SEMARAK ILMU PUBLISHING

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

Effect of Sea Current to Composites Cold Water Pipeline of Ocean Thermal Energy Conversion in Indonesia

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ARTICLE INFO

Article history:
Received 5 March 2023
Received in revised form 8 June 2023
Accepted 14 June 2023
Available online 2 July 2023

Keywords:
Current; cold water pipeline; drag force; pipe thickness

ABSTRACT

Ocean thermal energy conversion (OTEC) is a new source of future energy that is clean and environmentally friendly with zero emissions. It is very potential to be developed in Indonesia, which is located at the equator. to meet the electricity needs of the outermost and remote islands that are not currently covered by the main power plants in Indonesia. Indonesia has deep seas around the islands with temperatures of 5°C and surface temperatures above 25-28°C, so a temperature difference of 20°C can be obtained easily for OTEC power plants. Cold water supplied to the OTEC plant with a capacity of 2 MW at sea level requires a pipe with a diameter of 4 m and a length of 500 m. The pipeline must be insulating, not floating, corrosion-resistant, and resistant to current loads. Current is a very serious concern with the potential to cause pipe failure. The pipe material being investigated is a short fiberglass High-density polyethylene composite. In this study, a simulation of the effect of current on the composite pipe was carried out to obtain an overview of the stress that occurs and the proper pipe dimensions used. The highest current speed in Indonesian water is found in the Makassar Strait from July to September at 0.8 m/s at a depth of 100 m. Based on the OTEC Pro Simulation software for a capacity of 2 MW, resulted in the pipe size is 4 m and the pipe length is 500 m which refers to the temperature profile. In the simulation, the calculation of the dynamically moving current becomes the drag force on the pipe, and with the Autodesk inventor, it is known that the deflection in the pipe, and the yield stress cause failure in the pipe. Subsequently, from the deflection and yield stress data, a pipe thickness of 20-30 cm is obtained for the short fiberglass-HDPE composite material which is safe to use as an OTEC cold water pipe with a capacity of 2 MW. Pipes with a thickness smaller than 15 cm are too thin for a diameter of 4 m because the pipe wall has already experienced a deflection in a horizontal position and pipes with a thickness of > 30 cm are known from the simulation that the pipes cannot be connected rigidly and the pipes also experience stress due to current and pipe weight. so that the stress becomes greater in the pipe.

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https://doi.org/10.37934/arfmts.107.2.2740

1. Introduction

A potential new energy source for the future is ocean thermal energy conversion (OTEC) [1]. With no emissions, this energy source is clean [2], friendly and safe for the environment [3]. Growing demand for fossil fuels is predicted to aggravate the threat of climate change by increasing emissions from burning fossil fuels [4]. A promising renewable energy source is ocean thermal energy conversion. OTEC research has recently concentrated on improving energy extraction, and this technology is still being developed [5]. OTEC's economic capabilities allow any location to realize its full economic potential while taking into account technical, economic, and environmental factors [6]. Obtaining a 20°C differential in seawater temperature allows the ocean thermal energy conversion generator to produce electrical energy. Deep reservoirs provide the temperature differential. Obtaining a 20°C differential in seawater temperature allows the ocean thermal energy conversion generator to produce electrical energy. Deep seawater, which has a temperature of about 50°C, and warm water, which has a temperature of 26–28°C at sea level, are used to calculate the temperature differential [7]. Ammonia is vaporized using warm water to power the turbine generator, and ammonia vapor from the turbine is melted using cold water to produce steam again [8]. While cold water must be retrieved from the deep sea [9], which is more than 500 meters below the surface of the ocean, warm water may be found right at the sea's top with a temperature of 26°C [10]. Cold water from the deep sea that will be used in ocean-based ocean thermal energy conversion power plants that float on the sea surface is obtained by flowing through large-diameter pipes [11].

Ocean thermal energy conversion is very suitable to be developed in Indonesia to meet the electricity needs in the archipelago which are difficult to reach by the main electricity network that has been built in Indonesia at this time [12]. This energy plant is supported by Indonesia's geographical conditions which are located at the equator and have deep seas around the outer islands [11]. Likewise, it will easily get sea surface temperatures above 25-28°C and temperatures 5°C below the sea surface. In Indonesia, cold water can be obtained at a depth of ±500 m, as shown in Figure1.

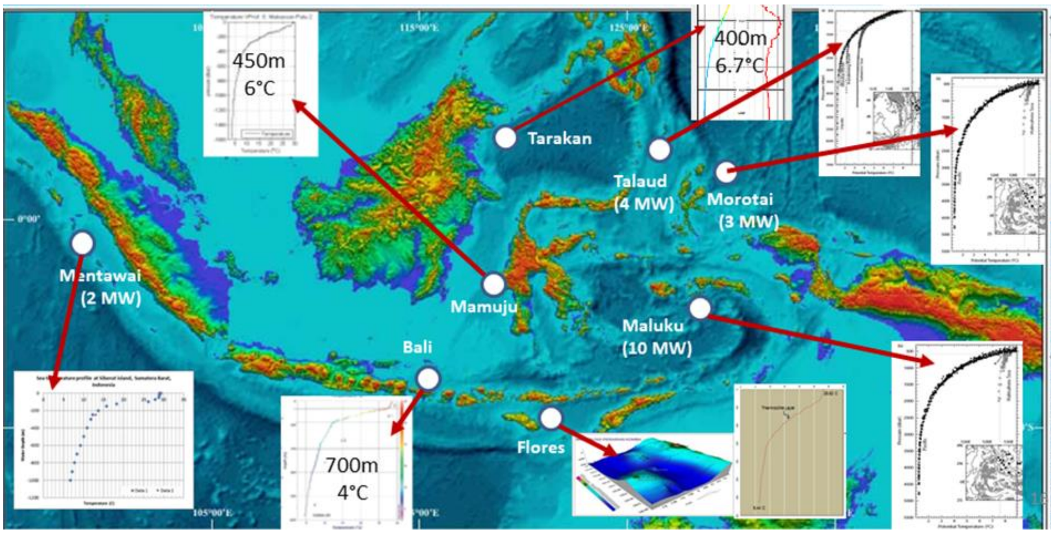


Fig. 1. Seawater temperature profile in Indonesia [11]

Temperature and current profiles have been surveyed by Jaswar and several students, in several marine areas in Indonesia, such as in Siberut, Mentawai Islands (Figure 2), Makassar Strait, Maluku, North Maluku, North Sulawesi, and North Kalimantan. It is known that the temperature at a depth of 400 – 600 m is 4-6°C, with a current speed of 0.4 m/s to 0.8 m/s [11], so with a temperature of 4-6°C it has great potential to build an ocean-based or floating type OTEC power plant in some of the islands of Indonesia. Because the temperature difference of 20°C required for the OTEC generator is fulfilled by the sea surface temperature in Indonesia which is quite high, namely 26-28°C.

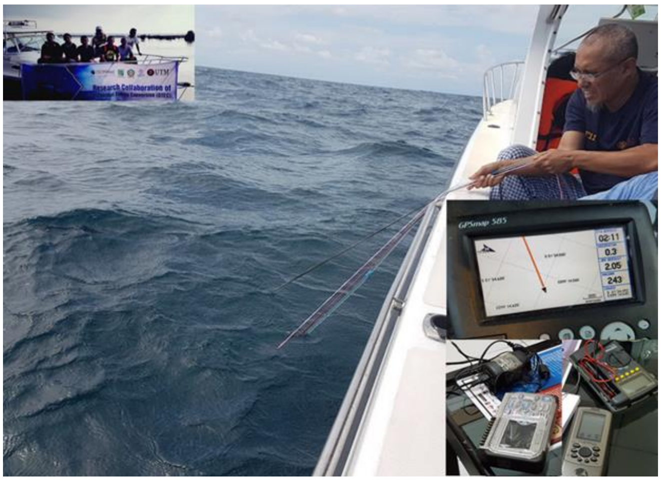


Fig. 2. One of the activities of taking the Seawater Temperature and Current Profile in Siberut, Mentawai Islands, Indonesia

The next challenge faced by ocean-based OTEC is to transport cooled water from the deep sea to the board which is referred to as Cold Water Pipe (CWP). Furthermore, CWP is subjected to the current load may cause instability to the pipe structure [2]. The specification of the pipe requires a length of ±500 m and a diameter of 4 m to be able to produce 2 MW of OTEC energy [11]. The pipes used to drain cold water from the deep sea are in a vertical position, and will dynamically move up and down due to waves and wind on the sea surface, move horizontally due to current loads, and experience vortex-induced vibrations [13].

The required characteristics of cold-water pipes are pipes that are light, flexible and do not float due to currents, and are strong against the pressure and hydrodynamic forces of seawater [14]. Therefore, a good pipe material to be used for seawater hydrodynamic conditions is high-density polyethylene fiberglass composites [15]. Because HDPE is low temperature resistant and corrosion resistant. But it has not investigated the hydrodynamic load resistance due to seawater currents, so this research was carried out which aims to determine the effect of hydrodynamic forces on high-density polyethylene fiberglass composite pipes that focus only on current. Because of current becomes one of the problems that concern marine applications such as Cold-Water Pipe (CWP) which is designed for ocean thermal energy conversion from the seabed [16]. With this research, it is also expected to obtain an overview of the pipe dimensions that must be used based on the current passing through the pipe in a direction perpendicular to the pipe position.

In the conversion into electrical energy there are three methods used, namely the method closed cycle, open cycle method and hybrid cycle method. cycle method closed using the surface heat of seawater to vaporize the working fluid have low boiling points such as ammonia. The ammonia vapor then enters the turbine and drives a generator that produces electricity as shown in Figure 3. While the hybrid method is a combination of and closed and open cycles that can produce electrical energy and pure distilled water.

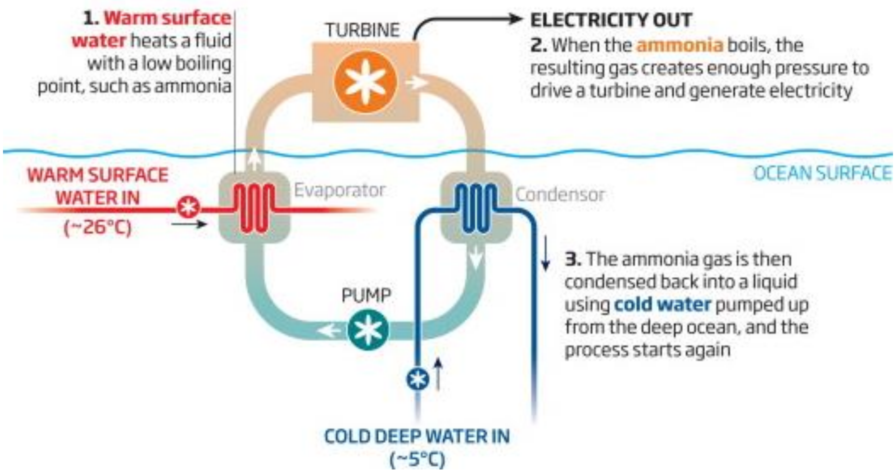


Fig. 3. Thermodynamic cycle

Ocean Thermal Energy Conversion (OTEC) has several benefits for human life. First, the hallmark of OTEC is deep potency provides baseload electricity, which means day and night as well throughout the year. This is a huge advantage on a typically tropical island do not have a power grid and can't handle a lot of power required. OTEC also offers many synergistic products as follows: freshwater, nutrient food, cooling system, and supply water.

2. Research Method

2.1 Cold Water Pipeline of OTEC

The proposed material for a cold-water pipeline in Ocean Thermal Energy Conversion installations is a short fiber fiberglass-high density polyethylene composite. The composite material consists of HDPE as a matrix with a density of 0.94 g/cm^3, the thermal conductivity of 0.52 W/mK, and E Fiberglass as a reinforcement with a density of 2.58 g/cm^3 [17], the thermal conductivity of 0.045 W/mK, with a length of 5 mm, and is formed into a composite with a ratio weight fraction 30% fiberglass and 70% HDPE [18].

After manufacturing by liquefying HDPE and mixing short fiberglass with a stirring and hot-pressing process, forming test specimens according to ASTM D3039 to obtain mechanical properties [19], forming test specimens according to ASTM D792 to determine density, and forming test specimens according to ASTM C177 to determine heat conductivity. And after testing, it was obtained that the maximum tensile strength of the HDPE-Short Fiberglass composite was 32.238 MPa, as shown in Table.1. and obtained a density of 1.22 g/cm^3 and a thermal conductivity of 0.337 W/mK.

Tabel 1
Properties of material cold pipe water

Material	Density	Thermal Conductivity	Tensile Strength
Pure High-Density Polyethylene (Granules)	0.94 g/cm^3	0.52 W/mK	26.370 MPa
Short E-Fiberglass (3B Chopped Strand)	2.58 g/cm^3	0.045 W/mK	72.5 MPa
Short Fiberglass-HDPE Composites, (30-70) %	1.22 g/cm^3	0.337 W/mK	32.238 MPa

Pipe construction in Figure 4(a). shows that the pipe structure is affected by the presence of wind, wave, current, vortex, and mooring line. The analysis of pipes that are impacted by current and stabilized by mooring lines, as shown in Figure 4(b), is the main emphasis of this research. In order to secure the pipe to the seabed and prevent the OTEC plant from moving, the top of the pipe is fixedly connected, and on the side of the pipe, a mooring line is utilized in three spots.

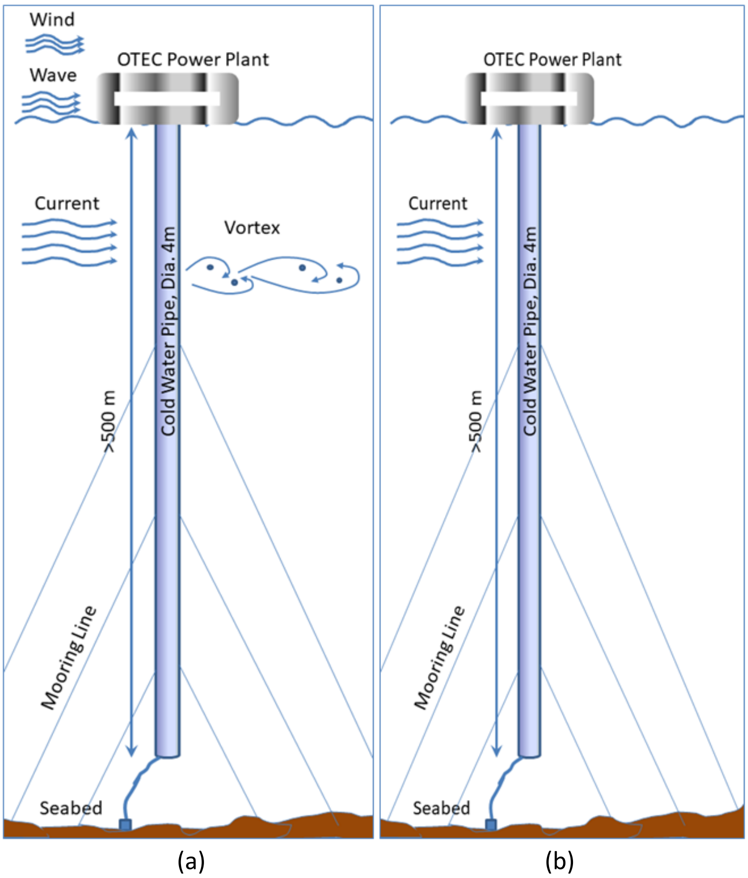


Fig. 4. Cold water pipe construction sketch (a) pipe against the wind, wave, current, vortex, and mooring line loads. (b) pipes with current loads and mooring lines which are the focus of the research

The diameter of the pipe is calculated based on the total energy required of OTEC and Cold-water flow rate. In this simulation is calculated by software OTEC Pro Simulations [Jaswar Koto]. The simulation data is a depth of 500 m, the electricity capacity to be generated is 2 MW, 28°C warm water to vaporize the ammonia, and to dilute the ammonia, 5°C cold water is needed with a flow rate of 3-5 m/s with the result that the required pipe diameter is + - 4 m at a flow rate of +-5 m/s. Based on the OTEC Pro software, to generate 2 MW of electricity, a 4 m diameter pipe is required to flow cold water to the condenser, to liquefy ammonia vapor.

The diameter of the pipe used is 4 m with a pipe length of 500 m which is calculated based on the average temperature profile in the territory of Indonesia and based on the total energy required and the speed of the water flow to be able to produce 2 MW of electrical energy at the OTEC power plant, calculated using the OTEC Pro software Simulation on the smooth surface of pipe conditions as shown in Table 2. Reynolds number refers to currents in the ocean depths. With drag coefficient for each level of depth on a 4 m diameter pipe.

The flow in the pipe is determined based on the temperature to be achieved. To achieve a smaller temperature difference between the top and bottom of the pipe, the flow rate is increased. Because the diameter of the pipe has been determined based on the needs of the 2 MW electrical energy capacity produced.

Table 2
Re for diameter of pipeline in 4 m

Sea Current Velocity, U(m/s)	Reynolds Number, Re	Temperature (°C)	Viscosity	Sea Current Density (kg/m³)	Water Depth (m)
0.80	3.16E+06	21.5	1.04E-03	1024	100
0.62	2.15E+06	16.0	1.18E-03	1025	200
0.46	1.40E+06	11.0	1.35E-03	1026	300
0.35	0.971E+06	8.0	1.48E-03	1027	400
0.28	0.733E+06	6.0	1.57E-03	1027	500

2.2 Sea Current

From the results of current measurements in Indonesia, it is known that the largest currents occur in the Makassar Strait from July to September at a depth of 100 m at 0.8 m/s [19,20]. While in other areas of Indonesia, such as Siberut it is 0.6 m/s [11], and in the waters of Batam Island it is 0.2 m/s. In this paper, the highest current speed is used, which is 0.8 m/s to obtain cold water pipes that are safe for use in OTEC power plants in Indonesia.

Hydrodynamic analysis of OTEC cold water pipes with simulations is carried out based on currents pressing on the pipes, while the effects of waves, vortexes, and wind, as well as the influence of water velocity in the pipes, are not used as simulation input data. So that it only focuses on the effect of current on the OTEC cold water pipes.The current velocity that causes the drag force on the pipe can be determined by the Eq. (1).

$$F_d = {}^{1}/_{2}\, \rho_f C_d D L U^2 \quad (1)$$

where, F_d = drag force (N), ρ_f = density (kg/m^3), C_d = drag coefficient, D = diameter of pipe (m), L = length of pipe (m), U = velocity (m/s).

The drag coefficient is determined from Re for a pipe diameter of 4 m based on Table 2 with the graphs as shown in Figure 5.

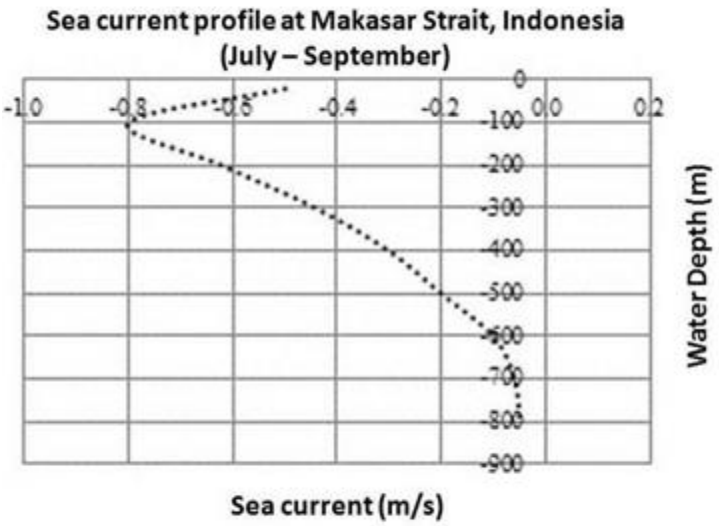


Fig. 5. Profile of ocean currents in the Makassar Strait from July to September during the Southeastern Monsoon (Jaswar)

Further, by using Eq. (1), it is obtained that the drag force at the maximum current condition is shown in Table 3.

Table 3
Drag force of the seawater current at depth and speed based on the pipe drag coefficient

Water Depth (m)	Current Velocity (m/s)	Drag Coefficient	Drag Force (kN)
20	0.5	0.890	2.278
100	0.8	0.98	75.833
200	0.62	0.904	59.313
300	0.46	1.07	29.435
400	0.36	1.16	15.960
500	0.28	1.24	7.804
600	0.23	1.25	4.298

Based on Table 3, the drag force profile curve is obtained as shown in Figure 6. It is known that the greatest drag force occurs at a depth of 100 m for a current speed of 0.8 m/s. and the drag force decreases with increasing depth, caused by the density of seawater, gravitational pressure, temperature, and viscosity.

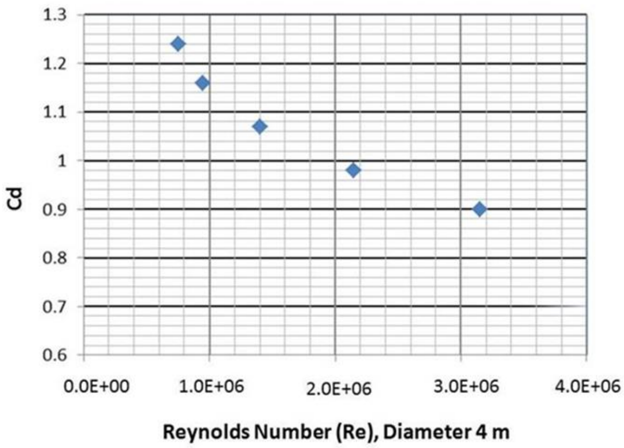


Fig. 6. Cd and Re for 4 m Diameter Cold Water Pipe

With the curve line equation Wd = 164,28 ln (Fd)-844,92 and R^2 = 0,9879, where Wd = seawater depth and Fd = the drag force of the current on the pipe. From the material and load data on the pipe due to the maximum current velocity above, a simulation is carried out using Autodesk Inventor (courtesy of BKSTM Indonesia) to obtain an overview of the stress contour on the pipe due to seawater hydrodynamics and an estimate of pipe dimensions that are safe to use as cold water pipes in OTEC generators.

Table 4
Details of meshing configuration

Statistics	Description
Number of Nodes	28401
Number of Elements	14153
Solution Method	Triangular Method

The upper pipe is a fixed connection, while at the bottom it is tied with an elastic band or roller connection to allow the pipe to be lifted due to the bending of the pipe. The load is applied along the pipe according to the drag force Figure 7. with the equation of the relationship line between the depth of seawater and the drag force, namely Wd = 164,28 ln (Fd)-844,92. In the simulation, the condition is that the pipe is empty and the pipe filled with liquid is stationary.

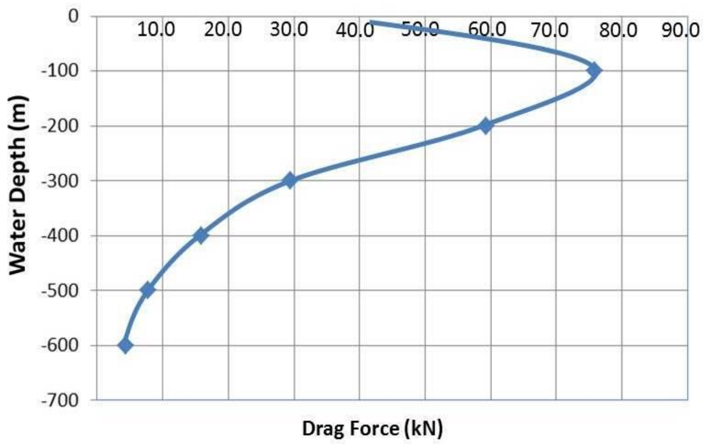


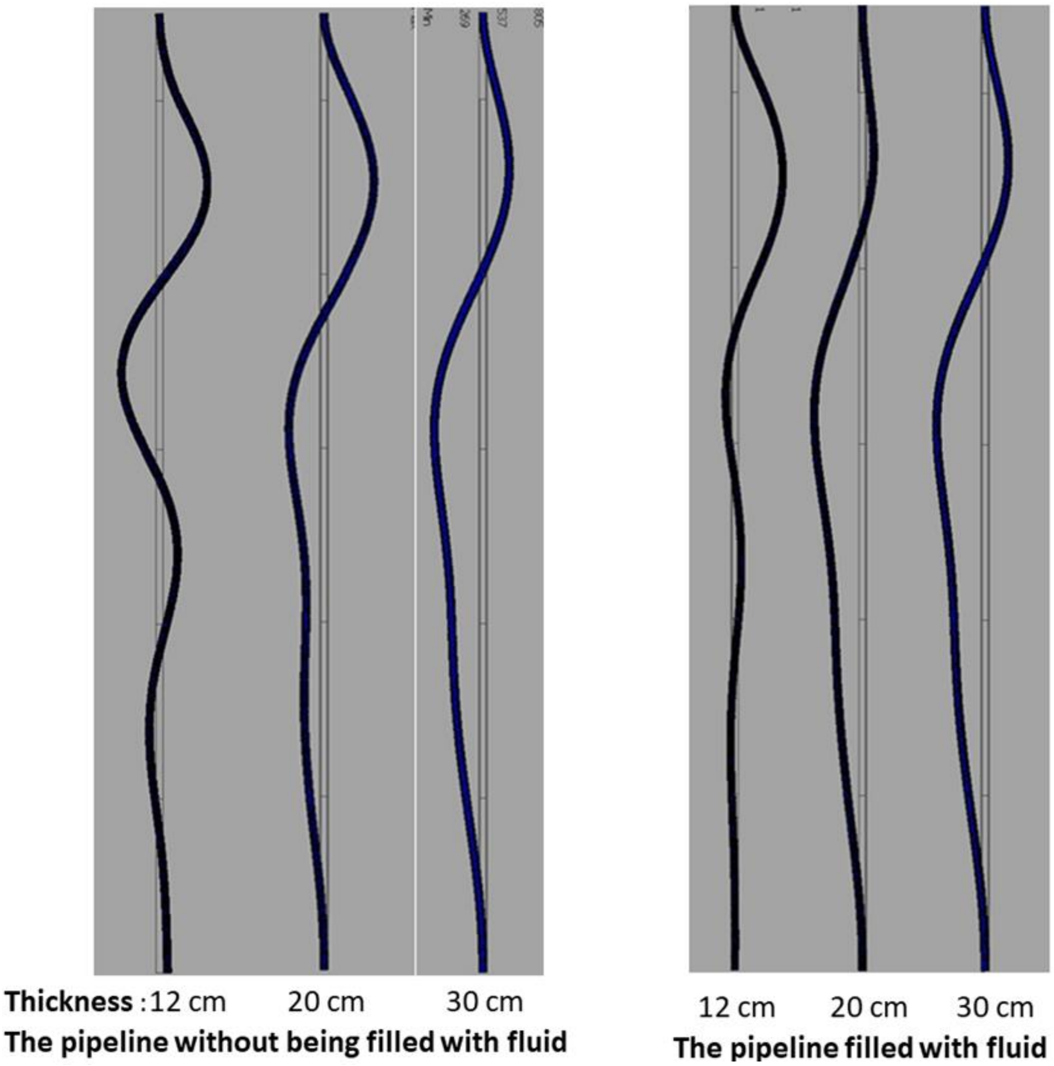
Fig. 7. Drag Force profile of the maximum current velocity 0.8 m/s

3. Results

The properties of HDPE short fiberglass composite materials for cold water pipes have been obtained by means of tensile testing, density testing, and conductivity testing, and a temperature and current profile survey has also been carried out in Siberut and several other areas in Indonesia, and then a hydrodynamic load simulation has been carried out on the pipe by changing the force of the flow of seawater currents becomes a drag force along the pipe. With this drag force, a von Mises stress is obtained which is the basis for the yield stress or pipe failure due to hydrodynamic loads.

By simulation, Additionally, as illustrated in Figure 8, the pipe shapes caused by current loads are known to exist for both fluid-filled and empty pipes. A pipe with a tiny thickness of 11 cm is known to experience significant deflection and curvature when loaded without any fluid within; the higher the pipe thickness, the less current bend or deflection. The pipe gets narrower. Additionally, it has been observed that as pipe gets thicker, it stiffens up and receives more stress in the middle. Whereas the highest tension in a thin pipe occurs at a distance of 100 m.

Therefore, for pipes filled with fluid, the stress contour is smaller, because with the presence of fluid in the pipe, the fluid helps the pipe not to experience greater bending or deflection.



(a) (b)

Fig. 8. Pipe contour due to drag force on pipes filled with liquid and without filled with liquid

Furthermore, based on the stress and deflection that occurs in the pipe, and with the drag force on the pipe, the pipe that is safe enough to use is a pipe with a thickness between 20-30 cm. Whereas pipes with a thickness smaller than 15 cm, the program inventor states that the pipe is too thin to be used as a 4 m diameter pipe. and for pipes with a thickness greater than 30 cm, the weight of the pipe greatly affects the drag force, so that the stress becomes greater due to the resultant drag force and the weight of the pipe, and the inventor's program also states that for composite pipes with a thickness greater than 30 cm, no can be connected rigidly. When connecting the pipes will experience a little difficulty, and will reduce the strength of the pipe structure due to the connection.

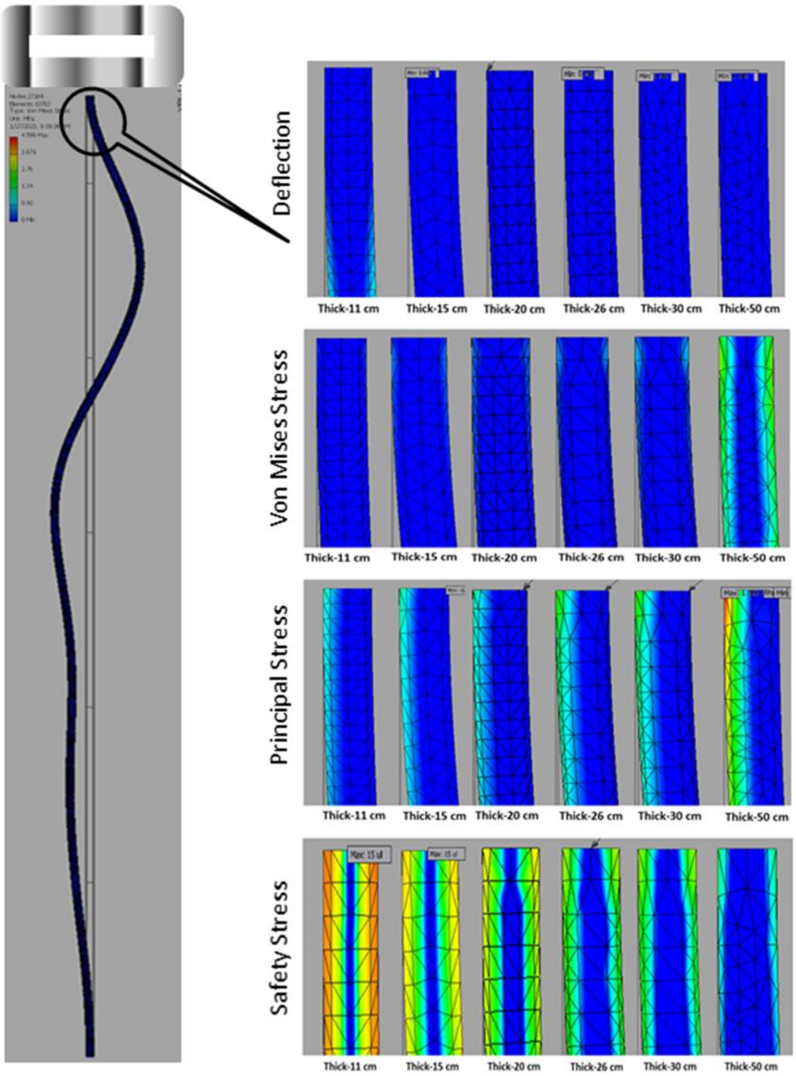


Fig. 9. Deflection and stress that occurs in the pipe with a current speed of 0.8 m/s

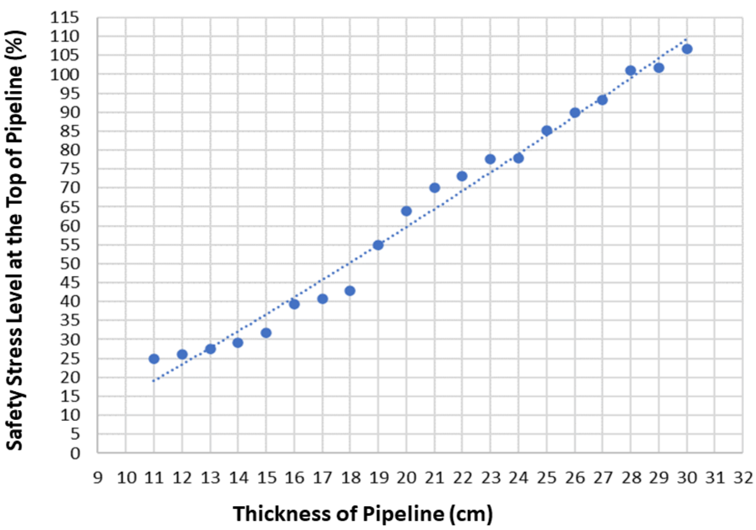


Fig. 10. The safety level of the pipe on the thickness of the pipe varies due to the current with a speed of 0.8 m/s

Figure 10, shows the safety level of the pipe at a certain thickness due to flow velocity. The pipe will be safe if the safety level is > 50% and if the pipe thickness is > 19 cm. The curve line in Fig.10 is arranged based on the safe stress shown in Fig.9. The pipe is called safe if the ratio of the area of the pipe that is under tension (red color) is smaller than the area of the part of the pipe that is not under stress (blue color). In Fig.9, it can be seen that the thicker the pipe, the smaller the area of the pipe that is under stress, so the ratio of safe stresses is greater. If the ratio is more than 50%, then the pipe is declared safe. Based on the stress simulation on the pipe due to the current, a safe level is obtained. High-density polyethylene fiberglass composite pipe with a diameter greater than 19 cm.

Figure 11 shows the deflection that occurs in a pipe due to a current with a speed of 0.8 m/s in a pipe with a thickness varying from 13 cm to 30 cm and it is known that the deflection gets smaller starting from the thickness of 16 cm to 30 cm and the lowest deflection is at 25-28 cm. so that from the level of safety and deflection that occurs temporarily it can be stated that the thickness of the pipe that is safe to use is 25-28 cm thick.

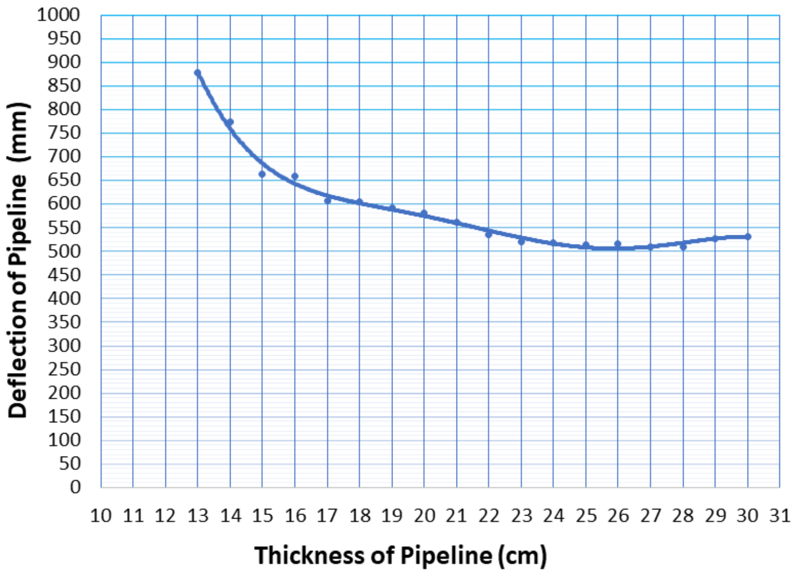


Fig. 11. The deflection of the cold water pipe against the pipe thickness varies due to the current with a speed of 0.8 m/s

Figure 11 shows the deflection that occurs in a pipe due to a current with a speed of 0.8 m/s in a pipe with a thickness varying from 13 cm to 30 cm and it is known that the deflection gets smaller starting from the thickness of 16 cm to 30 cm and the lowest deflection is at 25-28 cm. so that from the level of safety and deflection that occurs temporarily it can be stated that the thickness of the pipe that is safe to use is 25-28 cm thick.

Figure 12, is a review carried out based on the Von Mises stress which describes the yield or failure limit of a material and compared it with the tensile strength and fatigue endurance limit of the short fiberglass-HDPE composite. Pipes are formed with single walls and double walls. Formation of a double wall to observe OTEC pipes which has also been made by (15), from the stress that occurs it can be stated that for a single wall pipe filled with fluid, the Von Mises yield stress is below the fatigue resistance limit of the composite starting at 18 cm thickness and for pipes with double walls as well. Based on the deflection that occurs and the von Mises stress, which is significantly below the composite's strength and fatigue resistance limit, it is advised that OTEC cold water pipes have a pipe thickness of between 18 cm and 30 cm. Additionally, it can be seen from the line graph for pipes with double walls that, in comparison to pipes with single walls, the stress tends to be less safe the thicker the pipe. This is because there are voids between the pipe walls.

So based on the safety factor, deflection and von Mises stress on variations in the thickness of single and multiple pipes, it is recommended to use pipes with a thickness of 27 cm for safety and resistance to seawater currents.

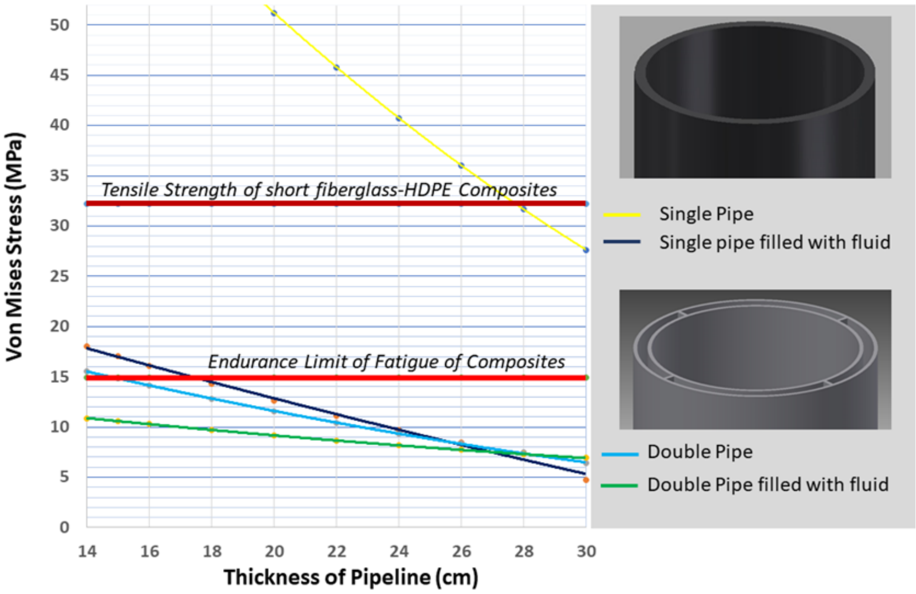


Fig. 12. Relationship of stress and thickness of cold water pipe with a solid and double layer of cold water pipe wall.

4. Conclusion

Sea water has a speed that varies at each level of depth. The greatest current occurs at a depth of 100 m and decreases with increasing depth. The greatest speed occurs in the Makassar Strait for the territory of Indonesia, which is 0.8 m/s. The cold-water pipe used for OTEC with a capacity of 2 MW a diameter of 4 m and a length of 500 m based on the OTEC Pro Simulation software, will experience bending loads in a horizontal direction due to currents that cause deflection and failure of the pipe. The dynamically moving current is calculated as the drag force on the pipe so that with the drag force it can be known the deflection in the pipe and the yield stress of the pipe with Autodesk inventor simulation under static conditions. From the deflection, von Mises stress and safe stress from the simulation results, it can be recommended that the thickness of the HDPE short fiberglass composite pipe is 20-30 cm. If the pipe thickness is less than 15 cm, it is known that the pipe is too thin for a diameter of 4 m with a large deflection, and a pipe with a thickness of > 30 cm, the pipe cannot be connected rigidly and experiences greater stress due to the current and the weight of the pipe.

Acknowledgment
I would like to thank the Postgraduate School, Department of Mechanical Engineering, Universitas Sumatera Utara, for supporting the research, Chemistry Postgraduate Program Faculty of Mathematics and Natural Sciences Universitas Sumatera Utara, Universitas Riau, Universiti Teknologi Malaysia.

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