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10 MW Plant Ocean Thermal Energy Conversion in Morotai Island, North Maluku, 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 on performance of 10 MW plant closed cycle of OTEC to be applied in Morotai Island North-Maluku, Indonesia. The working fluid used was pure ammonia with flow rate was assumed 275 kg/s. Simulation results show The surface and deep seawater flow rates were founded 27500 and 29000 kg/sec.

KEY WORDS: *Seram Island, Maluku, Indonesia, Ocean Thermal Conversion Energy.*

NOMENCLATURE

OTEC	Ocean Thermal Energy Conversion
SST	Sea Surface Temperature
NOAA	National Oceanic and Atmospheric Administration
MW	Mega Watt

1.0 INTRODUCTION

1.1 Background

Ocean Thermal Energy Conversion (OTEC) is a clean and friendly renewable energy with zero-emission. OTEC uses temperature difference between the sea surface and the deep ocean to rotate a generator to produce electrical energy. The sea surface is heated continuously by sunlight from surface up to 100 m. OTEC is capable of generating electricity day and night, throughout the year, providing a reliable source of electricity.

Beside electricity, OTEC can use a portion of its electricity to operate adjoining water desalination plants, thus producing abundant volumes of water for drinking, aquaculture, and agriculture. A small hybrid 1 MW OTEC is capable of producing some 4,500 cubic meters of fresh water per day, enough to supply a population of 20,000 with fresh water. OTEC-produced fresh water compares very favourably with standard desalination plants, in terms of both quality and production costs.

. The cold “waste” water from the OTEC is utilised in two ways. Primarily the cold water is discharged into large contained ponds, near shore or on land, where the water can be used for multi-species mariculture producing harvest yields which far surpass naturally occurring cold water upwelling zones, just like agriculture on land.

Another benefit of OTEC is refrigeration or Seawater Air Conditioning (SWAC). The cold water is also available as chilled water for cooling greenhouses, such as the Seawater Greenhouse or for cold bed agriculture. The cold water can also be used for air conditioning systems or more importantly for refrigeration systems, most likely linked with creating cold storage facilities for preserving food. When the cold water has been used it is released to the deep ocean

OTEC is one of the world’s largest renewable energy resources and is available to around the tropical countries as shown in Figure.1. OTEC have installed in certain countries as follows. Saga, Japan produces 30 kW which was operated since 1980 with the purpose of research and development. Gosung, Korea, KRISO produces 20 kW which was operated since 2012 with the purpose of research and development. Réunion Island, France - DCNS produces 15 kW 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. Hawaii, US under Makai Ocean Engineering produces 105 kW with grid connected operated since 2015 with the purpose of electricity production.

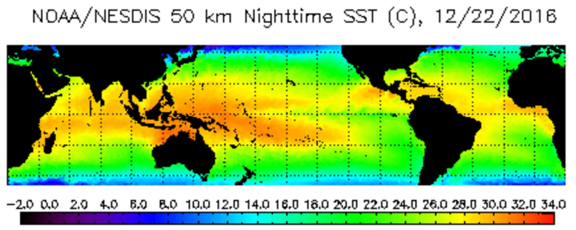

Figure 1: Sea Surface Temperature around the world [NOAA]

Many OTEC plants are under development such as Andaman and Nicobar Islands, India -DCNS- 20 MW, Bahamas, USA - Ocean 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

1.2 Advantages and Disadvantages of OTEC

OTEC has several benefits for human being living as shown in figure 2. Firstly, the distinctive feature of OTEC is the potential to provide baseload electricity, which means day and night and year-round. This is a big advantage for instance tropical islands that typically has a small electricity network, not capable of handling a lot of intermittent power.

OTEC also offers the possibility of co-generating other synergistic products as follows:

1. **Fresh Water**
   The first by-product is fresh water. A small hybrid 1 MW OTEC is capable of producing some 4,500 cubic meters of fresh water per day, enough to supply a population of 20,000 with fresh water. OTEC-produced fresh water compares very favourably with standard desalination plants, in terms of both quality and production costs.
2. **Nutrient Food**
   A further by-product is nutrient rich cold water from the deep ocean. The cold “waste” water from the OTEC is utilized in two ways. Primarily the cold water is discharged into large contained ponds, near shore or on land, where the water can be used for multi-species marine culture producing harvest yields which far surpass naturally occurring cold water upwelling zones, just like agriculture on land
3. **Cooling System**
   The cold water is also available as chilled water for cooling greenhouses, such as the Seawater Greenhouse or for cold bed agriculture. The cold water can also be used for air conditioning systems or more importantly for refrigeration systems, most likely linked with creating cold storage facilities for preserving food. When the cold water has been used it is released to the deep ocean
4. **Water Supplies:**
   The warm surface water can be supplied for aquarium, theme parks and fisheries such as lobsters and prawn.

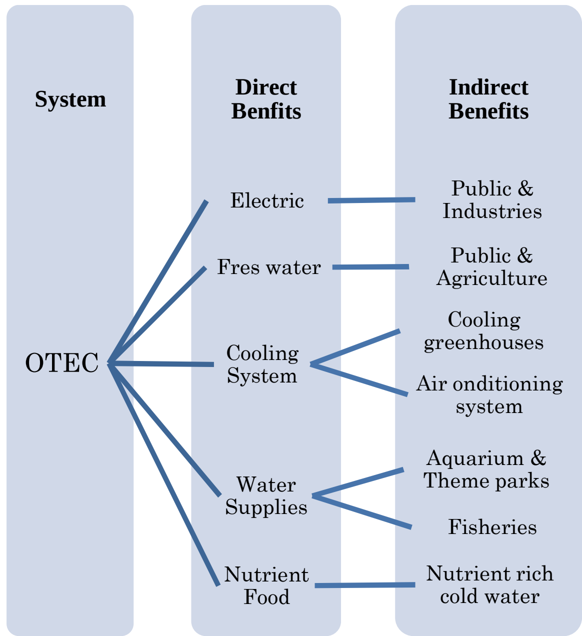

Figure 2: Direct and indirect benefits of OTEC for human being

OTEC requires expensive capital investment and operational cost compared to other energy resources, large-diameter pipes submerged about a mile below the ocean's surface.

2.0 POTENTIAL OTEC IN MOROTAI ISLAND, NORTH MALUKU, INDONESIA

2.1 Sea Surface and Deep Water Temperature in Indonesia

Indonesia is the tropical oceans country, approximately defined by latitudes less than 20 ^{0}C may be thought of as enormous passive solar collectors, therefore Indonesia has OTEC energy source is provided plentiful and constantly replenished during the sun was shining and the ocean currents naturally present. The Sea Surface Temperature (SST) patterns over the Indonesian region clearly demonstrate the effect of the monsoon cycle as shown in Figure 3. Colder temperatures are found from December to March in the South China Sea due to the Northwest monsoon and from June to August in the South of the equator due to the Southeast monsoon. The satellite data shows that the sea surface temperatures in the waters of Indonesia between 28-29°C which is relatively small influence in Indonesian waters.

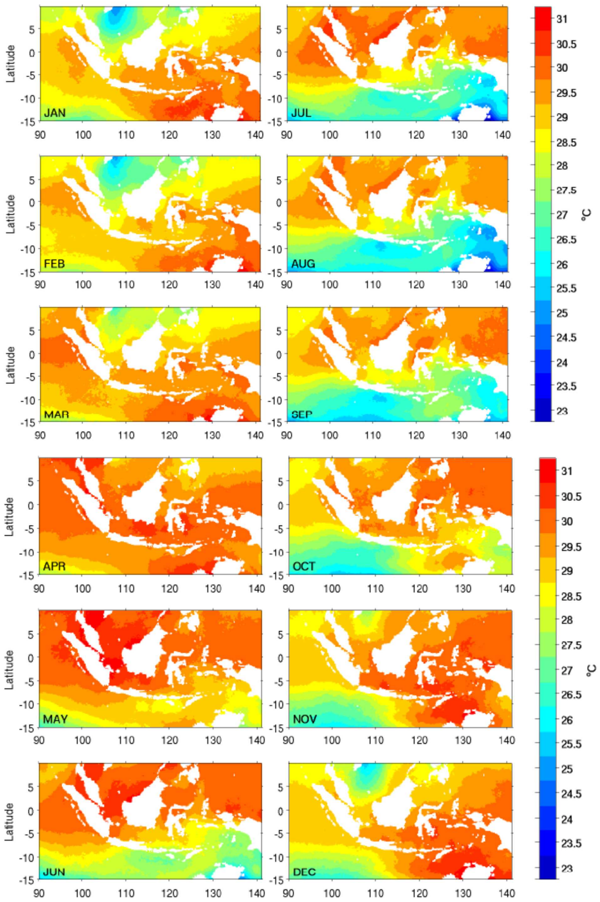

Figure 3: Monthly mean of SST derived from NOAA-AVHRR based on monthly mean data from January 1998 to December 2003 [R. Dwi Susanto. et.al]

2.2 Potential OTEC in Indonesia

Energy consumption in Indonesia increased annually in conjunction with the growth of population, economic and industrial growth. The People in the outer islands are still limited access to electricity, so it still needed another source of energy to cover the electricity needs of the entire territory of Indonesia. An alternative energy sources is required from the ocean thermal energy conversion. As The potential of OTEC in Indonesia is very large due to availability of deep sea, while the potential of ocean energy has not been developed yet and is still under investigation.

Bathymetry map of Indonesia shows that Indonesia has 77 % of total area covered by the ocean in which the Western and Eastern parts of Indonesia have water depth over 1000 meters as shown in Figure 4. Additionally, the Eastern part of Indonesia has a steeply sloping seabed morphology with various forms such as basin sand troughs, with water depths greater than 600 meters, 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. There are four potential areas for OTEC application, they are south of Sumatera such as Siberut Island (A), North of Sulawesi (B), North of Maluku (C) such as Morotai Island, South of Maluku such as Taliabu, Buru and Seram islands (D). This paper discusses performance 10 MW Plant of closed cycle OTEC to be applied in Morotai Island, North-Maluku, Indonesia.

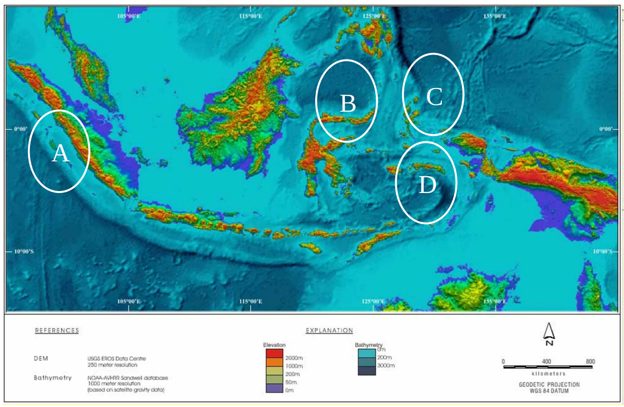

Figure 4: Bathymetry map of Indonesia [NOAA-AVHRR]

2.3 Surface and Deep seawater in Halmahera Sea

Morotai is a rugged, forested island lying to the north of Halmahera which located at 2.04184 of latitude and 128.319 of longitude as shown in Figure 5. The Morotai island has an area of some 1,800 square kilometres, stretching 80 kilometers north-south and no more than 42 kilometers (26 mi) wide. A part of Indonesia, the island is the most important home for the people which have population 54.876 people. Figure 6 shows the bathymetric map of the Morotai Island, North Maluku-Indonesia.

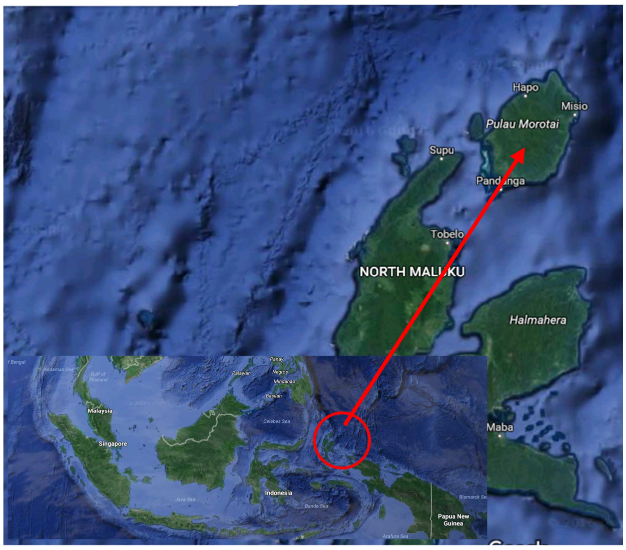

Figure 5: Schematic of the OTEC potential in Morotai Island, North Maluku, Indonesia [Google Map]

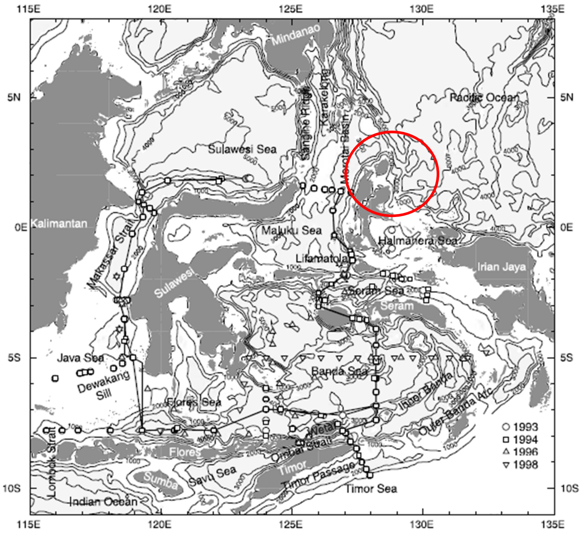

Figure 6: Bathymetric map of the Morotai Island, North Maluku, Indonesia (Red circle) [Arnold L.Gordon].

Figure 7 shows temperatures, salinity and oxygen profiles of Halmahera Sea. The Halmahera Sea is exposed at its northern end to the South Pacific water advected into the region by the New Guinea Coastal Current. The South Pacific water column may spread into the southern Halmahera Sea across a sill near 0.5N.The salinity and oxygen stratification do not display enough range amid the scatter to help define a sill depth, but the temperature field does a bit better

The Halmahera thermal stratification deviates from the Pacific Ocean with increasing depth below 490 m. Bottom-water potential temperature of 7.6C and salinity of 34.6 in the Halmahera Sea suggest complete blockage near 580 meter. Bottom water at near 2000 meter is matched by bottom water near 800 meter, probably just to the overflow side of the effective sill. The temperature shows 6.2 ^{0}C at 700 meter of water depth.

The shallow Halmahera Sea sill allows saline South Pacific lower thermocline water to enter the Seram Sea, but prohibits deeper water from entering the Indonesian seas, which have access to the interior seas only through the Sulawesi and Maluku Seas, with the Sulawesi pathway blocked near 680m by the sill in the southern Makassar Strait.

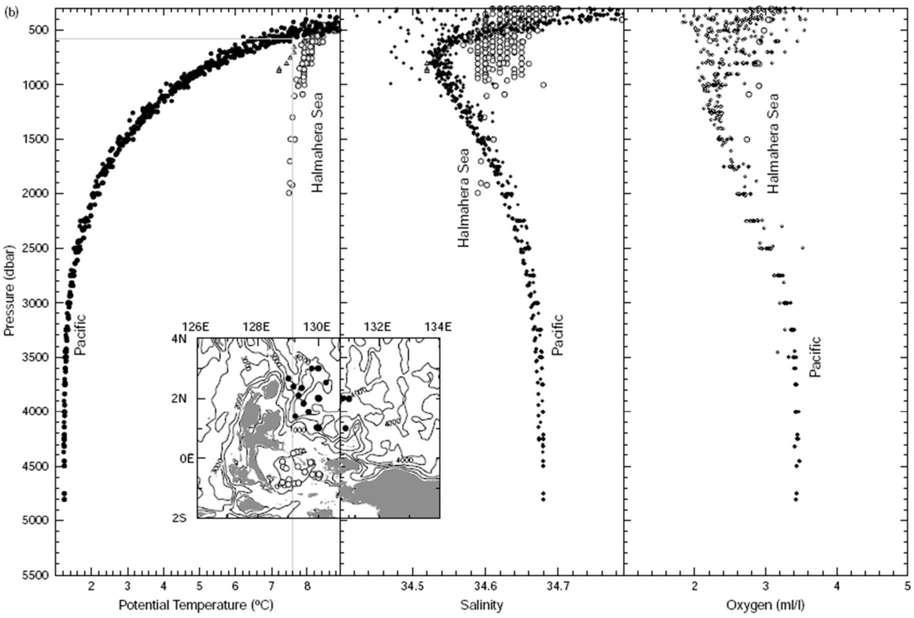

Figure 7: Temperature, salinity and Oxygen profiles of ocean water in Halmahera seas, North Maluku-Indonesia [Arnold L.Gordon]

3.0 SIMULATION AND ANALYSIS

3.1 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.

There are four available main types of OTEC which are open, closed, Kalina and Hybrid cycle systems which 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.

3.2 Closed Cycle System

Original concept of closed cycle employed a pure working fluid that would evaporate at the temperature of warm sea water. The higher temperatures surface water is used to provide heat to a pure 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]. This series of steps would be repeated continuously with the same working fluid, whose flow path and thermodynamic process representation constituted closed loops hence, the name 'closed cycle'. The specific process adopted for closed cycle OTEC is the Rankine cycle.

Figure 8 is a simplified schematic diagram of a 10 MW plant closed cycle OTEC 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. 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 repeat the cycle

The success of the Rankine cycle is a consequence of more energy being recovered when the vapor expands through the turbine than is consumed in re-pressurizing the liquid. In conventional Rankine systems, this yields net electrical power. For OTEC, however, the remaining balance may be reduced substantially by an amount needed to pump large volumes of sea water through the heat exchangers. OTEC is that tremendous energy must be expended to bring cold sea water up from depths approaching 700 meters. In reality, the natural hydrostatic pressure gradient provides for most of the increase in the gravitational potential energy of a fluid particle moving with the gradient from the ocean depths to the surface.)

Irreversibilities in the turbomachinery and heat exchangers reduce cycle efficiency below the Carnot value. Irreversibilities in the heat exchangers occur when energy is transferred over a large temperature difference. It is important, therefore, to select a working fluid that will undergo the desired phase changes at temperatures established by the surface and deep sea water. Insofar as a large number of substances can meet this requirement, other factors must be considered in the selection of a working fluid including: cost and availability, compatibility with system materials, toxicity, and environmental hazard. Leading candidate working fluids for closed cycle OTEC applications are ammonia and various fluorocarbon refrigerants. Their primary disadvantage is the environmental hazard posed by leakage; ammonia is toxic in moderate concentrations and certain fluorocarbons have been banned by the Montreal Protocol because they deplete stratospheric ozone.

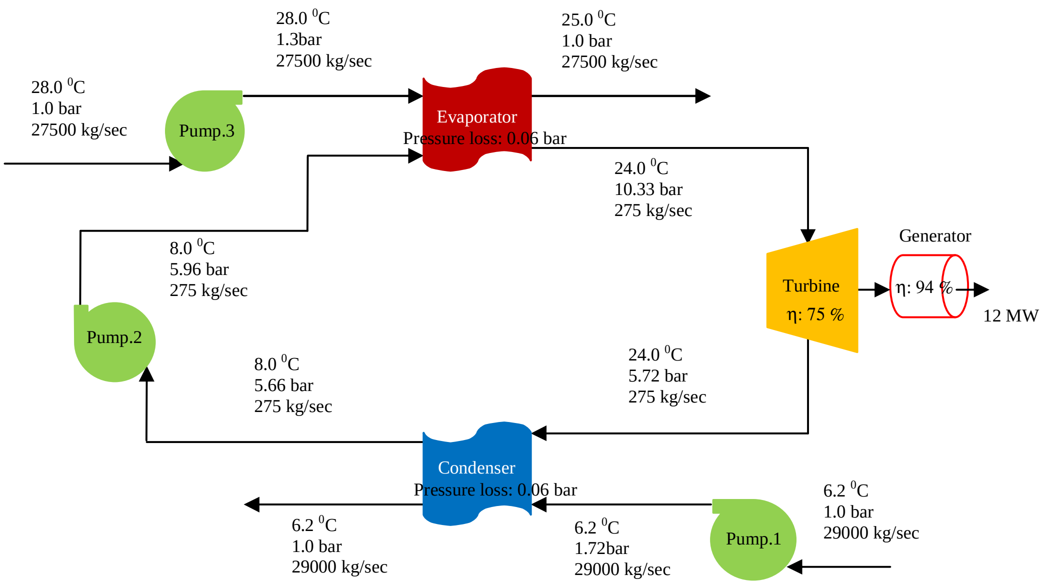

Figure 8: Detailed flow conditions for a single-stage 10 MW plant for Morotai Island, North Maluku-Indonesia.

3.3 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 ^{0}C.

Figure 9 shows diagram temperature (T) versus entropy (S) used to analyze performance of the cycle in Ocean Thermal Energy Conversion. Figure.8 shows closed cycle Ocean Thermal Energy Conversion Schematic.

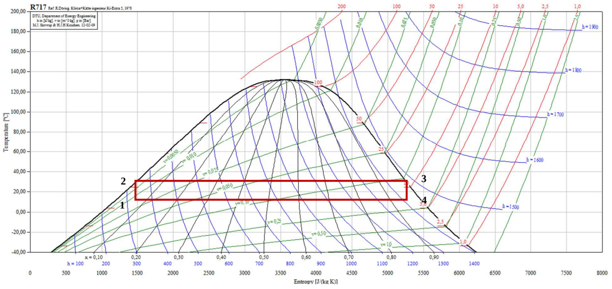

Figure 9: Diagram of temperature (T) versus entropy (S) of the cycle in OTEC.

Turbine work can be calculated using the following equation:

$$W_{Turbine} = h_3 - h_4 \quad (2)$$

Where; $h_{1,2,3,4}$ is enthalpy at points 1,2,3 and 4.

The pump work (W_{Pump}) can be calculated using the following equation:

$$W_{Pump} = v \cdot (P_2 - P_1) \quad (3)$$

Where; v is specific volume of the ammonia, P_2 is pressure at the boiler and P_1 is pressure at the condenser.

The work output (W_{net}) can be calculated using the following equation:

$$W_{net} = W_{Turbine} - W_{Pump} \quad (4)$$

Cycle Efficiency can be written as:

$$\eta_{Cycle} = \frac{W_T - W_P}{Q_H} \quad (5)$$

The enthalpy at point 2 can be written as:

$$h_2 = h_f + x_2 h_{fg} \quad (6)$$

Where; h_f is the saturated liquid enthalpy, h_{fg} is the enthalpy of vaporization and x_2 is the isentropic quality.

The isentropic quality can be written as:

$$x_2 = \frac{s - s_f}{s_{fg}} \quad (7)$$

Where; s_f is the saturated liquid entropy and s_{fg} is the entropy of vaporization.

The power output of the turbine can be calculated using the following equation

$$W_T = \dot{m}\,(h_1 - h_2) \quad (8)$$

Where; $\dot{m}$ is mass flow rate of the working fluid.

The pump power input (W_p) will be calculated along with the enthalpy at Point 4.

$$W_p = -v \cdot (P_4 - P_3) \quad (9)$$

Where; v is specific volume (m^3/kg), $P_{3,4}$ is pressure at point 3 and 4.

Total pump power input ($W_{Pump-Total}$) will be calculated along with the enthalpy at Point 4.

$$W_{Pump-Total} = -\dot{m}\,W_p \quad (10)$$

The heat supplied to the heat exchanger (q_h) can be written as:

$$q_h = h_1 - h_4 \quad (11)$$

Where; $h_1$is enthalpy at point 1.

$$h_4 = h_3 - W_p$$

The specific heat to the heat exchanger (Q_h) can be written as:

$$Q_h = \dot{m}\,q_h \quad (12)$$

The efficiency of the cycle can be calculated

$$\eta_{Cycle} = \frac{W_{net}}{Q_H} \quad (13)$$

3.4 Simulation Results and Analysis

Figures 10-11 show simulation results of OTEC performance to generate 10 MW plant of electrical power in Morotai Island North-Maluku, Indonesia using Subsea Pro. The simulation was based on following assumptions (yellow color):

- Energy consumption is assumed 1 ampere per person
- 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 ^{0}C
- The outlet surface and deep sea water temperatures were set up 25and 9 ^{0}C

- 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 ^{0}C, respectively. The mass flow rate of the working fluid was set up 275 kg/sec. The simulation results show the surface and deep seawater flow rates were founded 27000 and 29000 kg/sec.

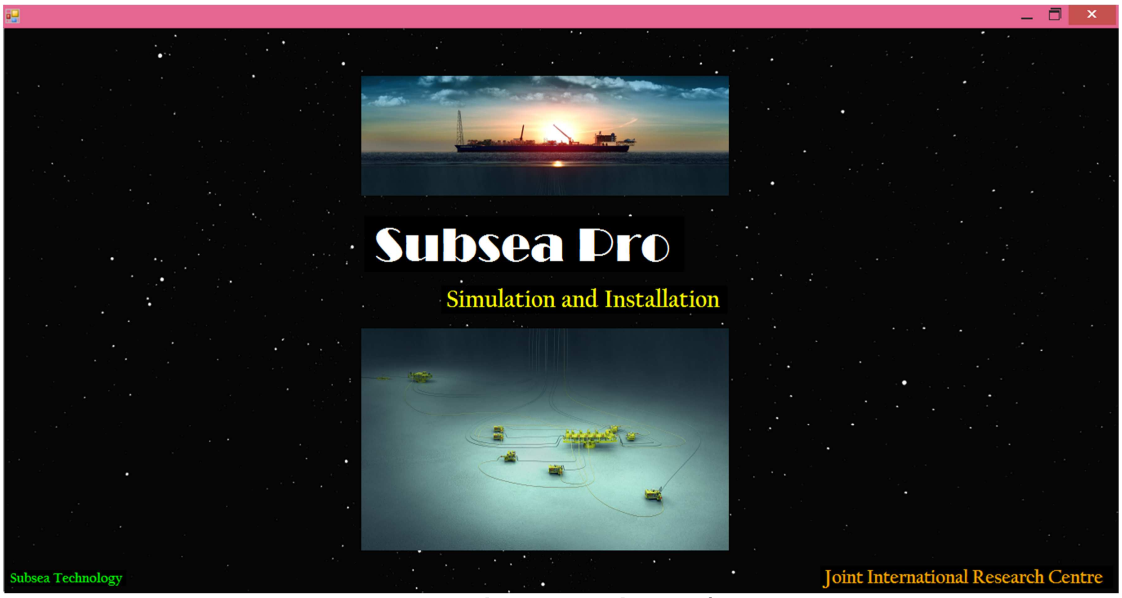

Figure 10: Subsea Pro Simulation Software.

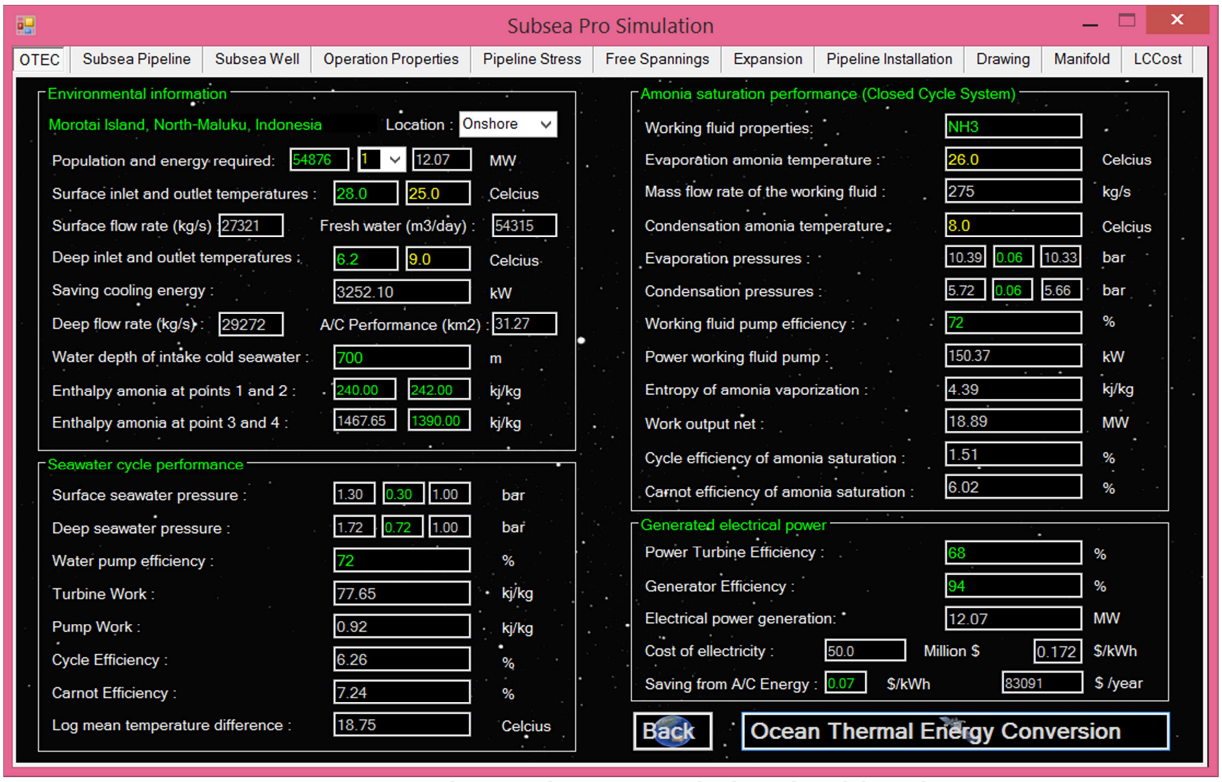

Figure 11: OTEC simulation results in Morotai Island, North-Maluku, Indonesia.

4.0 CONCLUSION

In conclusion, the results founded that Morotai Island, North-Maluku, Indonesia has gradient temperature more than 20 ^{0}C. It means they are suitable to install OTEC. 10 MW OTEC plant was possibly to be applied in Morotai Island, North-Maluku, Indonesia with flow rates of surface and deep seawater were 27500 and 29000 kg/sec, respectively.

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