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NUMERICAL APPROACH FOR HARNESSING ENERGY FROM OSCILLATING WATER COLUMN

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Energy, Flow Coefficient, Oscillating Water Column, Turbine Efficiency, Vent Diameter, Wave Power, Wave Velocity.

ABSTRACT

The sustenance of energy is life. Hence, the search for harnessing energy by researchers will be a continuous process in as much as the world exist. In view to this research presentation of harnessing energy from Oscillating Water Column (OWC) by numerical approach becomes imperative. The process is carried out with some governing equations using mathematical analysis and presented are summary of some vital results. It is being established that the diameter of the opening vent of the OWC determines the effectivenss and efficiency of energy generation by the system. Thus, as vent diameter is preset to increase from 0.2m to 1.0m, corresponding increase is noticed in the efficiency and wave power with values that ranges from (2.8 – 42.7)% and (98553.76 – 2341874)W respectively. Others are wave velocity with maximum value of 18ms^{-1}, 163.944m^3/s flow coefficient and rise in turbine efficiency from 43.85% to 45.57%. These results attest that harnessing energy from OWC technology will greatly enhance the energy sector of a nation.

Nomenclature

f	*Frequency*
V	*Volume of water*
λ	*Wave length*
A	*Area of Chamber*
α	*Volume phase fraction in VOF*
B	*Width of Chamber*
S	*Sound of Speed*
D	*OWC front wall draught*
g	*Gravity of wave*
h	*Chamber height*
H	*Height of water*
m	*Mass*
P	*Pressure*
P_w	*Power of air*
P_u	*Power of wave*
P_a	*Pressure of air*
q	*Energy flux vector of fluid*
r	*Cylindrical OWC radius*
T	*Period*
t	*Time*
U	*Fluid velocity vector*
V	*Wave velocity*
V_t	*Total volume*
V_w	*Volume of water*
X	*Horizontal axis*
Z	*Vertical axis*
σ	*Surface tension coefficient*
ρ	*Fluid density*

Introduction

The search for cleaner energy over the years has been in the fore front of research. The consideration in this paper is the conversion of wave energy to electrical power supply by means of OWC. This is possible due to the enormous energy such as oceans, seas, riv-

ers, etc. Also, the necessity of energy extraction from oceans round the globe will create some kind of sustainability in the energy sector since oceans cover over 70% of the earth surface [1]. Thus, this large coverage of the oceanic body serves as the biggest retainer and collector of the solar energy which increases its temperature and perhaps causes temperature differential across large water bodies. Meanwhile, study unveils that temperature variation is a likely possibility for the cause of wind; and the combination of wind and the forces of the solar system produces waves and tides [2]. The power generated from tidal energy is also as a result of the rotation of the earth around the moon and the sun. Thus, the flow of the water bodies causes raise and fall of the ocean periodically [3]. However, ocean energy is one amongst the renewable energy sources which is clean, environmentally friendly and it is also expected to vital role in future years to meet the global energy demand. These sources of energy have the potentials to alleviate the global climate change threat. It helps in the reduction of air pollution, especially carbon (iv) oxide (CO_2), nitrates of oxides (NOx), carbon monoxide (CO), soots, and other likely emissions produced by the use of conventional energy source such as fossil fuel. Among the renewable energy resources, wave energy is considered as an emerging technology which is still largely unuse. [4].
Therefore, the present study of OWC devices shows that mooring properties can have a significance influence on the energetic characteristics of the system and become an important element in the design of such system [5]. Likewise, this energy can also be harnessed in smaller quantities for rural settlement along the coastal lines. The production of OWC device can either be of a steel or concrete structure with a chamber presenting at least two openings, one in communication with the sea and the other with the atmosphere. Under the action of waves the free surface inside the chamber oscillates and displaces the air above the free surface. The air is thus forced to flow through a turbine that generates electrical power [6]. The oceanic wave is caused by Coriolis forces acting on the sea water in the major oceans is as a result of the movement of the Earth [7]. The ocean wave energy contains the kinetic energy of the wind, and can be harvested with little and less conspicuous devices to produce the same power. The possibility of converting wave energy into useful energy has inspired various scholars. The functioning and working principles of the OWCs is similar to the wind turbine, based on the principle of wave induced air pressurization. The working principle of OWC devices is simple, the incoming wave produces air compression within the chamber when the water column is moved towards the top of the chamber. The pressure in the chamber produces enough airflow through the turbine duct to make the turbine rotate which generates an electric power [8]. Conversely, the rotation of the turbine continues even as the wave recedes due to the percularity of the design. The vacuum produced within the OWC chamber during the wave recession produces the same airflow in the opposite direction [9].

Strutural Design of Oscillating Water Column

The design layout of the OWC is presented in figure 1 with an incident wave parameters include wavelength, λ = 5m, height of the air chamber *H* = 11.04m, the width of the chamber *B* = 9.20m, water depth of *D* = 8.00m, front wall submergence depth *d* =2.0m angle of inclination α = $\mathbf{45^0}$, volume of water, $V, =$ 2880cm^3. Other parametric specifications are presented in table 1.

Table 1: Geometrical Construction Parameters			
Parameter	**Symbol**	**Specification**	**Value**
Width of chamber	B	0.92h: 0.92(10), 0.42 λ, 0.84Ha	9.20m
Height of air chamber	H_a	1.20B	11.04 m
Front wall Submergence Depth	D	0.35-0.45h	4.50 m
Opening length	H_o	0.65-0.80h	8.00 m
Inclination angle	α	$45^0 – 50^0$	450
Vent Diameter	D_v	1.00 m	1.00 m
Total height of the chamber	H_t	$H_a + H_o$	19.4 m

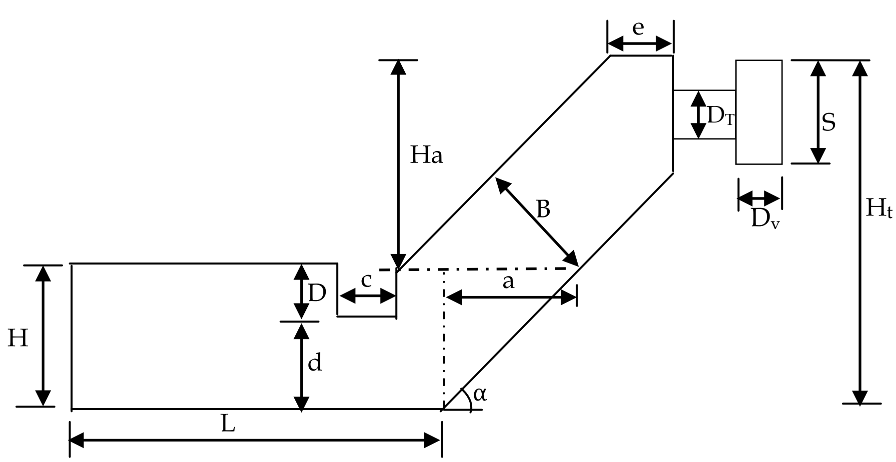

Figure1: Geometry of the OWC Chamber

Chamber Geometry

The main component of OWC is the chamber, which is exposed to the wave with submerged opening. The chamber controls the air flow and also the free surface of the water column to oscillate up and down within the chamber with all other component of OWC coupled on the chamber. The position of the turbine is determined by the structure of the chamber. The air chamber is placed above the water, allowing the passage of waves to change the water level. The frequently rising and falling water level increases and decreases the air pressure respectively within the chamber. Thus, in regards to the motion of water in this scenario; the turbine is placed on top of the chamber through which air may pass. The air would flow into the chamber during a wave trough and out of the chamber during a wave crest.
Conversely, the design of the chamber is based on one-hollow end with a motor place at the centre of two rotors connected to different blades. Meanwhile, some scholarly research with an open end chamber considering the incoming pressure from the wave in to the turbine is being studied but it is difficult to see the exact design of this current work [10]. This new innovation has made the study so significant as the out flow of wave energy is considered. Thus, the air pressure leaving the system is put to use likewise and it is never wasted. The basic principle of the system is that the wave pressure enters the chamber with the flow or pressure of air hitting the first blade which forces it to rotate with the help of the rotor. In same manner the returning wave with its pressure turns the second blade of the turbine still with aid of the rotor providing more sufficient energy as compared to the conventional design. The chamber geometry is presented in figure 2 with the aid of solidworks modelling tool. The structural components of OWC chamber have significant effect on the performance of the OWC. Also the performance of the OWC converter depends on the different energy exchange that take place during the process and in particular on the conversion of wave energy into pneumatic energy inside the chamber.

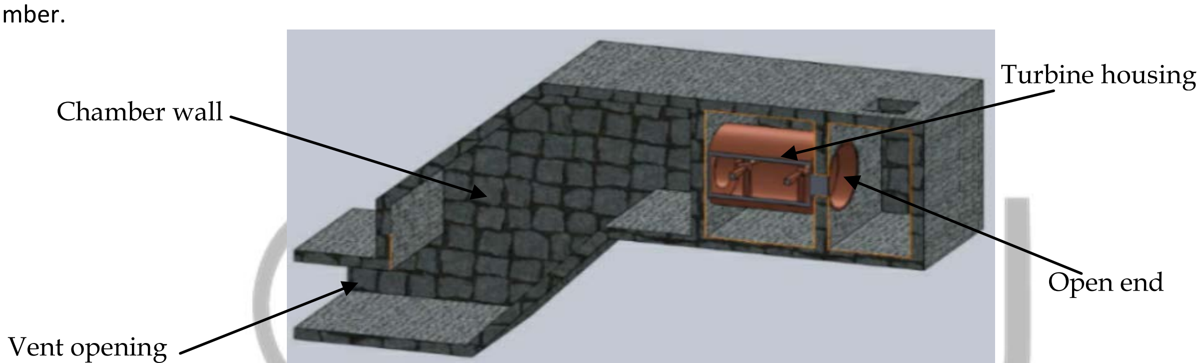

Figure 2: OWC Chamber Geometry

Numerical Analysis

The following governing equations as presented in equations 1 – 14 are the basis for the numerical analysis in harnessing energy from the OWC.

$$V = f\lambda \tag{1}$$

$$f = k\sqrt{gh} \tag{2}$$

$$V = \sqrt{gh} \tag{3}$$

$$f = \frac{1}{T} \tag{4}$$

$$\mathrm{P}_u = \left(\mathrm{P} + \frac{1}{2}\rho V^2\right)VA \tag{5}$$

$$A = LH_e \tag{6}$$

$$V = B\left((LH_e - CN_i) + \frac{1}{2}qH_e\right) \tag{7}$$

$$V_a = B\left[\frac{1}{2}\left(\frac{H-X}{\cos\alpha} + \frac{H}{\cos\alpha}\right)b + \frac{1}{2}(e-r)X + Sr\right] \tag{8}$$

$$V_t = V_c + \frac{BH}{K}k\sin\frac{kl}{2}\sin t \tag{9}$$

$$Q\,a(t) = BH_c\sin\frac{kl}{2}\cos ft \tag{10}$$

$$u = \frac{H}{2}\text{gk}\,\frac{\cosh\,(kz + kh)}{\omega\cosh\,(kh)}\cos(kx - \omega t) + \frac{3}{4}\left[\frac{H}{2}\right]^2 \omega k\frac{\cosh\;[2k(h+z)]}{\sin^4(kh)}\cos 2(kx - \omega t) \qquad 11$$

$$v = \frac{H}{2}\text{gk}\,\frac{\sinh\,(kz + kh)}{\omega\sinh\,(kh)}\sin(kx - \omega t) + \left[\frac{H}{4}\right]^2 \omega k\frac{\sinh\;[2\text{k}(h+z)]}{\cos^4(kh)}\sin 2(kx - \omega t) \qquad 12$$

$$\text{P}_w = \frac{1}{16}\rho g H^2\left[1 + \frac{2kh}{\sinh\,2kh}\right]\frac{\sqrt{gk\tanh\,kh}}{k} \qquad 13$$

$$\text{P}_w = E_{OWC}\,C_g \qquad 14$$

Presentation of Results and Discussion

The results so presented are the outcome of the wave energy analysis in determination of the effectiveness, efficiency and reliability of the OWC renewable energy source. Thus, results in table 2 is a summary from a spread sheet analysis with corresponding graphical results in figures 3 - 7. The numerical analysis is to check the correlation on the average pneumatic power generation by the system. It also estimates the viable turbine efficiency of the entire operation and thus helps to the evaluation of the flow coefficient at the open vents. Meanwhile, the effect of OWC geometry optimization, wave period on the performance of the system, the incident wave velocity and pressure are equally carried out. Consequently, subsequent results are presented in tables 3 and 4 with their corresponding graphical analyses in figures 8 and 9 respectively.

Table 2: OWC Result Summary

d_v (m)	P (N/m^2)	ρ (kg/m^3)	V (m/s)	V_w (m^3)	B (m)	L (m)	P_u (w)	P_w (w)	Ƞ (%)	Q (m^3/s)
1.0	57820	1.225	17.993	711.1	8	1	2341874	34667.33	42.7	163.944
0.8	29590	1.225	16.970	711.1	8	1	1478897	34667.33	35.4	135.760
0.6	23860	1.225	11.460	711.1	8	1	1226727	34667.33	27.6	91.680
0.4	14960	1.225	3.230	711.1	8	1	154627	34667.33	4.5	25.840
0.2	12070	1.225	1.615	711.1	8	1	98553.8	34667.33	2.8	12.920

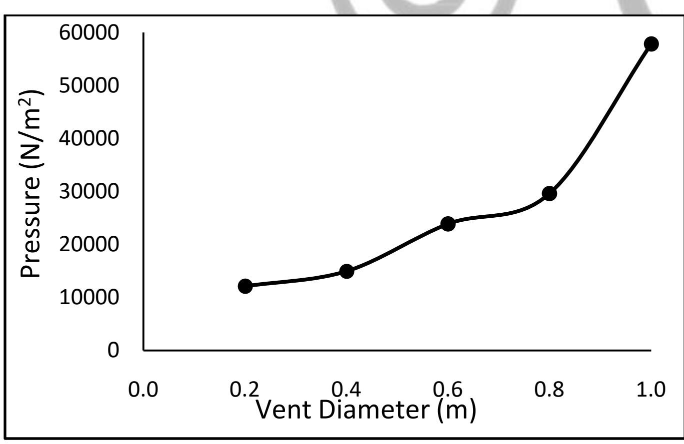

Figure 3: Pressure against Vent Diameter

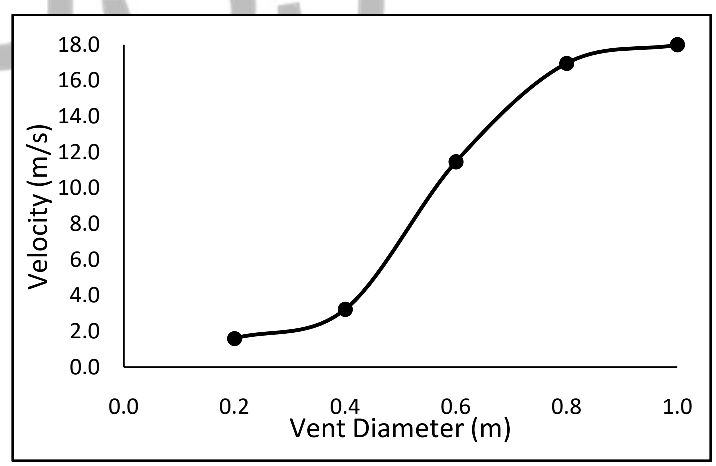

Figure 4: Wave velocity against Vent Diameter

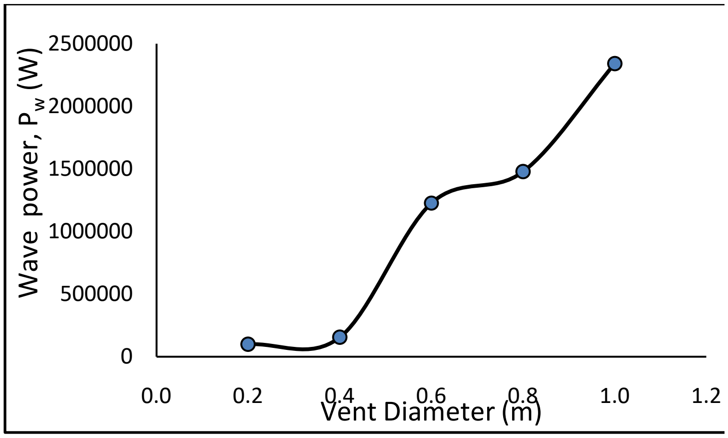

Figure 5: Wave Power against Vent Diameter

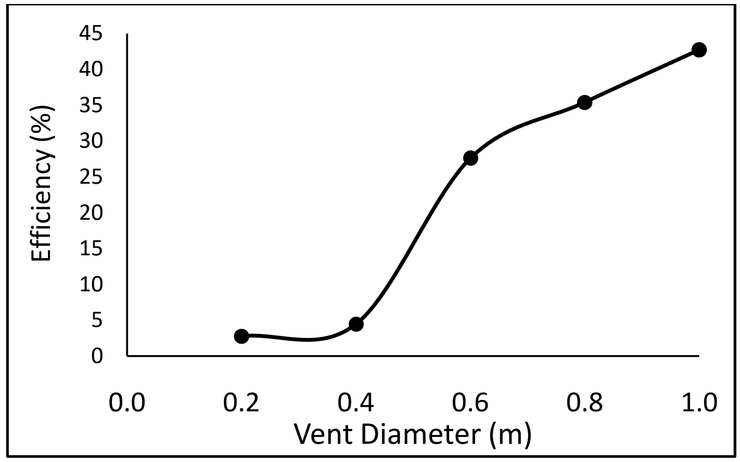

Figure 6: Efficency against Vent Diameter

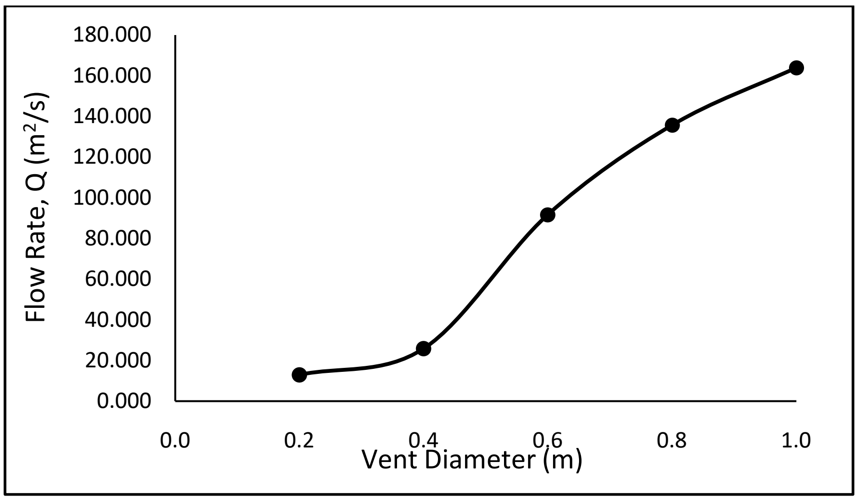

Figure 7: Flow Rate against Vent Diameter

Table 3: Turbine Efficiency with Variation in Front Wall Submerged Depth

H (m)	*Eff (%)*	*FWSD (m)*	*Af (m^2)*	*At (m^2)*	*At/Af*	*VD (m)*	*Av (m^2)*	*Av/At*	*d/h*
1.7	45.57	2.0	55.2	19.63	0.3557	1.0	0.785	0.0400	0.25
1.7	45.30	2.5	50.6	19.63	0.3880	0.9	0.636	0.0324	0.31
1.7	45.16	3.0	46.0	19.63	0.4268	0.8	0.503	0.0256	0.38
1.7	45.03	3.5	41.4	19.63	0.4743	0.7	0.385	0.0196	0.44
1.7	44.89	4.0	36.8	19.63	0.5336	0.6	0.283	0.0144	0.50
1.7	44.63	4.5	32.2	19.63	0.6098	0.5	0.196	0.0100	0.56
1.7	44.5	5.0	27.6	19.63	0.7114	0.4	0.126	0.0064	0.63
1.7	44.37	5.5	23.0	19.63	0.8537	0.3	0.071	0.0036	0.69
1.7	44.24	6.0	18.4	19.63	1.0671	0.2	0.031	0.0016	0.75
1.7	44.11	6.5	13.8	19.63	1.4228	0.1	0.008	0.0004	0.81
1.7	43.85	7.0	9.2	19.63	2.1342	0.0	0.000	0.0000	0.88

Table 4: Incident Wave Amplitude to Water Depth Ratio (Ai/h) vs OWC Efficiency						
H (m)	*d_v (m)*	*A_i (m^2)*	*Av/At*	*d/h*	*A_i/h*	η (%)
1.7	1.0	0.85	0.0400	0.25	0.119	45.57
1.5	0.9	0.75	0.0324	0.31	0.103	45.30
1.4	0.8	0.70	0.0256	0.38	0.096	45.16
1.3	0.7	0.65	0.0196	0.44	0.088	45.03
1.2	0.6	0.60	0.0144	0.50	0.081	44.89
1.0	0.5	0.50	0.0100	0.56	0.067	44.63
0.9	0.4	0.45	0.0064	0.63	0.060	44.50
0.8	0.3	0.40	0.0036	0.69	0.053	44.37
0.7	0.2	0.35	0.0016	0.75	0.046	44.24
0.6	0.1	0.30	0.0004	0.81	0.039	44.11
0.4	0.0	0.20	0.0000	0.88	0.026	43.85

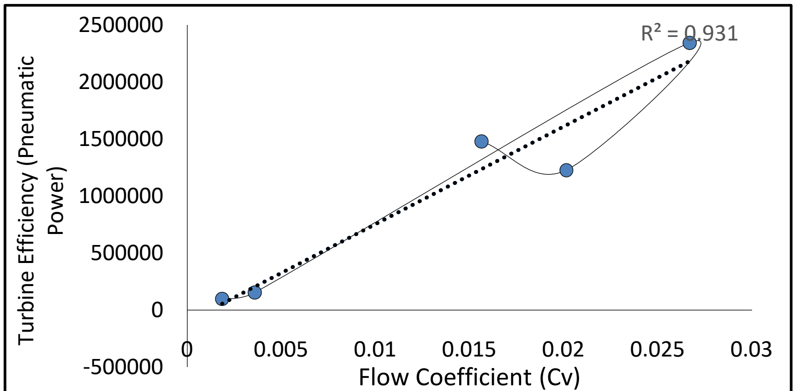

Figure 8: Turbine Efficiency against Flow Coefficient

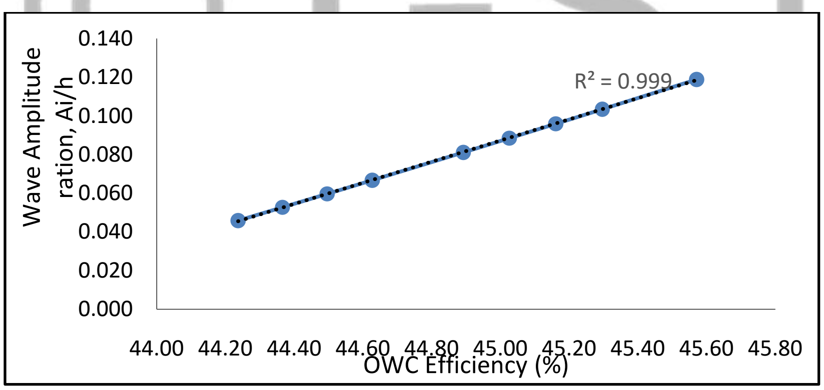

Figure 9: Turbine Efficiency against Front wall Submerged Area Ratio *(Af/At)*

The results of the OWC depedents on the variation of the vent diameter. It is obviously clear that as the design vent diameter increases from (0.2 to 1.0)m, the dependent variables such the water pressure (P), velocity (V), efficiency (Ŋ), all increases from (12070 – 57820)N/m^2, (1.6 – 18)ms^{-1} and (2.8 – 42.7)% respectively. Other parameters being influenced by this scenario is the flow coefficient (Q) and wave power (P_u) which rises from (12.92 – 163.944)m^3/s and (98553.76 – 2341874)W respectively. However, there are some static parameters which are preset in determining these measurable parametric values of OWC. They are the water density (ρ), the specified volume of water (V_w) and power of the air (P_w) which causes the wave with values such as 1.225kg/m^3, 711.1m^3 and 34667.33W respectively. This analytical result is being demonstrated and shown in the graphical plots of figures 3 – 7. They all have similar rising contours due to the gradually numerical increase in the design vent diameter of the OWC. This attests that the bigger the vent opening to allow greater bodies of water into the OWC the more effective it will generate usable energy.

In another similar result presentation in figure 8 shows the flow coefficient of the OWC in relation to the turbine efficiency, with the highest efficiency recorded at the flow coefficient at 0.026689 (2341874) and the lowest recorded at 0.001859 (98553.76). Conversely, the pneumatic power increases with respect to increase in flow coefficient, however a drop in this power system is observed as unsteady flow moves into the system which is indicated in the graph at point R^2 of figure 8. Meawhile, figure 9 shows clearly the effect of the front wall submerged area ratio of the OWC chamber on the turbine efficiency. Thus, the component efficiency is controlled by the design of the chamber such as its area and height. Therefore, plot of the incident wave amplitude to the water depth around the chamber against the turbine efficiency is a good correlation. Hence, result in figure 9 attests that the ratio of the chamber area/height increases with a rise in the turbine efficiency from 0.026(43.85%) to 0.119(45.57%) respectively. Consequently, in view of established results; harnessing energy from OWC analytically is proven to be feasible.

Conclusion

The study of harnessing energy numerically via OWC with the achieved results can be concluded based on the following views points that:-

- There is the possibility to harness energy from OWC through wave energy that is naturally endowed.
- The strength of the wave energy determines the actual amount of energy to be generated.
- The energy determining variables dependents on the open vent of OWC.
- Harnessing energy from OWC can be economical beneficial to the nation.
- Energy from OWC can stand as substitute to the fossil fuel conventional sources which is detrimental to the environment.
- Energy generation from OWC is confirmed to be environmentally friendly.

Thus, this affirms the peculiarity of harnessing energy from OWC mostly for countries having wide range of coastal lines like Nigeria. It will serve as a supportive source to the nation's energy grid, generating revenue and creating employment for job-seekers. Also, the diversification of the nation's energy sector is paramount since OWC technology is emissionless, reliable and will create energy sustainability.

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