Analysis of 100 kW ocean thermal power plant with butene as working fluid

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Abstract. As one of longest coastlines countries in the world where located in the tropical region, Indonesia has a prestigious potency of Ocean Thermal Energy Conversion (OTEC). In this paper, a study on working fluid of power plant generation based OTEC concept will be presented. Currently, ammonia is well known working fluid for OTEC applications. However, in this study it will be verified that the thermal efficiency of the OTEC can be improved significantly by adopting the Butene as the working fluid. Moreover, in term of mass flow rate, it needs only 4.21 kg/s of Butene to generate 100 kW output power.

1. Introduction

Due to economic growth, electricity demand in Indonesia significantly increases. By assuming economic growth of 6.2% per year, the realisation of electricity sales is projected to be 8.3% in term of average growth for next future 10 years [1]. Moreover, considering the facts that the fossil energy resources are unsustainable and their quantities continuously decrease, utilization of alternative energy resources, especially the renewable ones, is mandatory for supporting energy supplies in Indonesia.

Previous researches have proposed some alternative solutions based on renewable energy for electricity supply applications in Indonesia. Waste to Energy (WtS) can become one alternative solution to solve the municipal solid waste (MSW) problems and increase power generation supplies at the same time especially for some cities with MSW problems in Indonesia [2]. For some remote areas where due to their location, it is not possible to provide electrical power supply with conventional way, a hybrid system can be adopted to solve this problem [3]. The system consists of fuel cell and wind turbine to generate electricity for this kind of areas.

Regarding electricity supply, the Indonesia National Energy Policy states that the utilization of energy resources especially renewable energy shall be directed to utilization of geothermal energy, ocean wave and thermal energy, wind energy, and solar energy [1]. As tropical country with long coastlines, Indonesia has a prestigious of Ocean Thermal Energy Conversion (OTEC). However, this potency is still not well utilized as power generation in Indonesia. The basic principle of this power generation is based on the temperature difference between ocean surface water and ocean water at certain depth. Indonesia has 16 prospectus areas for OTEC application, such as coast of Bali, Jawa, North Sulawesi, East Kalimantan and Makassar Strait [4,5]. Figure 1 shows the surface ocean temperature in the world. Based on technical report, Indonesia has the theoretical potential of ocean thermal energy of 57 GW and 43 GW of practical potency [5]. However, this huge potency is still not well utilized and developed for alternative power generation in Indonesia. Thus, more advanced
researches in this area are needed to more explore the potency of ocean thermal and implement as alternative solution of electrical power supply in Indonesia.

This paper presents analysis of butene as the working fluid of OTEC-based power generation plant. The power plant is designed to generate 100 kW of electrical power output.

Figure 1. Temperature of ocean surface water contour in the world [6]

2. Ocean Thermal Power Conversion (OTEC)

Generally, the ocean thermal energy can be generated by ocean thermal difference between seabed and surface ocean water. The surface ocean water has a quite warm temperature due to solar radiation whereas the seabed temperature is very low as described in Figure 2. OTEC generates electricity by exploiting this temperature difference. For Indonesia, which is located in equator, the surface ocean water temperature should be much higher than other sub-tropical countries.

Figure 3 illustrates the basic principle of closed cycle OTEC system. The system has some main components as follows:

- Pumps
  These components are used to pump the warm water from the ocean surface to the evaporator, the cold water from the certain depth to the condenser, and also the working fluid from the condenser to the evaporator.
- Evaporator
  This component do the heat transfer work from the warm surface ocean water to the working fluid which has low boiling temperature point to generate the vaporous working fluid.
- Turbine
  The vaporous working fluid which has high enthalpy value will drive the turbine to drive the generator to generate the electrical power in output side.
- Condenser
  The condenser does the conversion of the working fluid from vaporous form to liquid form by utilizing the cold ocean water which is pumped from a certain ocean depth level.
3. Characteristics of Butene

Butene is an organic compound with general formula $\text{C}_4\text{H}_8$. At room temperature and atmospheric pressure, it is in gas phase form. Butene is colourless gas and has triple point temperature at -185.35 °C with normal boiling tar -6.31 °C. The critical point of butene is at temperature of 146.14 °C and pressure of 4.0051 MPa [8]. Figure 4 shows $T$-$S$ curve of butene at various pressure values.
4. System Modeling

To determine the system working points, a thermodynamic calculation was performed to obtain the thermodynamic properties in each point as illustrated in Figure 3. The input thermal power which used to convert the phase of working fluid from liquid phase form to gaseous form in evaporator can be formulated as follows

\[ Q_e = m_{ws} \times c_p \times (T_{ws-i} - T_{ws-o}) \]  

(1)

where \( Q_e \) is evaporator thermal power from warm ocean surface water, \( m_{ws} \) is mass flow rate of ocean surface water, \( c_p \) is heat transfer constant from ocean surface water to working fluid at inlet side of evaporator, \( T_{ws-i} \) is temperature of ocean surface water, and \( T_{ws-o} \) is temperature of ocean surface water at outlet side of evaporator.

Based on (1), the mass flow rate of the working fluid can be determined as follows

\[ m = \frac{Q_e}{h_1 - h_4} \]  

(2)

where \( m \) is working fluid mass flow rate, \( h_1 \) is enthalpy at point 1, and \( h_4 \) is enthalpy at point 4, as illustrated in Figure 3. The total output power can be obtained as follows

\[ W_{net} = W_t - W_p - W_{wsp} - W_{cwp} \]  

(3)

where \( W_{net} \) is net output power, \( W_t \) is generator output power, \( W_p \) is pumps power, \( W_{wsp} \) is power of surface water pump, dan \( W_{cwp} \) is cold water pump power.

5. Analysis Result

In this analysis, it is assumed that the working fluid can work in range of 4 °C to 29 °C. The properties values of cycle points are illustrated in Figure 5 and Figure 6. At inlet of the turbine, the working fluid temperature and pressure are 28 °C and 3.25 bar (0.325 MPa) with enthalpy of 434 kJ/kg, respectively. The enthalpy values of points 2, 3, and 4 are 409 kJ/kg, 27.1 kJ/kg and 27.4 kJ/kg.
respectively. In term of cycle thermal efficiency, this system has efficiency of 6.01%. The mass flow rate of the working fluid is 4.21 kg/s.

With the same output power and inlet turbine temperature condition, the system with the well know working fluid “ammonia” gives cycle thermal efficiency of 3.75% with working fluid mass flow rate of 5.31 kg/s. It is verified that by adopting butene as the working fluid the cycle thermal efficiency can be enhanced and the mass flow rate of the working fluid can be reduced. By reducing the mass flow rate, the dimension of piping can be reduced as well. The detail analysis of ammonia as working fluid of OTEC was presented in [9].

![Diagram](https://example.com/diagram.png)

**Figure 5.** Points properties

![Diagram](https://example.com/ts.png)

**Figure 6.** T-s curve
6. Conclusion
In this paper, butene as working fluid for OTEC application was analyzed. It was verified that the thermal efficiency of the OTEC can be improved significantly by adopting the butene as the working fluid. Moreover, in term of mass flow rate, it needs only 4.21 kg/s of butene to generate 100 kW output power with cycle thermal efficiency of 6.01%. It was verified that by adopting butene as working fluid of OTEC the cycle thermal efficiency can be enhanced and the mass flow rate can be reduced significantly.

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