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Calculation of Power pumps on OTEC Power Plant (Ocean thermal Energy Conversion)

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Abstract

In recent years, marine renewable energy has received more and more attention due to concerns regarding energy shortages, global warming and environmental pollution. Marine renewable energy includes tidal energy, current energy, wave energy, osmotic energy and ocean thermal energy. A recent study predicts a global growth in renewable energy as a response to increasing world energy demands. The OTEC (ocean thermal energy conversion) power plant is one candidate. OTEC transforms the heat stored in the surface water of tropical oceans, into mechanical work to produce energy. The purpose of this study is to create numerical equations about the amount of pump energy required in OTEC power generation systems. The results show that the energy and power of the pump is greatly influenced by OTEC power, pipe type, cold water discharge, and cold water depth.

Keyword: *OTEC, energy, pump*

Introduction

The study of OTEC (Oceans Thermal Energy Conversion) (Arcuri, Bruno, & Bevilacqua, 2015; A. Lavi & Jopling, 1980; G. H. Lavi, 1980; Morse, de Kanel, & Craig, 1979; Yeh, Su, & Yang, 2005) has been widely practiced by researchers due to the fact that OTEC energy and technology is not yet economically viable.

In recent years, marine renewable energy has received more and more attention due to concerns regarding energy shortages, global warming and environmental pollution. Marine renewable energy includes tidal energy, current energy, wave energy, osmotic energy and ocean thermal energy. In these kinds of resources, ocean thermal energy has the largest reserve and lowest power fluctuation, thus using ocean thermal energy has enormous potential (Li, Zhang, Duan, & Tian, 2018)

Increased regulation and societal concerns about the use of fossil fuels, and the harmful by-products from using them for power generation, has created an abundant need for alternative energy sources. Three engineering students at West Virginia Institute of Technology (WVUIT) have chosen to model OTEC systems using Aspen Plus software to determine how the systems efficiency and power output changes with the rise and fall of ocean surface water temperature. (Gresham, Thornton, & Rankou, 2015)

The growing demand for energy (Aoyama, 2015; Azghandi, Rouhi, & Ahmadi, 2014; Dhanju, 2016) demands more energy availability, on the other hand, mineral energy resources are increasingly depleted. Energy saving is necessary but the search for alternative energy is no less important. OTEC power plant (ocean thermal energy conversion) is one of the alternative energy providers of the future. As a maritime country, the potential of OTEC in Indonesia is very large.

Due to the close relationship of economic activities with energy, (CHAKWAT & RIDGWAY., 1980; COLEMAN, 1979; Dengler & Wilde, 1987; Dugger, Francis, & Avery, 1978; Fujita et al., 2012; J. Y. Jung et al., 2016; Khan, Kalair, Abas, & Haider, 2017; N. J. Kim, Ng, & Chun, 2009; Kusuda, Morisaki, & Ikegami, 2015; Mangarella & Heronemus, 1979; Nakaoka & Uehara, 1988; S. Balakumar, 2015; Sinuhaji, 2015; Wo, 1993; Wu, 1990), the increase in economic activity is usually followed by increased energy consumption. In Indonesia, this is reflected in the increase in economic growth, by an average of 7% per year, resulting in the growth of energy consumption, at an average of about 10% per year over 30 years. The OTEC power plant is well-suited as a provider of electric power to the archipelago. However, the archipelagic country does have many obstacles in terms of energy distribution. The long distance between islands adds to the burden of energy transportation financing.

Installation of Otec Power Plant

In the OTEC Power System (Ocean Thermal Energy Conversion), Steam generators use fuels or a medium of warm sea water and work fluids in the form of volatile substances such as ammonia. In Figure 1 shows the OTEC Scheme. (Faizal & Ahmed, 2013; Iqbal & Starling, 1976; H. Jung & Hwang, 2014; Odum, 2000; Pont, 1980; Rajagopalan & Nihous, 2013; Yuan, Mei, Hu, Wang, & Yang, 2013).

In a closed cycle system, ammonia is used as a work zalir. The system uses the principle of Rankine sklus. Figure 1 shows the closed-loop OTEC scheme. The energy surge in the spaced cycle system is as follows:

1. Addition of heat (J / kg) $q_A = h_1 - h_4$

2. turbine work $w_T = h_1 - h_2$
3. heat leftovers $|q_R| = h_3 - h_2$
4. pump work $|w_P| = h_4 - h_3$
5. Net cycle work $w_{net} = (h_1 - h_2) - (h_4 - h_3)$
6. Heat Efficiency $\eta = \frac{w_{net}}{q_A} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)}$

In closed-loop systems, to evaporate ammonia, warm sea-water surfaces are used, and steam flows through pipes to drive turbines and generate power through electrical generators. The vapor from the turbine exhaust is evaporated by a condenser using a water foam at a temperature of about 5 °C. Then, the liquid ammonia is pumped back into the evaporator to be evaporated again using warm ocean surface water (Faizal & Ahmed, 2013; H. Jung & Hwang, 2014; Rajagopalan & Nihous, 2013).

The vapor ammonia then expands by traveling through a turbine. This turns the turbine making electricity. The ammonia vapor pressure at the outlet of the turbine is 7°C higher than the cold seawater temperature. The cold seawater is therefore brought up from the depths where heat exchange occurs and ammonia vapor is changed back into a liquid. The liquid ammonia is then pressurized by a pump, starting the cycle once more. Rankine cycles, in theory, are able to produce non-zero net power due to the fact that less energy is required to increase the pressure of a liquid then is able to be recovered when the same fluid expands as a vapor. It is for this reason that phase changes are essential when producing energy this way. The advantages of using a closed-cycle system are that it is more compact then an open-cycle system and can be designed to produce the same amount of power. The closed-cycle can also be designed using already existing turbos (Berger & Berger, 1986; Bharathan et al., 2016; D. Kim & Kim, 2017).

In 1930 Claude devised a mini OTEC with 23 kWe output power, in Cuba. In general, OTEC is designed based on the Rankine cycle as well as Claude, Claude's design uses a boiler that can produce a pressure of 8.7 atm with an input temperature of 21C (70 ^{0}F), ammonia condensation using depth water of 5^{0}C temperatures, pumped from a sea depth of 700 to 900 m under the sea level. The thermal efficiency resulting from the Claude design is 2.5 to 3.3%. Figure 2 shows the temperature profile at each ocean depth.

Numerical Calculation Verification

As previously stated, the OTEC closed system power cycle is very similar to that of the steam power plant cycle. With this in mind, the first verification test was performed by making hand calculations based on an ideal Rankine OTEC cycle, with ammonia as the working fluid. In the ideal Rankine cycle the processes occur as follows, along with the T-s diagram of the cycle, Figure 3: 1-2: Isentropic compression of working fluid to compressed liquid. 2-3: Heat transfer to the working fluid at a constant pressure as the fluid moves from compressed liquid to saturated vapor. 3-4: Isentropic expansion of the working fluid to a liquid-vapor mixture. 4-1: Heat transfer from the fluid at a constant pressure as the fluid moves from a liquid-vapor mixture to saturated liquid.

Pump Configuration

One of the most important design issues for OTEC seawater systems is configuration of the pump. Pump configuration refers to the location of the pumps in the system as well as the type of pump (e.g., submersible, vertical wet pit). The pump configuration is closely coupled with other design parameters. such as the head losses in the supply and discharge pipes and the elevations of the heat exchangers. These are discussed in Sections 4.4 and 4.5. Several configurations for supply and discharge pumps were identified and their relative merits evaluated. Some were less attractive and were set aside.

A key decision reached, during the first working group meeting, was to use both supply and discharge pumps in the design of systems for both warm and cold seawater. This has the important advantage of allowing the heat exchangers to be located relatively close to grade, thus reducing overall height of the structure and keeping costs down. Another advantage is that net power production will be substantially disconnected from the tide and from variations in barometric pressure. For instance, the increase in pumping power of the seawater supply at low tide will be accompanied by a decrease in discharge pumping power. At high tide, just the opposite will occur. In either case, little change in net power will occur. (Observations at the pump station indicate that the cold-seawater sump is subject to tidal fluctuations just as is the warm-seawater sump. The disposal trench is also expected to respond to the tides.)(Bharathan et al., 2016)

Numerical Analysis of Pump

Zener has developed the use of ammonia as a working fluid on OTEC generating systems. At the boiler, the boiler pressure planned is Pboiler and is at depth Xbolier below sea level. Then the work of the cycle pump is:

$$P_{out}(kWe) = 64(lb / ft^3) \times 1(BTU / lb.^o F) \times Q(ft^3 / dt) \times \Delta t_{boiler}(^oF)$$

$$\times \frac{2,78.10^{-7} kWh}{0,949.10^{-3}} \times \frac{3600dt}{h} \times \frac{kWe}{kW} \qquad \ldots(10)$$

Then

$$Q_{alh} = \frac{0{,}0148P}{\Delta t_{boiler}} \qquad \text{..................(11)}$$

With :

Q_{alh} = warm water discharge required (ft^3/dt)

P = the desired output power (kWe)

Δt_{boiler} = decrease in temperature on the boiler (^oF)

when equation 7 is changed to:

$$m_{al} = \frac{m_{NH_3}\left(h_B - h_E\right)}{\Delta t_{boiler}}$$

And;

$$\frac{Q_{alh}}{v_{al}} = \frac{Q_{NH_3}\left(h_B - h_E\right)}{\Delta t_{boiler}} \times \frac{1}{v_{gas\_NH_3}}$$

$$Q_{gas\_NH_3} = \frac{Q_{alh} \times \Delta t_{boiler} \times v_{gas\_NH_3}}{v_{al} \times (h_B - h_E)}$$

Because $v_{al} = 1/64$ then the NH_3 gas discharge is needed:

$$Q_{gas\_NH_3} = \frac{0{,}0148P \times v_{gas\_NH_3} \times 64}{h_B - h_E}$$

$$Q_{gas\_NH_3} = \frac{0{,}9472P \times v_{gas\_NH_3}}{h_B - h_E} \qquad \text{.......(12)}$$

with:

$Q_{gas\_NH_3}$ = NH_3 gas discharge (ft^3/dt)

$v_{gas\_NH_3}$ = volume of gas type NH_3 (ft^3/lbm)

in order to calculate the turbine power using the following equation:

$$P_{turbin} = w_t \times Q_{gas\_NH_3} \times \frac{1}{v_{gas\_NH_3}} \text{......(13)}$$

with:

P_{turbin} = Turbine power (kW)

Using equation 8 can be determined also the NH_3 fluid discharge is formed or required:

$$Q_{cairan\_NH_3} = \frac{0,9472P \times v_{cairan\_NH_3}}{h_B - h_E} \text{......(14)}$$

with: $v_{cairan\_NH_3}$ = volume of fluid type NH_3

because the formed NH_3 fluid is channeled back to the boiler through the condenser so that the pumping power becomes:

$$P_{pompa} = w_p \times Q_{cairan\_NH_3} \times \frac{1}{v_{cairan\_NH_3}} \text{......(15)}$$

Based on the black principle then the process in condenser can be written as equation as : heat given = heat received

$$m_{ald} \times \Delta t_{kond} \times c_p = m_{NH_3}\left(h_C - h_D\right) \text{........(16)}$$

with:

m_{alg} = cold sea water mass

Δt_{kond} = the temperature difference on the condenser

If $c_p = 1$ then :

$$m_{ald} = \frac{m_{NH_3}\left(h_C - h_D\right)}{\Delta t_{kond}} \text{.............(17)}$$

With;

$$m_{NH_3} = \frac{0{,}0148P}{h_B - h_E} \ldots\ldots\ldots\ldots\ldots(18)$$

the substitution of equation (16) to equation (15) becomes:

$$m_{ald} = \frac{0{,}0148P(h_C - h_D)}{\Delta t_{kond}(h_B - h_E)} \ldots\ldots\ldots\ldots(19)$$

with m_{ald} = mass speed (lbm/det)

cool sea water discharge is required:

$$Q_{ald} = \frac{0{,}0148P(h_C - h_D)v_{ald}}{\Delta t_{kond}(h_B - h_C)} \ldots\ldots(20)$$

With ; Q_{ald} = cool sea water discharge.

To calculate the diameter of cold sea water pipe, warm sea water, NH_3 gas or liquid it is necessary new variables that is the determination of speed. This means that the flow rate own set. Suppose Vgas = gas speed. Vcair = fluid velocity. Then Diamater pipe becomes:

$$D = \left(\frac{2Q}{V}\right)^{0,5} \ldots\ldots\ldots\ldots(21)$$

in the same way can be calculated diameter for cold, hot and NH3 seawater pipes. To determine the pump power required to pump warm sea water from the surface or cold ocean waters in depth the following steps are required:

1. Determination of reynold numbers for warm or cold sea water

$$R_e = \frac{V \times D \times \rho}{\mu}$$

dengan:

R_e = renold number

V = speed (ft/dt)

D = diameter (ft)

ρ = density (lbm/ft^3)

μ = viscosity (lbm/ft.dt)

2. Using the graph specify the friction factor by matching the corresponding renold number
3. Determination of upstream loss (upstream lost = lost head) by using Darcy-Weisbach formula.

$$H_L = f \times \frac{L}{D} \times \frac{V^2}{2g}$$

With;

H_L = upstream lost

f = friction factor *(faktor gesekan)*

4. Determination of the head using the principle of giving:

Energy at point A + pump energy - lost energy = energy at point B

$$\left(Z_A + \frac{P_A}{A} + \frac{V_A^2}{2g}\right) + H_P - H_L = \left(Z_B + \frac{P_B}{B} + \frac{V_B^2}{2g}\right)$$

Changed become::

$$H_p = H_L + \left(Z_B + \frac{P_B}{B} + \frac{V_B^2}{2g}\right) - \left(Z_A + \frac{P_A}{A} + \frac{V_A^2}{2g}\right)$$

5. Determination of pump energy by using the equation as follows:

$$E_p = w \times Q \times H_p$$

Conclusion

Based on the calculation of pump power, the pump power equation is obtained as below.

$$P_{pompa} = w_p \times Q_{cairan\_NH_3} \times \frac{1}{v_{cairan\_NH_3}}$$

Then the work of the cycle pump is:

$$w_p = (h_E - h_D) + (X_{boiler} - X_{kond}) \times \frac{1}{778 lbf / BTU} \times \frac{32.2 ft / \sec}{32.2 lbm / lbf . \sec}$$

Power pumps developed the use of ammonia as a working fluid on OTEC generating systems. At the boiler, the boiler pressure planned is boiler pressure and is at depth of boiler below sea level. The results show that the energy and power of the pump is greatly influenced by OTEC power, pipe type, cold water discharge, and cold water depth.

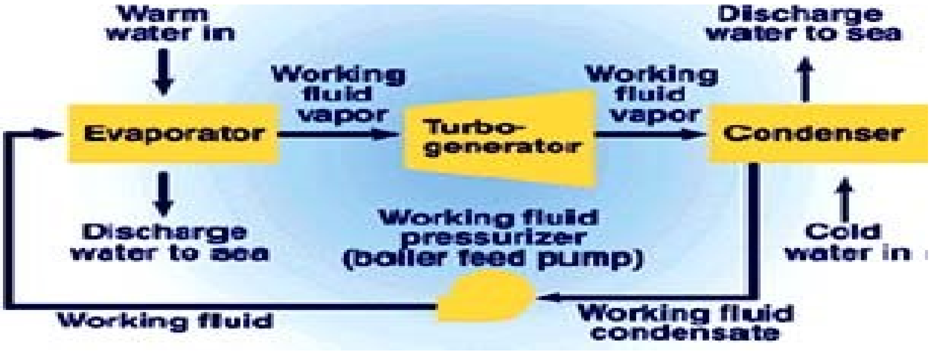

Figure 1: closed cycle OTEC scheme

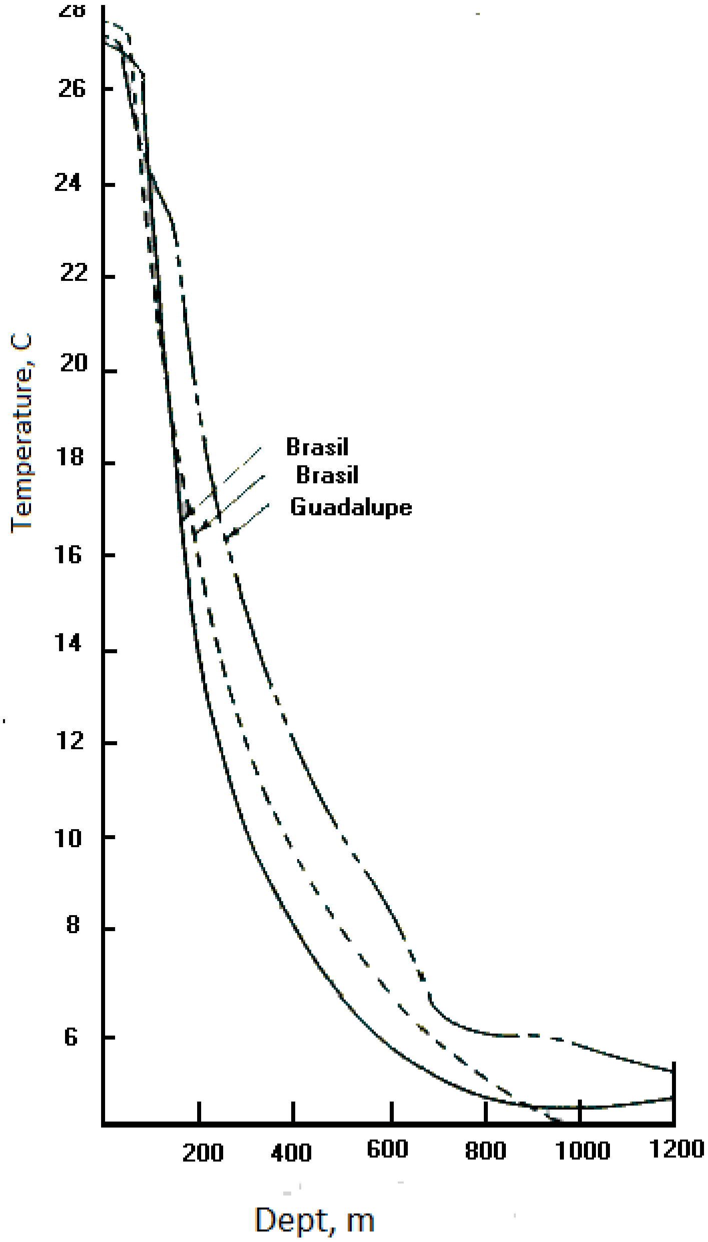

Figure 2: Temperature profiles at each ocean depth

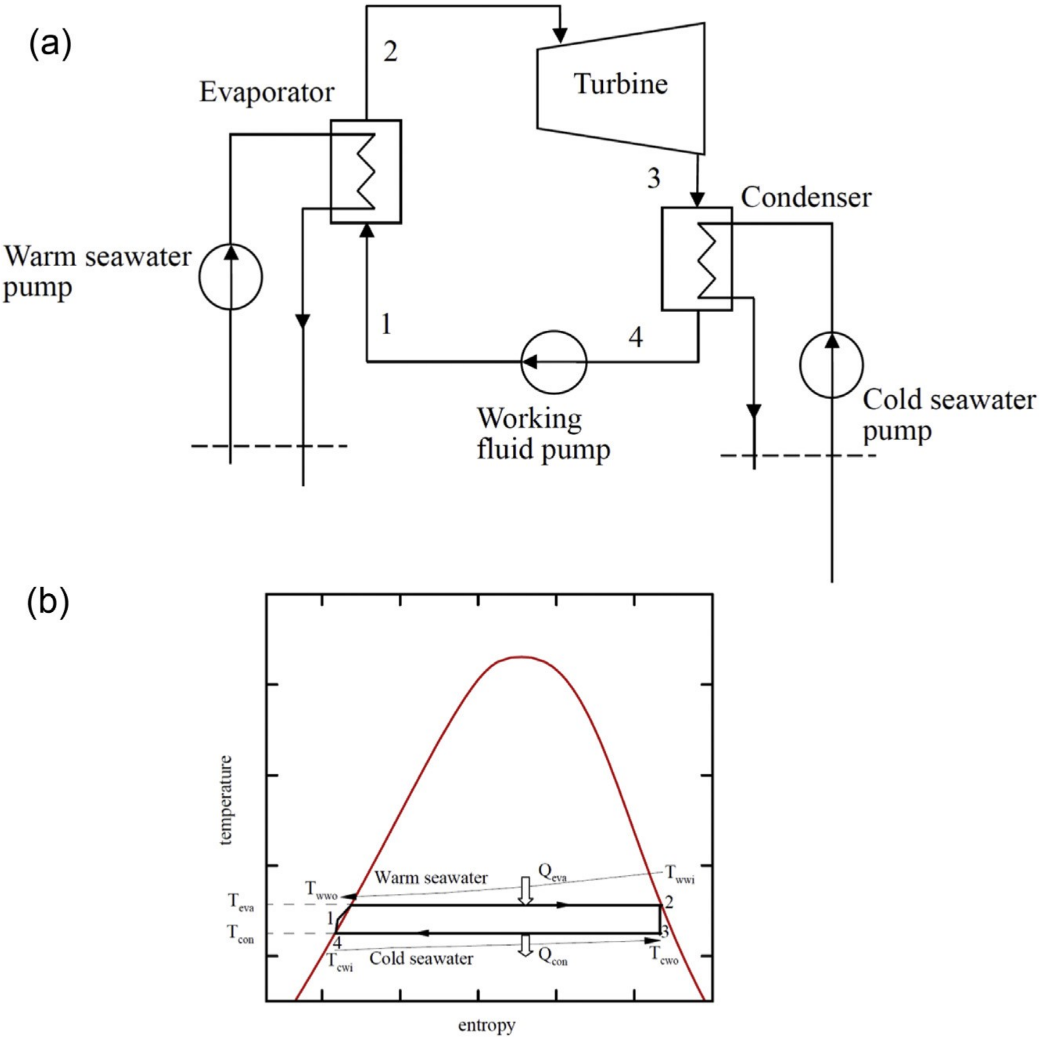

Figure 3: Rankine Cycle

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