Experimental Study on the Effect of Ocean Wave Characteristics on Air Pressure in Oscillating Water Column Device

Jahirwan Ut Jasron¹, Sudjito Soeparman², Lilis Yuliati², Djarot B. Darmadi²

1 Mechanical Engineering, Faculty of Science and Engineering, Nusa Cendana University Kupang, Indonesia
2 Mechanical Engineering, Faculty of Engineering, Brawijaya University Malang, Indonesia

Corresponding author’s: sudjitospn@ub.ac.id

Abstract. Ocean wave energy conversion process in Oscillating Water Column (OWC) device is affected by several parameters. Wave characteristics are an important parameter that determines the level of water fluctuations in the water column. The later parameter is a main factor which influences air pressure in the air column. One of the important wave characteristics is wave steepness (H/L), which is ratio of wave height to wave length. This experimental study analyzed the effect of wave steepness to wave energy. Furthermore, air pressure in the air column of the OWC device is influenced the effects of changes in wave energy converted by OWC device. Testing was performed with several variations of height and wavelength for three different water depths. Wave height change data was recorded with ultrasonic sensor and stored on the CPU via a data logger. The test showed that the deeper the water, the smaller the wavelength and the greater the wave height. In addition, wavelength increase with the increasing of wave period, vice versa wave height decrease with the increasing of wave period. This condition produced different wave steepness so that the wave energy also changes. Data analysis showed the wave steepness of the test results with the biggest pressure change that corresponds to the actual wave steepness generated by the wind at ocean achieved at water depths h = 240 mm with wave height H = 82.8 mm and L = 1250 mm.

Keywords: Ocean Waves, Wave Steepness, Wave Energy, Air Pressure, OWC

1. Introduction

The utilization of renewable energy is a realistic choice to solve the energy crisis problem, especially related to the lacking of fossil fuels energy source. Wave energy is a potential renewable energy source in Indonesia which has wide ocean area. Oscillating Water Column (OWC) is a type of device that has been widely used in the conversion of ocean wave energy into electrical energy. This device generates electrical energy from the rise and down of the water surface in the water column. This movement results air compression and expansion in the air column, which increase and decrease
air pressure respectively. The differences of air pressure inside and outside the column cause air flow through the exhaust channel, in which a wind turbine was installed at the channel [1].

The performance of OWC device depends on (1) the characteristics of ocean waves [2], (2) geometry of the device, i.e. dimensions and shape of the column [3], and (3) systems of exhaust channel consisting of the dimensions, shape and location of exhaust channel[4]. The characteristics of ocean waves consist of height, length and period of the wave. Ning et al. (2016) states that the column length, water depth, and length of the submerged front wall are the main parameters that determine the efficiency of the OWC by considering the influence of the front wall thickness of the column [5]. Wilbert et al. (2013) have considered parameters such as water depth and channel openings at the bottom of the water column. He found that the effective energy conversion of the OWC increases with the increasing in the opening of the lower channel section. Comparison of the bottom channel openings to the water depth of 0.80 reaches a maximum efficiency of 94% [6]. Celik and Altunkaynak (2018) state that geometry optimization and OWC system design are very important so that they can work optimally for different wave conditions. For all wave conditions, the largest water surface fluctuations occur at the ratio of the inlet openings to the water depth of 0.67 [7].

From the explanation above it turns out that the relationship of wave characteristics and geometry parameters of the device greatly determines the efficiency of OWC. This paper will discuss the wave characteristics specifically in the form of wave steepness, i.e. the ratio of wave height to wavelength, on the air pressure in the column of OWC device. The experiment will conduct for several series of waves due to changes in water depth and linear wave maker speed which generate different period, height and length of the wave. It is expected that these experiments will produce good wave steepness to generate maximum air pressure on the OWC device.

2. Experimental Procedure

The test was carried out using an open channel with a length of 9000 mm, a width of 500 mm and a height of 600 mm made from acrylic material so that the wave direction and the phenomenon can be observed. Wave makers using a piston system were placed at the end of the channel and at the other end were installed a breakwaters. The measurement instruments consist of ultra sonic sensors and air pressure sensors as shown in Figure 1 and Figure 2. Ultra sonic sensors were used to measure wave height in the canal and water level in the column. The air pressure sensors was used to measure air pressure inside the column.

![Fig.1. Schematic of the experimental setup.](image-url)
Fig. 2. Photos of laboratory wave flume.

The wave characteristics were investigated for three variations of water depth (h) which were 220 mm, 240 mm, and 260 mm, three variations of wave maker piston length steps (S) which were 100 mm, 150 mm and 20 cm, and seven variations of wave period (T) i.e. 1.1; 1.3; 1.5; 1.7; 2; 2.4; and 3 seconds by adjusting the motor rotation. Wave height data obtained from water level fluctuations measured by ultrasonic sensors, this parameter was measured in the water canal at the outside of OWC system. And wavelength data obtained by measuring the distance of two wave peaks in the water canal. Water level fluctuation in the column was measured with an ultrasonic sensor and air pressure in the column was measured with an air pressure sensor. All sensors were connected to a digital data logger and all measured data were storage in the computer's CPU unit.

OWC device was made from rectangular shaped acrylic material with dimensions of 250 x 250 x 520 mm3 with a length of a submerged front wall of 95 mm. The position of the exhaust line is located at the top of the air column with a diameter of 36 mm as shown in Figure 3.

Figure 3. Oscillating water column device.

3. Results and Discussions
3.1 Wave Characteristics
Figure 4 shows the wavelength variations to the wave period for several different water depths. Theoretically, the wavelength \( \lambda \) can be calculated using the equation (1):

\[
\lambda = \frac{gT}{2\pi} \tanh \left( \frac{2\pi h}{L} \right)
\]

(1)

This equation shows that the wavelength is directly proportional to the wave period and inversely proportional to the depth of the water where the \( h/L \) is the relative depth which is the basis of the wave classification. The experimental results show that the wavelength increases with the increasing period, and the wavelength decreases when the water depth increases. The results of this test show suitability with the theory, as shown at Figure 4.

Variations in wave height to periods for some different water depths can be seen in Figure 5. Theoretically, wave height is affected by wave components, namely period and amplitude differences. The experimental results show that the wave height will decrease with increasing wave period and will increase when the water depth increases [8].

![Figure 4](image4.png) Variation in wavelength to wave period for various water depths.

![Figure 5](image5.png) Variations in wave height to wave periods for various water depths.

3.2. Effect of wave steepness (H/L) on the air pressure in the column.

Wave steepness is the ratio of wave height to wavelength which is one of the important parameter in wave analysis. The steepness of waves generated by wind has steepness in the interval of 0.03-0.06 and in the real conditions at ocean it is rare to find wave steepness larger than 0.1. Figure 6 shows the results of wave testing for variations in wave period (T) 1 to 3 seconds. We can see that the maximum air pressure in the OWC column for the wave period in the range of 0.03 to 0.1 increases with the increasing of water depth. The maximum air pressure occurred at the larger wave steepness for higher
water depth. This is caused by reduced wavelength if the water depth increases. The results of this test explain the biggest air pressure of 140.68 Pa was achieved at \( h = 260 \) mm, \( H = 86.4 \) mm, \( L = 1200 \) mm, \( H/L = 0.072 \) and \( S = 200 \) mm. However, for the real wave conditions generated by the wind, the best wave characteristics occur at water depth \( h = 240 \) mm, wavelength \( L = 1580 \) mm, wave height \( H = 91.8 \) mm, and \( S = 150 \) mm with a wave steepness \( H/L = 0.058 \).

![Graph showing changes in air pressure due to wave steepness.](image)

**Figure 6.** Changes in air pressure due to wave steepness.

Furthermore, the wave steepness influences the changes of wave energy. Theoretically wave energy can be calculated by equation (2):

\[
E = \frac{\rho g H^2 L}{8}
\]

(2)

It is clear that wave energy is influenced by the height and wavelength which can be seen in Figure 7 which illustrates the relationship between wave steepness and wave energy for various water depths. It appears that the deeper the water, the greater the energy contained in the wave. This condition indicates the transfer of energy from the wave maker device on the water become maximum at maximum water depth refers to the contact surface width area between the piston and water [9].

![Graph showing relationship between H/L with wave energy for S = 100 mm.](image)

**Figure 7.** Relationship between \( H/L \) with wave energy for \( S = 100 \) mm

Changes in wave energy are the main factors determine water level fluctuations in the water column. The greater the wave energy, the greater the water level fluctuations will be. Next in Figure 8 we can
see that the fluctuation of the water level in the column greatly determines the change in air pressure that occurs in the air column. The larger water level fluctuation, the greater the change in pressure. It was seen that the biggest water level fluctuations were first achieved rather than the biggest changes in air pressure. Positive and negative air pressure indicates the exhalation and the inhalation process, i.e. the air outflow from and air inflow into the air column through the exhaust channel. However, the performance of OWC device is not only determined by wave characteristics but also determined by the geometry parameters of OWC devices. Figure 9 indicates that for variations in water depth at different H/L steepness, the lowest value of air pressure changes in the column occurs at a water depth of 260 mm. This happens because the width of the water column device is only 250 mm, while the maximum absorption of the wave energy occurs for the column width ranges from 0.8h - h [10].

![Figure 8. Fluctuations in water level to air pressure](image1)

![Figure 9. Relation of water depth and wave steepness to air pressure in a column.](image2)

4. Conclusion

In this study, experiments were carried out on twelve wave conditions at three different water depths to obtain the changes in air pressure in the column in the Oscillating Water Column (OWC). The results of the analysis show that the wave characteristics greatly influence air pressure in the column. The biggest air pressure is achieved for an increase in wave height accompanied by an increase in wavelength. In addition, the greater the depth of water, the greater the energy contained in the wave which results greater air pressure in the column. In this study the biggest air pressure of 140.68 Pa was achieved at h = 260 mm, H = 86.4 mm, L = 1200 mm, and S = 200 mm, but for wave
characteristic conditions that correspond to the actual wave steepness at the ocean between 0.03 - 0.06 occurred at h = 240 mm, H = 91.8 mm, L = 1580 mm, and S = 150 mm.

References

[1] A. El Marjani, F.C. Ruiz, M.A. Rodriguez, and M.T.P. Santos, (2008) “Numerical modeling in wave energy conversion system”, Energy, pp. 1246-1253.
[2] Bautista, E. G., Méndez, F., & Bautista, O,(2009), “Numerical Predictions of the Generated Work in an Air-Compression Chamber Driven by an Oscillating Water Column”, Open Ocean Eng. J., vol. 2, pp. 7–16.
[3] Nader, J.R., Zhu, S.P., & Cooper, P. (2014), ”Hydrodynamic and energetic properties of a finite array of fixed oscillating water column wave energy converters”, Ocean Engineering 88 : 131-148
[4] Patel, S. & Ram, R.A., (2012), “Effect of partial blockage of air duct outlet on performance of OWC device”, J Cent South Univ, vol. 19.
[5] Ning D.Z., Wang, R.Q., Zou, Q.P., & Teng, B., 2016, An experimental investigation of hydrodynamics of a fixed OWC wave energy converter. Applied Energy 168 : 636 - 648.
[6] Wilbert R., Sundar V., and Sannasiraj S.A., (2013) “Wave interaction with a double chamber oscillating water column device”, International Journal of Ocean and Climate System, Vol.4 No.1 pp 21-39.
[7] Anil Celik, dan Abdusselam Altunkaynak, (2018) “Experimental and analytical investigation on chamber water surface fluctuations and motion behaviours of water column type wave energy converter”, Ocean Engineering, Vol.150 pp 209-220.
[8] Liu Z. , Hyun B.S. , Shi H., & Hong, K., (2014), “Practical Simulation of Oscillating Water Column Chamber for Wave Energy Conversion”, International Journal of Green Energy, 7:3, 337-346.
[9] Krishnil Ram, Mohammed Faizal, M. Rafiuddin Ahmed, and Young-Ho Lee, (2010) “Experimental studies on flow characteristics in an oscillating water column device”, Journal of Mechanical Science and Technology, Vol.24, pp 2043-2050.
[10] Bouali, B. & Larbi, S., (2013), “Contribution to the Geometry Optimization of an Oscillating Water Column Wave Energy Converter”, Energy Procedia, vol. 36, pp. 565–573.