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Power Analysis of the Ocean Salinity and Temperature Energy Conversion (OSTEC) Experimental Model

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ABSTRACT

Background: Salinity and temperature difference between two bodies of water have been found capable in generating electrical energy by making use of upward buoyant force. An experimental model of Ocean Salinity and Temperature Energy Converter or OSTEC was developed using this principle. Fresh water was overflowed from an elevated fresh water tank placed on adjustable stand. Experiment was initiated by channeling the fresh water through a small down-tube into the bottom of a bigger up-tube. The up-tube with length 1.2 m is submerged in the center of sea water tank, with its top opening is kept 0.15 m below sea water surface. **Objective:** The present investigation is performed to estimate the power output from the OSTEC system. Kinetic power of upstream water mixture is estimated using viscosity model based on measurement of mixture salinity at the top of up-tube. **Results:** It was found that increasing the tube diameter ratio from 10% to 12.6% rises up the kinetic power output from 3.1 mW to 200 mW. **Conclusion:** In general, in this specific investigation, substantial increment in power output is obtained with small increment in the diameter ratio.

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INTRODUCTION

Ocean which covers more than 70% of the planet surface may provide huge potential resources of renewable energy if properly harnessed. To assess this potential, a number of initiatives are pursued by several governments such as New Zealand, United Kingdom, Australia, European Union, the United States, and Japan (Tengku Abdul Rashid and Abdul Mukti, 2006). As a consequence, in 2008, the first generation of commercial ocean energy devices - tidal stream generator known as SeaGen and wave energy converter known as Pelamis, were installed in UK and Portugal, respectively (Esteban and Leary, 2012). Among these energy resources such as ocean wave (Dinh and Kyoung, 2014; Jaswar *et al*., 2014; Wilberta *et al*., 2014), sea tide (Sanchez *et al*., 2014), sea water current (Akimoto *et al*., 2013) and temperature gradient (Morales *et al*., 2014), salinity gradient is the one less explored yet the prospect for electricity generation may be huge.

The authors have recently introduced additional parameter into the system that may further excite the upward buoyant force of the upstream water mixture, which is the temperature difference between two water bodies. This new system is known as Ocean Salinity and Temperature Energy Conversion System or OSTEC (Lee *et al*., 2012; Abd. Hamid *et al*., 2013; Lee *et al*., 2014; Lee *et al*., 2015). Sea water and incoming fresh water with different salinity and temperature are mixed in a vertical tube submerged from water surface to certain depth of sea water, this produces an upstream brackish mixture due to increased buoyant force. Kinetic power can be derived from the upstream water mixture by using appropriate turbine runner and dynamo generator.

Theoretical prediction model has been formulated which are Density Model (Lee *et al*., 2012) and later Viscosity Model (Abd. Hamid *et al*., 2013; Lee *et al*., 2014). Viscosity model predicts kinetic power by integrating the effect of dynamic viscosity into the fresh water channeling system.

An OSTEC Experimental Model is installed in Aquatic Hatchery, Universiti Malaysia Sabah for performance modeling and parametric optimization. In the current investigation, sea water and incoming

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fresh water at nearly the same temperature are mixed together in underwater piping apparatus to examine the effect on upstream water mixture. Kinetic power output of upstream mixture is predicted and compared based on types of measuring instruments.

Ostec Experimental Model:

Experimental testing of Ocean Salinity and Temperature Energy Converter (OSTEC) is performed in a large volume of natural sea water. Sea water is stored in a sea water on-ground fiberglass tank or in short SWOGT, with equal length and width of 1.5 m, and height of 2.0 m. Fig. 1 shows the actual OSTEC system.

Sea water is filled in SWOGT till the tank height of 1.6 m from the ground, where this height is in-line with the base orifice of incoming fresh water tank. This volume would equal to 3,600 L of sea water storage in SWOGT.

The experimental components consist of an open vertical tube or in short up-tube as shown in Fig. 1, with inner diameter of 15 cm and length of 1.20 m, is suspended vertically in the center of SWOGT. The top of vertical tube is kept 15 cm below the sea water surface. At the bottom of up-tube (0.80 m below the top opening of up-tube), a smaller tube or in short down-tube, with diameter of 2.00 cm is connected through for channeling fresh water into up-tube, to enable the mixing of fresh water with bottom sea water. Down-tube with length of 1.2 m is fixed diagonally from just above the sea water level (1.6 m from ground) and towards the bottom of up-tube. The outlet of down-tube is fastened with two 90^{o} elbows in a way that fresh water would channel upwards.

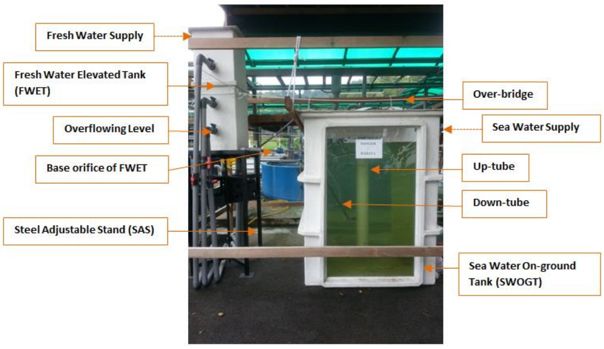

Fig. 1: OSTEC Experimental Model installed in Aquatic Hatchery of Universiti Malaysia Sabah.

The down-tube inlet is connected to a fresh water channeling system, which consists of Steel Adjustable Stand (SAS) and Fresh Water Elevated Tank (FWET) as demonstrated in Fig. 1. SAS is associated with manual gear kit set coordinated with Lycorwinch Motor (LCM 750 Model) where it can withstand maximum uploading system of 450 kg. It has frame size of equal length and width of 0.75 m and minimum elevation of 1.50 m, and it can be elevated for maximum increment of 1.00 m. At the present investigation, it was fixed at the minimum level without any elevations.

Fresh Water Elevated Tank (FWET) is used to store fresh water for channeling into the SWOGT through down-tube. FWET has equal length and width of 0.5 m, and height of 1.5 m. Between the down-tube inlet and the bottom orifice of FWET, a ball valve and a volumetric water meter (PSM Model, Inner Diameter 15 mm) are installed for controlling and monitoring the channeled volume of fresh water (in Fig. 2). As previously mentioned, with filling and storing of sea water in SWOGT till water level of 1.6 m, and continuous supplying with highest overflowing level of fresh water to FWET, experiment is initiated by turning on the controlling valve at the orifice of FWET.

In the experiment, the independent variable is salinity of the incoming water where it is preferred as minimum as possible if compared to high salinity of sea water. Therefore, fresh water with zero salinity is used and is channeled through FWET. The dependent variables are volume flow rate of incoming water and salinity of the upstream water mixture at the top of up-tube.

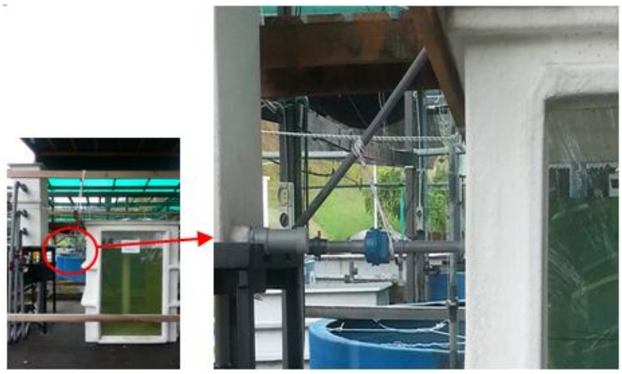

Fig. 2: Controlling fresh water valve and volumetric water meter (PSM Model, Inner Diameter 15 mm) for monitoring the channeled volume of fresh water.

The experiment is tested for 30 minutes with continuous supply of fresh water throughout the testing. Before testing is started, salinity and temperature of both sea water in SWOGT and fresh water in FWET are measured and recorded. The temperature of both types of water is basically same within 27 to 29 ^{o}C. The initial reading of volumetric water meter at the base orifice of FWET is checked and recorded. The salinity of water mixture is measured at the top of up-tube for every five minutes for half an hour, using Salinity Meter.

Experimental Prediction Of Kinetic Power Output:

By having measured salinity of water mixture $S_{2\_measured}$ and volumetric flow rate of incoming fresh water $Q_{3\_measured}$, kinetic power of water mixture at the top of up-tube (Point 2) can be predicted (refer to Figure 3 for schematic diagram of OSTEC). To quantify the amount of kinetic power at Point 2 (in Fig. 3), volumetric flow rate of water mixture Q_2 is required. From the theoretical formulation (Lee *et al*., 2012; Abd. Hamid *et al*., 2013; Lee *et al*., 2014), Q_2 is the summation of Q_3 and Q_4 in view that there are two inlets of flowing water into up-tube which are incoming fresh water (Point 3) and up-streaming sea water (Point 4) as written

$$Q_{2\_predicted} = Q_{3\_measured} + Q_{4\_predicted} \, . \qquad (1)$$

Volumetric flow rate of up-streaming sea water $Q_{4\_predicted}$ can be estimated based on the measurement of $S_{2\_measured}$ and $Q_{3\_measured}$ as written in (Pscheidt and Finley, 2003)

$$Q_{4\_predicted} = (Q_{3\_measured})(\frac{\rho_3}{\rho_4})(\frac{S_{2\_measured}}{S_{4\_measured} - S_{2\_measured}}) \, . \qquad (2)$$

where ρ_3 and ρ_4 are density of incoming water and sea water respectively, and S_4 is salinity of sea water. With the quantification of flow rate $Q_{2\_predicted}$ and density of water mixture ρ_2 flowing in up-tube diameter D_4, kinetic power of upstream water mixture $P_{2\_predicted}$ can thus be determined using

$$P_{2\_predicted} = 8\frac{(Q_{2\_predicted}{}^3)\rho_2}{\pi^2 D_4{}^4} \, . \qquad (3)$$

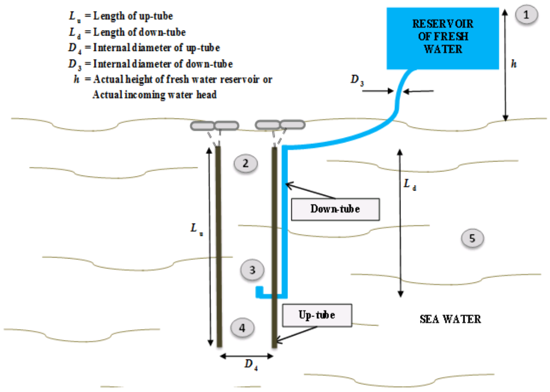

Fig. 3: Schematic design of OSTEC Model.

RESULTS AND DISCUSSIONS

Experimental testing is performed to mix sea water and incoming fresh water at overflowing level of 1.00 m for observing salinity change of water mixture. In the experiment, initial salinity of collected sea water in SWOGT is 28.4 ppt. Incoming fresh water with zero salinity is collected in FWET and later funneled into up-tube submerged in SWOGT to mix with sea water.

With the incoming fresh water flow rate $Q_{3\_measured}$ and maximum salinity of water mixture $S_{2\_measured}$, volume flow rate of sea water upraising into bottom of up-tube $Q_{4\_predicted}$ can be determined using equation (2). As a result, volume flow rate of upstream water mixture at top of up-tube $Q_{2\_predicted}$ would be the sum of $Q_{3\_measured}$ and $Q_{4\_predicted}$ as in equation (1). With the flow rate $Q_{2\_predicted}$ and density of upstream water mixture ρ_2, kinetic power at top of up-tube $P_{2\_predicted}$ can be estimated through equation (3). Figure 4 shows the prediction of kinetic power of upstream water mixture for down-tube diameter of 15mm.

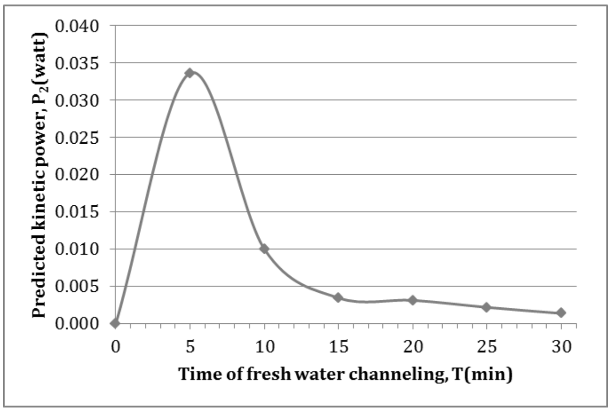

Fig. 4: Kinetic power output of the OSTEC system using down-tube diameter of 15mm.

From Fig. 4, abrupt increment of kinetic power happens within first five minutes is due to that incoming fresh water is not yet thoroughly reached the top opening of up-tube. Therefore, not much salinity change within that time period is observed and this causes to nearer initial salinity being measured. This time period is therefore not suitable for assessing since mixing of fresh water and sea water is not well developed yet. For this reason, time of minute-20 (second-1200) is selected as the point for assessing due to that the measured salinity is maintained throughout that time period, where this might signify osmosis mixing process and buoyancy which entrains out certain amount of bottom sea water. As a result, incoming fresh water passing through volumetric water meter (inner diameter=15mm) and mixes with sea water in the up-tube produces kinetic power of 3.1 mW at top of up-tube.

Average volume flow rate of incoming fresh water quantified using volumetric water meter Q3_meter is lower than the average flow rate quantified based on level changing Q3_level. With volumetric water meter, measurement is performed using rotary piston method, where this method is sensitive to high-pressure flow rather than low-pressure flow. It is observed that certain amount of flowing fresh water with low-pressure has passed through the flow meter and yet the meter hardly detects the usage, soon the water mixture flowing out through top of up-tube slowly. Consequences, the volumetric water meter would overlook certain amount of low-pressure flowing water.

To further assess the OSTEC system, the existing down-tube was replaced with a new tube with inner diameter 19mm. For this setting, an electronic water meter model TM075 was used. Figure 5 shows the kinetic power output for this setup.

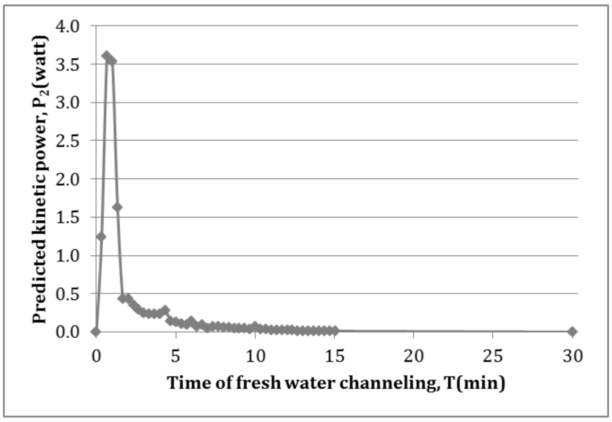

Fig. 5: Kinetic power output of the OSTEC system using down-tube diameter of 19mm.

From Fig. 5, it can be seen that incoming fresh water takes about two minutes to reach the top opening of up-tube. From about minute-2.0 onwards, incoming fresh water starts mixing with sea water in the up-tube. Time of minute-3.7 on-wards was selected for assessment due to that the measured salinity was almost constant and the system has reached the equilibrium state. Close inspection of Figure 5 shows that the system produces kinetic power of 0.24 W at top of up-tube at the stabilized state.

The kinetic power output from the OSTEC system at two diameter ratio is summarized in Table 1.

Table 1: Predicted kinetic power with different measuring water meters.

Types of water meter	[a]VWM	[b]EWM
Tube diameter ratio, D_3/D_4	10%	12.6%
Stability time of incoming fresh water before mixing, t_{fw} (minute)	10^{th}	2^{th}
Time selected of osmosis mixing process and buoyancy, $t_{selected}$ (minute)	20^{th}	3.7^{th}
Predicted kinetic power, $P_{2\_predicted}$	[c]3.1mW	[d]0.2W

[a]VWM = Volumetric water meter (inner diameter = 15mm); [b]EWM = Electronic water meter (inner diameter = 19mm); [c]Measured after 20 minutes; [d]Measured after 3.7 minutes

Conclusions:

Experimental investigation on Ocean Salinity and Temperature Energy Converter (OSTEC) has been performed with different configuration in terms of diameter ratio between up-tube and down-tube. With saline measurement, smaller down-tube (15mm) takes about 20 minutes equilibrium state while larger down-tube (19mm) takes about 4 minutes. Increasing of tube diameter ratio from 10% to 12.6% increased the kinetic power output from 3.1 mW to 200.0 mW.

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