Oscillating Water Column Wave Energy Conversion
– Study of Air Turbines

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Abstract: -

The study explores the most prolific technology of wave energy conversion existing in the world today which is the oscillating water column (OWC) technology. The major component of OWC wave energy converter is the air turbine which was taken up for a detailed study and analysis. While a validation of various existing models of air turbines have been studied and carried out in previous related papers, an invention called the “Hanna Turbine” has been identified in this study and it was used to carry out structural and CFD analysis.

The Hanna Turbine was developed by Mr. John Clark Hanna based in Oregon, United States. It is a bi-directional air turbine invented to improve on the characteristics of the pioneering Wells turbine. A comparison of these 2 turbines have been made in this research. Following which the Hanna Turbine was taken up for implementing a CFD analysis.

For wave energy conversion, Mr. Hanna developed 2 versions: i) the bent duct type and ii) the inline version. The former was selected for an initial modelling followed by detailed analysis. The prospect of these new models of air turbines would pave way in development of the entire wave energy conversion and its effectiveness around oceans in this world. Hence this dissertation could be the starting of an even more detailed study to be conducted on Hanna turbines. The model being relatively simple in design needs to be explored to varying degrees and experimental deployment is advised following the results of this analysis.
1. **Introduction:**

This dissertation paper was formulated with a view of exploring a relatively untouched area of renewable energy. Wave energy although being of great abundance and widespread potential, it has not been given prime focus like wind and solar exploitation. Out of the few developments, oscillating water column technology has been widely explored. This project aims to carry out the following:

- Conducting a detailed study of the various wave energy conversion technologies.
- Exploring different possibilities of oscillating water column wave energy turbines.
- Literature review and study of air turbines.
- Detailed study of wells turbine.
- Understanding the limitation with the wells turbine.
- Arriving at solutions to enhance the performance of the wells turbine.
- Structural and cfd analysis of the Hanna turbine – a new invention in the of air turbine.

This dissertation helps in supporting the claims made by Mr. Hanna on his bent duct design of the Hanna turbine which has been submitted for a patent application: **US Patent 8,358,026**. With Mr. Hanna’s new intricate models developed for addressing the wave energy conversion for utility grade paradigm, there is hope that the OWC technology will develop with this air turbine and provide a much better competition to other renewables in terms of energy conversion efficiency. This can be especially beneficial for countries with extensive shorelines and island nations.

2. **Research background:**

**Oscillating Water Column Wave Energy Conversion:**

The Oscillating Water Column technology, more popularly known as OWC, is one version of wave energy converters that have been designed, constructed and operated over a period of about 30 Years. They have achieved varying degrees of success in generating useful power from the waves (ARUP Energy, 2005). The OWC has the uniqueness of being implemented either onshore, breakwater integrated structures, or offshore in floating equipment. While an offshore equipment will have more power at its inlet, it is subject other crucial factors. The offshore device requires to be able to withstand the harsh effects of the oceans and all kinds of possible disaster. (Delmonte, et al., 2016). The OWC works on the principle of converting wave power to pneumatic power. The energized air column is responsible for driving a special class of turbines called the air turbines. The air turbines require to have the unique property of self-rectification. While rectification valves can also be considered an option for this purpose, the practicality of such valves have not been quite fruitful. Hence it is vital that self-rectifying turbines are
developed for this purpose. Therefore, the study and analysis of air turbines are essential in the development of the oscillating water column technology. Other possibilities that can be considered include air chamber characteristics, control strategies for the air column (Ceballos, 2015), integration with local storage options etc.

Energy Conversion in an Oscillating Water Column:

Since the fluid used in the OWC energy conversion is the air, the equations for OWC energy conversion is like the ones used in wind energy conversion. The power available due to air flow driving a turbine in the OWC can be obtained from the below equation (Vining, 2005):

\[ P_{OWC} = (p_{air} + \rho_{air}v_{air}^2/2) v_{air} A_{duct} \]

Where:

- \( P_{OWC} \equiv \text{power available to turbine in OWC duct [W]} \)
- \( v_{air} \equiv \text{airflow speed at the turbine [m/s]} \)
- \( A_{duct} \equiv \text{area of turbine duct [m2]} \)
- \( p_{air} \equiv \text{pressure at the turbine duct [Pa = N/m2]} \)
- \( \rho_{air} \equiv \text{air density [kg/m3]} \)

The equation basically shows how the power available in the OWC is the sum of the pressure energy and the kinetic energy. The components unique to this technology is the duct wherein the air column oscillates and the area of the duct and the pressure exerted on it play a standout role in the overall power output. However, like wind turbines, the velocity generated by the air and transferred to the turbine is the most important factor. The enhanced velocity provides a better potential for the power to be generated out of the turbine.

While designing an OWC, the closed housing or air chamber plays an important role, for air pressurization via wave induction. The water level change within the chamber based on the wave motion drives the air column as well. The alternating wave troughs and crests triggers the air column to move in and out. Designing an optimal turbine for this operation is the challenge.

**The Wells Turbine:**

The specialty of the Wells turbine is that it is a first of its kind self-rectifying equipment specifically designed for Oscillating water column technology. It can be called a bi-directional turbine as it is subject to oscillating or alternating air flows while only rotating in one direction.

The Wells turbine was modified and designed in various forms, some of the basic characteristics of the design were the symmetrical airfoil configuration of the blades. This design provided the turbine with necessary lift and ability to rotate in one continuous direction. The Wells could be used in single or dual configuration, future experimental models with and without guide vanes allowed for this. The guide vanes were developed to provide proper path for air flow as well as being a necessary component for pressure drop.
across the turbine blades. The Wells is an axial flow turbine and the blades are symmetric about the plane of rotation. It is suitable for high speed operation and requires high speeds at lower torque (Takao, 2006). The symmetrical airfoil configuration provided lift necessary for the rotation and although it was considered sufficient, certain improvements were necessary for the Wells. The turbine also had a constant impedance to the airflow and the energy transfer by it was substantial. It fared well in the fact that it was better performing over a range of speeds as compared to other self-rectifying models developed later. It however, had the issue of stalling and had poor self-starting characteristics. These were all validated within testing facilities on experimental models (Moisel, 2016) for aerodynamic and acoustic performances. The wells also generated huge amount of noise during its operation, even though this might not be a major concerning factor as they are set to operate next to ocean waves. The major issues that the Wells rotor had to overcome were the stalling and higher resistance to air flow.

The Wells model has been extensively used in OWCs in several versions. It has come with and without guide vanes. Like the wind turbines, several experimental modifications have also been performed on the wells to improve its performance and capture of air flow. Self-pitch controlled blades, biplane wells turbine with guide vanes and contra-rotating types are few examples (T. Ghisu, 2015). Although these experimental versions provided certain tweaks to the overall performance of the wells turbine, significant improvements were not achieved. It needed a much more radical research strategy to understand how to improve OWC technology. Apart from modifications in the design on the pioneering Wells, several other turbine prototypes were being invented and tested simultaneously.

**The Hanna Turbine:**

This paper aims to provide a proper introduction to the newest model of the wave energy conversion family – The Hanna Turbine. Specifically, the Hanna model is designed for the oscillating water column wave energy converter as an alternative and simple air turbine model. The Wells has been the only accepted model of the air turbines so far, but in the last few years the Hanna version has made a breakthrough in the field.

The Hanna Turbine was invented by Mr. John C Hanna of Oregon State in the USA. It was conceived by the inventor in his quest to fulfill a newer and better version of air turbines to rival and of course improve on the pioneering Wells concept (WETGEN, 2016). The Hanna turbine is also known as the WETGEN- Wave Energy Turbine Generator. This turbine was validated by a small-scale model created at Oregon State University in 2014, it was validated as a self-rectifying bi-direction turbine and was also compared with the Wells turbine for performance. The initial research has revealed the new model to have efficiencies much greater than its older counterpart.

The Hanna invention resulted in a special marine bi-directional turbine that rotated in one continuous direction irrespective of the air flow direction. The need at this point was to have an uncomplicated device, while the Wells was undergoing development for about 30 years now, other versions of air turbines or attempts at making uncomplicated ones were proving difficult. The Hanna model exemplifies this with its simplicity in design, which
is a necessity for wave energy based devices to be successful. Along with this a wave energy conversion device need to be cost effective and to be designed for long term usage. Hence survivability is a factor to be considered with the materials of construction, a robust structure with minimal maintenance requirements is the need of the hour. The other major claim is that the WETGEN can be used alternatively as a tidal turbine. This is staggering feature, however, will not be a subject of this research as the focus is on wave energy conversion as such.

The Hanna model conceptual design features:

The WETGEN or Hanna turbine (HT) is made of two rotors connected a common shaft. Instead of the symmetrical airfoil blades used in the Wells turbine, the Hanna turbine rotors has been created using asymmetrical airfoil blades. The asymmetrical blades project outward of the rotors and the two rotors have a mirrored blade configuration. Each rotor hub consists of a precise one-way clutch mechanism. This enable the rotors to alternate between the power stroke and the coast mode. This design allows the shaft to be turning in one continuous direction irrespective of the airflow direction. This implies that while one of the turbine rotors, say rotor 1 will be in the drive mode, the other, say rotor 2 will be in the coast mode during incoming air flow, and vice versa.

To be more specific, the responsive of the blades to air flow is of prime importance here, as they are sought to react differently to the oscillating air column. The drive or power mode of the rotor is a result of the air impinging on the blades' leading edges. Due to the mirror blade configuration, the incoming air flow or air flow due to a wave crest will be on the leading edge of one rotor (say rotor 1), while on the trailing edge of the other (rotor 2). Further, the outgoing airflow or the air flow due to a wave trough will strike the leading edge of rotor 2 and trailing edge of rotor 1. These role reversals of the rotors to move in power and coast modes alternatively as according to the air flows are the major advantage and a great concept brought into the design of dual rotor air turbine configurations. Thus, to maximize the energy output from the airflow, the blades are aerodynamically tuned and as compared to other axial flow rotors, the reverse flow aerodynamics does not cause either of the rotor blades to reverse their direction, in fact, a small amount of torque is generated in the same direction of the power stroke. An angular momentum is achieved in whichever rotor is in the freewheeling mode as the rotating mass of the annular rings act as flywheels in this system.

Now, with these features and concepts, the Hanna turbine is claimed to outmatch the Wells model in the following. With the dual rotor low speed operation, the HT develops more torque at lower speeds. The asymmetrical airfoils with low angles of attack increases lift and reduces stalling. This in turn enhance the self-starting characteristics which was a major drawback of the Wells turbine. It also had a wider operating range of air flow velocities and the fact that the common shaft is connected to two generators, in the view of doubling the power output with each stroke. The mixed flow configuration also aids a great deal in the making of a more efficient working of the HT.
Energy extraction from the HT:

With the description of the model, it is clear that the only moving parts of entire turbine are the two spinning rotors. For large scale HTs, i.e., for utility scale versions, certain elements may be incorporated such as mechanical turbulators which are non-moving components utilized to delay the flow separation between the blade. The use of such turbulators are a further development in enhancing aerodynamic efficiency. While the HT itself is characterized by greater lift and minimal stalling, the use of turbulators further improves this feature and eliminates the need for variable pitch blades. The HT has also undergone further innovation in this short period of its development. The incorporation of slots along the blade trailing edges is a means of efficiency improvement. The slots on the hollow turbine blades again provide a better lift coefficient and slants the high velocity air downwards, thereby avoiding stalling of the turbine at lower speeds.

The materials of construction for the HT are still open to research. With increasing development in the fields of high grade light weight plastics, carbon fiber and Nano technology, plenty of options are plausible. The major concern is for the constructed version to have high survivability along with good conversion effectiveness.

Other research areas into enhancing the HT’s efficiency is the design of the wave capture chamber. The key is to achieve the maximum possible conversion from the wave energy to the air energy. (WETGEN, 2016)

Although the HT is developed into 3 different unique models, the version used for research here is the bent duct model as described above.

3. **Modelling:**

The designing for the Hanna Turbine was based on the hand sketches and supporting Solidworks drawings provided by Mr. Hanna. Although the turbine was constructed to full size at the factory, computer models and analysis performed were limited. There was a simple CFD analysis performed by graduate students at Oregon State University validating the design and effectiveness of the Hanna model in bi-direction air flow. However, this dissertation has covered structural modelling, meshing followed by cfd analysis.

For the structural modelling, the pre-processor used was Hypermesh 13, the solver – Optistruct and the post processing in Hyperview. The method used for modelling is tetra meshing, elements used are second order tetras. For all other components except the rotor blades, auto meshing was used. However, due to the complex design of the blades, manual meshing needed to be done which turned out to be the challenging and time-consuming process in the modelling stage. The idea was to generate a properly design computer model initially and then take it up for the later analysis stage. The bent duct version of the Hanna Turbine was used during this study. The Fig. 3.1 shows the 3-D structure of the bent-duct Hanna turbine. This is further covered completely with an outer
casing which essentially is designed to provide the mixed flow to the incoming air and provide further turbulence and hence rotary momentum to the turbine.

While the Wells turbine model was patented with a symmetrical airfoil model, the Hanna rotors are made of asymmetrically shaped airfoil blades. For this model, the NASA GA(W)-1 was chosen, because of extensive data available from previous studies relating to the effects of force, pressure and flow field (W. H. Wentz, 1983). The design for the same is shown in Fig. 3.2. The blades used in this version of turbines are subject to environmental and fatigue factors and the property limit for the selection of materials would be the resistance to the same. Mechanical properties such as strength and weight further contribute to maximize the design objective (Saptono, 2004). Hence comparing with the selection of materials for wells turbine designs, the HT was also designed and modeled using carbon fiber reinforced composites. Such candidates for material selection needs to be further explored in detail. It further depends on the technical feasibility of the material and the local conditions.
4. Structural Analysis:

Analysis is done to find the effect of torque generated on the turbine shaft. For this purpose, since the HT did not have any established research papers to consider values, the approximate values were taken from established air turbine models’ research. The successful installations of OWC plant has resulted in a power output of 500 KW (Brad Stappenbelt, 2010). While installations of 2 MW were also tested, long term implementation and data were not available, so as an average case for the torque calculation, an output power from the turbine of 500kW was considered. The efficiency of the turbine is considered as 65%, this is comparable version of the Wells turbine efficiency which although is less as compared to other self-rectifying versions of impulse turbine, operates at a wider range of speeds (Toshiaki Setoguchi, 2006). A rotational speed of 5000 rpm was assumed for the structural analysis. An optimal algorithm based on airflow velocities is required to fix the rotational speeds on the turbine (Utku Şentürk, 2011)

Torque calculation:

power at generator =500kW

efficiency of the turbine =65%

rotational speed =5000Rpm (523 rad/s)

\[ P = \frac{2\pi NT}{60} \]

\[ T = 2.6 \times 10^8 \text{ Nm}; \]

Considering the 60% efficiency of turbine shaft to generator, Torque at turbine shaft is \( 4 \times 10^8 \) Nm
Deck preparation:

Model is constrained at the bottom in all 6 DOFs:

![Image showing the constraint on the model in all six degrees of freedom](image1)

Fig. 4.1 Image showing the constraint on the model in all six degrees of freedom

Shaft is connected at both ends using RBE2 elements and the rotational DOF about Z axis is released, so that the shaft will be free to rotate about Z axis.

![Meshed model with shaft attachment free to rotate about Z-axis](image2)

Fig. 4.2 Meshed model with shaft attachment free to rotate about Z-axis

The rotor is connected to the shaft via RBE2 elements, constrained in all 6 DOFs, so that rotor will be firmly attached to the shaft. But when rotor rotates, Shaft will rotate. Torque is applied on the shaft, at two locations where two rotors are connected to the shaft. When the torque is applied on the shaft, it will transfer to the rotors.

(In actual scenario torque is generated on the shaft due to tendency of rotors to rotate. But here we applied torque on the shaft and observing the effects, both provide the same effect.)
From the images of the von mises stress effects on the rotor element depicted in Fig.4.3, it is observed that the load factor on the blades and shafts are way below the maximum it can withstand which implies much more load can be applied to these elements. Hence with this version of the model more power can be generated. In terms of output power, if it is constrained, such a huge turbine model (rotors radius 2000mm, blade width 515 mm and length of 1385 mm) need not be considered. The HT can provide as much power from a smaller version. Considering this is the power of the most successful OWC installations around the world, this bodes well for the new technology.

However, a complete understanding can only be obtained with a CFD analysis of the HT. The geometry has been defined with the modelling and the corresponding structural analysis. A demonstration of the air flows within the Hanna model can be attained only with cfd analysis.
5. CFD Analysis:

Computational Fluid Dynamics software was used to validate the model of the Hanna turbine. Analyses are focused on the effects of air flow on the Hanna chamber as well as on the rotors and the stator. Similar to CFD analysis performed in various other turbine models, CFD is done by considering the turbine rotors as a porous medium in the cfd software fluent 14.0 (MARJANI, et al., 2011). Another tool available to perform cfd analysis is the blade element/actuator disc methodology, which can provide the lift and drag characteristics arising out of the blade (A. Gareev, 2009). Such characteristics can be compared with experimental results of lift and drag by getting the HT model subject to experimental setup with a wind tunnel accompanied with a wave simulator to obtain satisfying results.

Multiple reference frame was defined in order to study the flow characteristics of the Hanna turbine used in Oscillating water column wave energy converters. The inlet boundary condition was set at 3 m/s for a simulation time of 3 sec. This simulation made use of transient state condition. Since the working medium in this case is air, the operating conditions were: pressure of 101325 Pa, viscosity of 1.78e-05 Pa and density of 1.225 kg/cu.m. Various components taken into consideration for the CFD model were: inlet, outlet, turbine-1, turbine-2 and stator as shown in Fig.4.1 (a) and (b).

![Fig.4.1 (a) Top View Depicting Inlet (blue) and outlet (violet) and the shaft (in yellowish green); (b) Turbine rotor 1 (light green), stator in pink and Turbine rotor 2 (dark green)](image)
In case of the Hanna OWC, the flow is reversed based on the oscillations of the air column and hence the inlet and outlets are reversed accordingly. The dual rotor configuration in this case provides the advantage of generating power in each stroke or every push and pull of the air column. In this case, a dual clutch mechanism is incorporated so that the rotors operate between power mode and coast mode alternatively, i.e., when the inlet area is adjacent to rotor 1 and the incoming air impinges on the leading edges of rotor 1 blades, it acts in the power mode and drives the generator connected via the common shaft. During this stage, rotor 2 also rotates in the same direction albeit in the coast mode, generating no power as such. However, when the flow reverses as according to wave motion, rotor 2 receives incoming air on its blades on the leading edges and hence tends to be the drive rotor in this case, while rotor 1 is in the coast mode.

Fig.4.2 (a) Depicting the 2 rotors, (b) stator design

Meshing:
The CFD model was proceeded with meshing at the various zones. The figures depicted provides an idea of the different meshing patterns on the various components of the entire equipment including the skeletal structure, turbine rotors and stator as well.
Fig. 4.2 (a), (b) & (c) Meshing of the different components
Scope of Study:

Analysis – Case 1:

- To study the flow in Oscillating Water column by defining multiple Reference Frame for turbines (Twin).
- The inlet boundary condition was set at open to atmosphere in both inlet and outlet.
- The simulation time is in steady state condition and it ran for 1500 iteration before convergence.
- The simulation used boundary condition for MRF region as 1500 rad/ sec, to study the sturdiness and quality of mesh.
- The objective included obtaining the effect of pressure and velocities on the two rotors and the stator.
- The conditions were based on past simulations done on other air turbines (Zhu & Hu, 2016), (Falcão, et al., 2016), (Mahnamfar & Altunkaynak, 2016), (Demos P. Georgiou, 2012), (Khan, et al., 2009), (Tatum, et al., 2016)

Case 1 Results:

The simulation ran fine on the fluent processor, because of which the following results were obtained:

Pressure and Velocity Variation on turbine -1 along the Z-axis:

Fig.4.3 Contours of static pressure on turbine rotor-1 along the Z-axis
The Fig. 4.3 shows the contours of the static pressure on the turbine rotor-1. This is the rotor which undergoes the initial impact of the air column and responsible to overcome the static state of the turbine. As can be observed from the depiction, the static pressure values are relatively even and in a mediocre range along the surface of the rotor. The peaks of static pressure happen along the edges of the blades resulting in an impending pressure difference and a considerable drive. Hence the effect of the fluid, in this case air has on the turbine rotor-1 relative to when the latter is at rest is demonstrated here.

![Static Pressure Contours](image)

**Fig. 4.4 Contours of Total Pressure of turbine rotor -1 along Z-axis**

The total pressure contour is demonstrated in Fig. 4.4. This pressure is a result of the static pressure due to the airflow along with the velocity generated on the turbine due the same. There are slight variations in the total pressure along the surface created by the turbine rotor. On an average however, it is about 3e6 Pa. The variation occurs due to the difference in velocities and the effect of the mixed flow that is generated due to the device geometry. The velocity of the air is enhanced as a result of the rotor and is transferred onto the next set of blades. This allows the rotor on the next set to pick up momentum allowing considering rotational velocity. This shows that all the air that is pushed into the system is utilized to its maximum possible potential before it exits the system. This is further substantiated by the velocity contour depicted in Fig. 4.5 The velocity contours further enhances the result of the total pressure contour shown previously.
Fig. 4.5 Contours of Velocity on turbine-1 in Z-axis

Pressure and Velocity Variation on turbine-2 along the Z-axis:

The figures in this section demonstrate the pressure and velocity contours on turbine rotor-2 along the Z axis.

Fig. 4.6 Contours of Static Pressure on turbine-2 in Z-axis
The stator in this system is an essential component and the results generated essentially need to show the effect on the stator as well. Along with acting as a guide to the air transfer to different compartments of the turbine, the stator also serves as a part that causes major pressure differences and hence allows considerable velocities to be transmitted to the adjacent compartments. This make it a vital component of the Hanna model and hence the various contour in relation to the stator are also generated below:
Fig. 4.9 Contours of Static Pressure on Stator in Z-axis

Fig. 4.10 Contours of Total Pressure on Stator in Z-axis
As part of the results we also demonstrate the pressure and velocity variations on the entire structure:

**Fig. 4.11** Contours of Velocity on Stator in Z-axis

**Fig. 4.12** Contours of Static Pressure in X-mid -axis
The forces due to the total pressure was obtained at the 2 primary zones of consideration, namely, turbine 1 and turbine 2. In turbine 1, this force is 306968.48 N and in turbine 2, the forces increased to 342387.82 N. The mass flow rates were also obtained in the results. At the inlet, a mass flow rate of -124.62165 kg/s was obtained. The "-" sign indicates, the air flowing in the opposite direction of the Y-axis. The outlet generated a mass flow rate of +124.62164 kg/s. This value obtained from the analysis reinstates the validity of the model created and the meshing that was done. The value of mass flow rate confirms the conversation of mass in the system.
Case 2:
The second case taken up for analysis of the Hanna OWC was an inlet air flow of 3 m/s. While in the previous case, the shaft rotary speed was fixed, in this case a mild air column speed of 3 m/s was taken up. Such an analysis would demonstrate how the turbine set-up fared in mild conditions of wave motion. It needs to be studied whether the rotors can gain momentum in this condition. Hence such an analysis was also performed and detailed herewith. Along with the pressure and velocity contours, the major analysis result considered here was the velocity vectors on the various components of the set-up.

![Fig. 4.15 Zoomed in Contours of Velocity vector on top portion of Turbine-1 in Z-axis](image)

The fig.4.15 demonstrates the contours of the velocity vector on turbine rotor 1. As can be observed from the top portion of the turbine rotor, the velocity direction indicates a definitive clockwise rotation of the rotor owing to the blade geometry. The velocity generated is also at least an average of 1.5 times the initial velocity of 3m/s. This is a great indicator of the performance and lack of resistance of the system. The mixed flow design of the turbine provides this additional thrust capability to the rotor.
Fig. 4.16 Zoomed in Contours of Velocity vector on top portion of Turbine-2 in Z-axis

Fig. 4.17 Zoomed contours Of Velocity vector on Stator in Z-axis
The forces acting due to pressure on the two major zones, turbine-1 and turbine-2 were 9.6 N and 34.48 N respectively. This shows an increase in the forces acting on turbine 2 as a result of turbine 1. This paves way to show the effect that a dual rotor dome shaped configuration can have on the velocity and momentum generated from a turbine.

The mass flow rate at the inlet was -5.5043 and the outlet was +5.55021 demonstrating and confirming the conservation of mass within the system.

This complete CFD analysis for the two cases demonstrates the validity of the HT and the effects of pressure and velocity on the bent duct version of it. It proves how effective the bent duct design can be for generating additional velocity and inducing spinning momentum of the two rotors. It also shows how the stator plays an important role in guiding the airflow and for pressure drop across the 2 rotors. Due to the shape of the blades arranged about the periphery of the rotor, sufficient lift is obtained and the rotation is thereby induced.

6. Conclusions and Recommendations:

The Hanna turbine model had undergone a thorough analysis including structural analysis and CFD analysis. A brief research and study on the claims made my Mr. John Hanna, described the features of the Hanna turbine and how it stood out as compared to the Wells version. The concept reveals a simplified version of the wave turbine, without having to use complex technology such as contra rotating blades and variable pitch blades. It addressed the major concerns of the wells turbine namely self-starting issues and unwanted stalling. It also provided good lift characteristics and a dual rotor configuration which allowed to tap power in each stroke of the air column. Hence the maximum possible potential of the wave energy converting to pneumatic energy can be realized with this model. Further, the analysis in this paper focused only on the bent duct model, however, the inline model is claimed to
provide a better efficiency during experimental testing. The inline model has not been analyzed using CFD and future works should concentrate on realizing the complete potential of the inline model of the HT.

The bent duct model of the HT was found to be compact from the structural analysis. It revealed that the stresses acting on the device were minimal. For the analysis, the power to be generated by the turbine was fixed at 500KW, this was comparable to the average power production from a Wells turbine operated OWC wave energy conversion plant. It was observed that for the size of the model used, it could generate much more than 500KW. Hence an idea of the capacity of the Hanna turbine was obtained from this. Further the design of the HT did not show any weak links such that the stresses due to the oscillating flows or fatigue would affect it significantly.

Further, CFD analysis revealed the validity of the HT and its applicability in wave energy conversion. The air flowing into the chamber due the wave motion, is transferred to the first rotor and its further enhanced due to the chamber shape and is pushed into the next set of rotor blades via the stator. The use of two rotor system is a simplistic approach in doubling the overall power output and efficiency. Overall, the model bodes well as compared to previous OWC air turbines in terms of having a compact design to tackle the oscillating air column and generating power out of it. It also suggests that this design would be less expensive to manufacture owing to its limited moving parts and lesser complexity.

The challenges in this research study was the limited amount of sufficient data to conduct a full-fledged study. However, this dissertation should provide a good background for the HT to be subject to further study. A major suggestion coming from the inventor himself is to concentrate on the inline version of the Hanna model as experimental results showed better performance as compared to the bent-duct version.

7. References:


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