



(RESEARCH ARTICLE)



Experimental study to investigate the effect of using a cylindrical air chamber design in OWC wave energy converter

Mamdouh Elmallah *

Department of Marine Engineering Technology, College of Maritime Transport & Technology, Arab Academy for Science, Technology, and Maritime Transport, Egypt.

International Journal of Science and Research Archive, 2025, 14(03), 206-213

Publication history: Received on 29 January 2025; revised on 04 March 2025; accepted on 06 March 2025

Article DOI: <https://doi.org/10.30574/ijrsra.2025.14.3.0666>

Abstract

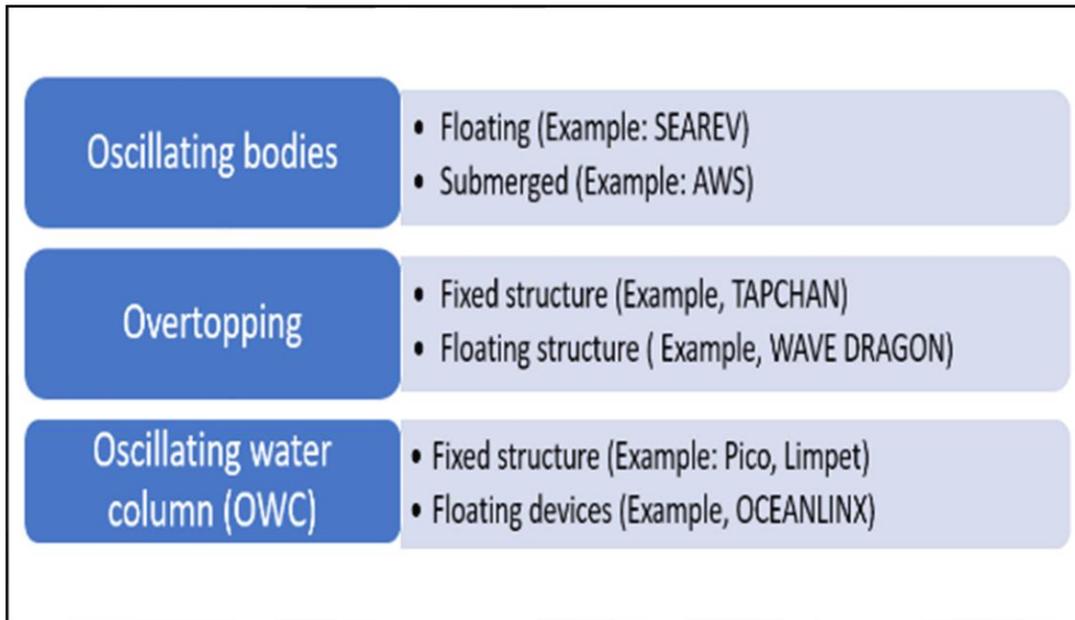
Wave energy conversion is one of the most active aspects of renewable energy. The Oscillating Water Column (OWC) device is one of the most widely used wave energy conversion methods. This study examines the effect of, Oscillating Water Column Wave Energy Converter, shape and design on the airflow response. Although most studies focus on the turbine design to maximize the performance of the oscillating water column OWC, the chamber geometry is as important as the turbine design. The main objective of this research is to optimize the Air Velocity entering the turbine, which will boost the device efficiency and output power. Experimental investigations are performed in the wave tank laboratory to study the effects of air chamber designs, such as rectangular and cylindrical air chambers with different cross-sectional areas. The results demonstrate a considerable increase in air velocity flow from 3.1 m/s in the rectangular air chamber to 3.5 m/s in the cylindrical air chamber.

Keywords: Greenhouse Gases; Oscillating Water Column; Renewable Energy; Wave Energy

1. Introduction

Many studies verify that fossil fuels are the main factor responsible for climate change and other environmental issues. The combustion of fossil fuels produces a major portion of the greenhouse gases (GHG) that blanket the Earth and trap the sun's heat [1,2,3]. Numerous studies have established that gasoline oil is the main factor contributing to both environmental and financial issues [4,5,6]. Due to growing worries about the environmental impact and cost of fossil fuels, the investigations for alternative renewable energy sources have become more urgent. One of the most active research areas for renewable energy is wave energy conversion [7]. Compared to other renewable energy sources like wind, solar, biomass, and geothermal, waves have the highest energy density. The principle of energy generation derives from the force of friction that the wind exerts on the surface of the sea. Wave energy extraction devices classified into 3 categories: oscillating water columns (OWC), oscillating bodies and overtopping systems [8]. Figure. 1 shows the categories of wave energy converters [9].

* Corresponding author: Mamdouh Elmallah



Figurer 1 The categories of wave energy converters [9]

The oscillating water column (OWC) device is one of the most common approaches for converting wave energy because of its simplicity. OWC offers various benefits while having few moving parts. The OWC's design can be modified. Along the coast, OWC can be applied to a variety of collector designs, and the air turbine's presence eliminates the need for gearboxes. OWC is reliable, simple to maintain, and effectively uses the available sea space. OWC can be differentiated into floating structures that are found offshore and fixed structures that are found near shore [10]. Table 1 shows the Differences between fixed and floating OWC [11,12].

Table 1 The differences between fixed and floating OWC devices

	Fixed structures	Floating structures
Marine environment	Safe even in severe weather	Less safe specially in severe weather
Power production	Loss of wave power due to the shallow water effect	They can exploit the full power of the wave
Transport of energy	Insignificant energy losses	Large energy losses because of the use of submarine cables
Mooring lines	Not necessary	necessary
Life span of the device	Fewer moving parts and longer life	More moving parts and risk of damage during rough seas
Maintenance	Low maintenance cost	High maintenance cost

Figure 2 demonstrates Schematic layout of oscillating water column (OWC) system [13].

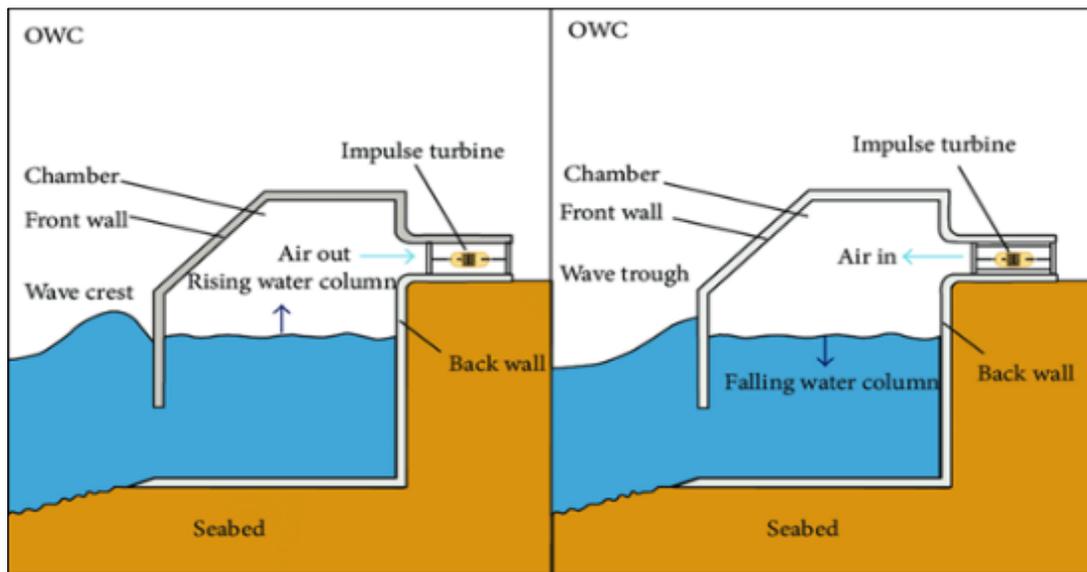


Figure 2 Schematic layout of oscillating water column (OWC) system [8]

OWC device is constructed of an empty chamber that is open to the sea under the surface. Due to wave action, the water column inside the chamber oscillates, alternately compressing and decompressing the air in the upper part of the chamber. The flow of air into and out of the chamber is the primary power source for the turbine. Self-rectifying air turbines are the most popular option that applies a unidirectional rotation to the turbines [14]. When it comes to maximizing the performance of an OWC device, the chamber geometry serves to be as important as the turbine design. The power needed to compute OWC efficiency is calculated by integrating the product of air pressure in the chamber and airflow rate over time [15], [16], [17]. This study was applied in the wave tank laboratory on a small-scale fiber model that represents the OWC. The air velocity entering the turbine plays a significant role to increase the overall power efficiency of the OWC. The purpose of this paper is to investigate the impact of various air chamber geometrical designs on air velocity entering the turbine.

2. Methodology and Model Design

One of the factors that affects the OWC's performance is the air velocity that enters the turbine. The air chamber design has a significant impact on the outlet air velocity [7].

The following equations are the geometric relations for designing the OWC chamber [18,19]:

$$B = 0,42\lambda \dots \dots \dots (1)$$

Where B is the chamber width and λ is the wave length.

$$Ha = 0,84B \dots \dots \dots (2)$$

Where Ha is the height of the air chamber.

This paper represents a small-scale fiber model for an OWC device with a hollow duct in the middle of the air chamber top. The hollow duct is the replacement for the turbine. The hollow duct represents the outlet airflow, which is supposed to be the turbine inlet. two air chamber cases will be illustrated in this paper to show the effect of air chamber design on the outlet air velocity. For Boundary conditions, all parameters applied are constant for the two cases. Wave Height (H) is 8.3 cm, Wave Length (L) is 71 cm, Liquid Depth (d) is 15 cm.

Calculations and mathematical operations are controlled by fluid flow governing equations. The Reynolds Averaged Navier-Stokes (RANS) equations, the continuity equation, and the conservation equations for momentum and energy

are various instances of these equations. The following are the continuity equations and Reynolds Averaged Navier-Stokes (RANS) equations

$$\frac{\partial u_i}{\partial x_i} = 0 \dots\dots(3)$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial \rho u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \rho f_{x_i} + \frac{\partial}{\partial x_j} \left(\nu \frac{\partial u_i}{\partial x_j} - \rho u'_i u'_j \right) \dots\dots(4)$$

Where, ρ , p , and f_{x_i} are the fluid density, fluid pressure, kinematic viscosity coefficient, and body force, respectively. $x_i = (x, y, z)$ and $u_i = (u, v, w)$ represent the Cartesian coordinates and corresponding Reynolds-averaged velocity components. The component $\rho u'_i u'_j$ are called Reynolds stresses.

The following are the momentum and energy conservation equations [20]:

$$\frac{\partial \rho u}{\partial t} + \nabla \cdot (\rho u u) = -\nabla p + \nabla \cdot \tau + \rho g + F \dots\dots(5)$$

$$\frac{\partial (\rho C_p T_f)}{\partial t} + \nabla \cdot (\rho C_p T_f u) = \nabla \cdot (\Psi_e \nabla T_f) + S_T \dots\dots(6)$$

where u is the fluid velocity vector; τ is the viscous stress tensor; g is the gravitational acceleration; t is the time; F is the source of momentum due to surface tension;

T_f is the temperature; C_p is the fluid specific heat; Ψ_e is the fluid thermal conductivity; and S_T is the source term in the energy equation.

The viscous stress tensor is:

$$\tau = \mu_{eff} [\nabla u + (\nabla u)^T] + \frac{2}{3} \mu_{eff} (\nabla \cdot u) I \dots\dots(7)$$

where I is the identity tensor and μ_{eff} is the effective dynamic viscosity:

$$\mu_{eff} = \mu + \rho \nu_t \dots\dots(8)$$

where μ is the dynamic viscosity of the fluid and ν_t is the turbulent kinematic viscosity.

3. Model Parameters

two different cases of the air chamber designs that will be studied in this paper to show their impact on the outlet air velocity. Figure. 3 shows the OWC 3D model and model geometry of the rectangular air chamber. Table 2 shows the rectangular air chamber model dimensions.

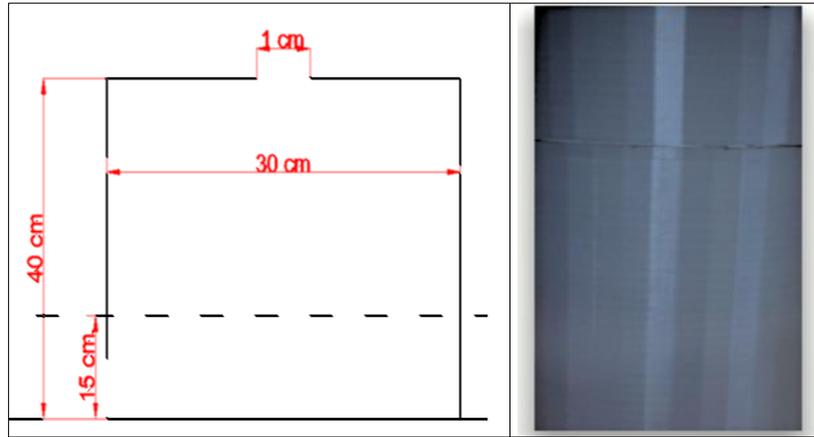


Figure 3 3D model and model dimensions of rectangular air chamber

Table 2 Rectangular air chamber model dimensions

Model dimensions	
Hole diameter	1 cm
Free surface elevation	25 cm
Still water depth	15cm
Chamber length	30 cm
Cross sectional area	707 cm ²

Figure 4 shows the OWC 3D model and model geometry of the cylindrical air chamber. Table 3 shows the cylindrical air chamber model dimensions.

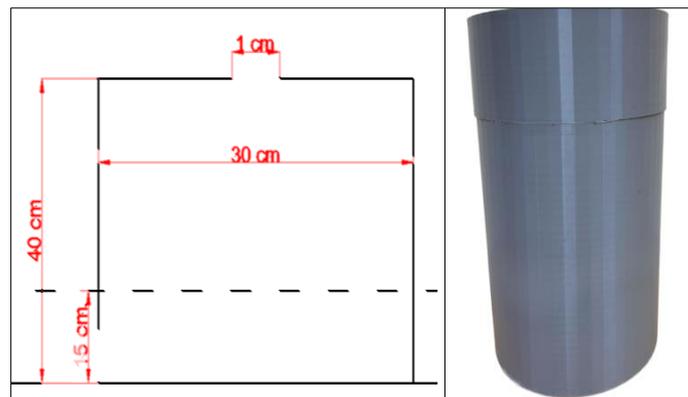


Figure 4 3D model and model geometry of the cylindrical air chamber

Table 3 Model dimensions

Model dimensions	
Hole diameter	1 cm
Free surface elevation	25 cm
Still water depth	15cm
Chamber length	30 cm
Cross sectional area	707 cm ²

Figure 5 shows the cylindrical air chamber model during the experiment in the wave tank and shows the anemometer that used in the experiment to measure the air flow velocity.



Figure 5 the cylindrical air chamber model and the anemometer

4. Results and Discussion

Recent advancements in air chamber design have focused on improving the air flow velocity to ensure higher air flow velocity to the turbine. Increasing the air velocity will lead to an increase in the total output power of the OWC. The following two cases will illustrate the air flow velocity results according to two air chamber designs. Figure. 6 shows the air flow velocity of rectangular air chamber with outlet air velocity 3.1 m/s.

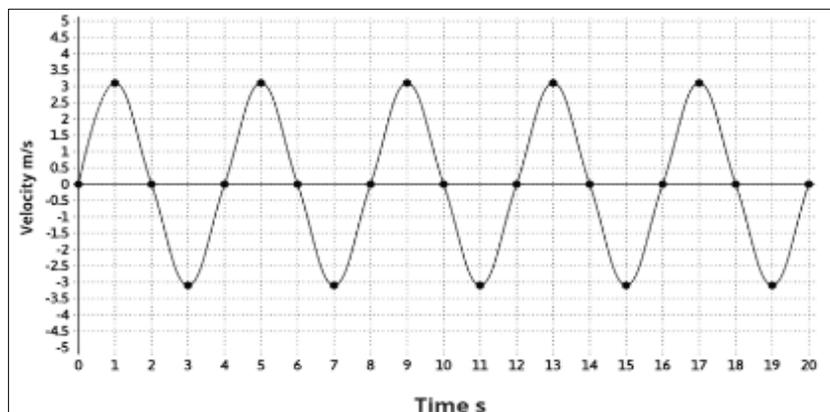


Figure 6 Air flow velocity of rectangular air chamber

Figure 7 shows the air flow velocity of cylindrical air chamber with outlet air velocity 3.5 m/s.

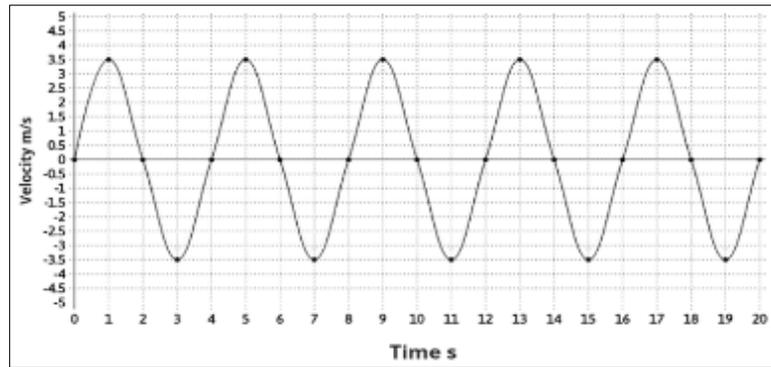


Figure 7 The air flow velocity of cylindrical air chamber

The results show that the air chamber design has a significant influence on outlet air flow velocity, which directly affects turbine efficiency. The cylindrical air chamber is more efficient than the rectangular one, as it avoids losses caused by sharp right-angle edges. The maximum outlet air velocity is due to continuity equation characteristics.

5. Conclusion

Recent developments in air chamber design have focused on increasing air flow velocity to the turbine. The total output power of the OWC will increase as the air velocity increases. The two cases shown in this study illustrate the air flow velocity results for two different air chamber designs. The results show that air velocity flow increased significantly from 3.1 m/s in the rectangular air chamber to 3.5 m/s in the cylindrical air chamber. The outlet air velocity of the cylindrical air chamber equals 112% of the outlet air velocity of the standard rectangular air chamber. The research results show that the air chamber design has a substantial impact on the exit air flow velocity, which has a direct impact on turbine efficiency. The cylindrical air chamber appears to be more efficient than the rectangular one. The cylindrical air chamber avoids the losses that occur in the rectangular air chamber due to corner effects.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

- [1] Elmallah, M. (2024, December 30). The impact of livestock emissions on the maritime sector. <https://www.jmr.unican.es/index.php/jmr/article/view/610>
- [2] Elmallah, M., Elgohary, M. M., & Shouman, M. R. (2023). The effect of air chamber geometrical design for enhancing the output power of oscillating water column wave energy converter. *Marine Technology Society Journal*, 57(1), 122–129. <https://doi.org/10.4031/mtsj.57.1.14>
- [3] Elmallah, M., Shouman, M., & Elgohary, M. (2024a, August 30). Numerical study on enhancing the performance of air turbines in Oscillating Water Column wave energy converters. <https://www.jmr.unican.es/index.php/jmr/article/view/1026>
- [4] Elmallah, M., Shouman, M., & Elgohary, M. (2024b). REDUCTION OF THE METHANE EMISSIONS ON LIVESTOCK SHIPS TO MITIGATE GREENHOUSE GAS EMISSIONS AND PROMOTE FUTURE MARITIME TRANSPORT SUSTAINABILITY. *Nativa*, 12(3), 551–558. <https://doi.org/10.31413/nat.v12i3.18180>
- [5] Elmallah, M., Shouman, M., & Elgohary, M. M. (2024). Reducing methane emissions on livestock ships in order to mitigate greenhouse gas emissions and promote future maritime sustainability. *TransNav the International Journal on Marine Navigation and Safety of Sea Transportation*, 18(4), 797–804. <https://doi.org/10.12716/1001.18.04.05>
- [6] El gohary, M. Morsy and Seddiek, I., (2013). Utilization of alternative marine fuels for gas turbine power plant onboard ship. *International Journal of Naval Architecture and Ocean Engineering*, 5(1), pp.141-149. <https://doi.org/10.2478/IJNAOE-2013-0115>.

- [7] Elmallah, M., Elgohary, M. M., & Shouman, M. R. (2023, February 27). The Effect of Air Chamber Geometrical Design for Enhancing the Output Power of Oscillating Water Column Wave Energy Converter. *Marine Technology Society Journal*, 57(1), 122–129. <https://doi.org/10.4031/mts.57.1.14>
- [8] W. Sheng, “Wave energy conversion and hydrodynamics modelling technologies: A review,” *Renew. Sustain. Energy Rev.*, vol. 109, no. July 2018, pp. 482–498, 2019, <https://doi.org/10.1016/j.rser.2019.04.030>.
- [9] Falcao A. Wave energy utilization: a review of the technologies. *Renew Sustain Energy Rev* 2010; 14(3):899–918. <https://doi.org/10.1016/j.rser.2009.11.003>.
- [10] T. V. Heath, “A review of oscillating water columns,” *Philos. Trans. R. Soc. A Math.Phys. Eng. Sci.*, vol. 370, no. 1959, pp. 235–245, 2012, <https://doi.org/10.1098/rsta.2011.0164>.
- [11] M. A. Mustapa, O. B. Yaakob, Y. M. Ahmed, C. K. Rheem, K. K. Koh, and F. A. Adnan, “Wave energy device and breakwater integration: A review,” *Renew. Sustain. Energy Rev.*, vol. 77, no. March, pp. 43–58, 2017 <https://doi.org/10.1016/j.rser.2017.03.110>.
- [12] T. Vyzikas, S. Deshoulières, M. Barton, O. Giroux, D. Greaves, and D. Simmonds, “Experimental investigation of different geometries of fixed oscillating water column devices,” *Renew. Energy*, vol. 104, pp. 248–258, 2017, <https://doi.org/10.1016/j.renene.2016.11.061>.
- [13] Cui, Ying & Liu, Zhen. (2014). Effects of Solidity Ratio on Performance of OWC Impulse Turbine. *Advances in Mechanical Engineering*, 7(1), 121373. <https://doi.org/10.1155/2014/121373>.
- [14] Falcão, A. F. O., Henriques, J. C. C., & Gato, L. M. C., (2018). Self-rectifying air turbines for Wave Energy Conversion: A Comparative Analysis. *Renewable and Sustainable Energy Reviews*, 91, 1231–1241. <https://doi.org/10.1016/j.rser.2018.04.019>.
- [15] Zhang, Y., Zou, Q. P., & Greaves, D. (2012). Air-water two-phase flow modelling of hydrodynamic performance of an oscillating water column device. *Renewable Energy*, 41, 159–170. <https://doi.org/10.1016/j.renene.2011.10.011>.
- [16] Nunes, G., Valério, D., Beirão, P., & Sá da Costa, J., (2011). Modelling and control of a wave energy converter. *Renewable Energy*, 36(7), 1913–1921. <https://doi.org/10.3182/20100329-3-PT-3006.00051>.
- [17] Sheng, W., Lewis, T., & Alcorn, R. (2012). On wave energy extraction of oscillating water column device, 4th International Conference on Ocean Energy. <https://doi.org/10.1016/j.apor.2012.05.004>.
- [18] Ning, D. Z., Wang, R. Q., Zou, Q. P., & Teng, B. (2016, April). An experimental investigation of hydrodynamics of a fixed OWC Wave Energy Converter. *Applied Energy*, 168, 636–648. <https://doi.org/10.1016/j.apenergy.2016.01.107>.
- [19] Gomes, M. N., Nascimento, C. D., Bonafini, B. L., Santos, E. D., Isoldi, L. A., & Rocha, L. A. O. (2012, December 31). two-dimensional geometric optimization of an oscillating water column converter in laboratory scale. *Revista De Engenharia Térmica*, 11(1-2), 30. <https://doi.org/10.5380/reterm.v11i1-2.61996>.
- [20] Liu, Z., Hyun, B. S., & Hong, K. (2011). Numerical study of air chamber for oscillating water column wave energy convertor. *China Ocean Engineering*, 25(1), 169–178. <https://doi.org/10.1007/s13344-011-0015-8>.