The Influence of Ocean Thermal Energy Conversion System Efficiency on Net Power Output

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Abstract. Indonesia has great potential for utilizing Ocean Thermal Energy Conversion (OTEC) due to its strategic tropical conditions. This study analyzes the sensitivity of main parameters on the net power output of a 10 MW OTEC system based on the Organic Rankine Cycle (ORC) using Aspen Plus simulation. Variations on surface seawater temperature, deep seawater temperature, turbine efficiency, working fluid pump efficiency, and seawater pump efficiency were carried out. The simulation results show that turbine efficiency is the dominant factor, where an increase from 92% to 96% raised the net power from 9332 kW to 9958 kW. Seawater pump efficiency also gave a significant contribution by increasing the net power, while the working fluid pump efficiency only produced small improvement on the scale of tens of kilowatts. On the other hand, variations in warm and cold seawater temperatures had a limited effect. This happens because other parameters, such as mass flow rate of working fluid and seawater, were kept constant in the simulation, so temperature increase alone was not enough to influence system performance. These findings confirm that OTEC optimization is more effective through improving the efficiency of main components, especially the turbine and seawater pump.

1 Introduction

Indonesia holds significant potential for harnessing Ocean Thermal Energy Conversion (OTEC) as a source of clean, renewable energy due to its strategic geographical position as an equatorial country with vast ocean areas and thousands of islands [1]. OTEC produces power by utilizing the temperature difference between surface warm seawater and deep cold seawater, making it highly suitable for application in Indonesia [2]. Oceanic islands around the Banda Sea basin show promising prospects for OTEC development, which could contribute significantly to regional energy security. The geography of Ambon Bay also strongly supports the implementation of OTEC technology [3]. To generate power, OTEC

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employs the Organic Rankine Cycle (ORC) with low-boiling-point working fluids, which reduces internal power consumption and improves exergy efficiency, thereby enhancing the overall performance of the system [4][5].
The Rankine Cycle is a general principle of power generation that involves the evaporation of a working fluid in the evaporator, expansion in the expander to convert heat into work, followed by condensation and pumping to close the cycle.

Several sensitivity studies on OTEC have been carried out. Chen et al. [6] examined the effect of warm and cold sea water temperature pumping depth on thermodynamic and economic performance. Rasgianti et al. [7] studied the type of working fluid, heat exchanger performance, and installation location in North Bali. Tobal-Cupul et al. [8] analyzed a small-scale OTEC prototype in Mexico with parameters including temperature difference, thermal efficiency, mass flow rate, and power output.

However, these studies have not specifically highlighted the role of main component efficiencies on net power output. This research aims to address that gap by analyzing the effect of inlet temperature variations and the efficiency of Turbines, seawater pumps, and working fluid pumps on net power output through Aspen Plus simulations of a 10 MW OTEC system. The findings are expected to serve as a basis for design optimization, emphasizing the importance of main component efficiencies in improving OTEC performance and sustainability.

2 Methodology

2.1 Research Flowchart

The study began with a literature review to understand OTEC technology and the factors affecting its efficiency, followed by validation of a 10 MW OTEC system model using Aspen Plus based on previous studies. Once validated, the model was optimized to meet the target net power output. Afterwards, a sensitivity analysis was conducted to identify the most influential parameters. The varied parameters included surface seawater temperature, deep seawater temperature, working fluid pump efficiency, turbine efficiency, and seawater pump efficiency. Simulation results from Aspen Plus were then statistically analyzed to determine the dominant factors affecting net power output. The overall research flow is illustrated in Fig. 1.

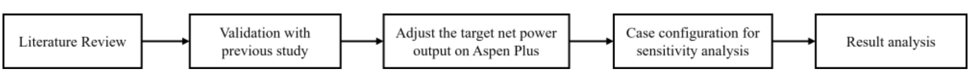

Fig. 1. Research Flowchart.

2.2 Research Validation

The validation of this study refers to the work of Rasgianti et al. [9], who developed an OTEC simulation model using Aspen Plus software with a target net power output of 10 MW. The simulation showed that the turbine produced more than 15 MW, causing the net power output to exceed the planned capacity. Therefore, in this study, input parameters were adjusted so that the system output would not exceed the capacity of the turbine used, which is 15 MW. The initial optimization results of the cycle with the adjusted net power output are presented in Fig. 2 with the details of the parameters presented in Table 1. The details of the adjusted parameters listed in Table 2.

Table 1. Parameter input for validation [9]

Parameters	Value	Parameters	Value
Warm seawater temperature	26 °C	Area of evaporator	41500 m^2
Cold seawater temperature	4.5 °C	Area of condenser	42500 m^2
Turbine efficiency	94 %	Mass flow rate working fluid	580 kg/s
Seawater pump efficiency	72 %	Mass flow rate warm sea water	50000 kg/s
Turbine efficiency	75 %	Mass flow rate cold sea water	28450 kg/s
Working fluid pump efficiency	72 %	Evaporator minimum approach temperature	1.2 °C
Thermal conductivity heat exchanger	4.693 $W/m^2.K$	Condenser minimum approach temperature	1 °C

Table 2. Adjustment of input parameters for the maximum gross power of the Turbine 15 MW

Parameters	Value
Warm seawater temperature	27 °C
Cold seawater t temperature	8 °C
Turbine efficiency	90 %
Seawater pump efficiency	90 %
Working fluid pump efficiency	90 %
Mass flow rate working fluid	415 kg/s
Mass flow rate cold seawater	40000 kg/s

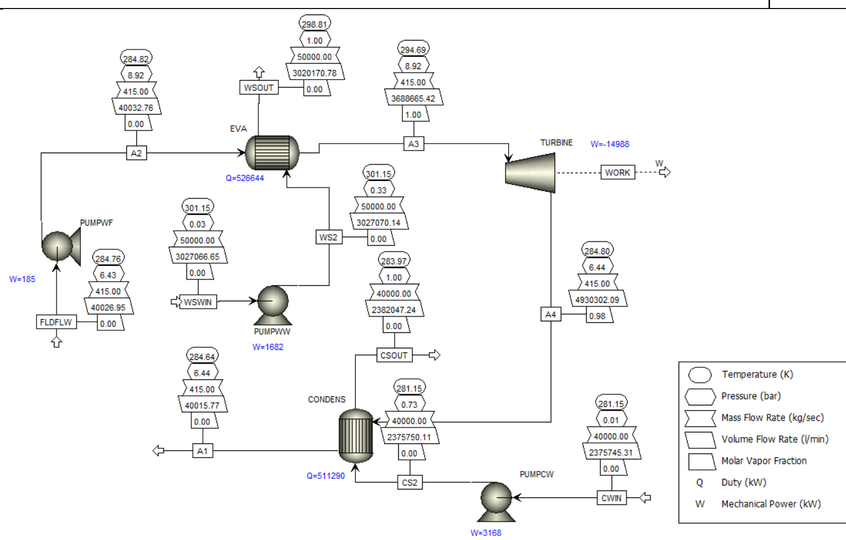

Fig. 2. Simulation of net power output target adjustment.

2.3 Case Configuration

The case configuration in this study focuses on varying parameters such as cold seawater temperature, warm seawater temperature, working fluid pump efficiency, turbine efficiency, and seawater pump efficiency. The initial values of each parameter were taken from efficiency data commonly used in previous studies, then a margin of ± 5% was applied to obtain the variation range. The warm seawater temperature was set based on surface seawater conditions during summer, ranging between 27–29 °C, while the cold seawater temperature was determined by the length or depth of the Cold Water Pipe. In this study, cold seawater temperature data were obtained from the HYCOM database for the Ambon waters, showing a range of 6–8 °C at depths of 500–800 meters. Meanwhile, the efficiency values of turbine, working fluid pump, and seawater pump were directly influenced by the technical specifications of the equipment used. The complete case configuration parameters are presented in Table 3, with variations derived from literature studies, including a turbine efficiency of 90% as reported by Romero et al. [10] All parameters were varied in a crosscombination manner, resulting in a total of 243 simulation cases, with the main output being the net power output of the OTEC cycle. The objective of this case study is to identify the most influential parameter and analyze the trends of parameter variations under three conditions: high (maximum values), medium (intermediate values), and low (minimum values), which are then compared with the resulting net power output.

Table 3. Main parameters case configuration.

Warm water temperature	Cold water temperature	Turbine efficiency	Working fluid pump efficiency	Sea water pump efficiency	Symbol
29 °C	8 °C	90 %	90 %	90 %	High
28 °C	7 °C	85 %	85 %	85 %	Med
27 °C	6 °C	80 %	80 %	80 %	Low

3 Result and Discussion

Through a sensitivity analysis involving 243 case configurations, the study determined the parameters that have the strongest impact on net power output. The simulation data were then processed using regression analysis, and the obtained regression coefficients are shown in Fig. 3. The result indicates that turbine efficiency has the highest regression coefficient, at 16660.76, followed by seawater pump efficiency at 6057.42, and working fluid pump efficiency at 230.76. Meanwhile, warm and cold seawater inlet temperatures have the lowest regression coefficients. These coefficients represent the level of influence of each parameter on the net power output based on the sensitivity analysis.

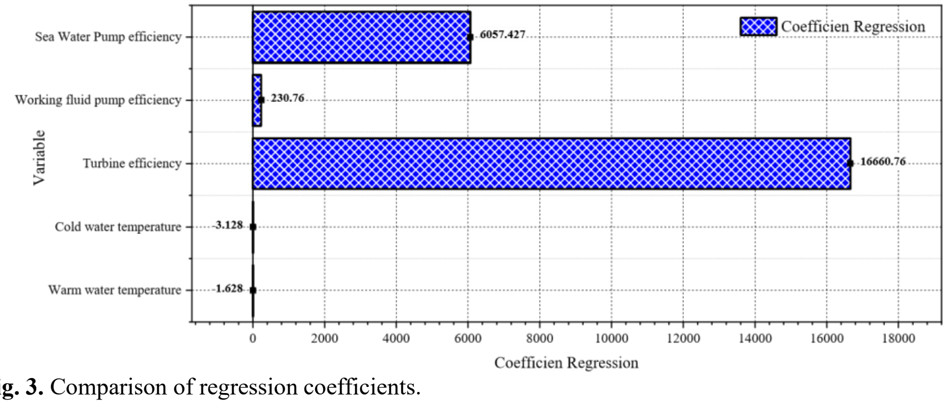

Fig. 3. Comparison of regression coefficients.

In this study, turbine efficiency was identified as the most influential parameter affecting the net power output of the OTEC system. Conceptually, this result contrasts with the conventional understanding of OTEC performance, in which the temperature differential between warm and cold seawater is typically regarded as the primary determinant of power generation, as a larger temperature difference is expected to yield higher net power output under optimal operating conditions [11]. The divergence observed in this work arises from the methodological approach adopted, wherein parameters such as mass flow rate and other related variables were held constant. Consequently, although variations in warm and cold seawater inlet temperatures were introduced, their impact on net power output remained limited, primarily influencing the pumping power requirements rather than the turbine output. This controlled approach was intentionally employed to enable a more rigorous and direct comparison of the relative influence of each parameter examined in the sensitivity analysis.

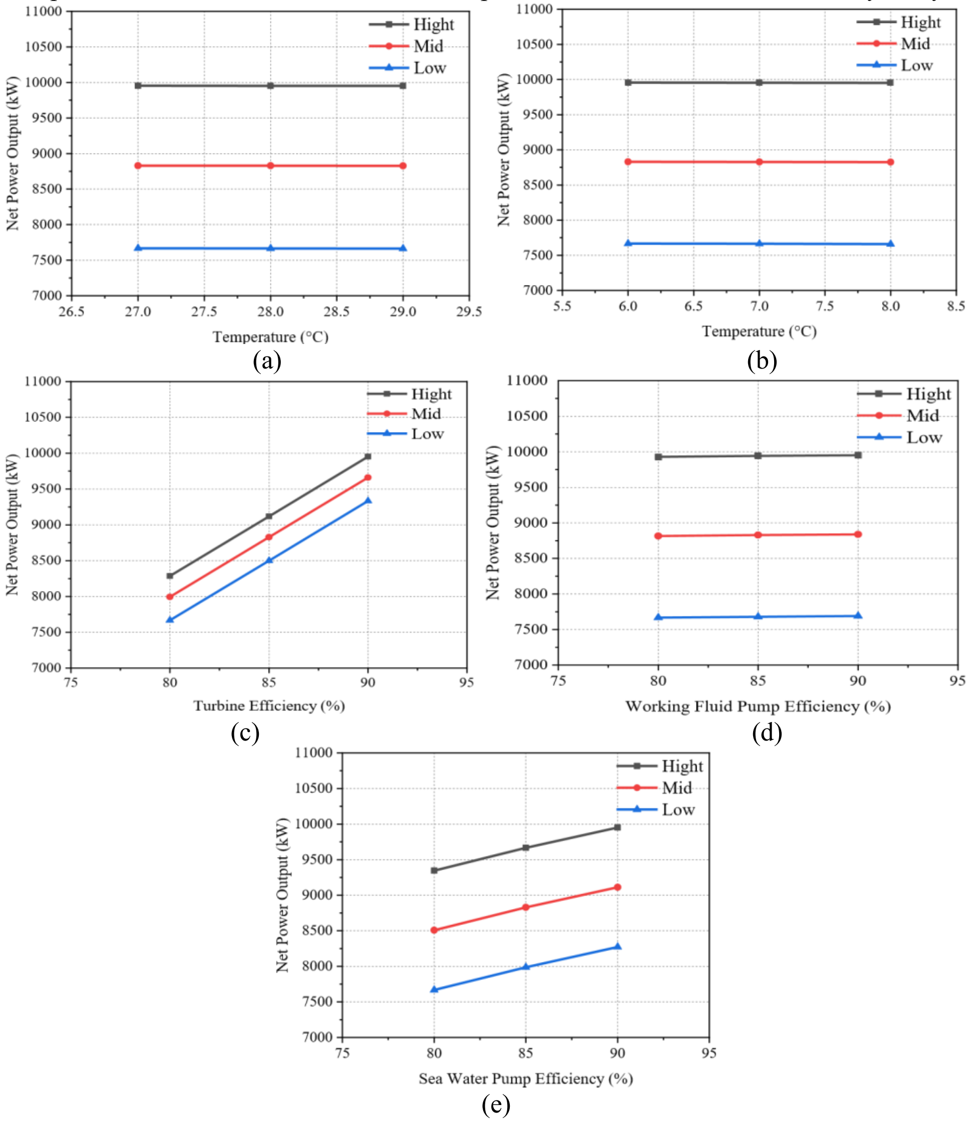

Fig. 4. Effect of parameter variations on net output power (a) Warm water temperature (b) Cold water temperature (c) Turbine efficiency (d) Working fluid pump efficiency (e) Sea water pump efficiency

Fig. 4(a) shows the effect of warm seawater temperature variation on net power output. The simulation results indicate that the difference in net power output for each temperature variation is relatively small. There is a tendency that a decrease in warm seawater temperature contributes to an increase in net power output. This occurs because the lower the warm seawater temperature, the smaller the power demand of the cold seawater pump, which reduces parasitic power from the warm seawater pump, thus increasing the net power output. By keeping the mass flow rate of warm seawater and working fluid constant, temperature variation does not significantly affect net power output but mainly influences pump power demand.

A similar trend is observed for cold seawater temperatures as shown in Fig. 4(b), where decreasing the temperature from 8 °C to 6 °C increases net power output. This increase is not purely due to a larger ΔT, but rather because of the reduced power demand of the cold seawater pump, which raises net power. This shows that single-parameter temperature variation is not always consistent with classical ΔT theory; therefore, OTEC optimization requires a multi-parameter approach that considers mass balance and system losses.

Fig. 4(c) shows that turbine efficiency has a dominant influence on net power output. Under high conditions, an increase in efficiency from 80% to 90% raised the output from 8286 kW to 9952 kW. This corresponds to an increase of about 20.1% net power output. This improvement occurs because energy losses in the mechanical–electrical conversion are reduced, allowing a larger proportion of energy to be effectively utilized. A higher generator efficiency allows a greater proportion of the mechanical power produced by the turbine to be converted into electricity with minimal losses, thereby directly increasing the net output.

The effect of working fluid pump efficiency is shown in Fig. 5(d). Although positive trend is observed, its influence is relatively small. Under low conditions, increasing efficiency from 80% to 90% only increased power from 7667 kW to 7690 kW (0.3% increase). This indicates that while higher working fluid pump efficiency reduces power demand, its impact on system output remains limited compared to the Turbine. On the other hand, seawater pump efficiency makes a significant contribution, as shown in Fig. 5(e). Under high conditions, raising efficiency from 80% to 90% increased power from 9345 kW to 9952 kW. This equals an increase of approximately 6.5%. Similar trends were also observed under mid and low conditions. This confirms that seawater pump efficiency strongly affects the system because seawater pumps consume a large fraction of the parasitic load. Improving their efficiency significantly reduces pumping power requirements, which translates into a considerable gain in net power output compared to other auxiliary components.

4 Conclusion

According to the results of the sensitivity analysis simulation on OTEC system efficiency, turbine efficiency was found to be the most dominant factor in determining the net power output of the Organic Rankine Cycle (ORC)-based OTEC. Increasing efficiency from 80% to 90% raised the net output from 8286 kW to 9952 kW (increase 20.1%), while seawater pump efficiency also showed a significant effect, with an increase from 9345 kW to 9952 kW within the 80–90% range. In contrast, the influence of the working fluid pump efficiency was relatively small, within the same efficiency range. Variations in warm and cold seawater temperatures had a limited impact because other parameters were kept constant. Therefore, improving the efficiency of main components, particularly the Turbine and seawater pump, proved to be more effective than relying solely on seawater temperature variations to optimize OTEC performance under conditions where other input parameters are considered constant.

The authors gratefully acknowledge support from the Institut Teknologi Sepuluh Nopember for this work, under project scheme of the Publication Writing and IPR Incentive Program (PPHKI).

References

1. M. Mukthasor, A. I. Firmansyah, D. Satrio, S. Rahmawati, R. Shadiq, and O. Yaakob, On Assessing a Potential Reuse of the Indonesian Post-Operation Offshore Oil/Gas Pipelines as A Cold-Water Pipe for an Ocean Thermal Energy Conversion (OTEC) System: A Thermal and Fluid Dynamic Perspective. J. Adv. Res. Fluid Mech. Therm. Sci. **123**, 53 (2024). https://doi.org/10.37934/arfmts.123.1.5368.
2. P. W. Adie, R. Adiputra, A. R. Prabowo, E. Erwandi, T. Muttaqie, N. Muhayat, and N. Huda, Assessment of the OTEC cold water pipe design under bending loading: A benchmarking and parametric study using finite element approach. J. Mech. Behav. Mater. **32**, (2023). https://doi.org/10.1515/jmbm-2022-0298.
3. G. G. Salamena, J. Martín, S. Likumahua, F. Kainama, D. D. Pelasula, I. S. Nurhati, Internal tidal dynamics and associated processes at highly supercritical slopes in Banda Sea: Lessons from the oceanic island of Ambon, eastern Indonesia. J. Mar. Syst. **246**, (2024). https://doi.org/10.1016/j.jmarsys.2024.104020.
4. R. Adiputra and T. Utsunomiya, Design Optimization of Floating Structure for a 100 MW-Net Ocean Thermal Energy Conversion (OTEC) Power Plant. in Vol. 10 Ocean Renew. Energy, American Society of Mechanical Engineers, 17 June (2018).
5. A. I. Firmansyah, Mukhtasor, D. Satrio, S. Rahmawati, H. Ikhwani, and W. A. Pratikto, A study of the temperature distribution in the OTEC cold water pipe using a heat and mass transfer approach. IOP Conf. Ser. Earth Environ. Sci. 1372, 012018, Ho Chi Minh City, Vietnam, 10 – 13 December (2024).
6. C. Fan, Y. Chen, Design Optimization of Ocean Thermal Energy Conversion (OTEC) Considering the Off-Design Condition. J. Therm. Sci. **32**, 2126 (2023). https://link.springer.com/10.1007/s11630-023-1884-x
7. Rasgianti, R. Adiputra, A. D. Nugraha, R. B. Sitanggang, W. W. Pandoe, . Aprijanto, T. Yasunaga, M. A. Santosa, System Parameters Sensitivity Analysis of Ocean Thermal Energy Conversion. Emerg. Sci. J. **8**, 428 (2024). https://doi.org/10.28991/esj-2024-0802-04.
8. J. G. Tobal-Cupul, E. Cerezo-Acevedo, Y. Y. Arriola-Gil, H. F. Gomez-Garcia, and V. M. Romero-Medina, Sensitivity Analysis of OTEC-CC-MX-1 kWe Plant Prototype. Energies **14**, 2585 (2021). https://doi.org/10.3390/en14092585
9. Rasgianti, R. Adiputra, R. B. Sitanggang, N. Puryantini, and N. Firdaus, Ocean Thermal Energy Conversions (OTEC) Working Fluid Comparison Based on the Numerical and Analytical Analysis, in 2024 Int. Conf. Technol. Policy Energy Electr. Power, IEEE, Bali, Indonesia, September (2024), pp. 222–227.
10. I. M. Hernández-Romero, V. M. Zavala, A. Flores-Tlacuahuac, F. Nápoles-Rivera, L. F. Fuentes-Cortés, and G. G. Esquivel-Patiño, Multi-objective optimization of an opencycle, ocean thermal energy conversion system with desalinization. Chem. Eng. Process.
- Process Intensif. **179**, 109091 (2022). https://doi.org/10.1016/j.cep.2022.109091
11. A. Ghaedi, R. Sedaghati, M. Mahmoudian, E. M. G. Rodrigues, R. Godina, Reliability assessment of the ocean thermal energy conversion systems through Monte Carlo simulation considering outside temperature variation. J. Mar. Sci. Technol. **29**, 36 (2024). https://doi.org/10.1007/s00773-023-00967-0.