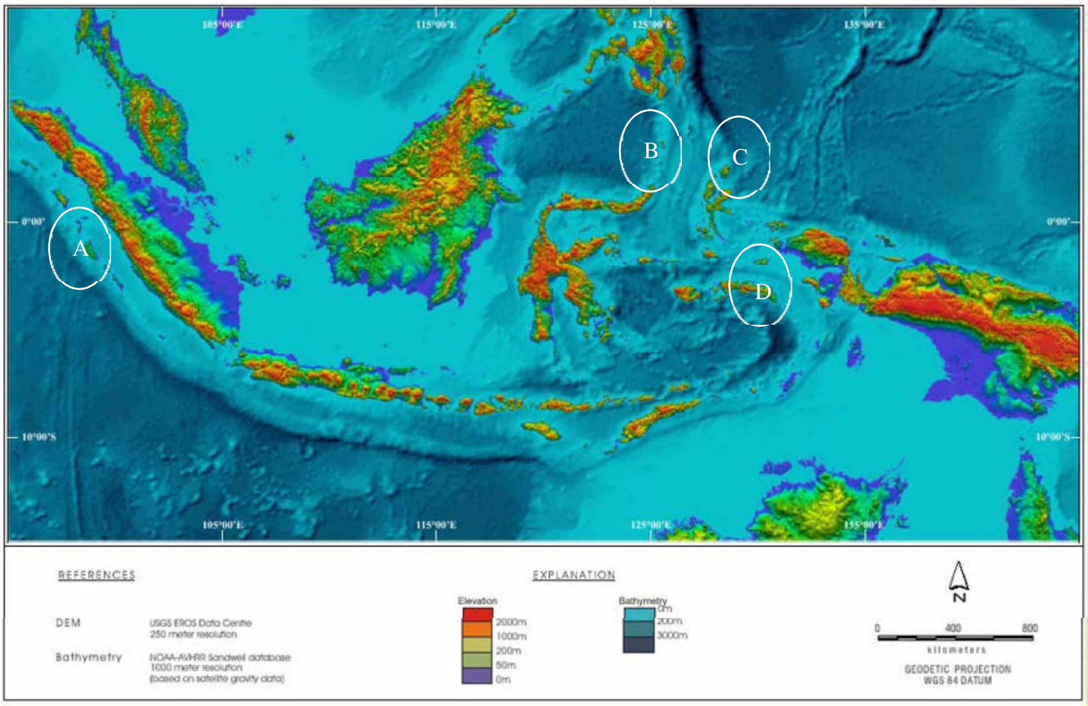


Figure 8: Bathymetry map of Indonesia [NOAA-AVHRR]

Figure 9: Scarcity of clean water and electricity in remote islands or outermost in Indonesia.

3.3 Geography of Karangkelong Island

Talaud region is one of the districts in the province of Sulawesi Utara, Indonesia with a capital city of Melonguane. This region is the most northerly region in eastern Indonesia, borders the Davao del Sur, Philippines. Population of Talaud region at the 2010 census is 83,441 inhabitants. Talaud region is a comprehensive maritime sea around 37,800 km2 which is 95.24% of total area and a land area of 1251 km2.

Talaud tribes inhabit the cluster of islands in the regency Sangir-Talaud, Sulawesi Utara. Their area consists of three main islands, namely Karakelong, Salibabu and Kabaruan. Another name of Talaud is Taloda, meaning "the sea". There was also a call "Porodisa". The main livelihood of these communities is fisher in the sea only small proportions are farmers in the fields or used as a side job. Their main crop is potatoes, even though it should also be given cultivating rice fields and rice paddies.

3.4 Temperature, Salinity and Density Profiles

In 1993, Arlindo Project is a joint oceanographic research endeavor of Indonesia and the United States conducted field measurement of profiles of temperature, salinity and oxygen within the Indonesia seas with CTD equipment and water samples for salinity and oxygen standardization as shown in Figure 11. CTD stands for conductivity, temperature, and depth. Bathymetric map of Sulawesi Utara, Indonesia is shown in Figure 10.

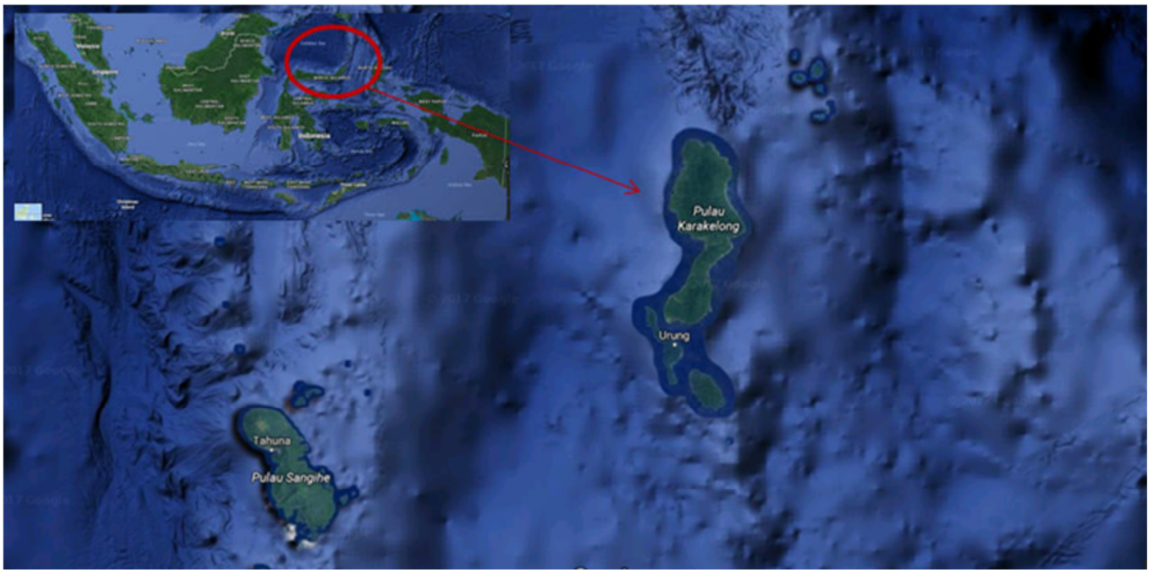


Figure 10: Schematic of the OTEC potential in Karangkelong Island, Sulawesi Utara [Google Map].

Sangihe Ridge stretches with distance from the northeast tip of Sulawesi to the southern tip of Mindanao as shown in Figure 8.3. Sangihe Ritdge divided into three channels are located respectively between 1000 and 1500 m in the north to which it Kawio sill at 5°10'N and two frames on the south end of the ridge: Biaro sill at 2 °00'N and Ulu Siau threshold at 2 300N. Comparison of the stratification from the Sulawesi Sea to the Pacific Ocean side of the ridge indicates that the profile of potential temperature, salinity and oxygen from the opposite side of the ridge deviate from one another with increasing depth at depths deeper than about 1000 m. This shows the limited communication between the bodies of water on both sides of the ridge below 1000 m. Seabed seawater temperature of 3.34 °C and salinity of 34.59 in the Sulawesi Sea near 4500m potentially matches Pacific east value of Sangihe Ridge at a depth of 1350 m. Therefor e, 1350m assigned as depth depth effective threshold in Sangihe Ridge. Bottom water oxygen level in Sulawesi is bit lower, 0.15 ml / l rather than the concentration of oxygen on the Pacific side sill oxygen. Effective this decrease is governed by the basic water residence time in the sea lau Sulawesi. Not enough evidence to determine the threshold is the main line. Seawater entering the sea of Sulawesi does not guarantee spreads in depth into the Flores and Banda Sea, because the Makassar Strait in the southern part Dewakang Sill near 680m inhibited all but the top layer to free communication with Flores Sea.

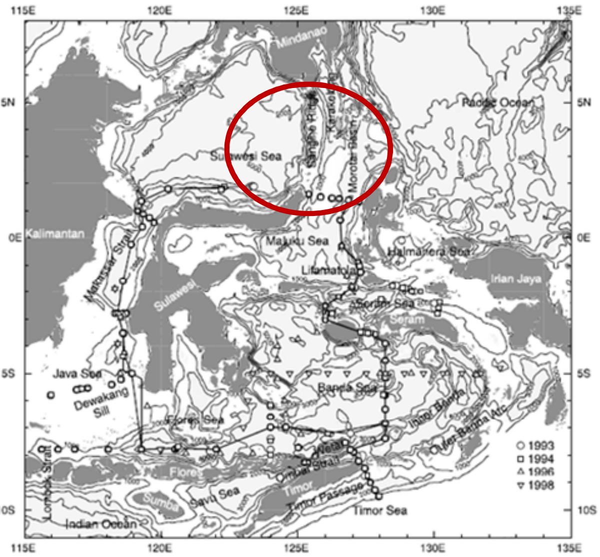


Figure 11: Bathymetric map of Sulawesi Utara, Indonesia [Arnold L].

Differences in the profile which is located in Karakelong Basin between the Sangihe Ridge and Karakelong Ridge (Figure 11: name for the island close to 4°N, 126.6°E; + symbol on Figure 12) was observed below a depth of 1700m as shown in Figure 12. The station in the valley shows the isolation of the open Pacific Ocean below the sill depth effective 2000 m. East of Karakelong Ridge is Morotai Basin leading to the Molucca Sea (see Figure 11; stations denoted with a solid triangle Figure 12) with a sill depth of 2800m effectively separated from the open Pacific Ocean

Figure 13 shows profile of mean monthly temperature on surface and deep water in Sulawesi Utara, Based on the figure the average value of surface temperature in the Sulawesi Utara was 29.22 °C, the temperature at 500 meter depth was 6.44 °C and difference temperature between surface and deep sea was 22.78 °C.

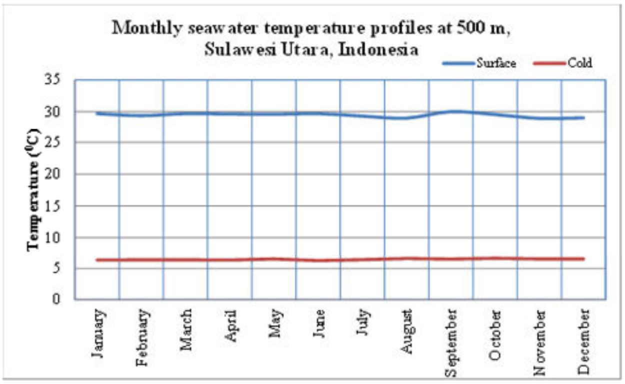


Figure 13: Mean monthly surface and deep seawater temperature profile in Sulawesi Utara-Indonesia.

3.5 Results and Discussion

In the study, the performance was simulated using Subsea Pro as shown in the Figure 8.5. The software was developed by Ocean and Aerospace Research Institute, Indonesia. The simulation was based on following assumptions:

- Surface temperature inlet was assumed 28 °C (the lowest surface temperature in Indonesia) and the temperature outlet was setup 25 °C.
- The evaporation and condensation ammonia pressures rose and decreased were assumed 0.06 bar.
- The surface and deep seawater pressures decreased were assumed 0.3 and 0.72 bar respectively.
- The evaporation and condensation ammonia temperatures were set up 25 and 8 0C
- The outlet surface and deep sea water temperatures were set up 25and 9 0C
- Turbine and generator efficiencies were assumed 75 and 94 %, respectively
- Working fluid was using pure ammonia
- Depth of inlet sea water was 700 meter.

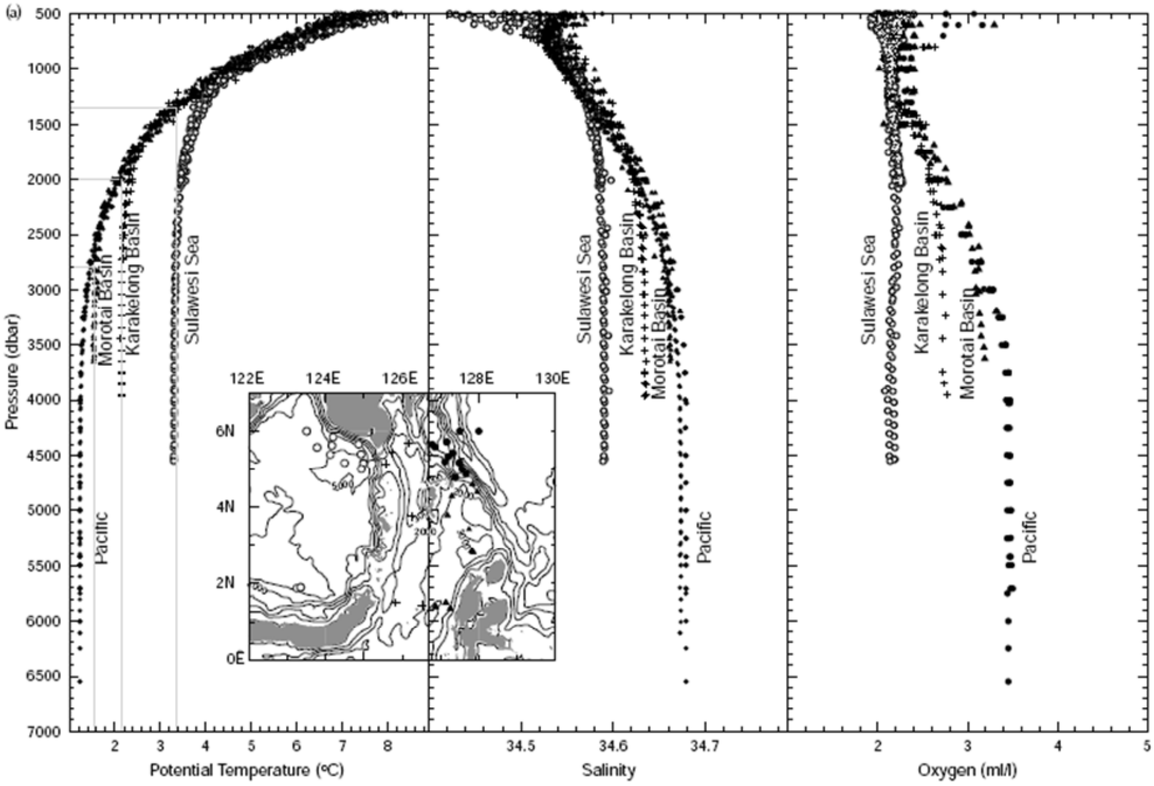


Figure 12: Temperature, salinity and oxygen profiles defining the controlling sill depths between the northern Indonesian Seas (open symbols) and Pacific Ocean (solid symbols) based on Arlindo data and archived regional data (Conkright et al., 1998): Sangihe Ridge, sill depth of 1350 m [Arnold L].

Figure 13: Subsea Pro Simulation Software

In the simulation, the principal components are the heat evaporator, condenser, turbine and generator, and seawater supply system. They did not included ancillary devices such as separators to remove residual liquid downstream of the evaporator and subsystems to hold and supply working fluid lost through leaks or contamination.

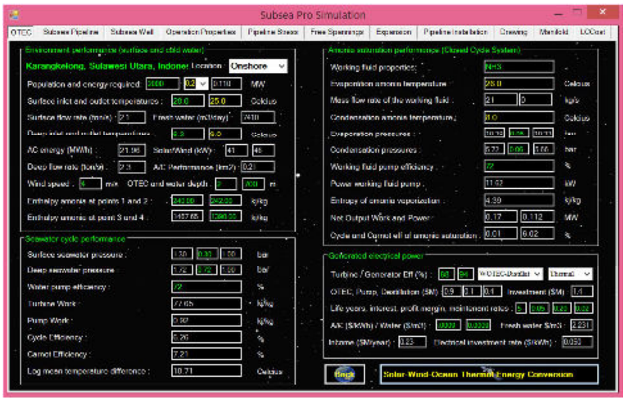
Figure 14 shows results of simulation for 100 kW of Net Output Power (NOP) in Karangkelong, Sulawesi Utara in Indonesia. In the simulation, the inlet surface and deep sea water temperatures are 28 and 6.2 0C, respectively. Heat transfer from high temperature occurs in the evaporator, producing saturated ammonia. The hot water is required 46 kW to pumped from surface seawater. Electricity is generated when this ammonia gas expands to lower pressure through the turbine. Latent heat is transferred from the vapor to the low temperature from deep sea water in the condenser and the resulting liquid is pressurized with a pump with 51 kW from wind energy. The low temperature of ammonia is pumped with 62 kW from solar energy

The results simulation shows that the suitable mass flow rate of the working fluid is 21 kg/sec. The surface and deep seawater flow rates were founded 2100 and 2300 kg/sec. The simulation shows several founding as follow:

- Long Mean Temperature Difference (LMTD) is 18.71
- Investment for generating electrical power is 0.042 $/kWh
- The OTEC system can produce 0.21 km2 of green-house cooling system
- The system can produce 7400 m3 per day of fresh water

for drink after distillation.

- The system can also produce 2300 kg per second seawater which can be used for fish farming.
- The Carnot efficiency of ammonia saturation is 6 percent
- The cycle efficiency of ammonia saturation is 0.17 percent



Environment performance (surface and cold water)
Karangkelong, Sulawesi Utara, Indone Location: Onshore
Population and energy required: 2000 0.2 0.110 MW
Surface inlet and outlet temperatures: 28.0 25.0 Celcius
Surface flow rate (ton/s): 2.1 Fresh water (m3/day): 7410
Deep inlet and outlet temperatures: [illegible] 8.0 Celcius
AC energy (MWh): 21.96 Solar/Wind (kW): 41 46
Deep flow rate (ton/s): 2.3 A/C Performance (km2): 0.21
Wind speed: 4 m/s OTEC and water depth: 2 700 m
Enthalpy amonia at points 1 and 2: 243.00 242.00 kj/kg
Enthalpy amonia at point 3 and 4: 1457.65 1280.00 kj/kg

Seawater cycle performance
Surface seawater pressure: 1.30 0.31 1.00 bar
Deep seawater pressure: 1.72 2.72 1.00 bar
Water pump efficiency: 72 %
Turbine Work: 77.65 kj/kg
Pump Work: 0.92 kj/kg
Cycle Efficiency: 6.26 %
Carnot Efficiency: 7.21 %
Log mean temperature difference: 10.71 Celcius

Amonia saturation performance (Closed Cycle System)
Working fluid properties: NH3
Evaporation amonia temperature: 28.0 Celcius
Mass flow rate of the working fluid: 21 0 kg/s
Condensation amonia temperature: 8.0 Celcius
Evaporation pressures: [illegible] [illegible] [illegible] bar
Condensation pressures: 6.72 0.06 1.06 bar
Working fluid pump efficiency: 72 %
Power working fluid pump: 11.62 kW
Entropy of amonia vaporization: 4.39 kj/kg
Net Output Work and Power: 0.17 0.112 MW
Cycle and Carnot eff of amonia saturation: 0.01 6.02 %

Generated electrical power
Turbine / Generator Eff (%): 88 94 [illegible] Thermal
OTEC, Pump, Destillation ($M): 0.9 2.1 0.1 Investment ($M): 1.4
Life years, interest, profit margin, maintainment rates: 5 0.05 0.20 0.02
A/C ($/kWh) / Water ($/m3): [illegible] [illegible] Fresh water $/m3: 2.231
Income ($M/year): 0.23 Electrical investment rate ($/kWh): 0.050

Figure 14: OTEC simulation results in Karangkelong, Sulawesi Utara Indonesia.

The electricity tariff generated from OTEC is lower than current PLN’s rate as shown in Figure 15 due to return value from waste surface and deep seawater used for fresh water and cooling system. It is clear to picture that the OTEC system will save million USD national economic impact compared using diesel energy. The OTEC system is more sustainable because the energy resource is taken from seawater surrounding the electric station.

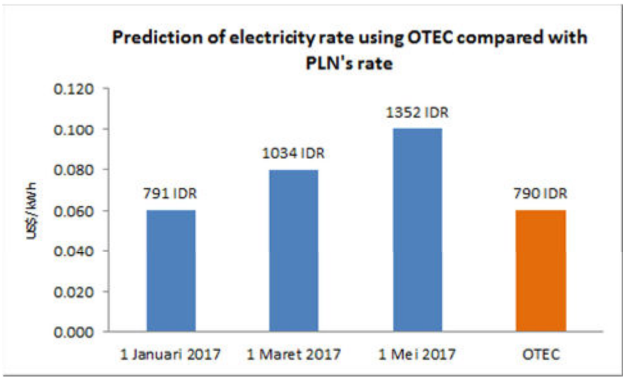


Figure 15: Electricity rate using OTEC compared with PLN’s rate.

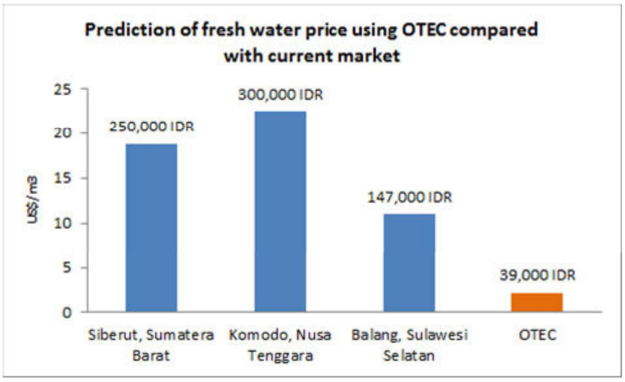


Figure 16: Fresh water price using OTEC compared with current market.

4.0 CONCLUSION

In conclusion, this paper discussed potential of OTEC in Karangkelong, Sulawesi Utara in Indonesia. In the study, closed cycle OTEC was proposed. The simulation results founded that Karangkelong was high potential for OTEC due to gradient temperature more than 20 ^{0}C. It means they are suitable to install OTEC. The electricity and fresh water produced using OTEC are lower than current market prices

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