

surrounding the plant can be used for aquaculture as shown in Figure 2. Hydrogen produced by subjecting the steam to electrolysis during the SWOTEC process can fuel hybrid automobiles, provided hydrogen can be transported economically to sea shore. Another undeveloped opportunity is the potential to mine ocean water for its 57 elements contained in salts and other forms and dissolved in solution. The initial capital cost of SWOTEC power station would look high, but an SWOTEC plant would not involve the waste treatment or astronomical decommissioning costs of a nuclear facility. Also, it would offset its expense through the sale of the desalinated water.

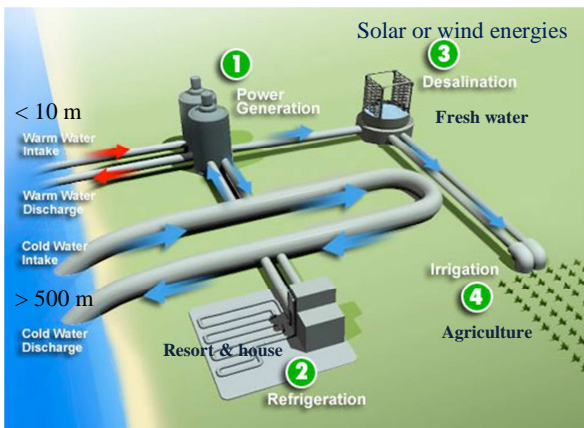


Figure 2: Several advantages of SOWTEC.

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]



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

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, Cabangon, 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, SWOTEC 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 SWOTEC 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 6.

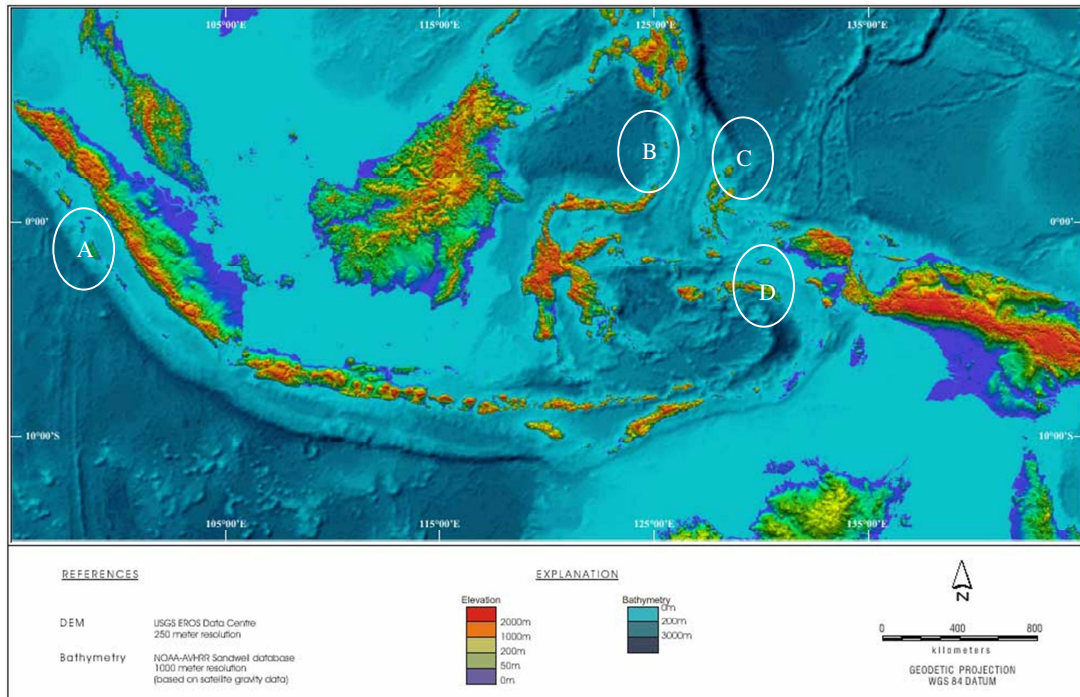


Figure 6: Bathymetry map of Indonesia [NOAA-AVHRR]

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 desalinated 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 which are open, closed, kalina and hybrid cycles as shown in Figure.2 [Jaswar, et.al]. 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.

2.2 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 °C.

The efficiency of the cycle can be calculated

$$\eta_{Cycle} = \frac{W_{net}}{Q_H} \quad (2)$$

where; W_{net} is work output and Q_h is specific heat to the heat exchanger.

3.0 OTEC IN MENTAWAI ISLAND, SUMATERA BARAT, INDONESIA

3.1 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 7. 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.

3.2 Overview of Mentawai Island

The Mentawai Islands are a chain of about seventy islands and islets off the western coast of Sumatra in Indonesia. The Mentawai islands with population 76,421 people are approximately 150 km from shoreline of Sumatra Barat as shown in Figure 8. The indigenous inhabitants of the islands are known as the Mentawai people. Mentawai Island has a hot and humid tropical rainforest climate, with an annual rainfall of 4,000 mm with temperatures range 22 - 31 °C and humidity averages 81-85%. Siberut is the largest and northernmost of the Mentawai Islands, lying 150 km 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 km² with population 35,091 people. Other major islands are Sipura, North Pagai and South Pagai.



Figure 7: Scarcity of clean water and electricity in remote islands or outermost in Indonesia.

3.3 Surface Seawater Temperature

The Sea Surface Temperature (SST) patterns over the Mentawai region clearly demonstrate the effect of the monsoons cycle as shown in Figure 9. The surface temperatures are influenced by the Southwest and Northeast monsoons. The SST increase from January to reach the maximum on May with 31 °C before down to the minimum at 28 °C. The average SST is at 29.8 °C.

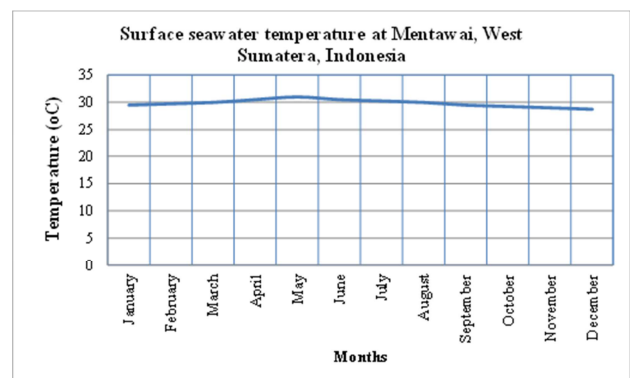


Figure 9: Mean monthly surface seawater temperature in Mentawai Islands, Sumatera Barat-Indonesia.

3.4 Surface Seawater Temperature

Figure 10 shows profile temperatures at different water depths in Sumatera Barat retrieved from NOAA. The temperature profiles

show a pronounced thermocline between 100 and 125 m with an almost homogeneous upper layer. At some stations off the west

coast, temperatures below 10 C were measured deeper than 400 meters.

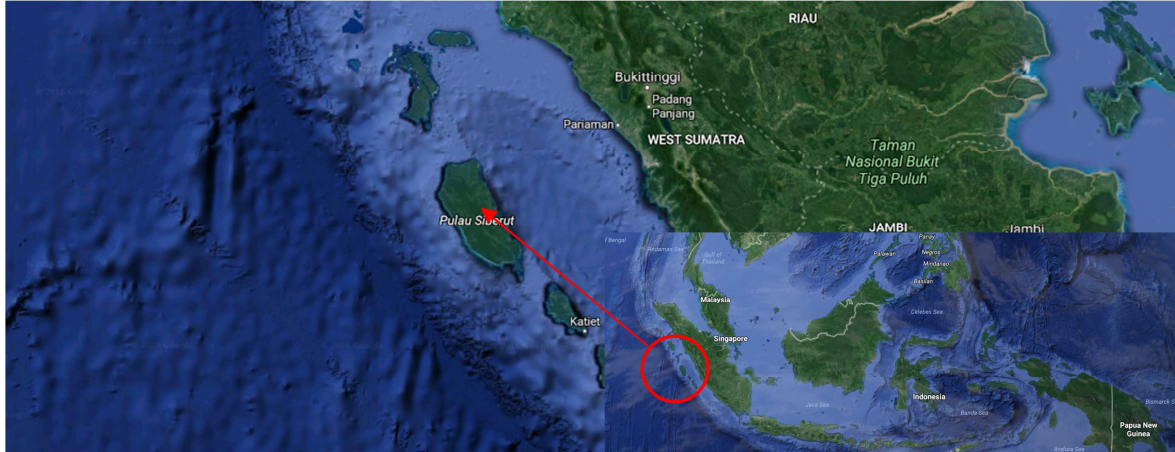


Figure 8: Schematic of the OTEC potential in Siberut Island, Sumatera Barat-Indonesia [Google Map].

The salinity profiles show the same tendency as the temperature, although a sharp boundary layer is not so pronounced. The profiles from the hydrographic section extending north on the west side of Breueh Island show some distinct differences at the two sides of the underwater ridge. On the northern side the 35 per mille isohaline is found at about 250 m while 35 per mille salinity is found below 150 m at the southern stations [FAO]. The discontinuity found in the profiles may reflect the strong currents in this area. Strong currents were as well observed visually at the surface.

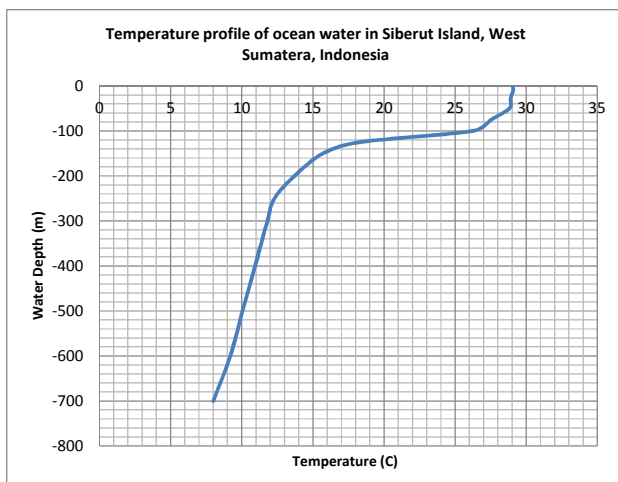


Figure 10: Temperature profile of ocean water in Siberut Island in Sumatera Barat-Indonesia.

The oxygen profiles show a distinct difference between the different sections. While the oxygen content decreases to be under 1 ml O₂ per litre below the thermocline north and north-east of Sumatra, the deep waters (down to 500 meters) off the west coast contain more than 1 ml oxygen per liter [FAO].

3.5 SWOTEC Closed System in Mentawai

In the study, the performance was simulated using Subsea Pro as shown in the Figure 11. The software was developed by Ocean and Aerospace Research Institute, Indonesia. The simulation was based on following assumptions:

- Surface temperature inlet was assumed 28 0C (the lowest surface temperature in Indonesia) and the temperature outlet was setup 25 0C.
- 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 25 and 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.
- The inlet surface and deep sea water temperatures are 28 and 6.2 0C, respective

Figure 12 shows a simplified schematic diagram of a 2 MW plant closed cycle SWOTEC system. The principal components are the heat evaporator, condenser, turbine and generator, and seawater supply system. The figure 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.

Heat transfer from high temperature occurs in the evaporator, producing saturated ammonia. The hot water is required 117 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 130 kW from wind energy. The low

temperature of ammonia is pumped with 33 kW from solar energy.

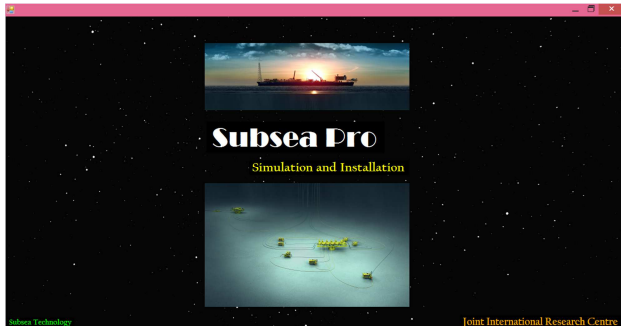


Figure 11: Subsea Pro Simulation Software.

Figure 13 show simulation results of OTEC performance to generate 2 MW plant of electrical power in Mentawai, Sumatera Barat-Indonesia. In the simulation, the inlet surface and deep sea water temperatures are 28 and 6.2 0C, respectively. The results simulation shows that the suitable mass flow rate of the working fluid is 72 kg/sec. The surface and deep seawater flow rates were founded 6000 and 6600 kg/sec. The simulation shows several founding as follow:

- Long Mean Temperature Difference (LMTD) is 18.75
- Investment for generating electrical power is 0.314 \$/kWh
- The SWOTEC system can produce 7.0 km2 of green-house cooling system
- The system can produce 8730 m3 per day of fresh water for drink after distillation.
- The system can also produce 13000 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 0.41 percent

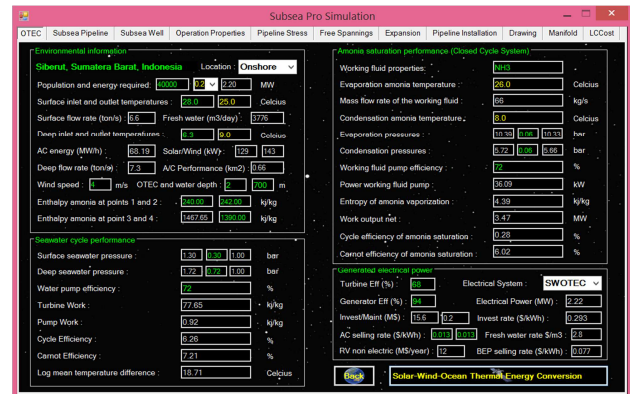


Figure 13: OTEC simulation results in Mentawai, Sumatera Barat.

SWOTEC is not only benefit to the needs of the population in the Mentawai islands, Indonesia, but the SWOTEC can also provide a major economic impact through affordable prices or more cheaper than the price in the field right now. For electricity, the prediction using SWOTEC in electricity rates remote islands and outermost Indonesia is cheaper than the rate of Perusahaan Listrik Negara (PLN) as shown in Figure 14. Prediction price of clean water using SWOTEC is also much cheaper than the price of the field at this time as shown in Figure 15.

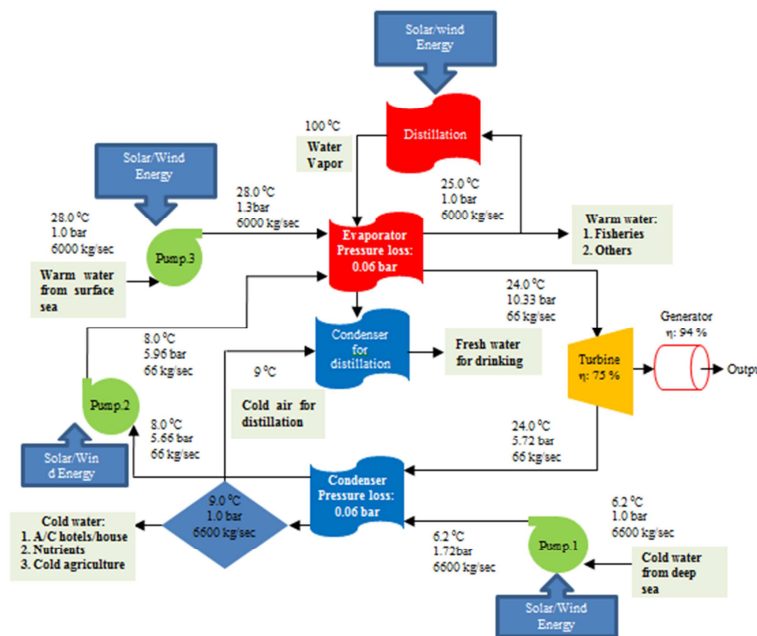


Figure 12: Detailed flow conditions for a single-stage 2 MW plant in Mentawai, Sumatera Barat-Indonesia.

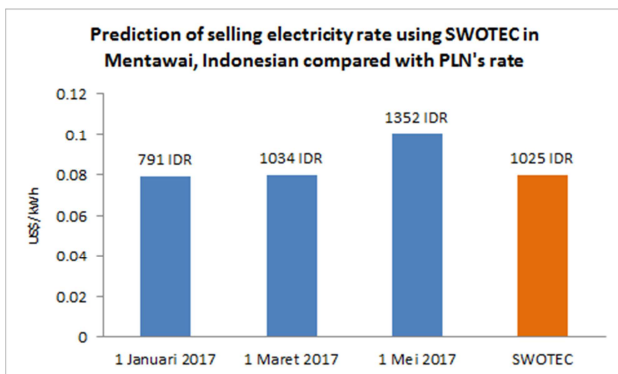


Figure 14: Electricity rate using SWOTEC compared with rate of Perusahaan Listrik Negara (PLN) in Mentawai, Sumatera Barat.

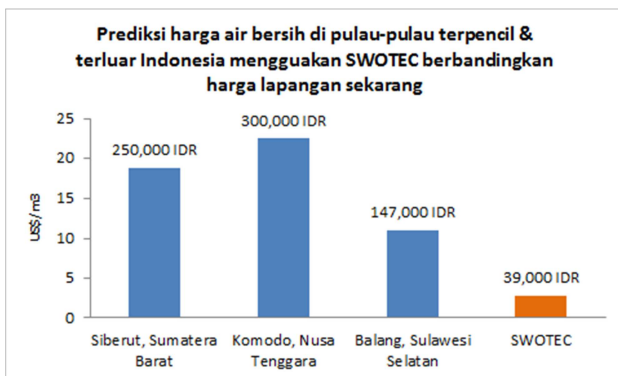


Figure 15: Electricity rate using SWOTEC compared with rate of Perusahaan Listrik Negara (PLN) in Mentawai, Sumatera Barat, Indonesia

4.0 CONCLUSION

In conclusion, this paper discussed potential of SWOTEC in Mentawai, Sumatera Barat, Indonesia. The results founded that Siberut island, Sumatera Barat, Indonesia has gradient temperature more than 20 °C. It means they are suitable to install SWOTEC. SWOTEC technology is high potential to be applied in the islands due to giving lower electricity and fresh water rates compared with current rate.

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