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# Experimental Study of The Fan Turbine Performance in Oscillating Water Column with Airflow System in Venturi Directional as Wave Energy Converter

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## ABSTRACT

The Indonesian Ocean Energy Association has ratified the potential for ocean wave energy in Indonesia with a theoretical possibility of 141.472 x 109 watts. Unfortunately, this vast potential has not yet been utilized optimally in the Indonesian seas. Ocean wave energy technology has developed rapidly in various countries worldwide. The Oscillating Water Column (OWC), which uses the oscillating movement of ocean waves' airflow, is one of the most well-known systems for generating power from waves. A novel model of ocean wave power generation was created with the use of a more basic fan turbine and inspiration from OWC. It is directly integrated with an electric dynamo and an internal flow system in a venturi tube, which can increase airspeed based on continuity theory. The experiment's results succeeded in creating up and down movements of ocean waves with a high tide of 15 cm and a low tide of 12 cm. Ocean wave oscillations can produce gusts of air with a speed of 1.56 m/s. The final result is obtained by model performance with an average turbine rotation speed of 42.191 rpm, an average electric voltage of 0.809 volts, and a more optimal turbine efficiency of 67.9%.

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## INTRODUCTION

Indonesia is a world maritime axis country that has enormous marine resources. In addition, Indonesia is also an archipelagic country, so people's activities cannot be separated from the ocean area. But ironically, the sea area in Indonesia still needs to be optimally utilized from the existing potential, like the energy that comes from seawater bodies that have not been used until this moment. If ocean energy resources in Indonesian territory can be utilized, it will solve the lack of electrical energy supply. Ocean energy, as a sustainable and environmentally friendly renewable energy, can be used as a substitute for fossil fuels, which are not environmentally friendly. The Ocean energy potential in Indonesia is theoretically 4.677 x 1012 watts. The Indonesian Ocean Energy Association has ratified the magnitude of this potential from ocean thermal sources, ocean waves, and ocean currents (Mukhtasor, 2014).

Ocean waves are a renewable energy source originating from seawater bodies, which can be used as renewable energy to overcome the current energy crisis, known as ocean wave power generation. The magnitude of the potential for ocean wave energy in Indonesia based on the theoretical, technical, and practical the Indonesian Ocean Energy Association ratification is 141.472 x 109, 7.985 x 109, and 1.995 x 109 watts, respectively (Mukhtasor, 2014).

The working principle of ocean wave power generation is to convert potential energy into rising and falling sea water, which is then converted into mechanical energy with devices wave energy and then electrical energy by generators. The development of wave energy technology continues to be carried out with various innovations to obtain the most optimal production of electrical power to be applied. Multiple innovations in wave energy technology models have been developed to reach thousands of patents. Wave energy technology generally has two systems: the Oscillating Water Column (OWC) and the Bottom Fixed Oscillating Flap (BFOP). The system combining OWC and BFOP is the Flap Float Horizontal (FFH), successfully tested on a lab scale by (Madi et al., 2022). However, the most popular and first-generation wave energy technology is OWC.

One of the most well-known ideas for ocean wave energy devices is OWC, which will significantly impact the advancement of wave energy (Doyle & Aggidis, 2019). Various OWC innovations, such as Limpet OWC (Sun et al., 2018) and Yongsoo OWC (Curto et al., 2021), continue to be created. The respective OWC technologies are shown in Figure 1.


**(a)** **(b)**

**Figure 1. OWC technology, (a) Limpet OWC, (b) Yongsoo OWC**

OWC technology generally uses power take-off (PTO) from a more compact turbine generator, making it complicated to manufacture on a small scale. Turbines are crucial and sensitive because they are one of the leading technologies used to generate electricity besides generators (Madi et al., 2018). The main component in the turbine is the blade, which is the most critical part of converting kinetic energy into mechanical energy (Madi et al., 2021b). The turbines currently used operate at high speeds, so they cannot be immediately applied in Indonesia, which tends to have low speeds (Madi et al., 2019). Turbine performance needs to be improved to produce optimal electrical energy, such as using a deflector (Madi et al., 2021a).

The fan turbine is very simple because it is directly integrated with an electric dynamo and is easy to manufacture on a small scale. However, the performance of the fan turbine could be more optimal. Thus, to optimize the performance of the fan turbine in the wave energy, an airflow system through a directional venturi is applied. According to continuity theory, speed is inversely proportional to area (Blevins, 1984). Thus, if the fan turbine area is placed in a smaller venturi tube, the flow velocity becomes more significant and can produce optimal turbine performance.

## METHOD

### Geometry

**Table 1. Column geometry**

| Geometry | Value | Unit |
|---|---|---|
| Base Length | 50 | cm |
| Base Width | 50 | cm |
| Front Wall Length | 50 | cm |
| Front Wall Height | 20 | cm |
| Front Wall Side Length | 21 | cm |
| Front Wall Side Height | 20 | cm |
| Center Vertical Wall Length | 50 | cm |
| Middle Vertical Wall Height | 15 | cm |
| Back Wall Length | 50 | cm |
| Back Wall Height | 30 | cm |
| Back Wall Side Length | 14 | cm |
| Back Wall Side Height | 30 | cm |
| Mid-Sloping Wall Length | 50 | cm |
| Mid-Sloping Wall Width | 29 | cm |
| Mid-Side Wall Length | 15 | cm |
| Mid-Sloping Side Wall Height | 30 | cm |

The geometry of the wave energy with the directional venturi model can be briefly shown in Figure 2 and, in total, can be shown in Tables 1, Table 2, and Table 3.

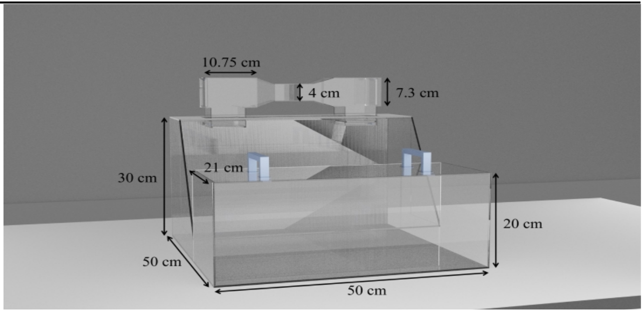

**Figure 2. Design and geometry model**

**Table 2. Venturi geometry**

| Geometry | Value | Unit |
|---|---|---|
| Large Tube Outside Diameter | 7.30 | cm |
| Large Tube Inside Diameter | 7.00 | cm |
| Horizontal Large Tube Length | 10.75 | cm |
| Vertical Large Tube Length | 4.80 | cm |
| Conversion Tube Outer Diameter | 7.30 | cm |
| Inside Diameter of Conversion Tube | 7.00 | cm |
| Convert Tube Length | 4.17 | cm |
| Small Tube Outside Diameter | 4.30 | cm |
| Small Tube Inside Diameter | 4.00 | cm |
| Small Tube Length | 4.17 | cm |

**Table 3. Fan turbine geometry**

| Geometry | Value | Unit |
|---|---|---|
| Turbine Length | 4.00 | cm |
| Turbine Width | 4.00 | cm |
| Turbine Thickness | 1.00 | cm |
| Turbine Shaft Radius | 0.35 | cm |
| Turbine Radius | 0.38 | cm |
| Turbine Area | 0.02 | $cm^2$ |

### Fabrication

The wave energy with a directional venturi model consists of three main components: the column used to simulate the formation of ocean waves made of acrylic is inspired by the shape of the Tidal Power Modifier column (Febrianto et al., 2015), a venturi for circulating airflow made of acrylic, and a fan turbine as an energy converter. The results of the wave energy fabrication with the venturi directional model can be shown in Figure 3. It is making a physical model with geometric adjustments based on the model design that has been designed according to Figure 2.

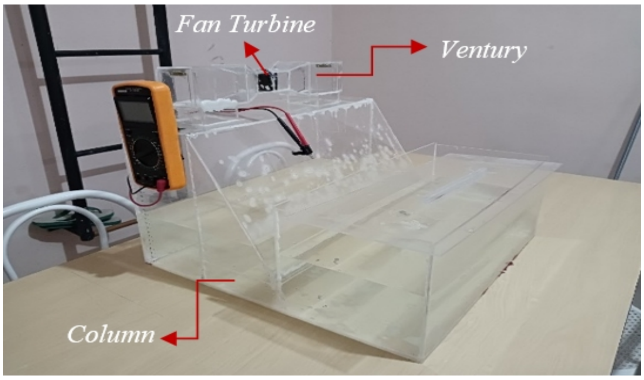

**Figure 3. Fabrication model**

## Data Processing

Data were collected by directly measuring the wave energy with the directional venturi model. The data taken is the rotational speed of the turbine (rpm) using a non-contact tachometer and the electric voltage (volts) using a multimeter. Figure 4 displays the simultaneous retrieval of electric voltage and turbine rotation speed data for 22 seconds.

In addition, for 22 seconds, wave height (m) measurements during high, low, and airflow velocity data (m/s) were collected using an anemometer.

After collecting data through measurements, theoretical data processing is carried out to process the amount of performance generated by the wave energy with the directional venturi model. The theoretically processed data consists of airflow power resulting from oscillating ocean waves using Equation (1).

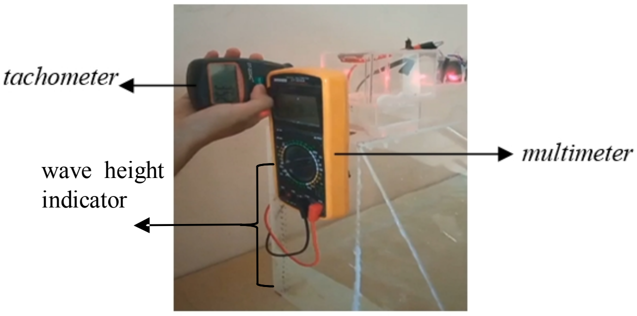

**Figure 4. Data collection**

$$- \cdot \quad \cdot \quad \cdot \qquad (1)$$

*Pa* is the wind power (watts), $\rho$ is the density of air (1.25 kg/m$^3$), *A* is the area of the turbine (m$^2$), and *v* is the airflow velocity (m/s). In addition, turbine power calculations are also carried out using Equation (2).

$$- . \quad . \quad . \quad . \; .2 \qquad (2)$$

*Pt* is the turbine power (watts), *R* is the turbine radius (m), and *n* is the turbine rotational speed (rad/s). Next, calculate the efficiency of the turbine (η) using Equation (3).

$$—.\,100\% \qquad (3)$$

## RESULTS AND DISCUSSION

### Model Principle

The wave energy with a venturi directional model system has its advantages, namely, the optimization of efficiency. The movement of air circulation hitting the fan turbine by modifying the previous wave energy technology system is supported by the renewal of a one-way, two-air flow system using a venturi tube so that the performance produced by the turbine is even more fantastic and optimal. This is because the turbine space is narrower than the inlet and outlet parts, so the continuity of the airflow hitting the turbine becomes faster. The movable dimensions of the structure, with a size of 0.5 x 0.5 m and made of acrylic base materials, make the wave energy model easy to locate and move. The placement of the model location layout is after the occurrence of tidal waves, where the detailed location can be adjusted to the morphology of the beach being reviewed.

The working principle of the wave energy with the directional venturi model is that when a tidal wave is generated, as shown in Figure 5 (a), the air in the column will move towards the turbine through valve 1. After hitting the turbine, the air will move through valve 3 (Figure 5 (c). After the high tide ends, the receding wave (as shown in Figure 5 (b) will take in air from the outside through valve 2. After passing through valve 2, the air will move into the column's air column. On air travel, the air will hit the turbine first and then enter the air column through valve four, as shown in Figure 5 (d).

## Turbine Rotation Speed Results

Simulation testing of the wave energy with a directional venturi model will produce data on turbine rotational speed (rpm) and electric voltage (volts), where the data is time series (seconds), shown in Figure 6.

From these tests, the lowest turbine rotational speed was obtained at 35.2 rpm, the highest turbine rotational speed was 46 rpm, and the average turbine rotational speed was 42.191 rpm. At 1-4 seconds intervals, water conditions will rise to high tide, increasing the turbine's rotational speed because air is pushed in and accelerated into the venturi chamber. Meanwhile, at 4-8-second intervals, the water conditions will begin to recede until it finally ebbs periodically. The turbine's rotational speed has decreased because the air has passed through the turbine and left the venturi chamber. This condition will continue to repeat and form almost the same pattern at intervals during the column's ocean wave cycle.

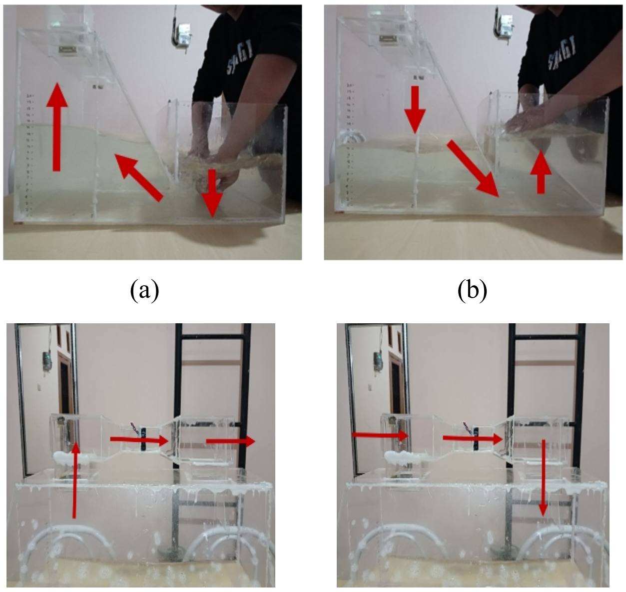
(a) (b) (c) (d)

**Figure 5. The working principle model, (a) tidal ocean waves, (b) low ocean waves, (c) airflow on venturi during the tide, (d) airflow on venturi during low**

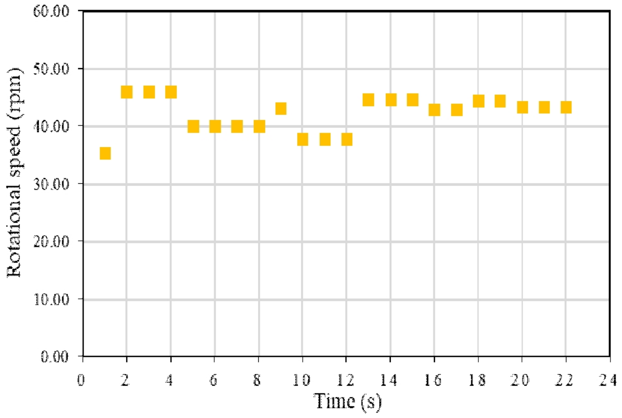

**Figure 6. Rotational speeds**

## Electrical Voltage Result

Based on the results of measuring the electric voltage using a multimeter shown in Table 4, which includes several factors, such as voltage, time, and wave height, a graph of the relationship between electric voltage and time is obtained, as shown in Figure 7.

**Table 4. Electrical voltage**

| Electrical voltage (volts) | Time (s) | Wave height (cm) |
|---|---|---|
| 0.00 | 0 | 12 |
| 0.83 | 1 | 13 |
| 1.94 | 2 | 15 |
| 0.56 | 3 | 13 |
| 0.03 | 4 | 12 |
| 0.22 | 5 | 13 |
| 2.26 | 6 | 15 |
| 0.88 | 7 | 13 |
| 0.01 | 8 | 12 |
| 2.02 | 9 | 15 |
| 1.46 | 10 | 13 |
| 0.16 | 11 | 12 |
| 0.11 | 12 | 12 |
| 2.21 | 13 | 15 |
| 0.81 | 14 | 13 |
| 0.01 | 15 | 12 |
| 0.50 | 16 | 13 |
| 1.23 | 17 | 15 |
| 0.13 | 18 | 12 |
| 0.01 | 19 | 12 |
| 1.70 | 20 | 15 |
| 0.71 | 21 | 13 |
| 0.01 | 22 | 12 |

Figure 7 shows the results of the electric voltage obtained through the relationship between the electric voltage and time. The existence of continuity of electric voltage at each time interval proves that a wave oscillation can be transformed into electrical energy through the kinetic energy of the movement of circulating air through the turbine. This phase is directly proportional to the turbine's rotational speed, which has the same interval pattern as the interval pattern at the primary voltage.

The average electric voltage obtained is 0.884 Volts. In low tide conditions, the average electric voltage is 0.52 volts, then in high tide conditions, the average electric voltage is 0.51 volts, and when tide pattern, the average voltage generated is at 1.89 volts. After calculating the data obtained, the average total voltage generated by the wave energy with the directional venturi model is 0.8 volts. This average proves that venturi directional provides a relatively significant influence to increase turbine performance.

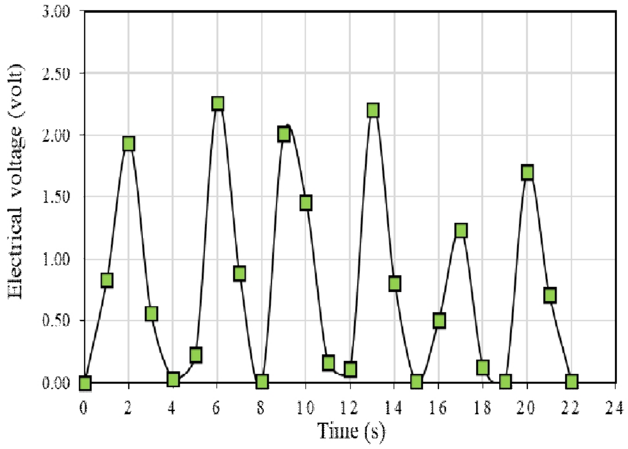

**Figure 7. Electrical voltage**

## The Fan Turbine Efficiency Results

The ability of the fan turbine to absorb the kinetic energy of the airflow resulting from the blowing of sea waves, known as turbine efficiency, determines the optimization of turbine performance. Based on Equation (1), the kinetic power of the airflow with a speed of 1.56 m/s is obtained at 0.412 watts. While the mechanical energy of the turbine, as in Equation (2), is received at 0.279 watts. So, with Equation (3), it is obtained that the fan turbine efficiency is 67.9%. Based on that, the turbine performance in the wave energy with the directional venturi model is optimal because it has produced great efficiency with only an energy loss of 32.1%. This can be obtained because the rotation of the turbine in the venturi rotates stably from the two directions of airflow during high and low tides.

## CONCLUSION

Experimental studies on wave energy with a directional venturi model using fan turbines have been successfully carried out. The experiment's results succeeded in creating up and down movements of sea waves with a high tide of 15 cm and low tide of 12 cm. Ocean wave oscillations can produce gusts of air with a speed of 1.56 m/s. The final result is obtained by model performance with an average turbine rotation speed of 42.191 rpm, an average electric voltage of 0.809 volts, and a more optimal turbine efficiency of 67.9%.

This research is the first step in contributing to technological innovation on a model for ocean energy technology recommendations in Indonesia. This research has provided optimal results and has a great opportunity to be optimized even better in the future. As for some of the author's recommendations in optimizing for the continuation of this research, namely, i) choosing a more compact type of turbine such as Welss turbine, bulb turbine, and other types of turbines; ii) this study can be investigated by numerical methods using computational fluid dynamics; and iii) adding components to direct and accelerate flow such as channels or ducts around the turbine.

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