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Offshore Ocean Thermal Energy Conversion in Layang-Layang Island, Sabah-Malaysia

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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 Malaysia is an equatorial country located at latitudes less than 20 degrees covered by ocean, many islands, strain and many difference of topography, OTEC is very compatible build in Malaysia. This paper discussed the potential areas of OTEC to be applied in Layang-Layang Island, Sabah in Malaysia. The paper found that Layang-Layang Island was high potential for application of OTEC. Using site measurement data, 4 MW electricity generated by OTEC was simulated as a case study.

KEY WORDS: *Ocean Thermal Conversion Energy; Offshore; Layang-Layang Island; Sabah.*

NOMENCLATURE

OTEC	Ocean Thermal Energy Conversion
GIS	Geographic Information System
SWOTEC	Solar-Wind-Ocean Thermal Energy Conversion

1.0 INTRODUCTION

Oceans potentially have been utilized as s source of virtually inexhaustible renewable energy as it covered almost seventy percent of the world. Ocean Thermal Energy Conversion (OTEC) is a clean marine renewable and alternative energy technology which converts the temperature difference between the warmer surface water and the deep cold ocean water into electrical energy. According to Vega (2003), the absorption of energy by the sea is equal to 4000 times the amount presently utilized by humans. The sun continuously warms the surface ocean layer than the deep ocean layer, thus creating the temperature gradient or thermal energy. These temperature gradients primarily occur in equatorial countries.

OTEC harnessed the warm water surface heated by sunlight to vaporize the working fluid such as ammonia which has lower boiling point to rotate the turbine coupled to generator in order to generate electricity. Due to its capability to generate electricity day and night throughout the year, OTEC is compatible to build in order to provide base-load power continuously around the tropical and subtropical countries especially for the countries near the equator.

In Asian countries, Indonesia and Philippines have their own strategies on applying this promising renewable technology. The potential of OTEC in Indonesia is very large due to availability of deep ocean (Koto et.al, 2016) meanwhile Philippines had passed the Renewable Energy Act of 2008, aimed to harness first ocean energy facility. In line with this deployment of OTEC, Bakar (2009) clearly stated that Malaysia is one of the countries that having potential of this renewable energy harnessing it as an alternative source for stabilizing its grid system. Malaysia also was among 98 Country listed for OTEC development which include fresh water production (Vega 1992).

Malaysia is situated in the south east part of Asia which also situated at 2’30’ North latitude and 112’30’ East longitude in the global map. Malaysia has a land area of 334556 km2 comprising with two medium regions, Peninsular Malaysia and the States of Sabah and Sarawak.

As one of the tropical country, Malaysia has tropical weather which is influenced by monsoonal climate. As a result, Malaysia has a hot summer and high humidity level. Besides, the monsoon comes twice a year. On top of that, Malaysia also has about 1007 islands located in its coastal waters which 544 are located in Peninsular Malaysia, 397 in Sabah and 66 in Sarawak

According to UTM OTEC Centre, a friendly sustainable energy source that capable of providing base-load power without affecting the surrounding environment, regardless of seasonal weather conditions, for providing electricity to Malaysia does not exist. Thus, by creating this OTEC technology, the limitation of the energy issues within the regions with water and electricity scarcity can be solved immediately. However, the design of an OTEC plant may require some preparation and also face outstanding challenges due to its cost and suitable location (Koto, 2017).

Recently, UTM OTEC Centre be given a concession under the relevant laws of Malaysian waters, in order to pioneer OTEC development with an allocation for R&D and Commercialization Grant of RM 18 million plus USD 40 million of commercial-demo 4 MW OTEC plant off Pulau Layang-Layang, aimed to attract further investments by deep-water oil and gas industry (Bakar, 2013). However, the design of OTEC plant has not been developed yet and is still under investigation and research on sea water temperature profile. Hence, the thesis focus on potential of Ocean Thermal Energy Conversion (OTEC) in Malaysian seawater

2.0 MULTI FUNCTIONALITY OF OTEC

2.1. History of OTEC

The first concept of OTEC was proposed by D'Arsonval in 1881 which applied the basic thermodynamic Rankine cycle using the closed-cycle concept with ammonia as the working fluid (LAVI, 1980). After that, former student of D'Arsonval and also a French engineer, Georges Claude, demonstrated the feasibility of this concept in 1928 in Ougree-Marhaye in Belgium by harnessing the warm water at 30C from a steel plant for the evaporator and cold water at 10C from the Meuse River as the condensing fluid (Hilbertanderson, 1985). The test was successfully operated and achieved turbine speeds of 5000 rpm and delivered the power output of 50 kW. In 1930, Claude conducted an OTEC project 1600m off the shore of Mantazas bay in Cuba after get financial support. This project aim to delivered 50kW but the land based operated only for 11 days before it’s cold water pipe destroyed by the storm (Avery, 1994).

In 1940, Claude proposed to the French government to build a 40MW plant at Abidjan, Ivory Coast but the project operated slowly until 1948 when the government established the company "Energie de Mer" with purpose to develop the concept. Unfortunately, this project was dissolved in favor of a large hydro-electric plant in Abidjan. From that time, the French government shows no interest in the technology (Takahashi et.al, 2010). Subsequently, OTEC research and deployment fell off after the World War II since there was no commercial activity in OTEC until the late 1970s when the Dillingham Corporation, Lockheed Corporation and Hawaii State government successfully completed an at-sea test of the OTEC system called “Mini-OTEC” in August 1978. The system successfully generated a net of 18 kW for 3 months before its planned terminated (Uehara, 1995).

In 1980 – 1981, the deployment of OTEC came with the experimental OTEC-l project at Kalua-Kona, Hawaii. This project was conducted by the US Department of Energy program aboard a modified T-2 tanker, Chepachet which served as a floating platform. The turbine-generator was not installed in this platform as it was not built to provide electrical power; rather, it was designed as a platform to test various OTEC-related technologies such as the platform, cold water pipe, the mooring systems, energy transfer systems and heat exchangers. Even though it was shutdown in May 1981 due to funding restrictions, OTEC-1 successfully reached several milestones. It success to deploy of a 670 meter long cold water pipe, mooring in 1370 m of water, success in operation of the cold water pipe during wind, wave and current changes, operate in a shell-and-tube heat exchanger in a closed ammonia cycle at 38MW heat duty and demonstration of bio-fouling control with low-level chlorine injection.

In 1980, OTEC experiment off the coast of Shimane was conducted by Saga University. After that, a 100 kW gross power land-based plant was built in the republic of Nauru in 1981-1982 (Kamogawa, 1980). The programs aimed to improve the OTEC design with information on advanced materials, design methods and processes. In 1986, the oil price suddenly dropped. There was a cut back in financial support of OTEC projects. However, the studies and experiments of the project were still continued all over the world until the OTEC in island of Hawaii successfully operated from 1993 to 1998 and delivered the power output of 103kW. This 103kW were still the world record for the OTEC output (Vega, 2002). Since then, the results from the experimental projects will assist the frame work of commercially scaling up OTEC systems. Most experimental works in a closed Rankine cycle have focused on working fluid, ammonia (except for Nauru, 1981 where Freon was used due to its thermal characteristics).

Lately, the United Stated Department of Energy (DOE) spend a $1.2 million contract to design and fabricate the special cold water pipe, to demonstrate transferring large volumes of seawater for commercial-sized of OTEC plants. After that, in 2009, a Two Grants worth $1 million was awarded to Lockheed Martin. Firstly, the purposes of the grant was to develop a Geographic Information System (GIS)-based tool to estimate the energy that can be extracted from OTEC and identify suitable locations for OTEC and seawater air-conditioning. Besides, the second grant was to conduct the study life-cycle costs in order to demonstrate economic feasibility of utility-scale OTEC systems.

2.2. Benefits of OTEC

OTEC technology has been revived through technological capabilities and updates and it is not a new concept, making harnessing the temperature differential of the ocean water (Boehlert et.al, 2008). OTEC can provide more energy than the combination of the waves and wind energy (Spellman, 2014). A thermodynamic working fluid were use (e.g. Ammonia or Freon) in a completely closed system where warmer surface water used to evaporate the liquid meanwhile cold deep ocean water condensed the fluid (Idris et.al, 2014). According to Rani et.al (2017), the principle of the OTEC system functions to generate

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electricity from converting power derived from the movement of a turbine coupled to generator that is linked and solely powered by a working fluid

Koto (2017) stated that the potential of OTEC plants to provide not only the clean and sustainable renewable energy but also offers the fresh water desalination, possibility of supporting building air-conditioning system, refrigeration system or agriculture which can be listed as:

2.2.1. Fresh water desalination

According to Balaikumar (2015), desalination process can be done via OTEC technology which the fresh water can be fashioned in open-cycle OTEC plants when the warm water is vaporized to turn the low pressure turbine. The water vapor is summarized to make fresh water after the energy was produced. Magesh (2010) explained that the hybrid OTEC system is capable to generate nearly 2.28 million litres of desalinated water every day for every megawatt of power. Besides, the production of electricity and fresh water at the same time will give benefit for countries which water scarcity (Koto et.al, 2017).

2.2.2. Air conditioning and refrigeration

Koto (2017) stated that the deepwater from OTEC plant can assist to cool buildings in district cooling configuration and provide a large and efficient possibility for overall electricity reduction in coastal regions, helping to balance the peak demand in electricity as well as overall energy demands. According to Muralidharan (2012), the cold, deep sea water can be used to maintain cold storage spaces, and to provide air conditioning. A new deep seawater utilization test facility in Okinawa also employs cold seawater air conditioning. Similar small-scale operations would be viable in other locales. Economic studies have been performed for larger metropolitan and resort applications.

2.2.3. Marine Culture

Muralidharan (2012) clearly stated that marine food production is a potential by-product of OTEC power plants. With the alarming loss of topsoil throughout the world our agricultural production will not be able to keep up with increase in demand. Hence, ocean may well become our most important source of food, even more important than the power generated. The ocean is the one of the greatest potential source of food and OTEC might just be the answer for producing more food.

2.4. OTEC as an energy carrier

OTEC economic viability can be improved by producing energy-intensive products (Muralidharan, 2012). In this case, the production or transmission of electricity on land was not required. The electrolysis of sodium chloride water solution give the three benefit products as they are high-demand throughout the world which are Caustic soda, Chlorine and Hydrogen. Other products of OTEC process are oxygen, nitrogen and carbon dioxide. The oxygen dissolved in sea-water is almost 34% of the gases.

This means that during the water desalination process, the gases removed contain a higher percentage of oxygen than normal air. It can become a convenient source for a gas separation plant which can produce carbon dioxide, oxygen and nitrogen. The oxygen separation process more efficient, since power is conveniently available for this process and cold water is also available. Therefore, OTEC can become an excellent source for these valuable gases.

3.0 OTEC PROGRESS AROUND THE WORLD

According to the study conducted by United Stated Department of Energy (DOE) in 1981, ninety-eight nations and territories with access to the OTEC thermal resource were identified. These sites have 20℃ temperature difference between surface water and deep ocean water. Besides, the thermal resource for countries in the Caribbean and the Pacific is available throughout the year round and their deep ocean water is relatively close to the shore. They also can support land-based, shelf-mounted or moored platform designs as it can be the most attractive sites for cost effective commercial OTEC plants. The technology can be viable if the appropriate sites are chosen with the natural resources and the socio-economic conditions favoring a market for OTEC by-products. Favorable OTEC thermal resource regions across the world are:

The first choice are equatorial waters between 10'N and 10'S but there are concerns raised for the west coast of South America due to temperature inconsistencies through the year, especially impacting the surface temperature during the winter months.

Equatorial tropical waters stretching to 20'N and 20'S. However, the West Coasts of South America, Southern Africa, West Coast of Northern Africa, Horn of Africa and off the Arabian Peninsula were not include due to the similar weather temperature inconsistencies.

Countries along the east coast of Africa, Central and Latin American Islands and Islands in the Pacific Ocean

Several demonstrations of OTEC plants have been discovered in the past several decades as depicted in Figure 1. All these studies give a great impact to the OTEC development and research since they assisted scientists and engineers understand further on some part of the OTEC system and components. The limitation of the knowledge about the OTEC study will close the funding on OTEC by the certain countries.

An appropriate location must be considered for the planning of OTEC plant where the facility must be located in a region with access to warm surface waters and deep cold ocean water where generally located at deep sea area. However, if adjacent to a shelf or rapid decrease in depth, OTEC facility must be located on land but it is required the long length of the cold water intake pipe to reach the required temperature (National Oceanic and Atmospheric Administration, 2010). Nowadays, there are five land-based OTEC plants are in operation with energy generated between 15kW to 105kW (refer to Table 1).

Recently, technological advancements in the offshore oil industry have made the floating OTEC platforms a possibility. These floating platforms can be located virtually anywhere above deep water as long as they can be adequately moored, and the power cable can reach a land-based power grid for electricity production (National Oceanic and Atmospheric Administration, 2010).

There are two major floating OTEC facilities is under construction at La Martinique (France) and Tarawa Island (Kirabati) with output energy up to 11MW. The current major OTEC developments are summarized in Table 1. A few of the most popular demonstrations studies are:

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3.1 Hawaii

In 1979, one of the first-ever OTEC plant was commissioned in Hawaii and it was an offshore demonstration 50 kW closed-cycle plant which utilized 40 kW in running the plant and generated 10 kW as the net output. Besides, the platform was moored by using a 30,000 lb weight. The temperature of the cold water is 4.4'C at depth 670 m. The working fluid used in this plant was Ammonia and the cold water pipe was made out of Polyethylene in order to reduce bio-fouling which was one of the biggest concerns for the cold water pipe then. On the other hand, the heat exchangers installed were made out of Titanium. The continuous running time of this plant at 120 hours was one of longest continuous running time of an OTEC plant (W. H. Avery and C. Wu,1994).

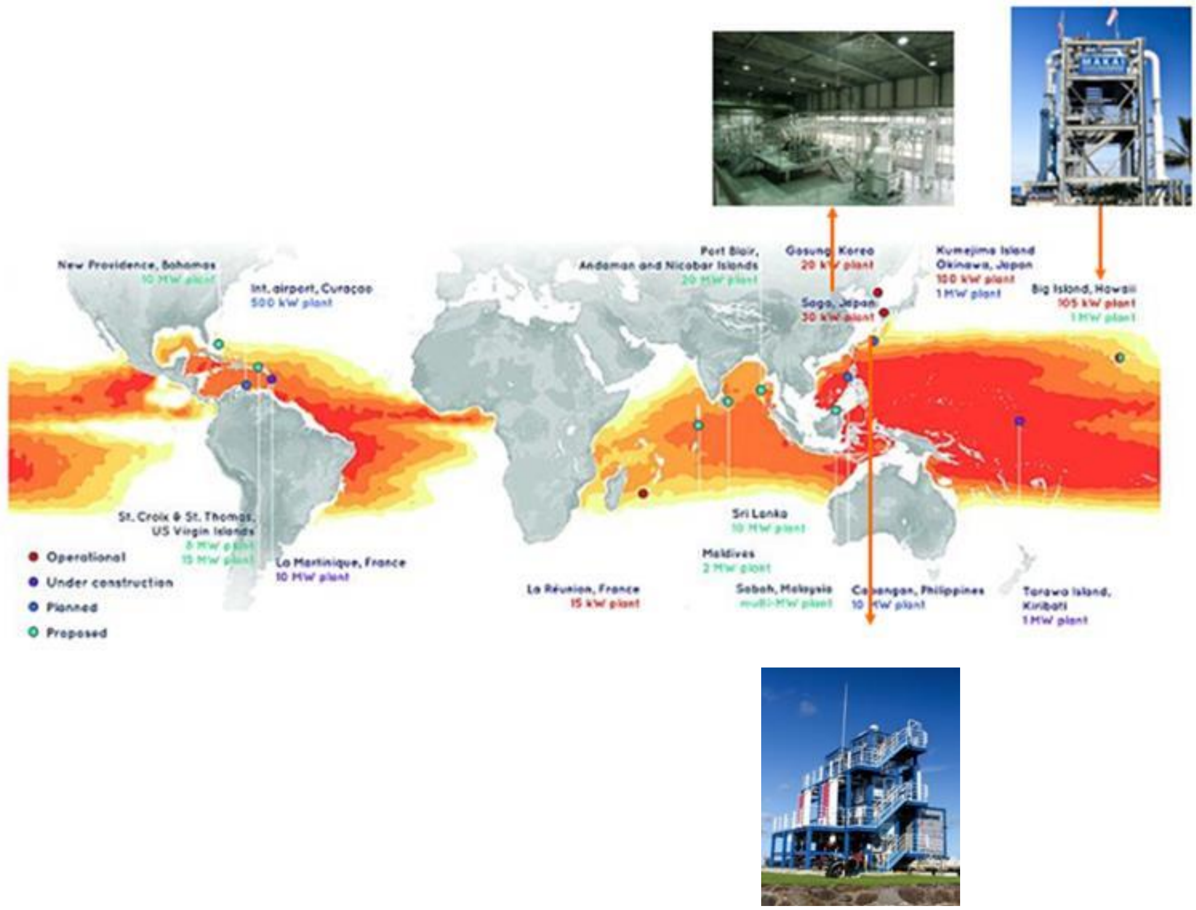

Figure 1: Distribution of the OTEC potential around the world [Koto et.al, 2017]

Table 1: Current major OTEC developments around the world

Development Status	Location	Description	Output Energy	Water depth	Structure type	OTEC
In Operation	La Réunion, France	Operational since 2012 with the purpose of research and development	15kW	1000 m	Land based	Closed cycle
	Gosung, Korea	Operational since 2012 with the purpose of research and development	20kW	1300m	Land based	Closed cycle
	Saga, Japan	Operational since 1980 with the purpose of research and development	30W	1000m	Land based	Hybrid cycle

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	Kumejima Island Okinawa, Japan	Operational since 2013 with the purpose of research and development and for electricity production	100kW	600m - 1000m	Land based	N/A
	Big Island, Hawaii	This is the first true closed-cycle ocean Thermal Energy Conversion (OTEC) plant to be connected to a U.S. electrical grid. Capable of generating enough electricity to power 120 homes a year	105kW	1000m	Floating plant	Closed cycle
Under Construction Under C	La Martinique, France	2016- pilot plant Awarded under NER300 programme by the European commission for NEMO project Nominal capacity of 16MW to be operate by 2019	11MW	1000m	Floating plant	Closed cycle
	Tarawa Island, Kiribati in the South Pacific Ocean	The first practical level of plant on a pathway to building a 100MW commercial system	1MW	1300m	Floating plant	N/A
Planned and Proposed	Int. Airport, Curacao	Expected to provide reduction of approx. 2.500 tons of CO_2/year is expected with implementation of the Curacao Ocean Eco park alone.	500kW	1000m	Pilot plant	Closed cycle
	Zambales, Philippine	The Philipines' first ocean energy facilitie start operate commercially by 2018 is expected to	10MW	1000m	Floating Pilot plant	Closed cycle
	Kumejima Island Okinawa, Japan	For a 1MW plant, the plant would make 1.3- 1.5 megawatts of power and sell 1 megawatt of net power.	1MW	1000m	Land based	Closed cycle
	St. Croix & St. Thomas, US Virgin Island	Memorandum of Understanding (MOU) signed for feasibility study for world's first US-based commercial on-shore OTEC plant and Sea Water Air Conditioning (SWAC) systems in USVI	8MW 15MW	1000m	N/A	N/A

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	Maldives	The first commercial OTEC system to be installed in an eco-resort in Maldives. It is expected to be completed by early 2018	2MW	1000m	Floating plant	Closed cycle
Planned and Proposed	Indonesia	Banda, Maluku	10 MW	700m	Onshore	Closed cycle
		Halmahera, Maluku Utara	3 MW	700m	Onshore	Closed cycle
		Siberut, Sumatera Barat	2 MW	700m	Onshore	Closed cycle
		Karangkelong, Sulawesi Utara	4 MW	700m	Onshore	Closed cycle

3.2 Nauru
After the demonstration of 50 kW OTEC plant in Hawaii, a 100 kW land-based plant in the Republic of Nauru built by Japan in October 1981. The system in this plant operated with a temperature difference of about 20'C between the warm surface water and the deep cold ocean water at a depth of 500-700 m. A pipeline length of 945 m used to cover the depth of 580 m. Besides, the heat exchanger tubes used were surface treated with titanium in order to improve the performance. The working fluid used was Freon-22 was which considered less harmful to the environment compared to ammonia. The cold water pipeline was made of polyethylene. The load response characteristics, turbine, and heat exchanger performance tests were tested in this project. The efficiency of the turbine recorded at over 80%. The plant was succeed to be operated in 10 days and achieved a continuous power generation of 31.5 kW.

3.3 East coast of India
A 1 MW floating plant was built by National Institute of Ocean Technology (NIOT), India, off the coast of Tamil Nadu close to Tuticorin in the South east coast of India. The plant had a gross power generation capacity of 1 MW and net power of 500 kW and it was integrated on a floating barge. The plant used the ammonia as a working fluid with evaporators coated with special steel on the ammonia side to enhance nucleate boiling. A four-stage turbine was used to generate the power. A one-meter-diameter high-density cold water pipe made of polyethylene was used to be moored the floating barge on a single point mooring at a depth of 1200 meters. However, the project was abandoned because of problems that crept in while deploying the pipe to the platform. The project shifted focus to desalination using the OTEC cold water pipe after the incident.

4.0 OTEC PROGRESS IN ASIAN COUNTRIES

In Asian countries, the deployment of OTEC was still in research and some countries manage to set up the frame work on OTEC development. The favorable of OTEC in these countries were very high. However, there are still some problems arise when installing the OTEC plant due to the high capital cost and proper plan are required. Many developing countries in Asia, are suffering quality of life challenges because of the water and electricity scarcity. As a result, people in these countries are living in the most appalling conditions.

In recent years, Malaysia and Indonesia have studied the feasibility of OTEC plant in their countries since they have potential sites of OTEC as depicted in Figure 2. The survey as shown in Figure 2 is the potential locations which are significant in designing an OTEC plant. The collection of data on the sea surface temperature and the deep ocean water are vital in order to ensure the viable operation of an OTEC plant.

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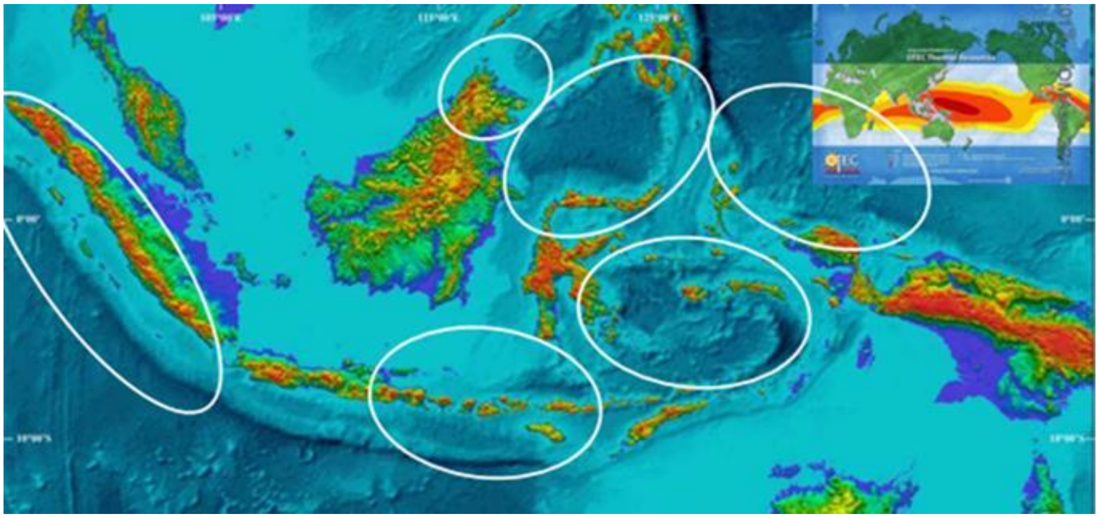

Figure 2: Potential of OTEC in Malaysia and Indonesia [Koto 2017 & UTM OTEC, 2017]

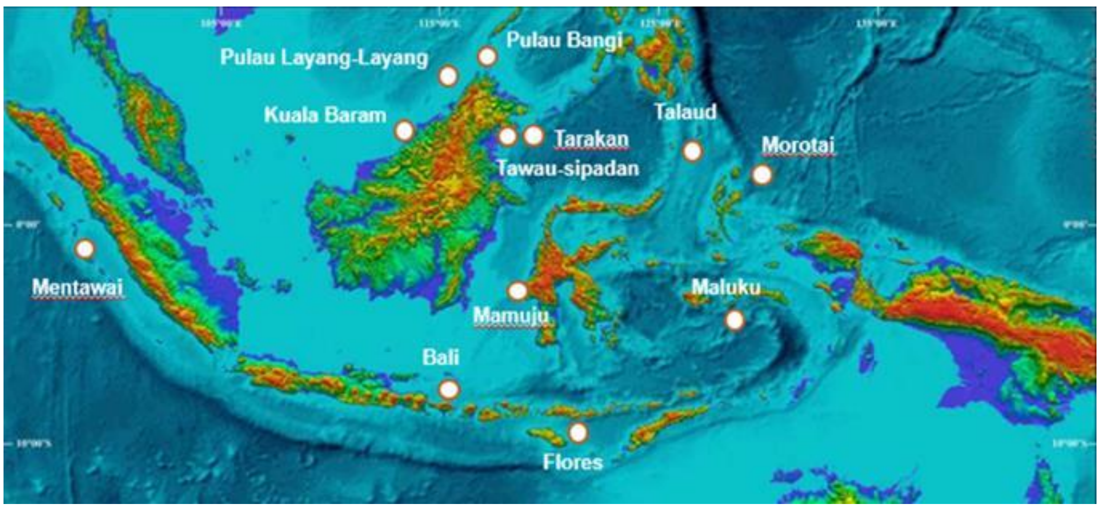

Figure 3: OTEC survey in Malaysia and Indonesia [Koto 2017 & UTM OTEC, 2017]

The potential for OTEC commercialization is greater now than it was 30 years ago because of the extensive growth and maturation of the offshore oil and gas industry. Oil and Gas platforms now operate a hundred miles of the coast, and in water that is thousands of feet deep, whereas most platforms in the 1970s were still limited to submerged towers located on the continental shelf.

4.1 OTEC in Malaysia

Malaysia is one of the tropical ocean countries located in the south east part of Asia which also situated at 2’30’ North latitude and 112’30’ East longitude in the global map. According to Yunus (2012), Malaysia Prime Minister Dato’ Seri Mohamad Najib Tun Abdul Razak has approved the study to generate electricity from the deep sea in Sabah which conducted by Ocean Thermal Energy Corporation. According to Bakar (2017), the abundant existence of deep-sea bed off its territorial water (Sabah Trough) make the potential of this location is worthy to be further investigated and capitalized upon by Malaysia.

Boon (2015) explained that there is a high potential to utilize ocean-based energy sources since Sabah is covered by coastal zone of 27549 km² in Malaysia. Besides, the 11th Malaysia Plan (2016-2020) aims to manage the 1st Public-Funded OTEC project off Pulau Layang-Layang. On top of that, it require the ability to attract investments and expansions of similar industries into a high value-added activity in line with the latest 11th Malaysia Plan (2016 – 2020) to ensure the exploration of ocean energy (Economic Planning Unit, 2015).

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Figure 4: Potential sites of OTEC in Malaysia

4.2 OTEC in Indonesia

Indonesia is an archipelago island nation along the equator and tropical areas, lies between the Indian Ocean and the Pacific Ocean. Achiruddin, et.al (2010) has mentioned in their study that OTEC plants can be applied in the regions of along southern Sumatra, Java, Bali, Nusa Tenggara archipelago and Eastern Indonesia. Donny (2015) proposed a strategy to develop OTEC in Indonesia by taken economic and environmental issues. He stated that Indonesia has excellent ocean thermal energy conversion technology resources, especially along southern Sumatra, Java, Bali, Nusa Tenggara archipelago and in eastern Indonesia.

Adrian (2015) stated that OTEC could be a solution to produce electricity and also can produce fresh water and cold water for agricultural and cooling purposes especially in the tourist area in Bali. Fanny et.al (2016) studied potentially of OTEC Installation as Power Plant in West Sumatera, Indonesia. They proposed three potential locations for OTEC application as follows: Pesisir Selatan, Padang and Mentawai Islands. Delyuzar (2016) has conducted sites seawater temperature measurement in Indonesian waters by MGI Team at the following locations: Mamuju located in the Makassar Strait, Tarakan, Flores Sea, North Bali and Lembata, Nusa Tenggara Timur.

Koto et.al (2016, 2017) has studied feasibility OTEC in Indonesia such as Mentawai, Karangkelong, Maluku and Morotai. They respectively designed and analyzed SWOTEC in Banda, Maluku, Halmahera, Maluku Utara, Mentawai, Sumatera Barat, Karangkelong and Sulawesi Utara. The sustainable issues, economic impact on tourism industry, cold agriculture, fishery, electricity and fresh water, equitable national devlopment, politic stability and national defence caused by SWOTEC in Indonesia stated in his present were also study.

4.3 OTEC in Philippines

The use of ocean thermal energy can be very interesting in the seas and streets of the Philippines due to its geographical position near the equator. According to the Uehara (1988), in order to determine suitable OTEC power plant sites in the Philippines, an extensive temperature reading were obtained. The surface seawater is in the range of 25 to 29 C throughout the year meanwhile deep water at 500 to 700 m depth remains at a low temperature of 8 to 4 C, respectively. Nakaoka (1988) stated that there are 14 potential sites for OTEC within the Philippine seas.

Currently, a 10 MW closed-cycle OTEC facility in Cabangan, Philippines was constructed by the UK Company Energy Island Bell Pirie Ltd. as a pilot project. Philippines had passed the Renewable Energy Act of 2008 (or R.A. 9513) as it was signed into law on December 16, 2008, aimed to develop a "strategic program" to increase renewables' usage stating that the law would develop the 'first ocean energy facility for the country'. This also shows that the Philippines government's commitment to accelerate the exploration and development of renewable energy resources.

Figure 5: Current projects and OTEC research's in Philippines

5.0 4 MW HYBRID OTEC IN LAYANG-LAYANG ISLAND, SABAH

5.1 Overview of Layang-Layang Island

Layang-Layang Island is located at Latitude/longitude: 05°20 ˊ 59″N 115°10 ˊ 59″E which is 300km northwest of Kota Kinabalu, Sabah or. It is clear that flying from Kota Kinabalu which is the proper option to get to Layang Layang Island.

Layang Layang is a must-visit destination for scuba diving enthusiasts. There are no tropical beaches on the island; only the naval base, the resort and diving school and the air strip. The (only) resort on the island, Layang Layang Island Resort, is closed from September till February; as during this time the area is being plagued by the monsoon.

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Figure 6: Dive site in Layang-Layang Island, Sabah.

5.2 OTEC Simulation

The water around the island is extremely deep, around 2000 m and in the middle of the open sea. In order to find the seawater temperature profile, field measurement was conducted by Ocean Department of Malaysia in the Layang-Layang Island in Sabah as shown in the Figure 7.

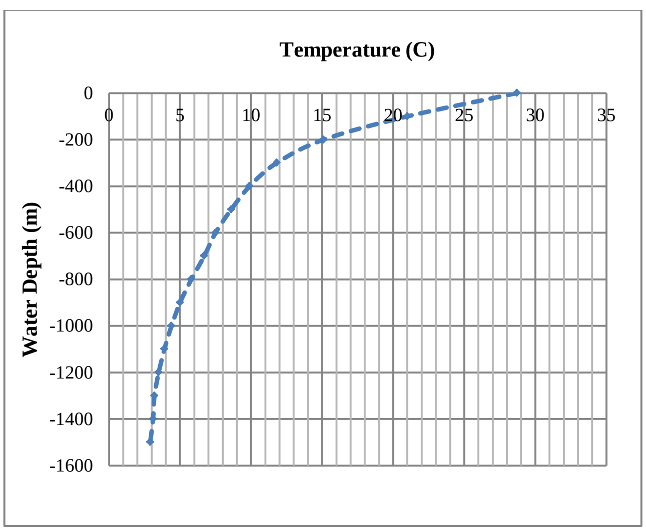

Figure 7: Sea Surface Temperature Data in Layang-Layang, Island, Sabah.

In the study, the performance was simulated using Ocean Thermal Energy Conversion Pro Simulation as shown in the Figure 8. 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 the region) 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 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 800 meter.
- The inlet surface and deep sea water temperatures are 28 and 6.2 0C, respectively.
-

Figure 8.a: Front screen of Ocean Thermal Energy Conversion Pro Simulation Software.

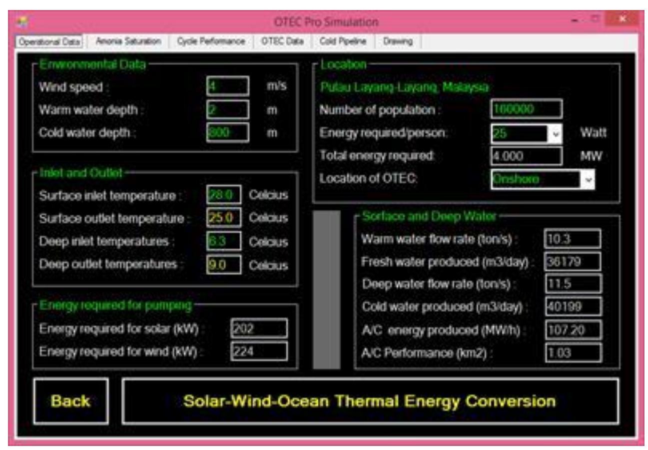

Figure 8.b: Operational condition of OTEC.

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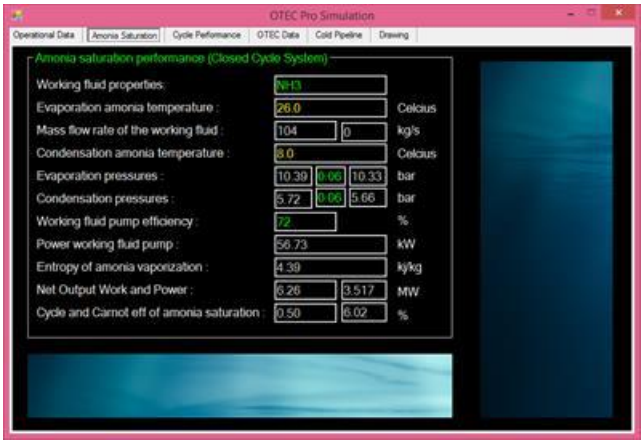

Figure 8.c: Ammonia saturation of OTEC.

Figure 8.d: Cycle performance of OTEC.

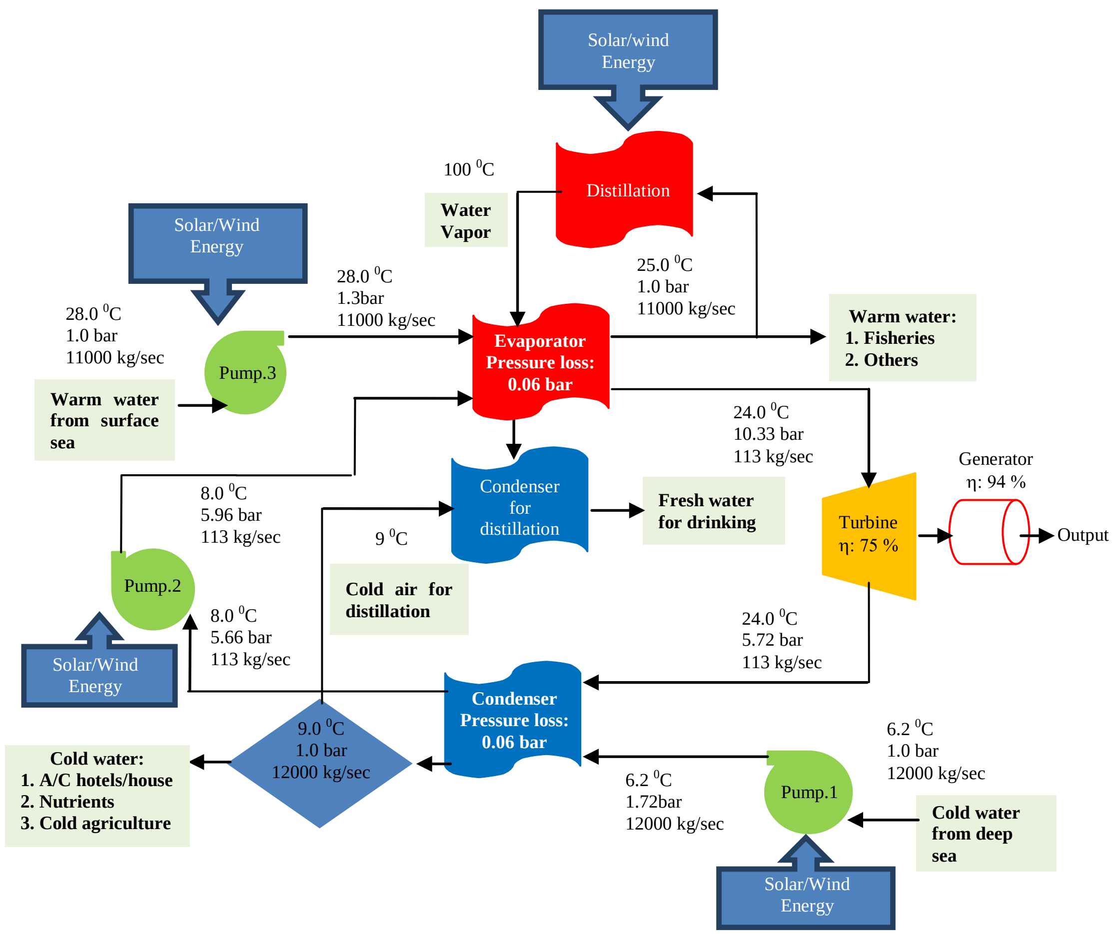

Figure 9: Detailed flow conditions for a single-stage 4 MW plant in Layang-Layang Island, Sabah.

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Figure 8.6 shows a simplified schematic diagram of a 4 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 220 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 245 kW from wind energy. The low temperature of ammonia is pumped with 62 kW from solar energy.

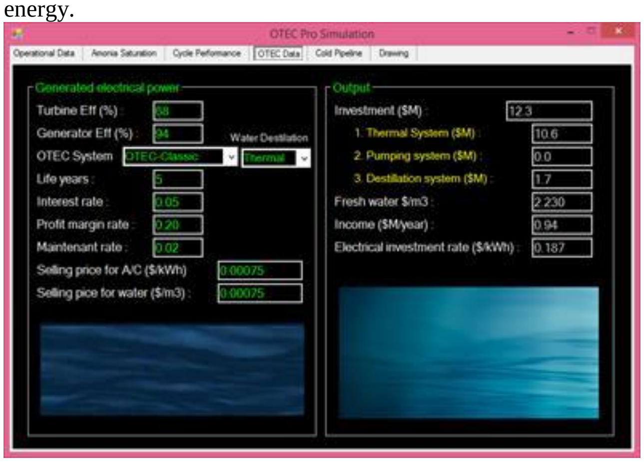

Figure 10: SWOTEC simulation results in Layang-Layang Island, Sabah.

Figure 10 show simulation results of SWOTEC performance to generate 4 MW plant of electrical power Layang-Layang Island, Sabah. 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 113 kg/sec. The surface and deep seawater flow rates were founded 11000 and 12000 kg/sec. The simulation shows several founding as follow:

1. Long Mean Temperature Difference (LMTD) is 18.71
2. Investment for generating electrical power is 0.219 $/kWh
3. The SWOTEC system can produce 13.3 km2 of green-house cooling system
4. The system can produce 20000 m3 per day of fresh water for drink after distillation.
5. The system can also produce 23000 kg per second seawater which can be used for fish farming.
6. The Carnot efficiency of ammonia saturation is 6 percent
7. The cycle efficiency of ammonia saturation is 0.41 percent

5.0 CONCLUSION

In conclusion, this paper discussed potential of OTEC in Layang-Layang Island, Sabah. In the study, closed cycle OTEC was used to simulate 4 MW OTEC system. The simulation results founded that Layang-Layang Island, Sabah was high potential for OTEC due to gradient temperature more than 20 0C. It means they are suitable to install OTEC. The electricity and fresh water can be produced from OTEC system.

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