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Physical Computations And Parametric Study Of Ocean Salinity And Temperature Energy Conversion (Ostec)

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ABSTRACT

Background: Oceanic salinity and temperature gradient power is an often-overlooked renewable energy. It uses the salinity and temperature difference between incoming freshwater and ocean seawater to generate energy through the use of turbine generator. Recently, a new system named Ocean Salinity and Temperature Energy Conversion (OSTEC) is developed in UMS, Sabah to harvest energy based on this concept. **Objective:** In this paper, a computational GUI model is developed using MATLAB to predict the expected power output of the system for varying effects of downtube and uptube diameter, height of reservoir, rection temperature, and salinity. **Results:** The theoretical formulation using kinematic viscosity model as actual imitation to the OSTEC system has proven its feasibility in this work. Comparison between the predicted power output and experimental results confirm the model performance for varying effects studied**. Conclusion:** With good knowledge of the input parameters, the model could help to quantify the possible change on the expected power output for varying effects and counter react for optimization in real prototype.

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INTRODUCTION

Over the past decades, dedicated technology for renewable energy is explored as substitution to fossil fuels. Although fossil fuels are continually being formed via natural processes, they are generally considered to be non-renewable resources because they take millions of years to form and the known viable reserves are being depleted much faster than new ones are being made. Besides, the emission of carbon dioxides from the use of fossils fuels also caused serious environmental concerns on Earth. The key to reduce the use of fossil fuel for ever raising global energy consumption is the sustainable renewable energy that harvestable from natural sources. An-often overlooked renewable energy is ocean energy derived from salinity and temperature gradient.

Salinity gradient power is the energy created from the difference in salt concentration between two fluids, commonly freshwater from river and seawater from ocean. The mixture, called brackish water, also known as by-product of the system generates energy by two processes Pressure Retarded Osmosis (PRO) and Reversed Electro Dialysis (RED). The literature review of these two processes are available elsewhere (Post *et al*., 2010; Helfer *et al*., 2014). An important factor governs the performance of both processes are the membranes. Current net power density of commercially available membranes is maximum 2.5-2.7W/m^2 (Kempener & Neumann, 2014). Higher power densities could be obtained by changing the cell design mainly on membrane resistance, cell length, and the use of nanotubes (Chou *et al*., 2012).

Ocean thermal energy conversion (OTEC), on the other hand, uses the temperature difference between cooler deep and warmer shallow or surface seawaters to run a heat engine and produce useful energy. Systems may be either closed-cycle or open-cycle (Pelc & Fujita, 2002; Vega, 2002). Closed-cycle engines use working fluids that are typically thought of as refrigerants such as ammonia. Open-

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cycle engines use vapor from the seawater itself as the working fluid (Zener, 2008).

Recently, in UMS, both technologies are combined into one system, named Ocean Salinity and Temperature Energy Conversion System (OSTEC). Preliminary results found that higher fluid velocity can be obtained when the temperature of the incoming freshwater is increased (Hamid *et al*., 2012; Lee *et al*., 2012). When the freshwater from the reservoir is funneled into the up-tube, the fresh water will mix with ocean water and form brackish water. The incoming freshwater has a temperature which is higher than the temperature of the ocean water deep in the sea. This will increase the buoyant force of the brackish water as the incoming water with higher temperature and lower salinity concentration will affect the density and viscosity of the brackish water. The upward flow of the rising mixture drives a turbine rotor and electricity is generated (Hamid *et al*., 2012; Lee *et al*., 2012).

In this paper, a computational GUI model of the OSTEC system is developed using MATLAB. The model simulates the power output for different temperature, salinity between incoming water and ocean water, diameter of up-tube and down-tube. Model predicted values are further compared with experimental measured values to investigate the model performance. The physical effect of the system is crucial to understand the energy change mechanism. This helps to identify the dominant factor that has the most significant effect on the expected power output of the system. With that, the developed model is useful in consideration of the construction cost and technical limitation for real prototype in future,

Method:

Theoretical Formulation:

Figure 1 shows the conceptual design of the QSTEC theoretical experiment. The fresh water from the reservoir is funneled through a down-tube into an up-tube installed under the sea level with diameter D_4 and length L_u. The down-tube is with internal diameter of D_3 and length of L_d. The kinematic viscosity, v of the system is expressed as

$$v = \frac{\mu}{\rho} \tag{1}$$

where μ is the dynamic viscosity

$$\mu = (\mu_W)(\mu_R) \times 10^{-3} \tag{2}$$

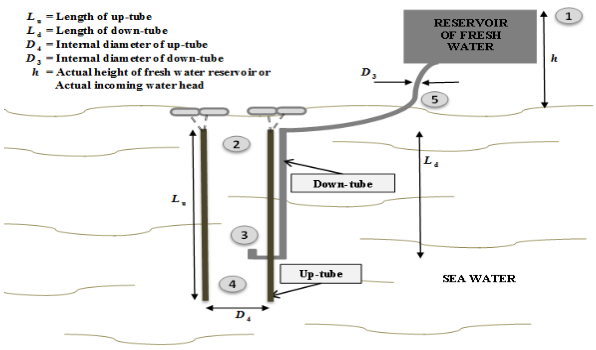

Fig. 1: Conceptual design of OSTEC system

S is the salinity and *T* is the temperature of the incoming fresh water from the reservoir.

A mixture called brackish water is formed when the fresh water from reservoir mix with the ocean water. The fluid density, ρ of the brackish water is (Gill, 1982)

$$\rho = (A_1F_1 + A_2F_2 + A_3F_3 + A_4F_4) \times 10^3 \tag{3}$$

The frictional head loss is the loss of energy that occurs in pipe flow. It is categorized into major loss and minor loss. The major loss is the loss due to the friction of the pipe wall and the minor loss is the loss due to friction of the components in the system. The frictional head loss, h_f is expressed as (Franzini & Finnemore, 1997)

$$h_f = f \frac{L}{D_s} \frac{V_T^2}{2g} \tag{4}$$

where *L* is the pipe length of 1.00 m, *h* is the height of the reservoir from the sea level, *g* is the gravity of the Earth, *f* is the Darcy friction factor, and V_T is the theoretical velocity which is derived as

$$V_T^2 = u^2 + 2gh \tag{5}$$

$$V = \sqrt{2gh} \tag{6}$$

Darcy friction factor, *f* is the theoretical description to estimate the frictional loss in the pipe flow. It is usually selected from Moody diagram. Moody diagram is a family curves that relate the friction factor, *f*, to Reynolds number, N_R, and the relative roughness of a pipe, e/D. The Darcy friction factor, *f* is expressed as

$$f = \frac{0.25}{\left[\log\left(\frac{e/D_s}{3.7} + \frac{5.74}{N_R^{0.9}}\right)\right]^2} \tag{7}$$

where e is the relative roughness and N_R is the Reynolds number.

The Reynolds number is the quantity to estimate similar flow patterns in different fluid flow situations. It is the ratio of inertial forces to viscous forces and which consequently quantifies the relative importance of these two types of forces for given flow conditions (Falkovich, G., 2011). The Reynolds number, N_R is expressed as

$$N_R = \frac{D_s V_T}{v_1} \quad (8)$$

where v_1 is the kinematic viscosity.

The flow rate at Point 3 is expressed as

$$Q_3 = A \times v \quad (9)$$

where A is the area of the down-tube, and $V = \sqrt{2gh}$ with height difference, $h = h_T - h_f$. h_T is the height of reservoir from sea level while h_f is the frictional head loss.

The flow rate at Point 4 is expressed as

$$Q_4^3 = Q_3^3 (\frac{\rho_3}{\rho_4})(\frac{D_4^4}{D_3^4}) \quad (10)$$

where ρ_3 is the fluid density and ρ_4 is the density of sea water, $1024.76 kg/m^3$.

The salinity of the brackish water at Point 2 is expressed as

$$S_2 = (S_4 Q_4 \rho_4)/(Q_3 \rho_3 + Q_4 \rho_4) \quad (11)$$

where S_4 is the salinity of sea water, which is approximately $35 g/L$.

The temperature at Point 2 is expressed as

$$T_2 = \frac{m_4 C_4 T_4 + m_3 C_3 T_3}{m_4 C_4 + m_3 C_3} \quad (12)$$

where mass movement of seawater, $m_4 = Q_4 \rho_4$, Q_4 flow rate of seawater at Point 4

$C_4 = 3993 Jkg^{-1}K^{-1}$

Temperature of seawater, $T_4 = 20°C$

Mass movement of fresh water, $m_3 = Q_3 \rho_3$

$Q_3 =$ Flow rate of fresh water at Point 3

$\rho_3 =$ Density of fresh water at Point 3

$C_3 =$ Specific heat capacity of fresh water

$T_3 =$ Temperature of fresh water at room temperature

The flow Rate at Point 2 is expressed as

$$Q_2 = Q_3 + Q_4 \quad (13)$$

The expected output power is expressed as

$$P_2 = 8 \frac{Q_2^3 \rho_2}{\pi^2 D_4^4} \quad (14)$$

where fluid density at Point 2, $\rho_2 = (A_1 F_1 + A_2 F_2 + A_3 F_3 + A_4 F_4) \times 10^3$.

Software Development:

The computational model is started with parameters input by users. These parameters include diameter of down-tube and up-tube, height of reservoir from sea level, salinity and temperature of incoming water from reservoir.

The theoretical formulae calculate the power output is converted into programming language. The kinematics viscosity, frictional head loss, velocity of incoming water and flow rate of brackish water at Point 2 is determined. Then, the expected power output is estimated.

To visualize the data for examination, data is displayed in graphical form for varying diameter of down-tube and up-tube, height of reservoir from sea level, temperature of incoming water from reservoir and salinity of water from reservoir. Data saving function is also added to enable users to save the data entered for future reference or execution.

RESULTS AND DISCUSSION

The program testing is done by inserting various sets of data into the program. It begins with the input of the variables as shown in Figure 2. The variables in the OSTEC system are the diameter of downtube, the diameter of uptube, the height of reservoir, the temperature and salinity of the incoming fresh water. The data range is based on the real OSTEC prototype.

Effect of Downtube and Uptube Diameter:

Figure 3 shows that the expected power output is directly proportional to the downtube diameter. Larger diameter of downtube leads to greater expected power output. This statement is strongly supported by theoretical formulation in Eq. (4, 7, 8, and 10).

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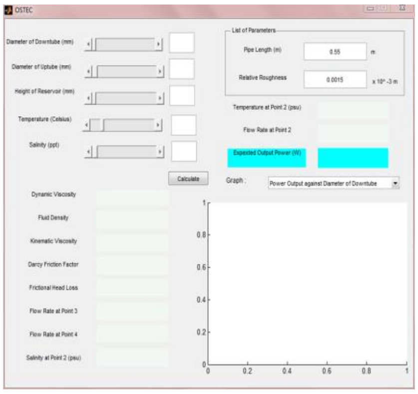

Fig. 2: The expected power output versus downtube diameter.

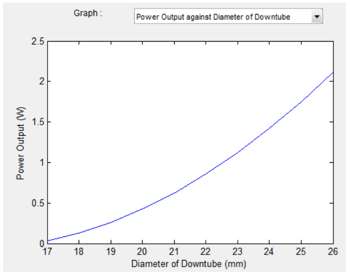

Fig. 3: The expected power output versus downtube diameter.

On the other hand, Figure 4 shows the inverse relationship between the expected power output and uptube diameter. The larger diameter of uptube brings to a smaller expected power output as shown in the formulation of OSTEC system in Eq. (14).

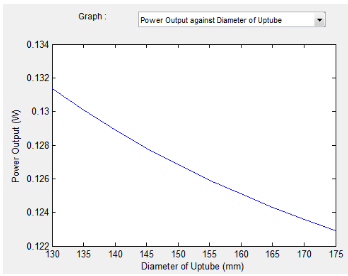

Fig. 4: The expected power output versus diameter of uptube.

Effect of Height of Reservoir:

Figure 5 shows the direct relation between the expected power output and the height of reservoir. This phenomenon can be explained using the formulation in the OSTEC system.

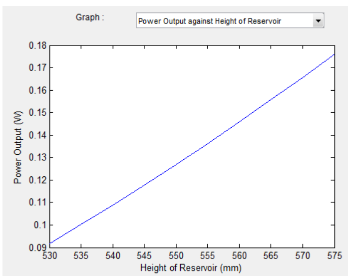

Fig. 5: The expected power output versus height of reservoir

Effect of Reaction Temperature:

Figure 6 shows the expected power output directly proportional to the temperature of incoming fresh water. Higher temperature of incoming fresh water leads to greater difference in temperature between the fresh water and the sea water. This temperature difference greatly affects the dynamic viscosity of the mixture, causing the fluid to be less viscous (Lee, 2012). The corresponding effect is the increase in the power output of the system.

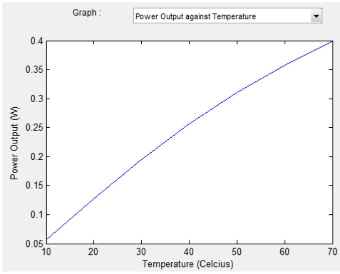

Fig. 6: The expected power output versus reaction temperature

Effect of Salinity:

Figure 7 shows the salinity effect of incoming fresh water on the expected power output. Higher salinity of the incoming water from reservoir lowers the expected power output of the OSTEC system. This is because the fluid salinity is directly proportional to the dynamic viscosity. The increase in the fluid salinity causes the dynamic viscosity increases (Lee, 2012). As a result, the increase in dynamic viscosity lowers the power output at the end of the system.

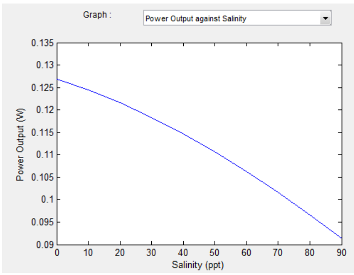

Fig. 7: The expected power output versus salinity

Model Performance:

Figure 8 shows the comparison of each effect on the expected power output in radar chart. The most significant effect is the down-tube diameter such that, on average, one meter increase is expected to rise the power output by 0.23W. Other effects are reaction temperature (~0.006W/°C), followed by height of reservoir (~0.002 W/mm), salinity (~0.0004W/ppt), and the least on up-tube diameter (~-0.0002W/mm).

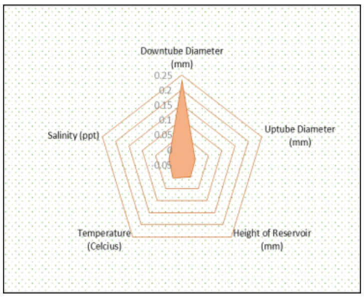

Fig. 8: Radar chart of varying effects on expected power output in Watts per respective parameters.

Table 1 shows that the simulation result predicted from the computational model has small percentage of difference range from ±0.1~0.4% when compared to the experimental results. On average, the percentage error is approximately of ±0.2%. The model is capable to predict the expected power output for varying effects of down-tube and up-tube diameter, height of reservoir, reaction temperature and salinity.

Table 1: Performance analysis of the model between simulation and experimental results at constant downtube diameter 18 mm, uptube diameter 150 mm, height of reservoir 550 mm and salinity 0 ppt

Temperature (Celcius)	Expected Power Output (W)		Percentage of Difference (%)
	Simulation Results	Experimental Results	
10	0.057121	0.0569	±0.39%
20	0.126836	0.1269	±0.05%
30	0.194452	0.1946	±0.08%
40	0.255932	0.2564	±0.18%
50	0.310394	0.3109	±0.16%
60	0.35803	0.3584	±0.10%
70	0.399394	0.4000	±0.15%
Average Percentage of Difference			0.159%

Conclusion:

In this work, a computational GUI model of OSTEC system was developed using MATLAB. On singular effect perception, greatest power output is expected from the increase in down-tube diameter. Similar but lower yield is observed for increase on height of reservoir, and reaction temperature. Meanwhile, up-tube diameter and salinity have the inverse effect on the power output. Analysis of power output for an overall system should base on the combined effects as whole. At this point, the developed model has successfully provided an imitation to the OSTEC system using theoretical formulation.

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REFERENCES

Chou, S., R. Wang, L. Shi, Q. She, C. Tang, and A.G. Fane, 2012. Thin-film composite hollow fiber membranes for pressure retarded osmosis (PRO) process with high power density. Journal of Membrane Science, 389: 25-33.

Falkovich, G., 2011. Fluid mechanics: A short course for physicists. Cambridge University Press.

Franzini, J. B. and E. J. Finnemore, 1997. Fluid Mechanics with Engineering Applications. 9th ed. New York: McGraw-Hill.

Gill, A.E., 1982. Atmosphere-Ocean Dynamics. Academic Press.

Abd. Hamid, A.S., S.K. Lee, J. Dayou, R. Yusoff, R. and F. Sulaiman, 2012. Viscosity Model for Predicting the Power Output from Ocean Salinity and Temperature Energy Conversion System (OSTEC) Part 1: Theoretical Formulation. International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering, 7(10): 453 - 457.

Helfer, F., C. Lemckert and Y.G. Anissimov, 2014. Osmotic power with pressure retarded osmosis: theory, performance and trends - a review. Journal of Membrane Science, 453: 337-358.

Kempener, R. and F. Neumann, 2014. Salinity gradient energy. Technology Brief 2. IRENA Innovation and Technology Centre.

Lee, S.K., J. Dayou, A.S. Abd Hamid, E. Saleh and B. Ismail, 2012. A Theoretical Investigation on the Potential Application of Ocean Salinity and Temperature Energy Conversion (OSTEC). International Journal of Renewable Energy Research, 2(2): 326-331.

Pelc, R. and R.M. Fujita, 2002. Renewable energy from the ocean. Marine Policy, 26(6): 471-479.

Post, J.W., C.H. Goeting, J. Valk, S. Goinga, J. Veerman, H.V.M. Hamelers and P.J.F.M. Hack, 2010. Towards implementation of reverse electrodialysis for power generation from salinity gradients. Desalination and Water Treatment., 16(1-3): 182-193.

Vega, L.A., 2002. Ocean thermal energy conversion primer. Marine Technology Society Journal., 36(4): 25-35.

Zener, C., 2008. Solar sea power. Physics Today., 26(1): 48-53.