SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

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

Mukhtasor[1], Arfie Ikhsan Firmansyah[1,2,*], Dendy Satrio[1], Shade Rahmawati[1], Rehan Shadiq[3], Omar Yaakob[4]

[1] Department of Ocean Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia
[2] Research Centre for Energy Conversion and Conservation (PRKKE), National Research and Innovation Agency (BRIN), B. J. Habibie Science and Technology Park Bldg. 620, South Tangerang 15314, Province of Banten, Indonesia
[3] School of Engineering, University of British Columbia, Okanagan Campus, 1137 Alumni Avenue, Kelowna, BC, Canada
[4] Faculty of Mechanical Engineering and Marine Technology Centre, Universiti Teknologi Malaysia, Malaysia

ARTICLE INFO

Article history:
Received 7 June 2024
Received in revised form 30 September 2024
Accepted 12 October 2024
Available online 30 October 2024

Keywords:
Decommissioning; offshore platforms; OTEC; CWP; CFD simulation; renewable energy; energy transition; ocean energy

ABSTRACT

One of the main issues arising in offshore oil and gas decommissioning is associated with significant required costs. Research assessing the potential reuse of the post-operation offshore oil and gas pipeline (POGP) in Indonesia for the Ocean Thermal Energy Conversion (OTEC) system offer double the potential cost reductions in POGP decommissioning and OTEC development. In the context of OTEC development, research on increasing system efficiency makes a significant effort by modifying working fluids and usually by employing the assumption that the temperature of the cold seawater at the surface outlet of the Cold-Water Pipe (CWP) is practically the same as that at the inlet of the CWP at a depth of about 900 m. Unfortunately, this was not the case when the POGP was to be reused for the OTEC system because there was difficulty in applying additional insulation to the existing subsea pipelines. The temperature change in the cold seawater is even more critical considering that oil and gas operations at a depth of 900 m could be associated with more than 60 km of pipeline length to reach an onshore system for a typical seabed bathymetry. This paper assesses the potential reuse of the POGP as a CWP for the Ocean OTEC system. The temperature distribution within CWP is analyzed using a thermal and fluid dynamics approach. The results show that the reuse of POGP for the OTEC system could offer an excellent opportunity for capital cost reductions because the POGP has a remaining service life of over 20 years. However, the results of the analysis of heat and mass transfers show that the temperature change in cold seawater at CWP is about 3 to 6 °C, depending on the technical scenarios of the pipelines. The POGP used in the OTEC system could be suitable for a 20 kW OTEC system with practically no cost of pipelines, which usually accounts for a significant investment cost.

---

[*] *Corresponding author.*
E-mail address: arfi004@brin.go.id

https://doi.org/10.37934/arfmts.123.1.5368

1. Introduction

Alongside increasing use of renewable energy, the annual energy consumption of petroleum in Indonesia is steadily rising, and it is projected to reach 496,090,105 Barrels of Oil Equivalent (BOE) in 2021 [1]. The Indonesian Government is actively pursuing methods to meet its petroleum needs, including independent exploration and exploitation of petroleum reserves through national or multinational business entities. The map (Figure 1) illustrates the allocation of the Indonesian Government's endeavors as indicated by the distribution of exploration wells in Indonesia, suggesting that offshore oil/gas activities play significant roles.

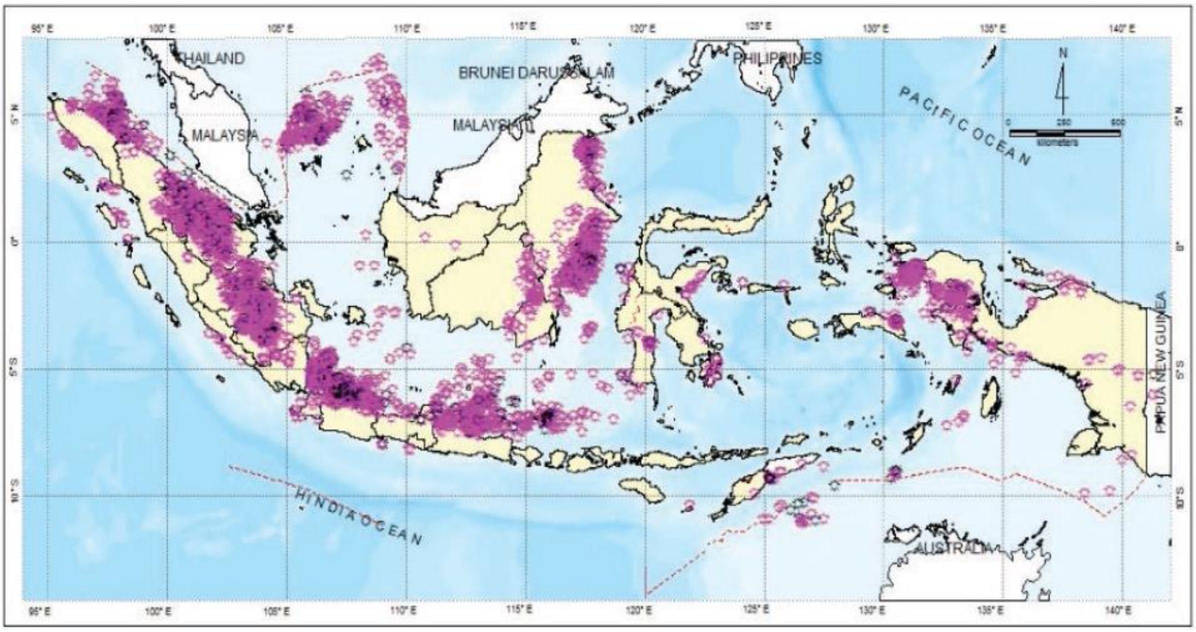


Fig. 1. Exploration oil/gas well distribution map [2]

Offshore oil/gas exploration and production require infrastructure supporting the system, typically consisting of offshore platforms and associated facilities and pipelines. These platforms, associated facilities, and pipelines pose environmental and economic concerns from construction to operation and post-operation. Hundreds of oil/gas offshore platforms that have completed operations in Indonesia must be dismantled or decommissioned as required by the regulations [3,4].

High decommissioning costs become a significant obstacle for operators and the Indonesian government, where the price of dismantling a typical offshore platform facilities is estimated to reach about US$ 6 million - US$ 7 million [5]. In Indonesia, the decommissioning of oil and gas structires must be carried out based on Ministry of Energy and Mineral Resources (ESDM) Regulation No. 15/2018. This regulation define post-operation activities as a series of activities for dismantling equipment, installations and supporting facilities including permanent healthy closure, site restoration, and handling the disposal or transfer of equipment, installations, and facilities in oil and gas upstream business activities.

The offshore platforms constructed before 1994 did not require operators to prepare decommissioning costs during the production phase [6,7]. However, such decommissioning is needed to remove parts above the surface for components and equipment that are otherwise harmful to the environment and shipping traffic or to submerge parts that are safe for the environment, such as fish aggregating devices (FADs), etc. [8,9].

In this context, an innovative decommissioning approach may reduce costs, such as reusing the post-operation offshore oil/gas pipeline (POGP) [10]. This action can support energy transition as one of Ocean Energy type [11-13]. Furthermore, reusing such a POGP as a cold-water pipe (CWP) might result in less investment for an Ocean Thermal Energy Conversion (OTEC) system. According to research by Vega [14], the CWP forms about 13% of the investment cost in the OTEC system . Therefore, depending on a careful design and comprehensive feasibility study, this initiative could offer double the potential cost reductions in POGP decommissioning and OTEC development.

In the OTEC system, a CWP is a pipe used to draw cold seawater from the deep sea to the surface, either offshore or onshore, for thermodynamic processes in the power plant to produce electrical energy [15,16]. For a typical OTEC design, drawing 5 ^{o}C cold seawater from a depth of about 900 m requires a CWP longer than this depth because of the nature of bathymetry of the seabed from the point of the 900 m depth to the surface at the OTEC power plant onshore. In cases of reuse of the POGP, this length could typically be more than 60 km, during which the flow of the cold seawater in the CWP will gradually be exposed to the ambient temperature through the thickness of the pipe. Since the ambient temperature gets warmer as the water depth is closer to the seawater surface, the cold seawater in the CWP will theoretically be warmer as it moves from the deep sea to a distance closer to the surface at the onshore OTEC power plant.

For optimal efficiency, typical OTEC sytems are designed for temperature difference of 20 ^{o}C between the deep cold seawater and the sea surface [17,18]. For this reason, an analysis of the temperature distribution of the fluid in the CWP is required to obtain the temperature of the fluid mass flowing in the pipeline reaching the terminal at the OTEC power plant onshore. Therefore, one of the critical needs in the required feasibility study is to assess the temperature changes in the fluid flowing in CWP from the deep sea to the surface.

This assessment is even more critical considering that in the previous research on this related topic, the temperature distribution in CWP is usually regarded as insignificant and then neglected in the design of power plants using OTEC systems. This is because it is normally assumed that the the vertical CWP length is about 900 m or less for an offshore system, for which the temperature change within an insulated CWP may typically be less than 1 ^{o}C. However, no potential onshore OTEC sites in Indonesia has been identified requiring 900 m or less CWP length [19-21]. In fact, in cases of reuse of POGP, it is practically impossible to install insulation as usually required because the POGP has been on the seabed before reuse as a CWP.

The above conditions and the pipe length of 60 km or more have raised a question on how this may affect the temperature changes in the cold seawater in the CWP as well as the suitability of such cold seawater for the OTEC system. Therefore, this paper aims to assess the potential reuse of POGP as a CWP in an OTEC system by considering the temperature change in the cold seawater in the CWP to deliver a designed power capacity of an OTEC system. A heat and fluid dynamics approach using a Computational Fluid Dynamics (CFD) method was employed in the analysis, as shown in the following sections.

2. Data Analysis

2.1 The Case Under Consideration

2.1.1 Location of post-operation platform and pipeline

The location under consideration is in Makasar Strait, East Kalimantan Province, Indonesia. This was based on permits issued by the Indonesian Government through the Ministry ESDM and the Coordinating Ministry for Maritime Affairs and Investment on February 1, 2022, regarding decommissioning of platform production facilities by converting offshore oil and gas platforms into become artificial coral reefs. The post-operation facilities were dismantled in East Kalimantan in the Attaka-I, Attaka-UA, and Attaka-EB [22]. The permits give rise to opportunities for other oil and gas platform equipment reuse, such as for OTEC in the same area. The POGP ,located in West Seno, East Kalimantan, is used to transport il and gas to the Santan terminal managed by Indonesia Oil Company [23].

The depth of the sea influences the difference in surface temperature, and the temperature in the depths of the sea is greatly influenced by the local climate, which affects the duration of sunlight that is reflected and absorbed by seawater, resulting in the differences between temperature at the sea surface and at the sea bottom [24]. Based on this, secondary bathymetric data was collected for alternative research locations using GIS data issued by the British Oceanographic Data Center (BODC) in ASCII format. Using the Global Mapper application, the data was input as a map theme at alternative locations in East Kalimantan Waters. Figure 2 shows the bathymetry map of water depth at the oil and gas platform locations, at depth interval of 60 m. Alternative 2 (West Seno Block) has better potential because the oil and gas platform is located at a water depth of 900 m compared to other options 1 (Attaka I) and 3 (Attaka II), which are in shallow water ofless than 100 m. According to data from the Ministry of Energy and Mineral Resources, the cooperation contract at Alternative Location 2 will end on December 3, 2027 [25]. Due to the deep water at the site, Alternative 2 is believed to have a difference between the bottom and surface temperatures suitable for OTEC system.

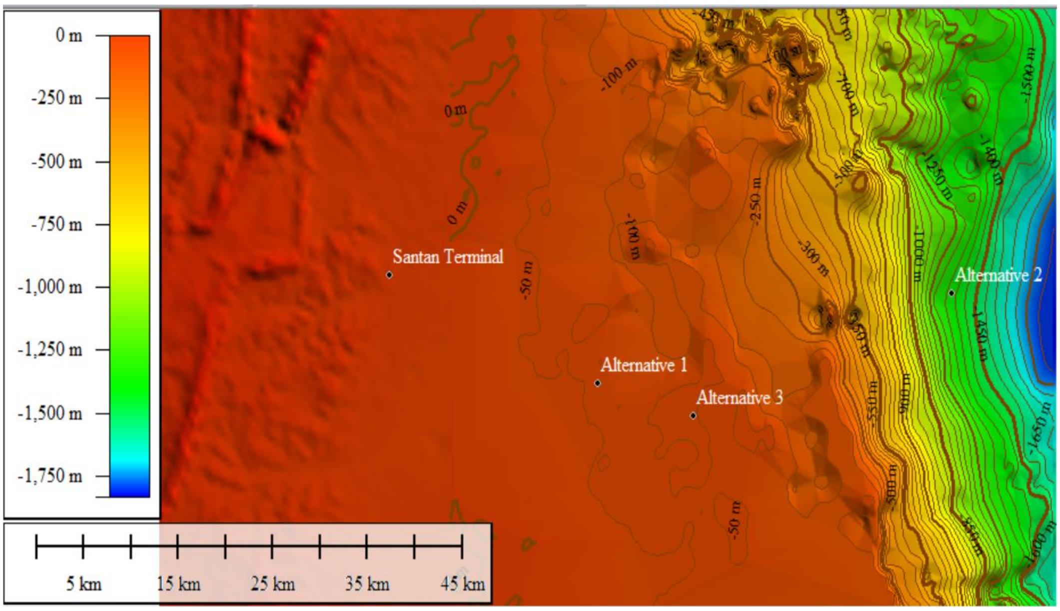


Fig. 2. Bathymetry of the research location

2.1.2 Temperature of deep seawater

Indonesia has a tropical climate that gets sunlight almost all year round, and the average surface seawater temperature is 27 to 31°C [24]. The depth-temperature profile in the North of Makassar Strait near alternative 2 (West Seno Block) location is shown in Figure 3 [26]. It shows temperature differences of more than 20°C between the surface and depth of 900m.

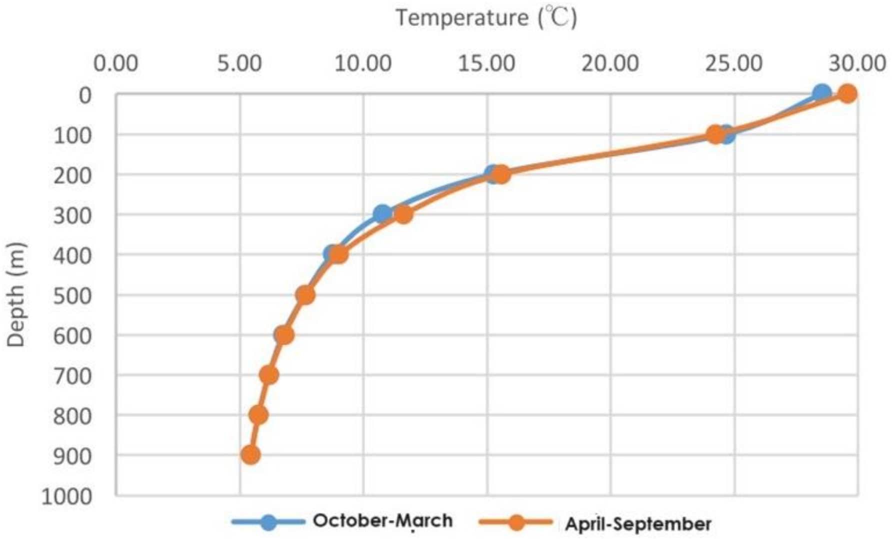


Fig. 3. Monthly Average Sea depth-temperatures profile in the North of Makassar Strait 2009-2018 [26]

The data in Figure 3 represents the recorded measurements of seawater depth and temperature collected using the conductivity, temperature, and depth (CTD) probe. From October to March, the average surface temperature was 28.5°C, while, the surface temperature is higher from April to September, with an average of 29.5°C. Different temperatures can happen because the west monsoon blows from October to April, namely when the sun's apparent position is in the southern hemisphere, while the east monsoon blows from April to October [26]. The temperature measured at a depth of 900 meters below the sea surface is almost constant at 5.1°C. This paper assumes that variations in CWP depth occur at a rate of 100 meters per unit of seawater depth, which subsequently affect changes in seawater temperature. The length of the CWP is divided into segments of 6000 m each, with a total of ten segments. This division is used to calculate the heat transfer in the water mass within the CWP using the seawater temperature [27].

2.2 Cold Water Pipe (CWP)

The material used in this research is a conventional 12-inch steel pipe commonly employed in the oil and gas industry, adhering to the API 5L specifications [23]. This study compares various pipe thicknesses based on the API 5L X52 pipe schedule. The subsequent information as shown in Table 1 outlines the specifications of the CWP material utilized in this paper:

Table 1
Specifications of material [28]

No	Parameter	API 5 L
1.	Mass Density	7840 Kg/ M^3
2.	Thermal Conductivity	42 W/ m.K
3.	Specific Heat	430 J/ Kg.K
4.	Outside Diameter	323.8 mm
5.	Thickness	Sch 80: 17. 48 mm; Sch 100 : 21.44mm; Sch 120 : 25.4 mm
6.	Yield Strength	360 Mpa
7.	Tensile Strength	460 Mpa

2.3 CWP Condition

Currently, the deep-sea oil and gas distribution pipeline that will be used as the CWP at alternative location 2 has been in operation for more than 20 years, starting from the year 2003 [29,30]. Based on the information, it is likely that the oil and gas distribution pipeline that will be used as the CWP has undergone degradation due to operational and environmental factors, one form of which is uniform/general corrosion. The inspection data from the oil and gas distribution pipeline at alternative location 2 in the year 2008 is presented in Table 2.

Table 2
Inspection pipe defect in Location of Alternative 2 in 2008 [31]

ID	Location	Pressure operation	Pipe defect depth (d)		Measured pipe defect length (Lm)
		(Mpa)	(%t)	(mm)	(mm)
IP-1	59500	15.86	6.34	1.11	59.5
IP-2	59420		7.14	1.25	80
IP-3	59380		4.51	0.79	40
IP-4	59250		9.48	1.66	130

3. Method

3.1 CWP Corrosion Rate and Remaining Life

The prediction of future pipe defects in order to estimate the remaining life of the pipe is obtained by using a consistent assessment of the corrosion rate (CR) [32]. Defect parameters at a particular time, such as the length and depth of corrosion, can be evaluated with the corrosion rate obtained on an annual basis in this study, calculated linearly [33]. In this study, the CR value is assumed to be constant each year. The corrosion rate value on the pipe is analyzed using Standard API 570 with Eq. (1) as follows [34,35]

$$Corrosion\ Rate\ (CR) = \frac{t_{initial} - t_{actual}}{time} \tag{1}$$

Where $t_{initial}$ is the pipe thickness at the time of initial installation (mm), t_{actual} is the pipe thickness at the time of inspection, and time is the duration of measurement between the installation of the pipe and the time of inspection (years).

The steps to estimate the remaining life of the pipe based on Standard API 570 begin with estimating the required thickness variable for the operating pipe (Thickness Required (t_r)) using Eq. (2), as follows [34,35]

$$t_r = \frac{P.D}{2.S.E} \tag{2}$$

P is the design pressure (MPa), D is the outside diameter of the pipe (mm), S is the allowable stress of the pipe (MPa), and E is the longitudinal weld efficiency. The next step is to estimate the Remaining Service Life (RSL) of the pipe using the following equation [34,35]

$$RSL = \frac{t_{initial} - t_r}{Corrotion\ rate} \tag{3}$$

3.2 Conceptual Design of Closed System OTEC

The OTEC system design uses a closed Rankine cycle, which utilizes a working fluid with a boiling point far below sea water, which can be used to rotate the turbine to move the generator to run the generator [36,37]. In this paper, the working fluid used is Ammonia (R717) because the heat transfer coefficient is high compared to other working fluids such as R134A, R245FA, R152, and R600A, to ensure optimal heat transfer on the condenser and the evaporator [38,39]. Designing the optimal working range of the working fluid using R717 needs to be done based on the operational temperature ladder of the OTEC system.

In Figure 4, the planned OTEC cycle is depicted, namely the working fluid in the pump to the heat exchanger (evaporator) to change phase with heat transfer (1), the working fluid which has changed phase from subcooled to saturation vapor and high temperature is used as a fluid to drive the turbine (2), the fluid that comes out of the turbine has changed phase due to a decrease in pressure and temperature into two phases is condensed to become a liquid (3) and the fluid that has become a saturated liquid from the condenser is increased by pressure with a pump to go to the evaporator (4) [40-42].

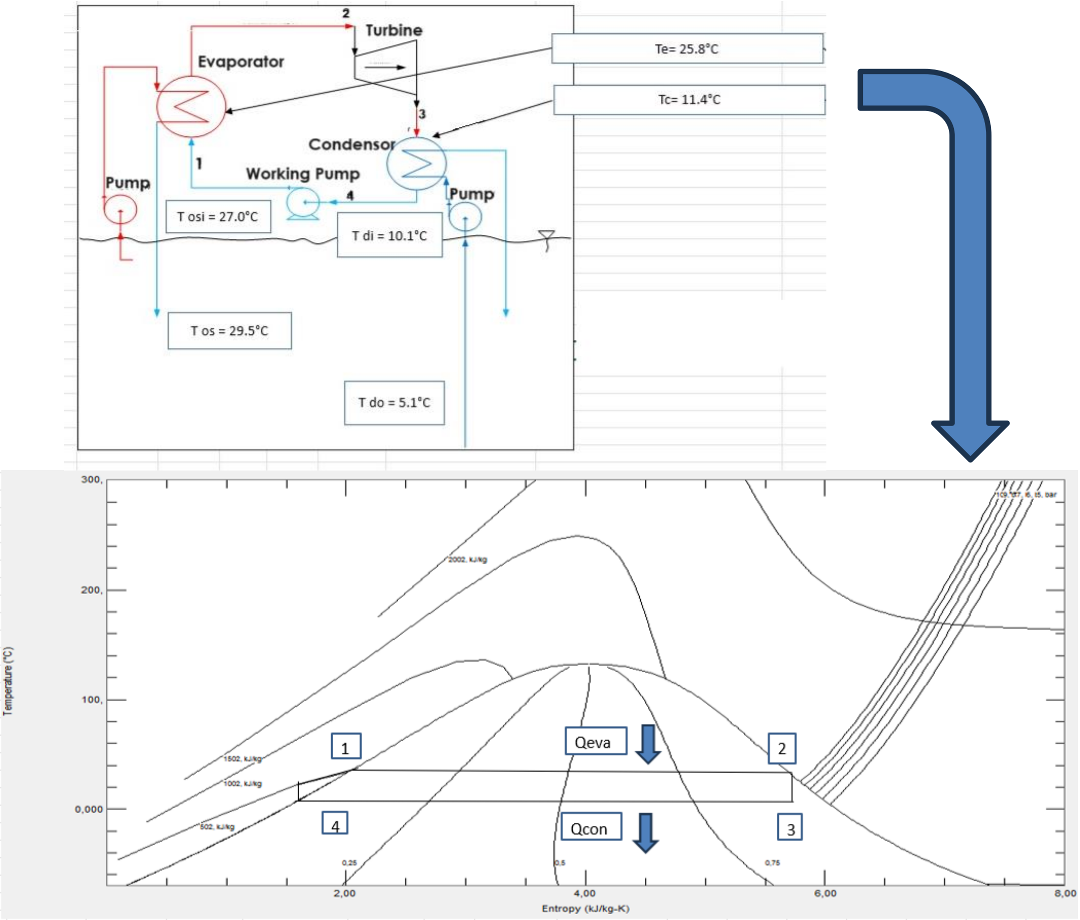


Fig. 4. Conceptual OTEC system using R717 working fluid

The first step of the design begins by calculating the maximum OTEC power using the following equation [36,37]

$$P_n = \frac{\rho c Q_{di} \varepsilon_{tg}}{8T_{osi}} \left(\frac{3\gamma(\triangle T)^2}{2(1+\gamma)} - 0.18\left(\triangle T_{design}\right)^2 - 0.12\left(\frac{\gamma}{2}\right)^{2.75}\left(\triangle T_{design}\right)^2 \right) \tag{4}$$

Where ρ is the density of seawater (1025 kg/m^3), c is the specific heat of seawater (4.1806 kJ/kg K), Ɛtg is the generator turbine efficiency (0.8), Q_{di} is the 12-inch schedule 40 CWP discharge, which is based on the continuity equation Qdi = A_{di}. V_{di} [43]. With pipe speed assumed to be 0.1 m/s, the discharge is 0.007 m^3/s, Tosi is the surface temperature minus the correction factor (27°C), γ is the ratio of warm water and cold water flow rates (±2), △T is the difference between warm water with a correction factor and cold water with a correction factor (16.9°C) and $\triangle T_{design}$ the difference between warm water with a correction factor and cold water with a correction factor (14.4 °C). The maximum power generated using a 12-inch CWP is ± 20 kW (Pn).

The second step of the design continues with knowing the working fluid flow requirements using the mass balance equation, as follows [44]

$$\dot{W}_{net} = \dot{m}_f\,(h_2 - h_3) - \dot{m}_f\,(h_1 - h_4)$$

$$\dot{m}_{wf} = \frac{\dot{W}_{net}}{(h_2-h_3) - (h_1-h_4)} \tag{5}$$

where $\dot{W}_{net}$ is the planned power generated by the OTEC system, which is a maximum power of 20 kW (Eq. (2)), based on Table 5, it can be determined that the value of h2 is the enthalpy in position 2, namely 1627,100 kJ/Kg, h_3, namely 1613,850 kJ/Kg, h_1, namely 481,753 kJ/ Kg and h_4 are 396,290 kJ/Kg. Based on Eq. (3), the design mass of the R717 working fluid ($\dot{m}_f$) Is 0.2 kg/s.

The design continues by determining the need for mass flow of deep-sea water using the following mass balance equation [44]

$$\dot{Q}_c = \dot{Q}_{di}$$

$$\dot{m}_f(h_3 - h_4) = \dot{m}_{di}.C.(T_{di} - T_c) \tag{6}$$

Based on Eq. (4), the design of seawater mass flow depth (m_{di}) is 45.4 kg/s.

The final step is to calculate the mass flow rate of surface seawater flowing in the warm temperature pipe using Eq. (5), as follows [44]

$$\dot{Q}_e = \dot{Q}_{0s}$$

$$\dot{m}_f(h_2 - h_1) = \dot{m}_{osi}.C.(T_{osi} - T_e) \tag{7}$$

Based on Eq. (4), the deep seawater mass flow (m_{OSI}) design is 46.26 kg/s.

3.3 CWP Heat Transfers Analysis in CWP

The objective of this study was to perform a comprehensive analysis of heat and mass transfer to collect data about the water temperature in the CWP. This analysis examined the fluctuations in water depth on the CWP surface, which subsequently impacted the temperature of the seawater flow within the CWP (Figure 5). The equations utilized in calculating heat and mass transfer phenomena are presented as follows [44]:

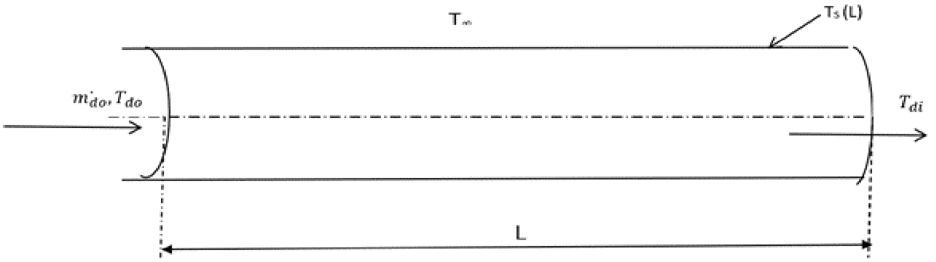


Fig. 5. Schematic of heat and mass transfer in CWP

$$\ddot{q}_s(L) = \frac{T_{di}-T_\infty}{\left[\frac{1}{h_x(L)}\right]+\left[\frac{1}{h_0}\right]} \quad (8)$$

where $\ddot{q}_s(L)$Is the heat flux along the pipe (w/m^2); Tdi is the temperature of the seawater flow in the pipe along the pipe (^{o}C); T∞ is sea water temperature (^{o}C); h_x(L) is the inside convection heat transfer at x=L and h_o is the convection heat transfer from seawater to the pipe surface. The equation used in calculating the h_x value is as follows

$$Re_d = \frac{4\dot{m}_{do}}{\pi D\mu} \quad (9)$$

$$Nu_D = 0.023Re_D^{4/5}Pr_d^{0.3} \quad (10)$$

$$h_x(L) = Nu_d\frac{k}{D} \quad (11)$$

where $Re_d$is the Reynolds number of the pipe; $\dot{m}_{do}$ is the fluid flow in the pipe (kg/s); D is the pipe diameter (m); μ is viscosity dynamics (N.s/m^2); Nu_DIs the Nusselt number of the pipe; Pr_d is the Prandtl Number of the pipe, and k is the thermal conductivity (W/m.K). The equation used to calculate the T_s (L) value is the temperature at the pipe surface (^{o}C), as follows

$$\ddot{q}_s(L) = \frac{T_{di}-T_s}{\frac{1}{h_x}(L)} \quad (12)$$

3.4 Computational Fluid Dynamics (CFD) Analysis

To carry out the CFD analysis, the CWP was divided into 10 segments to make numerical calculations easier [27]. The distance between location 2 in West Seno Block and the Santan terminal on Kalimantan Island, is 60000 m (60km) at a depth of 900 m. The CFD analysis carried out in this paper has assumed that the speed of seawater flow over the surface of the pipe is neglected.

CFD analysis is used to obtain seawater mass temperature values at the surface; the approach used is finite volume [45]. The equation used in the software solver to assist with calculations is the Navier-Stokes equation in the first law of thermodynamics, which calculates energy transfer, namely heat, thermodynamic work, and mass transfer [46]. The general equation used in the solver is as follows

$$\rho\left[\frac{\partial h}{\partial t}+\nabla.(hv)\right] = -\frac{\partial p}{\partial t}+\nabla.(k\nabla T)+\emptyset \quad (13)$$

$$\frac{\partial(E_T)}{\partial t}+(E_t.\nabla)=-p.\nabla u-\frac{1}{Re_dPr_d}\nabla q\left(\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right)+\frac{1}{Re_d}u.\nabla(u\tau_{xx}+u\tau_{xy}+u\tau_{xz}) \tag{14}$$

where ρ is the density of seawater (Kg/m^3); h is enthalpy (kJ/kg); t is time (s); p is pressure (atm); Et is total energy (watts); q is heat flux (w/m^2), and u is speed (m/s).

Discretizing the computational domain into a computational grid (or mesh) is essential for solving discretized fluid flow equations. A grid dependency analysis aims to achieve an independent grid solution. In a new study, the initial grid typically needs more resolution to capture the flow physics accurately. For this study, a low-resolution initial grid was created, and the same meshing scheme was used to generate higher-resolution grids. All simulations for the grid study were conducted using the CWP with material API5L X52 12 Inch Schedule 80 at a seawater temperature of 5.1°C, a mass flow rate of 45.4 kg/s, and a pressure of 1 bar. The results are presented in Table 3.

Table 3
Grid convergence study

No.	Resolution (cell)	Fluid Temp (K)
1	2,005,764	278.315
2	2,142,312	278,316
3	2,816,096	278.316

As shown in Table 3, the fluid temperature inside CWP between the first and third grids changes insignificantly after the second grid. As a result, the third grid with a resolution of 2,816,096 cells was selected as the base for all grids in this work.

4. Results and Discussion

The use of POGP as the CWP in the OTEC system requires a corrosion rate analysis to determine adequate pipe thickness. Additionally, a remaining life service analysis needs to be conducted to determine how long it can be used if utilized as the CWP in the OTEC system. Table 2 shows the average reduction in POGP thickness over five years due to a corrosion rate of 1.20 mm). The results of the CWP Corrosion Rate analysis using Eq. (1) show the corrosion rate over five years for each pipe with different thickness (pipe schedule) as presented in Table 4.

Table 4
Corrosion rate

POGP API 5 L X52	t (mm)	t-d (mm)	CR (mm)/ years
Sch.80	17.48	16.28	0.24
Sch.100	21.44	20.24	
Sch.120	25.4	24.2	

The Remaining Service Life (RSL) calculation of POGP considers the corrosion rate occurring in the pipe and calculates the remaining life of the pipe using Eq. (2) and Eq. (3). The calculation were made using baseline data from the inspection of oil and gas distribution pipes at alternative location 2 in 2008 with a working pressure in the pipe of 15.86 MPa, while the end of the calculation period is in 2027 [25,31]. The results are shown in Table 5. The RSL of POGP at alternative location 2 indicates that its use as the CWP in the OTEC system can last for more than 20 years, assuming the working pressure as the CWP does not exceed 15.86 MPa.

Table 5
Remaining Service Rate

POGP API5L X52	P (Mpa)	t_r (mm)	$t_{initial}$ (mm)	RSL (Years)
Sch.80	15.86	7.13	17.48	24
Sch.100			21.44	41
Sch.120			25.4	57

The design results of the OTEC power plant using POGP using Eq. (4) to Eq. (7) show that the theoretical power generated by API5L X52 pipes with an outer diameter of 12 inches is 20 kW. The mass of low-temperature deep sea water is 45.4 kg/s to change the phase of the R717 working fluid by 0.2 kg/s. Calculation verification was carried out using thermodynamics analysis software (Figure 6) and also the Korea Research Institute of Ships & Ocean Engineering (KRISO) 20 kW OTEC pilot plant, where a flow rate of 44.85 kg/s was required to produce power of 20 kW [47].

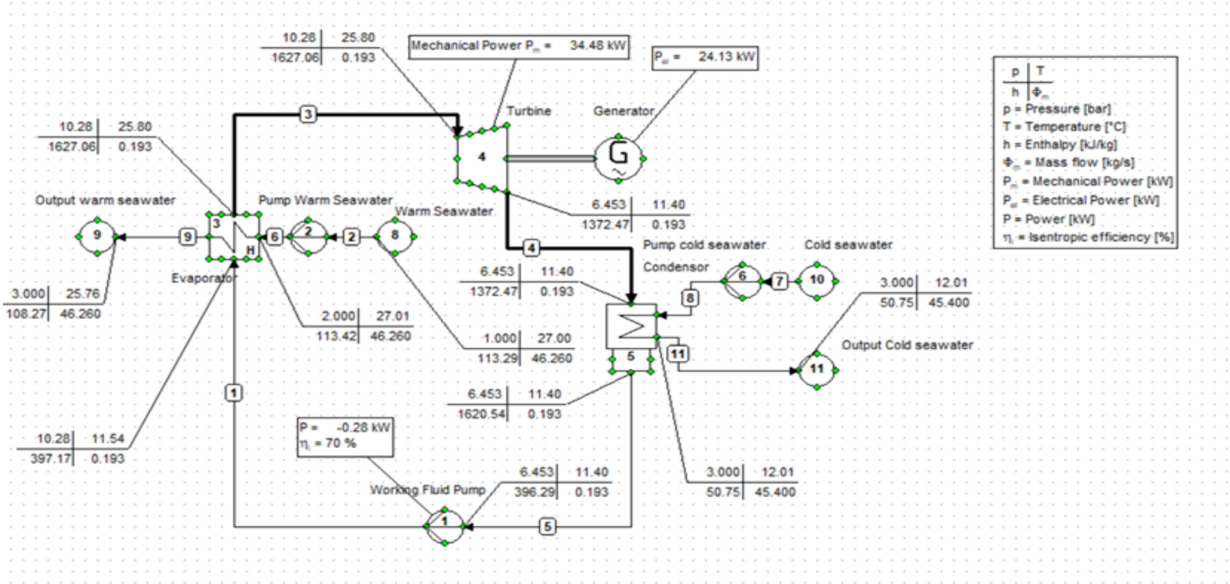


Fig. 6. Thermodynamics analysis of OTEC system

Heat transfer rate analysis on CWP using oil and gas distribution pipes was calculated using Eq. (8) to Eq. (12). The object of this analysis is to obtain the heat transfer rate in the distribution pipe, assuming that the CWP placement design is divided into ten segments; the CWP heat transfer rate results with mass flow 45.6 kg/s are shown in Figure 6. The mass flow rate in the CWP affects the heat transfer coefficient that occurs, where the mass flow rate in the CWP uses a Sch pipe. 40 has a smaller heat transfer coefficient than Sch 120. The above happened due to Sch. 80 being thinner than Sch. 120 (Table 2) with the same flow rate. Then, according to the law of continuity, the flow speed is higher [43]. Increasing the flow velocity in the CWP increases the heat transfer coefficient [46].

In Figure 7, CFD analysis shows that CWP using API5L x52 12-inch sch 40 pipe experiences the lowest temperature changes compared to pipes with other specifications because the heat transfer coefficient value of Sch 80 is smaller than that of various types of pipes (Table 1). The flow of cold deep-sea water with a mass flow rate of 45.4 kg/s along the 60 km distance to the Santan Terminal on the island of Kalimantan causes a temperature increase of between 3 °C – 6 °C for the 12-inch API5L X52 CWP (Figure 8 and Figure 9). The value of temperature changes due to heat and mass transfer has been verified using data on temperature changes in subsea distribution pipes in the oil and gas industry. The temperature changes occurring over a range of more than 60 km are significantly influenced by the flow rate of the fluid within the pipe. Distribution pipes generally maintain a constant temperature distribution. In addition to the pipe flow rate, the position of the oil pipe buried on the seabed also plays an essential role in ensuring heat transfer from the environment [48,49]. Based on the above information, these assumptions and analyses can be used primarily in designing CWPs for OTEC, which are built on land more than 60 km from potential ocean thermal locations.

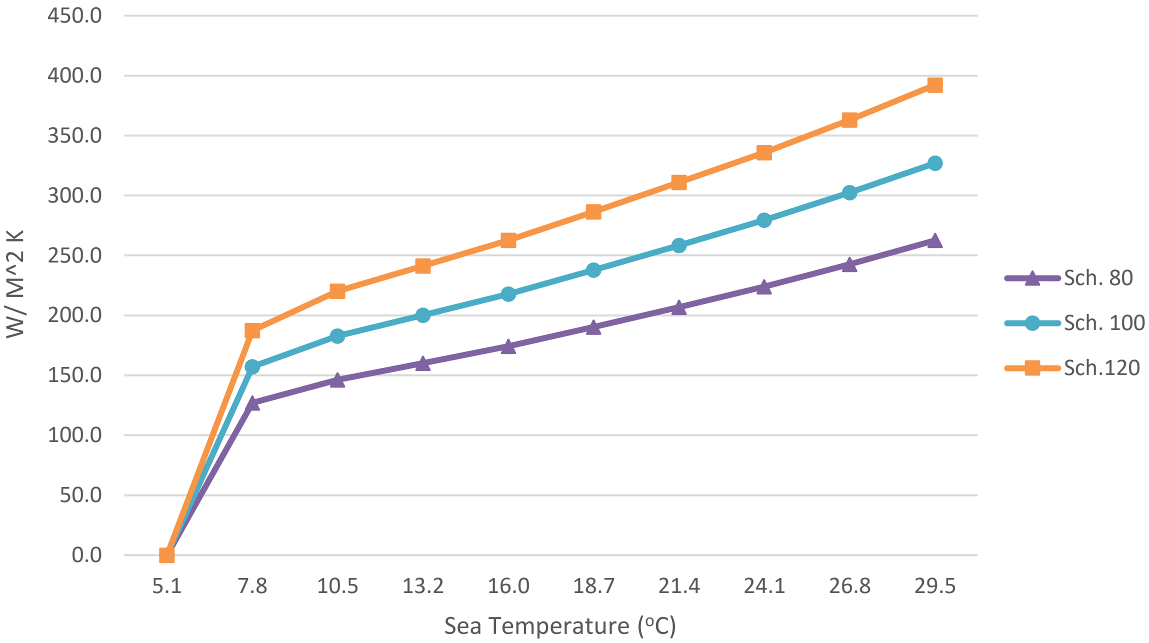


Fig. 7. Heat transfer coefficient in CWP

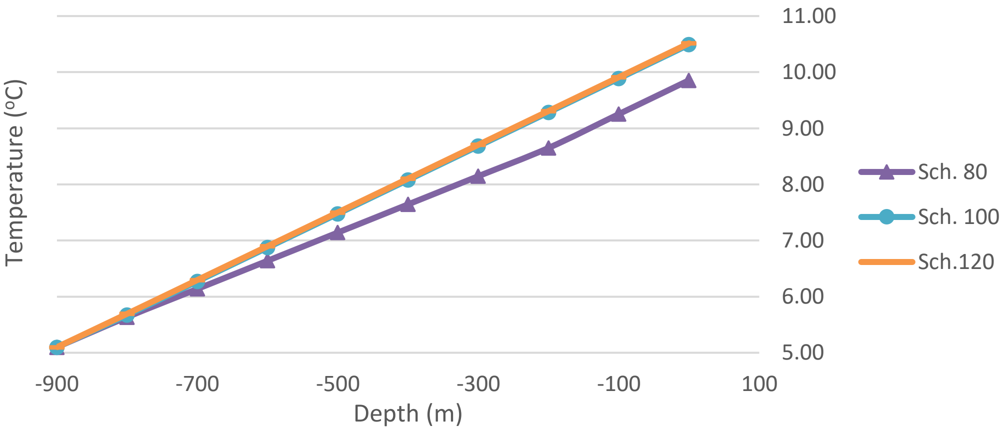
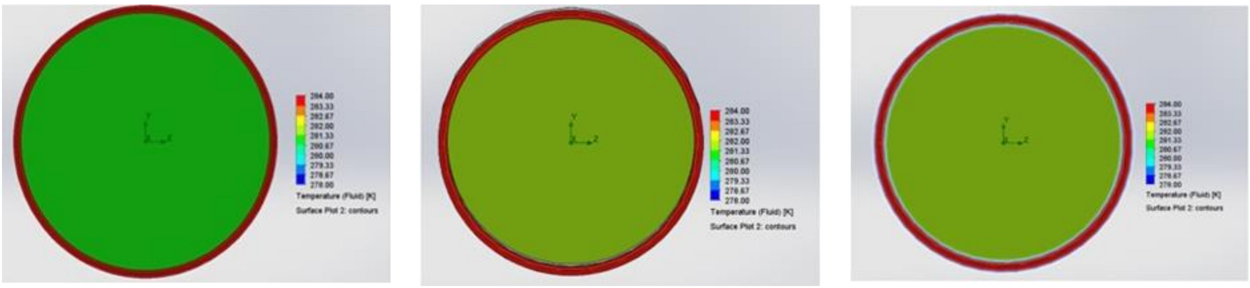


Fig. 8. Temperature of seawater inside CWP



(a) (b) (c)

Fig. 9. Temperature distribution in CWP at sea temperature 21.4°C; (a) Sch 80 (b) Sch 100 and (c) Sch 120

Temperature differences at the CWP output substantially impact the pressure and temperature of the working fluid used in the OTEC system. The increase in temperature influences the performance of the OTEC system in the condenser between the working fluid and the cooling medium [50,51]. The cold water temperature in the CWP is permitted to rise by less than 3°C to enable its use in condensing the working fluid in the condenser [52]. According to Figure 8, inaccurately estimating the temperature of the cooling fluid affects the pressure and temperature of the working fluid in the closed OTEC system [53,54]. Utilizing the Conceptual OTEC system (Figure 4) in the Sch variation of the API 5 L pipe resulted in a discrepancy in assumptions Table 6. Variations in the working fluid's design quantity lead to changes in pressure, temperature, and the mass flow requirements of the working fluid passing through the condenser. The selection of critical components in the OTEC system, including the turbine, condenser, working fluid pump, and evaporator, is significantly influenced by information about the temperature of the cooling medium.

Table 6
Comparison of simulation results and initial assumptions temperature in CWP on working fluid in the condenser

Variable	Assumed Working Fluid in Condenser [36]	Result of Thermal and Fluid Dynamics Simulation in Condenser		
		Sch. 80	Sch.100	Sch. 120
Temperature (°C)	11.4	10.9	11.6	11.6
Pressure (atm)	7.3	6.3	6.4	6.4
Enthalpy (kJ/kg)	1620.8	1613.4	1614.1	1614.1
Mass Flow (kg/s)	0.20	0.20	0.21	0.21

5. Conclusion

Thermal and fluid dynamics analyses for the cold seawater in the CWP of the OTEC system reusing POGP has been performed in this paper. The results show that the reuse of POGP for the OTEC system could offer an excellent opportunity for investment cost reductions because the POGP has a remaining service life of over 20 years for CWP. However, temperature changes in cold seawater temperature with POGP with no insulation are typically around 3 to 6 ^{O}C, depending on the technical scenarios of the POGP. In this case, this system may deliver a power capacity of around 20 kW of OTEC systems without an investment in the CWP. Reusing POGP for OTEC systems may offer an excellent opportunity for cost reductions in the OTEC investment and the decommissioning cost. For more definitive decision-making, the reuse of POGP as a CWP in an OTEC system requires a more comprehensive assessment, including, among others, assessing the strength and remaining useful life of the POGP.

Acknowledgments

The authors are grateful to the Ministry of Education, Culture, Research, and Technology Indonesia and The Sepuluh Nopember Institute of Technology (ITS) for fully funding this study through grant contract numbers 1950/PKS/ITS/2023. The authors also thank Dwi Purnomo Hendradhata for supporting the research.

References

[1] Ministry of Energy and Mineral Resources. "Handbook of Energy and Economic Statistics of Indonesia 2022." *Ministry of Energy and Mineral Resources, Republic of Indonesia*, 2023.

[2] Direktorat Jenderal Minyak dan Gas Bumi. "Laporan Tahunan: Capaian Pembangunan 2018." *Direktorat Jenderal Minyak dan Gas Bumi*, 2018.

[3] Ridwan, Muhammad. "Pembongkaran Anjungan Migas, Skema Cost Recovery Bisa Jadi Opsi." *Bisnis Indonesia*. March 24, 2021.

[4] Umah, Anisatul. "Heboh 100 Anjungan Migas RI 'Nganggur', Ternyata Ini Sebabnya." *CNBC Indonesia*. March 24, 2021.

[5] Lidyana, Vadhia. "Butuh Rp 300 M Benahi 3 Anjungan Offshore yang Nganggur." *DetikFinance*. March 23, 2021.

[6] Ridwan, Muhammad. "Rencana Pembongkaran 100 Anjungan Migas Terkendala Masalah Dana." *Bisnis Indonesia*. March 23, 2021.

[7] Fajar, Taufik. "Miris! SKK Migas Sebut 100 Anjungan Migas Lepas Pantai Mangkrak." *IDX Channel*. March 23, 2021.

[8] Sommer, Brigitte, Ashley M. Fowler, Peter I. Macreadie, David A. Palandro, Azivy C. Aziz, and David J. Booth. "Decommissioning of offshore oil and gas structures-Environmental opportunities and challenges." *Science of the Total Environment* 658 (2019): 973-981. https://doi.org/10.1016/j.scitotenv.2018.12.193

[9] Bagheri, Mohammadsaeid, and Pedram Edalat. "A Knowledge Based Decommissioning Alternative Selection System for Fixed Offshore Oil and Gas Platforms in Persian Gulf." *International Journal of Coastal, Offshore And Environmental Engineering (IJCOE)* 3, no. 2 (2018): 45-55. https://doi.org/10.29252/ijcoe.2.2.45

[10] Firmansyah, A. I., 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." In *IOP Conference Series: Earth and Environmental Science*, vol. 1372, no. 1, p. 012018. IOP Publishing, 2024. https://doi.org/10.1088/17551315/1372/1/012018

[11] Kasharjanto, Afian, Dendy Satrio, Daif Rahuna, Eko Marta Suyanto, Cahyadi Sugeng Jati Mintarso, Zulis Irawanto, and Maulana Akbar Ramadhani. "Numerical Analysis of Resistance and Motions on Trimaran Floating Platform for Tidal Current Power Plant." *International Review on Modelling and Simulations* 17, no. 1 (2024): 6-16. https://doi.org/10.15866/iremos.v17i1.24366

[12] Satrio, Dendy, Hadian Bagas Widyawan, Maulana Akbar Ramadhani, and Maktum Muharja. "Effects of the distance ratio of circular flow disturbance on vertical-axis turbine performance: An experimental and numerical study." *Sustainable Energy Technologies and Assessments* 63 (2024): 103635. https://doi.org/10.1016/j.seta.2024.103635

[13] Madi, Madi, Mukhtasor Mukhtasor, Dendy Satrio, Tuswan Tuswan, Abdi Ismail, Risfihan Rafi, Putty Yunesti, Setiadi Wira Buana, and Jarwinda Jarwinda. "Experimental Study on the Effect of Foil Guide Vane on the Performance of a Straight-Blade Vertical Axis Ocean Current Turbine." *NAŠE MORE: Znanstveni Časopis za More i Pomorstvo* 71, no. 1 (2024): 1-11. https://doi.org/10.17818/NM/2024/1.1

[14] Vega, Luis A. "Economics of ocean thermal energy conversion (OTEC): an update." In *Offshore Technology Conference*, pp. OTC-21016. OTC, 2010. https://doi.org/10.4043/21016-MS

[15] Brown, Martin G. "White Paper Ocean Thermal Energy Conversion (OTEC)." In *The Executive Committee of the IEA Ocean Energy Systems*. 2021.

[16] Hamedi, Amir-Sina, and Sadegh Sadeghzadeh. "Conceptual design of a 5 MW OTEC power plant in the Oman Sea." *Journal of Marine Engineering & Technology* 16, no. 2 (2017): 94-102. https://doi.org/10.1080/20464177.2017.1320839

[17] Dalil, Muhammad, Basuki Wirjosentono, Jaswar Koto, Dodi Sofyan Arief, and Abdulkhair Junaidi. "Effect of Sea Current to Composites Cold Water Pipeline of Ocean Thermal Energy Conversion in Indonesia." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 107, no. 2 (2023): 27-40. https://doi.org/10.37934/arfmts.107.2.2740

[18] Rajagopalan, Krishnakumar, and Gérard C. Nihous. "An assessment of global ocean thermal energy conversion resources with a high-resolution ocean general circulation model." *Journal of Energy Resources Technology* 135, no. 4 (2013): 041202. https://doi.org/10.1115/1.4023868

[19] Ilahude, Delyuzar, Ai Yuningsih, Yani Permanawati, Mira Yosi, Rina Zuraida, and N. Annisa. "Site determination for OTEC turbine installation of 100 MW capacity in North Bali Waters." *Bulletin of the Marine Geology* 35, no. 1 (2020). https://doi.org/10.32693/bomg.35.1.2020.594

[20] Andayani, Ni Komang Sri, Delyuzar Ilahude, Alfi Satriadi, and Purwanto Purwanto. "Studi Potensi OTEC Berdasarkan Distribusi Suhu, Salinitas dan Densitas di Perairan Timur-Utara Pulau Bali." *Indonesian Journal of Oceanography* 2, no. 4 (2020): 386-395. https://doi.org/10.14710/ijoce.v2i4.9346

[21] Mukthasor, Mukthasor. "Pengembangan Energi Laut di Indonesia." *Jakarta: Asosiasi Energi Laut Indonesia (ASELI)*, 2012.

[22] Biro Komunikasi KESDM. "Implementing Arrangement Decommissioning Anjungan Migas Attaka Diteken." *Kementerian ESDM*. February 1, 2022.

[23] Gallup, D. L., P. C. Smith, J. F. Star, and S. Hamilton. "West Seno deepwater development case history-production chemistry." In *SPE International Conference on Oilfield Chemistry?*, pp. SPE-92969. SPE, 2005. https://doi.org/10.2523/92969-MS

[24] Yunita, Nurul Fatimah, and Muhammad Zikra. "Variability of sea surface temperature in Indonesia based on Aqua

Modis satellite data." *IPTEK The Journal of Engineering* 3, no. 3 (2017). https://doi.org/10.12962/joe.v3i2.3083

[25] Ministry of Energy and Mineral Resources. "ESDM One Map." *Ministry of Energy and Mineral Resources, Republic of Indonesia*, 2021.

[26] Hammad, Fadhil Karunia, Baskoro Rochaddi, Purwanto Purwanto, and Harjo Susmoro. "Identifikasi Potensi Ocean Thermal Energy Conversion (OTEC) di Selat Makassar." *Indonesian Journal of Oceanography* 2, no. 2 (2020): 147-157. https://doi.org/10.14710/ijoce.v2i2.8058

[27] Mao, Liangjie, Changjiang Wei, Song Zeng, and Mingjie Cai. "Heat transfer mechanism of cold-water pipe in ocean thermal energy conversion system." *Energy* 269 (2023): 126857. https://doi.org/10.1016/j.energy.2023.126857

[28] Lycke, Rolf. "Seamless steel pipe for offshore applications in API x52 Modified." *OSLO*, 2004.

[29] Landeck, Christopher R., and William D. Pasma. "West Seno Field production, utilities and export facilities." In *Offshore Technology Conference*, pp. OTC-16522. OTC, 2004. https://doi.org/10.4043/16522-MS

[30] Sibuea, Clinton, Yeyes Mulyadi, and Imam Rochani. "Analisis On-Bottom Stability dan Local Buckling: Studi Kasus Pipa Bawah Laut dari Platform Ula Menuju Platform Uw." *Jurnal Teknik ITS* 5, no. 2 (2017). https://doi.org/10.12962/j23373539.v5i2.18134

[31] Akbar, Bilal. "Analisis Kuantitatif Kekuatan Sisa Dan Pengaruh Parameter Cacat Pada Offshore Pipeline Yang Telah Terdegradasi Studi Kasus: West-Seno Riser Pipeline." *Institut Teknologi Bandung*, 2010.

[32] Fatah, M. C., A. Diaz, and A. Darwin. "Corrosion assessment of a leakage pipeline in the seabed: A case study." In *Journal of Physics: Conference Series*, vol. 1402, no. 6, p. 066001. IOP Publishing, 2019. https://doi.org/10.1088/1742-6596/1402/6/066001

[33] Nasser, A. M. M., O. A. Montasir, NA Wan Abdullah Zawawi, and Shamsan Alsubal. "A review on oil and gas pipelines corrosion growth rate modelling incorporating artificial intelligence approach." In *IOP Conference Series: Earth and Environmental Science*, vol. 476, no. 1, p. 012024. IOP Publishing, 2020. https://doi.org/10.1088/1755-1315/476/1/012024

[34] Timashev, Sviatoslav, and Anna Bushinskaya. *Diagnostics and reliability of pipeline systems*. New York: Springer, 2015. https://doi.org/10.1007/978-3-319-25307-7

[35] Code, API Piping Inspection. "API 570: In-Service Inspection, Rating, Repair and Alteration of Piping System." *American Petroleum Institute*, 2016.

[36] Nihous, Gérard C. "A preliminary assessment of ocean thermal energy conversion resources." *Journal of Energy Resources Technology* 129, no. 1 (2007): 10-17. https://doi.org/10.1115/1.2424965

[37] Adiputra, Ristiyanto, Tomoaki Utsunomiya, Jaswar Koto, Takeshi Yasunaga, and Yasuyuki Ikegami. "Preliminary design of a 100 MW-net ocean thermal energy conversion (OTEC) power plant study case: Mentawai island, Indonesia." *Journal of Marine Science and Technology* 25 (2020): 48-68. https://doi.org/10.1007/s00773-019-00630-7

[38] Gunawan, Budi, Sugeng Slamet, and Ahmad Syahroni. "Perbandingan Nilai Kalor Biobriket yang Terbuat dari Bottom Ash Limbah PLTU dan Biomassa Cangkang Kopi dengan Variasi Komposisi dan Jenis Pengikat yang Berbeda." *Teknik* 36, no. 2 (2015): 81-84. https://doi.org/10.14710/teknik.v36i2.8688

[39] Simangunsong, Rudi Gustian, and Dendy Satrio. "Numerical Analysis of a Shell and Tube Heat Exchanger Using Computational Fluid Dynamics Software." In *2021 International Electronics Symposium (IES)*, pp. 630-635. IEEE, 2021. https://doi.org/10.1109/IES53407.2021.9594049

[40] Ariansyah, M. N., L. Diana, and D. Satrio. "Numerical study the effect of gap ratio on flow characteristics and heat transfer in staggered tube banks." In *IOP Conference Series: Earth and Environmental Science*, vol. 972, no. 1, p. 012065. IOP Publishing, 2022. https://doi.org/10.1088/1755-1315/972/1/012065

[41] Yudhatama, A. R., A. G. Safitra, and D. Satrio. "Numerical Simulation of Low Pressure Evaporator Modified with Vortex Generator for Improving the Heat Transfer Characteristics." In *IOP Conference Series: Earth and Environmental Science*, vol. 972, no. 1, p. 012066. IOP Publishing, 2022. https://doi.org/10.1088/1755-1315/972/1/012066

[42] Kurniawati, Ischia, Joke Pratilastiarso, and Dendy Satrio. "Analysis of the effect of cooling water condenser to power plant cycle using cycle-Tempo software." In *2020 International Electronics Symposium (IES)*, pp. 37-42. IEEE, 2020. https://doi.org/10.1109/IES50839.2020.9231722

[43] Asrori, Asrori, Sugeng Hadi Susilo, Eko Yudiyanto, and Gumono Gumono. *Mekanika fluida dasar*. Penerbit Qiara Media, 2021.

[44] Incropera, Frank P., David P. DeWitt, Theodore L. Bergman, and Adrienne S. Lavine. *Fundamentals of Heat And Mass Transfer*. John Wiley & Sons, 2007.

[45] Elfaghi, Abdulhafid M. A., Alhadi A. Abosbaia, Munir F. A. Alkbir, and Abdoulhdi A. B. Omran. "Heat transfer enhancement in pipe using Al_2O_3/water nanofluid." *CFD Letters* 14, no. 9 (2022): 118-124. https://doi.org/10.37934/cfdl.14.9.118124

[46] Mohamadi, S., M. H. Yazdi, E. Solomin, A. Fudholi, K. Sopian, and Perk Lin Chong. "Heat transfer and entropy

generation analysis of internal flow of nanorefrigerant with slip condition at wall." *Thermal Science and Engineering Progress* 22 (2021): 100829. https://doi.org/10.1016/j.tsep.2020.100829

[47] Jung, Jung-Yeul, Ho Saeng Lee, Hyeon-Ju Kim, Yungpil Yoo, Woo-Young Choi, and Ho-Young Kwak. "Thermoeconomic analysis of an ocean thermal energy conversion plant." *Renewable Energy* 86 (2016): 1086-1094. https://doi.org/10.1016/j.renene.2015.09.031

[48] Li, Guoyu, Yu Sheng, Huijun Jin, Wei Ma, Jilin Qi, Zhi Wen, Bo Zhang, Yanhu Mu, and Guiquan Bi. "Forecasting the oil temperatures along the proposed China-Russia Crude Oil Pipeline using quasi 3-D transient heat conduction model." *Cold Regions Science and Technology* 64, no. 3 (2010): 235-242. https://doi.org/10.1016/j.coldregions.2009.08.003

[49] Christiansen, Hakon Eidem. "Temperature profile in subsea pipelines." *NTNU Norwegian University of Science and Technology, Trondheim*, 2011.

[50] Wu, Zhixiang, Huijun Feng, Lingen Chen, and Yanlin Ge. "Performance optimization of a condenser in ocean thermal energy conversion (OTEC) system based on constructal theory and a multi-objective genetic algorithm." *Entropy* 22, no. 6 (2020): 641. https://doi.org/10.3390/e22060641

[51] Ikegami, Yasuyuki, Takeshi Yasunaga, and Takafumi Morisaki. "Ocean thermal energy conversion using double-stage Rankine cycle." *Journal of Marine Science and Engineering* 6, no. 1 (2018): 21. https://doi.org/10.3390/jmse6010021

[52] Arief, Dodi Sofyan, Basuki Wirjosentono, Jaswar Koto, Muhammad Dalil, and Abdul Khair Junaidi. "Hydrodynamic Load Effect on Composite Polymer Cold-Water Pipe Joint in Ocean Thermal Energy Conversion." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 113, no. 1 (2024): 141-152. https://doi.org/10.37934/arfmts.113.1.141152

[53] Abbas, Safaa Malik, Hend Dakhel Skhaal Alhassany, David Vera, and Francisco Jurado. "Review of enhancement for ocean thermal energy conversion system." *Journal of Ocean Engineering and Science* 8, no. 5 (2023): 533-545. https://doi.org/10.1016/j.joes.2022.03.008

[54] Kim, Hyeon-Ju, and Albert S. Kim. *Ocean thermal energy conversion (OTEC): Past, present, and progress*. IntechOpen, 2020.