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Ocean Thermal Energy Conversion in Layang-Layang and Kuala Baram, Malaysia

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ABSTRACT

Ocean Thermal Energy Conversion (OTEC) is a clean marine renewable energy and alternative energy technology by utilizing temperature differences between warmer surface water and cold deep sea water to drive generators. Designing an OTEC system is challenging and the process requires detailed analysis and assessment. As Malaysia is an equatorial country located at a latitude of less than 20 degrees covered by the ocean with many islands with many topographic differences, OTEC is very compatible in Malaysia. In this paper, a feasibility study on the Sea Heat Energy Conversion in Layang-Layang Island and Kuala Baram, Malaysia has been discussed. The study found that Layang-Layang and Kuala Baram islands have great potential for the implementation of OTEC. Using field measurement data, 4 MW of electricity generated by OTEC is simulated as a case study. In addition, the OTEC system will produce fresh water through a distillation process. A numerical calculation and simulation analysis are presented in this study for both potential OTEC locations.

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

NOMENCLATURE

OTEC	Ocean Thermal Energy Conversion
LMTD	Log Mean Temperature Difference

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 [1]. 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 [2, 3]. 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.

1.1 Ocean Thermal Energy Conversion

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 [1, 4]. OTEC can provide more energy than the combination of the waves and wind energy [5]. A thermodynamic working fluid were use such as ammonia in a completely closed system where warmer surface water used to evaporate the liquid meanwhile cold deep ocean water condensed the fluid. According to Aydin et al., (2013), the principle of the OTEC system functions is to generate electricity from converting power derived from the movement of a turbine coupled to generator that is linked and solely powered by a working fluid [6].

1.2 Multi Functionality of OTEC

Koto.et.al [7-14] 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:

1.2.1 Freshwater Desalination

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 [14, 15]. The water vapour 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 [16]. Besides, the production of electricity and fresh water at the same time will give benefit for countries which water scarcity [7-14].

1.2.2 Air Conditioning and Refrigeration

Koto (2017) stated that the deep water 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, assisting to balance the peak demand in electricity as well as overall energy demands [7-14]. A new deep seawater utilization test facility in Okinawa also employs cold seawater air conditioning.

1.2.3 Mariculture

Muralidharan (2012) clearly stated that marine food production is a potential by-product of OTEC power plants [17]. 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

1.2.4 Hydrogen

The other products of OTEC are hydrogen and oxygen which can be produced from pure water by electrolysis by one of the several industrial processes that have been developed for this purpose. Besides, OTEC plant can be an excellent source of hydrogen production as it can be used as fuel or can be combined with other chemical for other products in future.

2.0 OTEC IN ASIAN COUNTRIES

In Asian countries, Malaysia, 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 [14]. In line with this deployment of OTEC, Bakar (2013) 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 [18]. The potential sites of OTEC in Asian countries can be referred in Figure 2.1 and 2.2.

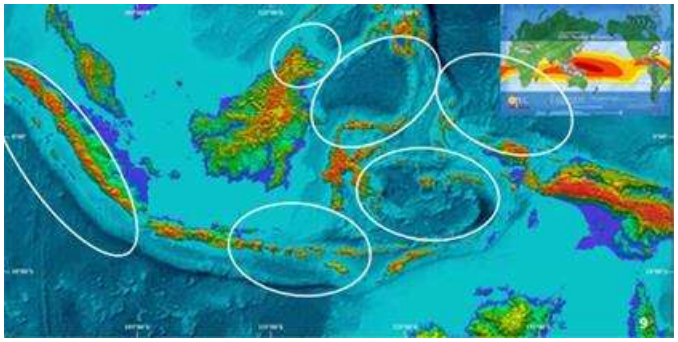

Figure 2.1: Potential of OTEC in Malaysia and Indonesia [Koto 2017 & UTM OTEC, 2017]

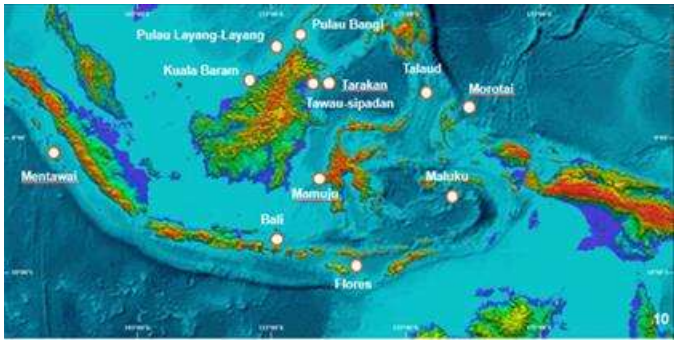

Figure 2.2: OTEC survey in Malaysia and Indonesia [Koto 2017 & UTM OTEC, 2017]

2.1 OTEC in Malaysia

Malaysia also was among 98 Country listed for OTEC development which include fresh water production [2, 3]. 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.

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 [19]. 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 requires 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 [19].

Figure 2.3: Potential sites of OTEC in Malaysia

2.2 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 [21]. Donny (2015) proposed a strategy to develop OTEC in Indonesia by taken economic and environmental issues [22]. 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 [23]. Fanny et.al (2016) and Koto.et.al (2017) studied potentially of OTEC Installation as Power Plant in West Sumatera, Indonesia [7, 24]. 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 [25].

Koto et.al has studied feasibility of OTEC in Indonesia such as Mentawai, Karangkelong, Maluku and Morotai [7-14]. They respectively designs and analyses 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 development, politic stability and national defense caused by SWOTEC in Indonesia stated in his present were also study.

2.3 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 et.al (1988), in order to determine suitable OTEC power plant sites in the Philippines, an extensive temperature reading were obtained [26]. 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. Uehara et.al (1988) stated that there are 14 potential sites for OTEC within the Philippine seas [26].

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 resource.

Figure 2.4: Current projects and OTEC research in Philippines

3.0 FEASIBILITY STUDY OF OTEC IN MALAYSIA

In verifying the validity of the numerical calculations and suitability of selected design parameter towards Malaysian seas usage, a comparison is being made between the calculated data with the actual data. For this reason, Layang-Layang Island and Kuala Baram were selected.

3.1 Sea surface temperature profile

The data for sea surface temperature profile were provided by

UTM OTEC Centre are as follows:

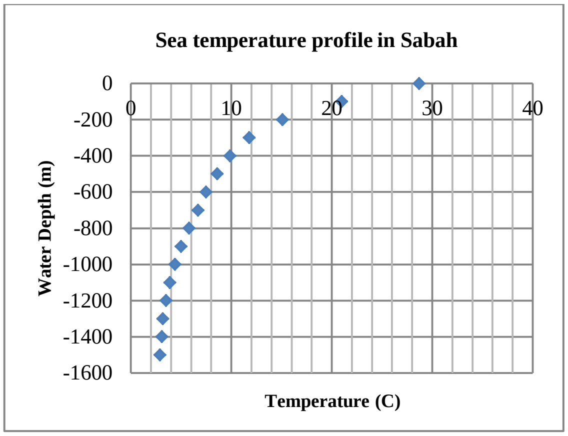

Figure 3.1: Sea Surface Temperature Data in Layang-Layang Island [UTM OTEC**].**

3.2 Layang-Layang Island

Layang-Layang Island as depicted in Figure 3.2 is situated 300km northwest of Kota Kinabalu in Sabah, Malaysia also known as 'The Jewels of the Borneo Banks'. It is clear that flying from Kota Kinabalu which is the proper option to get to Layang Layang Island. Besides, Layang Layang is a must-visit destination for scuba diving enthusiasts. In this island, there are no tropical beaches but 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.

Figure 3.2: Layang-Layang Island

3.2.1 Platform Specification

In Layang-Layang, the type of platform proposed was the floating OTEC Platform.

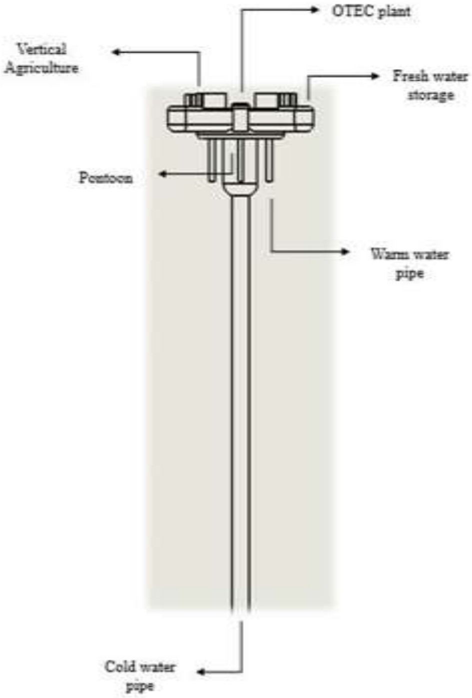

Figure 3.3: Fixed structure OTEC Platform in Layang-Layang

3.3 Kuala Baram

Kuala Baram as shown in Figure 3.4 is located in Miri, Sarawak. Miri is a coastal city in northeastern Sarawak, Malaysia, located near the border of Brunei, on the island of Borneo. This city covers an area of 997.43km^2, located 798 kilometres northeast of Kuching and 329 kilometres southwest of Kota Kinabalu. Besides, Miri is the second largest city in Sarawak, with a population of 358,020 as of 2016. In Kuala Baram, there are various types of economic activities including oil and gas activities, residential, industrial and tourism industry as the major role in local economy. These industries will keep increasing and survive by being innovative and even overcoming great handicaps.

Figure 3.4: Kuala Baram

3.3.1 Platform Specification

In Kuala Baram, the type of platform proposed was the fixed structure OTEC Platform.

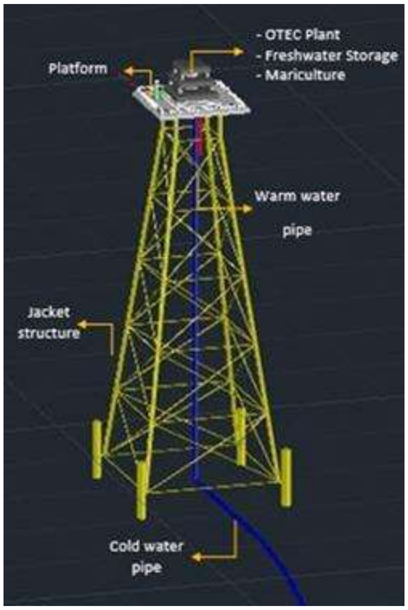

Figure 3.5: Fixed structure OTEC Platform in Kula Baram

4.0 RESULTS AND DISCUSSIONS

4.1 Layang-Layang Island

OTEC Pro Simulation Software was used to evaluate the seawater and working fluid cycle performance of OTEC. These simulations used the same sea surface temperature profile as they lies at the same location which is Sabah Trough. The results obtained for Kuala Baram and Layang-Layang were shown in Figure below:

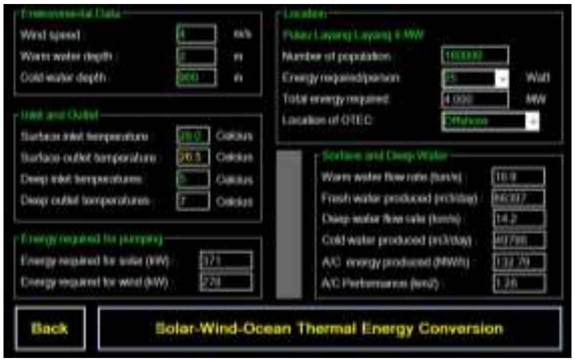

Figure 4.1: Result simulations in OTEC Pro

Figure 4.2: Result simulations in OTEC Pro

Figure 4.3: Result simulations in OTEC Pro

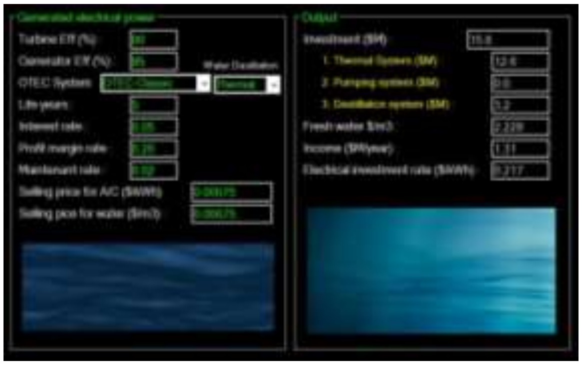

Figure 4.4: Result simulations in OTEC Pro

4.2 Kuala Baram

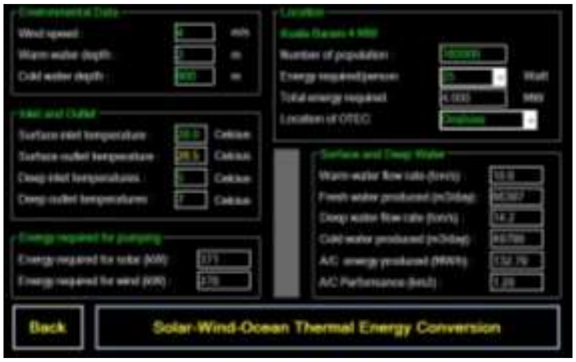

Figure 4.5: Result simulations in OTEC Pro

Figure 4.6: Result simulations in OTEC Pro

Figure 4.7: Result simulations in OTEC Pro

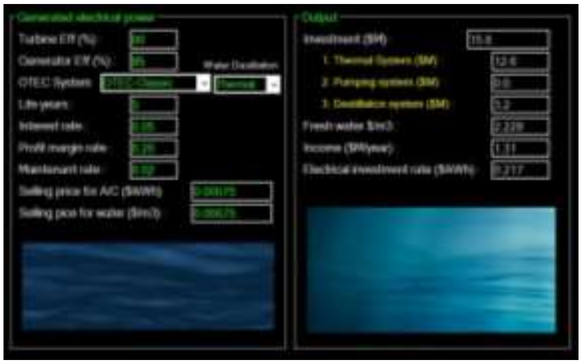

Figure 4.8: Result simulations in OTEC Pro

4.2 Results verification

The desired results were obtained from the numerical analysis in Microsoft Office Excel is compared with the results in OTEC Pro simulation. The validation of the results will refer to the Table 4.1 indicates this comparison using percent difference, the equation for which is listed below.

Table 4.1: Result comparison between OTEC Pro and numerical calculations

Results	OTEC Pro	Numerical	Difference (%)
Turbine work (kJ/kg)	73.65	69.24	5.98
Pump work (kj/kg)	0.95	0.50	47.37
Power working fluid pump (kW)	48.56	45.55	6.20
Net output power (kW)	3313	3320.54	0.23
Carnot Efficiency (%)	7.64	7.64	0.00
Cycle Efficiency (%)	5.84	5.55	4.97
$\dot{m}_{ws}$ (ton/s)	18.90	19.50	3.17
$\dot{m}_{cs}$ (ton/s)	14.20	14.10	0.70
LMTD (℃)	21.20	21.25	0.24

From the table above, it is clear that the percent difference from the model to the numerical calculations is acceptable. However, the percent difference for turbine work are larger than 5% which the values are 5.98%. But, the value is still acceptable. Since, the difference exist because of the values of enthalphy at point 1 and 2 are difference between OTEC Pro and numerical calculation.

Besides that, the different for the power of working fluid pump is 47.37%. But, it also acceptable since the value for the work input to the pump was so small compared to the other work and heat transfer calculation. The value would still reasonable fit if used in data acquisition. Other than that, the determined $\dot{m}_{cs}$ /$\dot{m}_{ws}$ is 0.75, falling into the acceptable range.

4.3 Power Consumption

The OTEC system estimated net power generation is 4 MW, indicating that 41.93% of the turbine-generator power is consumed by seawater pump and working fluid pump as depicted as Table 4.2. Meanwhile, the net output for the overall power is 3320.5 kW which is 58.07% from the turbine-generator power. Since the power of the pumps not more than 50% from the overall power, the system is acceptable. Besides, the power of the pump can be decrease by reducing the mass flow rate of the fluid used. Avery et al, (1994) stated that the higher the water depth, the higher pumping head requirements, thus needs higher costs [27].

Table 4.2: Power consumption by the pumps

Description	Consumption (%)
Working fluid pump	1.13
Warm seawater pump	14.95
Cold seawater pump	25.85

Total **41.93 %**

4.4 Cold and warm water piping design

In Layang-Layang Island, it is estimated that the availability of the deep cold ocean water at 5℃ lies at 1.5 km from shore. For the offshore floating OTEC, it is observed that the lower the cold seawater temperature is, the higher the cold water pipe is required in Table 4.3. It should be noted that, the higher the cold water pipe used, the higher the cost will require for the installation of the pipe.

Table 4.3: Variation of length for the cold water pipe with cold seawater temperature in Layang-Layang

Temperature (℃)	Length of cold water pipe (m)
9.9	400
8.6	500
7.5	600
6.7	700
5.8	800
5.0	900
4.4	1000
3.9	1100

Meanwhile for the land-based OTEC plant in Kuala Baram, the length of cold water pipe required at 5℃ is 28800.5 m as depicted in Table 4.4. In this case, the length of the cold water pipe required is longer compared to the offshore floating OTEC plant, thus can be more expensive when required longer pipe to access the cold seawater.

Table 4.4: Variation of length for the cold water pipe with cold seawater temperature in Kuala Baram.

Temperature (℃)	Length of cold water pipe (m)
9.9	28301.3
8.6	28401.0
7.5	28500.8
6.7	28600.7
5.8	28700.6
5.0	28800.5
4.4	28900.4
3.9	29000.4

Besides, C.B. Panchal (1984) stated that the effect of biofouling on the interior and exterior of the cold water pipe is not significantly impact the performance of the OTEC plant [28]. This is because the smooth interior surfaces of the CWP achieved by coatings and additives which mitigate the biofouling effect. In order to monitor cold water pipe performance and detect any damage, fiber optics will be used for the purpose since it is a well-understood technology that is borrowed from the offshore oil industry. Other than that, the emergency preparedness is required in designing the cold water pipe. In this case, the design may include the ability to detach the pipe from the platform in order to prevent damage due to extreme weather. The proper design of the platform/pipe interface will increase complexity and cost.

4.5 Diameter for cold and warm water pipe

In this study, the obtained diameter of cold and warm water pipe was 5m and 1.6m respectively. The values lie in acceptable range according to the present study. According to the National Oceanic and Atmospheric Administration (2009), the fabrication for the cold water pipe suitable for a ≤ 10 MW plant (~7 m) is currently available. However, only smaller scale (< 2m diameter) cold water pipe successfully demonstrated. Construction and deployment of a cold water pipe for a ≥ 100 MW cold water pipe have not been attempted. Therefore, the increased of cold water pipe size required for larger than 100 MW OTEC facility will rise some challenges and it is primarily due to lack of experience with pipes in that size class.

4.6 Platform-pipe interface

Other than that, the fixed and gimbal interfaces has been selected for the OTEC system in both location because they are simpler to design and manufacture. Besides, they also can be scaled easily to larger power output OTEC plant, since the power output of OTEC in this study is 4 MW which is absolutely within the range. However, it will require frequent maintenance and cleaning due to additional fatigue points and connections.

4.7 Heat Exchangers

In this study, the titanium (Ti) shell and-plate type heat exchanger as been selected. It should be noted that the thermal resistance of the Ti plate is ignored since it is extremely small compared to other thermal resistances. The heat transfer coefficient of the working fluid plays the most critical role in determining the overall thermal conductance. In the numerical calculations the overall thermal conductance at both locations were obtained for evaporator is 5540.31 kW/m^{2}K and while condenser is 5295.79 kW/m^{2}K. Since, the thermal conductance is the ability of a material to transfer heat, therefore the titanium is the best material.

4.8 Fresh water Production

The power block of the 4 MW floating OTEC plant is based on a closed cycle with some modification as illustrated in Figure 6.9 in order to produce freshwater and reduce the pumping power of the warm seawater. The simulations show that the fresh water production at both locations are 66397m^3 per day. Since, the pumping power for the seawater pump may affect the power consumption of the plant and the cost of OTEC plant, the reduction of the pump power will be significant in order to increase the electricity production in cost effective manner. Therefore, the distillation process was added to the discharge of the warm seawater. In this case, the warm seawater pump can be eliminating if the steam can vaporize the working fluid successfully without the intake of warm seawater to the system.

Distillation is the process of boiling water into steam and then condensing back the steam into water. Since, the discharge of warm seawater already hot, the process requires less temperature in other to boil the water into steam. The 100℃ steam will flow to the evaporator with the warm seawater but they do not mix with each other. Then, it will condense with the discharge deep cold water which the temperature is 7℃ and produce the freshwater. This process removes heavy metals, micro-organisms, poisons, bacteria, contaminants, sediment, minerals and viruses and they will be collected in the boiling chamber but requires proper cleaning.

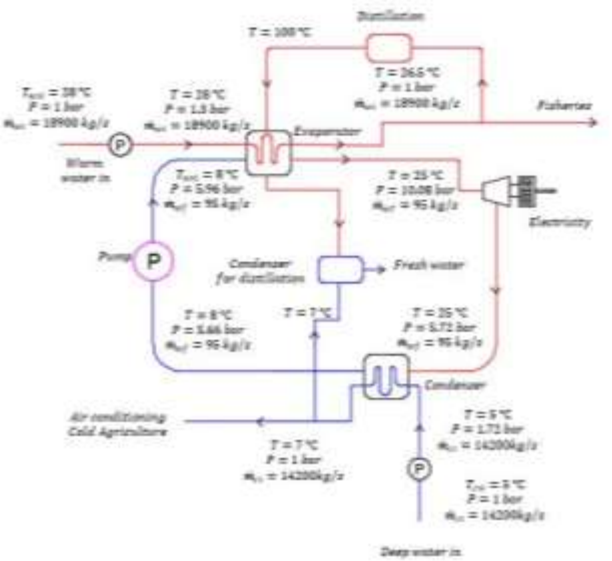

Figure 4.9: Closed Cycle OTEC with distillation process

In this study, the floating offshore OTEC plant was the most suitable primarily because of closeness to the ocean and relatively lower cost to onshore system. According to Multon et al., (2013), offshore OTEC design has little impacts to the land and minimizes the impact of leakage of ammonia [29]. Since, the floating OTEC plant is located in the ocean kilometres away from shore, there is no need to find land as an added resource for the system. Besides, ammonia is one of the hazardous thermodynamic working fluid, even in small concentrations. The impact of the system to communities on land can be reduced as the plant is far away from inhabited areas.

Besides, there are several aspects must be take into consideration in order to design offshore OTEC plant with longer lifespan. Weather, corrosion and fatigue problem are factors that will likely shorten the lifespan of an offshore OTEC system.

5.0 CONCLUSION

A preliminary design of a 4 MW closed cycled OTEC system for the production of electricity in Sabah, Malaysia has been completed. Besides, the study presented research about the potential of OTEC in Malaysia. For this purpose, a closed-cycle OTEC system capable of generating 4 MW Gross Power was designed numerically. Besides, this system constituted the base OTEC system to be improved thermodynamically. Designed system using ammonia as its working fluid was able to produce 3.3 MW of net power with net carnot efficiency of 7.64 % and net cycle efficiency of 5.84 %. The simulation results founded that Sabah, Malaysia was high potential for OTEC due to gradient temperature more than 20℃. It means they are suitable to install OTEC.

Decent design considerations have been successfully implemented in designing cold water pipes from the OTEC platform. Some of the main problems related to OTEC challenges have been discussed in this paper. In addition, existing platforms, mooring lines, pumps, turbines and heat exchanger technologies in the offshore oil industry can generally be scalable for this OTEC system. However, power cables, cold water pipes and platform-pipe interfaces present the challenge of fabrication and deployment for greater power output of more than 100 MW.

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