MODELLING AND ANALYSIS ON GRAVITATIONAL WATER VORTEX TURBINE

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Abstract: Energy generation through water is one of the most economic sources of power. Among the hydro-power plants, micro-hydro power plants are more preferred since they require lower heads and smaller flow rates to generate electricity. The main advantage of micro-hydropower plants is the combination of feasibility, ease of installation, efficiency, and economy into a single source of power. In the category of micro-hydro power plants, gravitational water vortex turbines are emerging currently due to their ease of installation, reduced setup time and minimal expertise required for installation. Generally, a gravitational water free vortex turbine, which mainly comprises a runner and a tank, generates electricity by introducing a flow of water into the tank and using the gravitation vortex generated when the water drains from the bottom of the tank. This water turbine can generate electricity using a low head and a low flow rate with relatively simple structure. However, the turbine has a low efficiency. Although changes in geometry could increase it. In this study is focused on the optimization of the runner to improve the efficiency of the gravitational water free vortex turbine. The analysis is carried out runner blade profiles. The 3D model of the turbine is done using the CATIA V5 software. ANSYS CFX(FLUENT) was used to analyze the fluid flow through the channel, basin, turbine hub and blade, and results were used to evaluate the efficiency of the runner design.

Keywords: hydro-power plants, micro-hydro power plants, feasibility, ease of installation, efficiency, gravitational water free vortex turbine, runner, tank, gravitation vortex, CATIA V5, ANSYS CFX(FLUENT), channel, basin, turbine hub, blade

I. INTRODUCTION

There are 1.2 billion people around the world that lack access to electricity, some 85% of them in rural areas. Based on current trends, 1.2 billion people or 15% of the world's population will still lack access in 2030. This growing demand for electrical energy, whilst reducing carbon emissions, is one of the main reasons pushing the advancement and implementation of renewable resources such as solar photovoltaics, wind, and hydropower. Implementing these in rural areas allow communities to generate and manage their own resources locally. Water energy being a clean, cheap and environment friendly source of power generation is of great importance for sustainable future; being aware of this fact, still major of the hydro energy is under-utilized. There are mainly two approaches to harness energy from water, namely, hydrostatic, and hydrokinetic methods. Hydrostatic approach is the conventional way of producing electricity by storing water in reservoirs to create a pressure head and extracting the potential energy of water through suitable turbo machinery hydrokinetic approach, the kinetic energy inside the flowing water is directly converted into electricity by relatively small-scale turbines without impoundment and with almost no head.Hydro-electric power plants can serve as a solution to the current energy crisis of the world since they use the energy stored in a free stream of water to generate electricity rather than using oil and other fuels. In hydro-electric power plants, water is stored at a higher potential. This water is then passed onto the blades of a hydraulic turbine. Using the turbine, mechanicalenergy can be harnessed from the potential and kineticenergy of the flowing water. Once mechanical energy has been generated, then this energy may be converted to electrical power which can be transmitted through electric lines for use.

Free surface vortices are a common and an important phenomenon in the field of hydraulic engineering. Vortices are formed at the intake of hydraulic structures due to a design flaw, where a large amount of water is drained into the intake. This flow into the intake causes a vortex to initiate at the free surface due to the Coriolis force. This vortex gradually intensifies, causes the water rotation to speed up and in turn causes the pressure in the center of the vortex to decrease. This pressure gradually decreases to an extent that ultimately it reduces below the atmospheric pressure and sucks the air into the intake and forms an air core.The radius of the air core gradually reduces while moving from the free surface to the intake. The Gravitational Water Vortex Trubine (**GWVT**)uses this vortex to generate the electricity.

2. PROBLEM STATEMENT

The shape of blades plays an important role in increasing or decreasing the efficiency of the turbine. We can increase the efficiency of the turbine by adding the baffle plates to the blades. In this paper we had taken the dimensions of a turbine with real-life turbine and design is modified by adding baffle plates to increase the efficiency.

3. LITERTURE SURVEY

Pongsakorn Wichian et.al [1]: This article is based on a study that focuses on increasing the efficiency of the water free vortex turbine by installing baffle plates on the propellers order to find the most suitable size and proportion for the baffle plates, the study used the CFD program to design baffle plates which have a diameter of 45 cm. and a height of 32 cm. The results showed that 5 baffle plates, with a propeller baffle area of 50% gave the highest degree of torque. Propellers, with no baffle plates, were also created and were tested along with a turbine with 50% baffle plates at the flow rate of 0.04 - 0.06 m s The results showed that the propellers with a 50% baffle plate proportion helped to increase the torque at an average of 10.25% and with an average of overall efficiency of 4.12%.**P Sritram et.al. [2]:** This article presents the results of the study on the effect of blade number and turbine baffle plates on the efficiency of a free-vortex water turbine. The laboratory experimentation performed to determine the power generation efficiency. The 2 to 7 blade water turbines were built and tested to find the most appropriate number of blades, and the result showed the 5-blade turbine being appropriate because it yields the highest torque from receiving impact from water flow. Next, the baffle plates were designed and attached to the top and bottom of the turbine blades. Four different sizes of space from 25% to 100% of the curve area around the blades were used. Experiments were carried out at the water flow rates of 0.04 to 0.06m3/s. The finding showed the 50% proportion of the curve area being most appropriate, and the blades installed with top and bottom baffle plates had the highest efficiency of 43.83%, which was 6.59% higher than without baffle plates. It was also found that when the water flow rate increased, the system efficiency became higher.**SagarDhakal, et.al [3]:** This study is for the development of efficient basin design. We have optimized the conical basin of this plant by changing the four design parameters of basin such as: notch angle, canal height, notch inlet width and cone angle. Different geometric models are developed by using SolidWorks software and simulation is done with the help of Commercial CFD code ANSYS Fluent. Mathematical relationship among these design parameters with the water velocity are established. Thus, formed mathematical model is optimized using different optimization tools which is followed by experimental verification by measuring the power output.**R. Dhakal, et.al [4]:** The gravitational water vortex power plant (GWVPP) is a new type of low head turbine system in which a channel and basin structure is used to form a vortex, where the rotational energy from the water can be extracted through a runner. This study is focused on the optimization of the runner to improve the efficiency of the GWVPP. Computational fluid dynamics (CFD) analysis is carried out on three different runner designs with straight, twisted, and curved blade profiles. ANSYS CFX was used to analyse the fluid flow through the channel, basin, turbine hub and blade, and results were used to evaluate the efficiency of each of the runner designs. The CFD analysis showed curved blade profile to be the most efficient profile, with a peak efficiency of 82%, compared to 46% for the straight blade runner and 63% for the twisted blade version. An experimental test of the turbine system was carried out to validate the runner analysis, in a scale version of the GWVPP. The testing showed that the runner behaved as predicted from the CFD analysis and had a peak efficiency point of 71% at 0.5m head.

Haryadi et.al [5]: Vortex turbine is one of the solutions to utilize the low head hydro energy resources. In recent studies, researchers employ four main runner types, namely: flat radial, paddle, centrifugal, and modified form. The turbine performance can be increased by improving the turbine runner from these types into three dimensions (3D) type. In this present work, the performance of a 3D type runner was designed and examined experimentally. The experiment showed that the maximum efficiency was around 24%, at rotational speeds about 90 to 120 rpm. The maximum efficiency was reached at the design condition**. Alejandro et.al [6]:**The small hydroelectric power plants have become a great solution to the energy problem in the non-interconnected zones that have a low flow river. The gravitational vortex turbine is a small power plant easy to install, low maintenance and economically viable for these areas. However, the turbine has a low efficiency. Although changes in geometry could increase it. In this study, concave and convex designs are proposed for the gravitational vortex turbine tank, which are studied numerically and experimentally. The numerical study was developed in ANSYS CFX V19.1 software and the experimental phase was carried out in the fluid’s laboratory of the Instituto Tecnológico Metropolitans. The numerical and experimental results of the concave and convex design show a difference of 62% and 60%, respectively. The vortex formation and output velocity are the numerical parameters analysed with the software, and the electric power and torque are the parameters on the experimental phase. The tank geometry is the most important parameter to increase the turbine’s efficiency, so it is recommendable to select a suitable design. **Gheorghe-Marius MARIAN et.al[7]:** For a new concept of micro hydropower plant with gravitational vortex and turbine with rapidity steps has been modelled the waterflow through the conical channel in the absence and the presence of steps. In the first case , the power lines appear as conical propellers. Axial and radial velocity of the water are not zero only in the boundary layer. In the second case the structure of the water flow is changes with the formation of swirls every area of the blades. The water velocity increases rapidly as proximity to the drain hole and strongly depends on water flow. **V. Naderi, S. Gaskin [8]:** A free surface vortex is a mass of water rotating around an axis which at a low intensity of rotation results in a dimple at the water surface and at a high intensity of rotation can result in an air-core at its centre. Air-core vortices can occur at intakes withdrawing water from eservoirs. Existing vortex models provide general information about the symmetric vortex structure. The aim of the present study was to examine the vortex structure at the critical submergence condition occurring in an approach flow which results in a non-symmetric velocity distribution and structure of the vortex throughout the flow depth. A steady strong air-core vortex over a bottom intake was created in a recirculating flume in which the water depth, mean velocity of the approach flow, and intake discharge could be adjusted. A combination of flow visualization and detailed PIV data allowed the asymmetric structure of the strong air-core vortex in an approach flow to be studied. Flow visualization was used to observe the formation and evolution of the three-dimensional structure of the air-core. Planar particle image velocimetry (PIV) was used in a series of horizontal and vertical planes to reconstruct the three-dimensional structure of the (strong air-core) vortex. Analysis of this data revealed an asymmetric vortex structure in the horizontal plane throughout the flow depth due to the approach flow creating a mixing zone upstream of the vortex.**M. M. Rahman, et.al[9]:**Gravitational water vortex power plant is a green technology that generates electricity from alternative or renewable energy source. In the vortex power plant, water is introduced into a circular basin tangentially that creates a free vortex and energy is extracted from the free vortex by using a turbine. The main advantages of this type of power plant is the generation of electricity from ultra-low hydraulic pressure and it is also environmental friendly. Since the hydraulic head requirement is as low as 1m, this type of power plant can be installed at a river or a stream to generate electricity for few houses. It is a new and not well-developed technology to harvest electricity from low pressure water energy sources. There are limited literatures available on the design, fabrication and physical geometry of the vortex turbine and generator. Past researches focus on the optimization of turbine design, inlets, outlets and basin geometry.

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4.MODELLING AND ANALYSIS OF GRAVITATIONA WATER VORTEX TURBINE

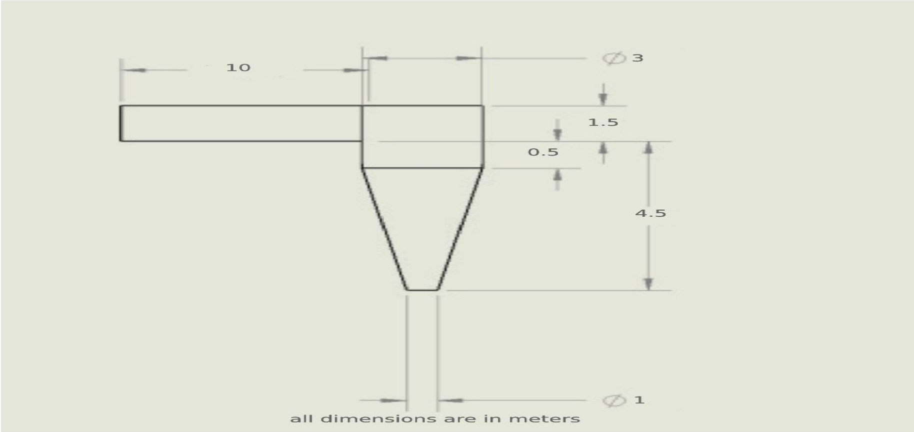


Fig. 4.1 Gravitational Water Vortex Turbine 2 D Model.

4.1 DIMENSIONS OF THE RUNNER BASIN

4.1 Table Runner basin Dimensions

RUNNER BASIN	DIMENSIONS
Channel width	4m
Channel basin height	2m
Inlet diameter	3m
Outlet diameter	1m
Channel length	10m
Channel height	1.5m
For turbine blades:	
Height	1.5m
Length of blades	1.5m (along the length up to baffle plates)
Length of blades	1.3m (up to starting of baffle plates)

4.2 EQUATIONS Efficiency of system, ŋ $= \frac{\text{power transmitted to the wheel}}{\text{kinetic energy supplied by the jet per unit time}}$

$$= \frac{\rho A v(v-u)(1+\cos\theta).u}{\frac{1}{2}\rho A v.v^2}$$

$$ŋ = \frac{2u(v-u)(1+\cos\theta)}{v^2}$$

Where, v – initial velocity of the water

u – peripheral velocity

ŋ – efficiency of the turbine

θ – vane angle (90 for our design consideration)

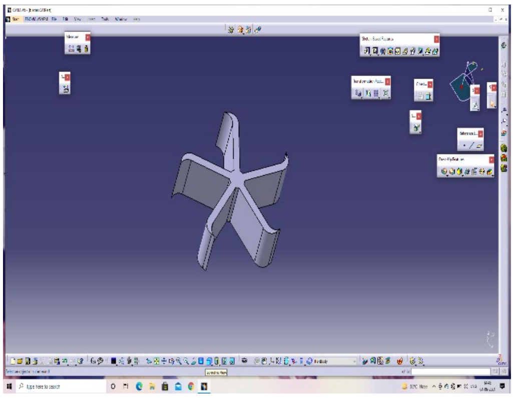
4.3 DESIGN OF TURBINE BLADES

4.3.1 Basin

1. consider a plane X-Y draw a circle of diameter 1m.
2. consider a plane parallel to X-Y at 4 m and draw another circle of diameter 2m. combine them using multi section solid option.
3. Pad the bigger circle upward to a length of 2m. draw the outline of runner shape and pad to produce as shown in the fig 2 below.

4.3.2 Turbine Blades

1. draw a circle and pad it to get the cylinder.
2. draw a rectangle shape on the same plane of the circle and pad it to the surface of cylinder.
3. Taking an angle place the baffle plates at the end of rectangular plate as shown in the fig 1 below.



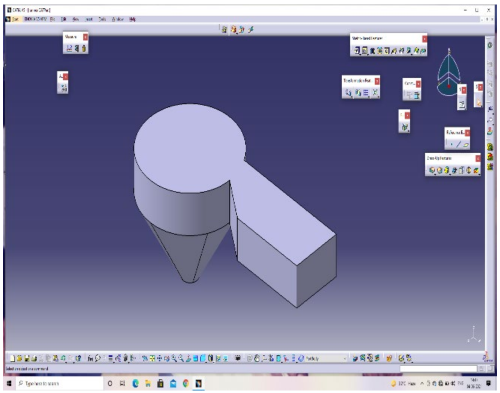


Fig. 4.2 Turbine blades Fig .4.3 model of gravitational water vortex turbine

Assembly:

Import the Runner and fix it using fix option, again import the turbine blades. With the help of surface constraints and offset constraints assemble them.

4.4 ANALYSIS OF GWVT:

ANSYS:

The Ansys finite element solvers enable a breadth and depth of capabilities unmatched by anyone in the world of computer-aided simulation. Thermal, Structural, Acoustic, Piezoelectric, Electrostatic and Circuit Coupled Electromagnetics are just an example of what can be simulated. Regardless of the type of simulation, each model is represented by a powerful scripting language.The Ansys Parametric Design Language (APDL). APDL is the foundation for all sophisticated features, many of which are not exposed in the Workbench Mechanical user interface. It also offers many conveniences such as parameterization, macros, branching and looping, and complex math operations.All these benefits are accessible within the Ansys Mechanical APDL user interface. The ANSYS Workbench platform automatically forms a connection to share the geometry for both the fluid and structural analysis, minimizing data storage and making it easy to study the effects of geometry changes on both analyses. In addition, a connection is formed to automatically transfer pressure loads from the fluid analysis to the structural analysis.

Insert Geometry: Import the 3D model which was earlier done in CATIA which will be in '.CATpart' format. Convert it into the '.igs' format to import it to the ANSYS and do the analysis of GWVT.
Define the boundaries: Define the boundaries for the imported model in the ANSYS using the option of 'create named selection'. Create all the domains, walls etc.
Generate Mesh: Now the model must be broken into finite number of pieces which are called as elements. This process is known as meshing. At boundaries to get the accurate results we do inflation. Inflation is the process of producing the finer elements.
Apply the conditions: The inlet velocity, the velocity head, or the acceleration due to gravity its axis is specified to get the results, specify the model of flow (steady or transient).
Obtain solution and plot results: Use the method six DOF to obtain the results, we must give the moment of inertia of the turbine wheel which we can get from the CATIA. We can set the plot results which can be plotted to get the result graphs.

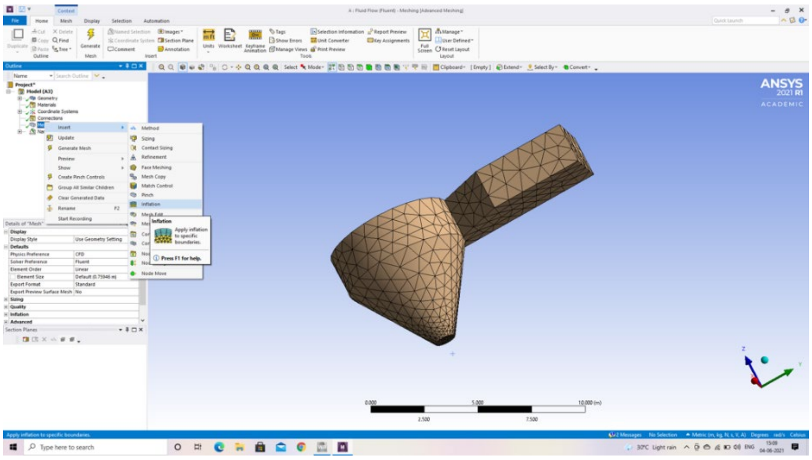
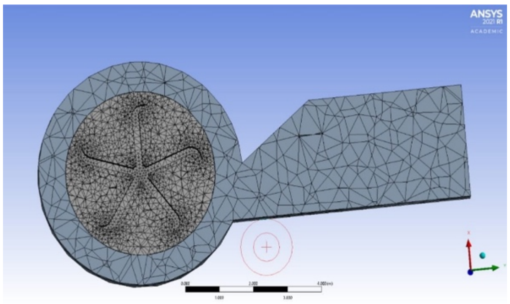


Fig. 4.3 After complete meshing.



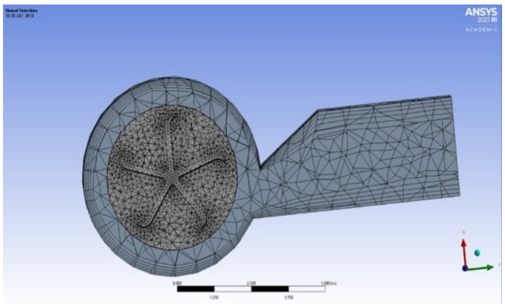
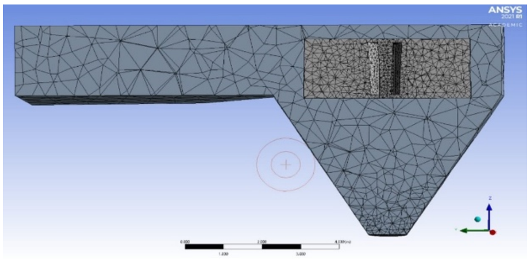


Fig .4.5 Before inflation. **Fig .4.6 After inflation.**



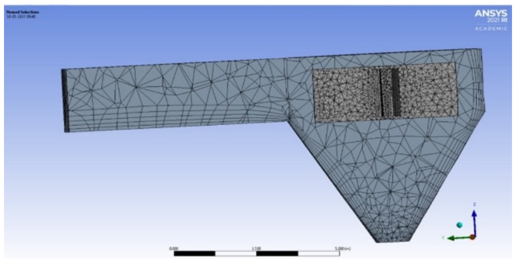


Fig .4.7 Before inflation. **Fig .4.7 After inflation.**

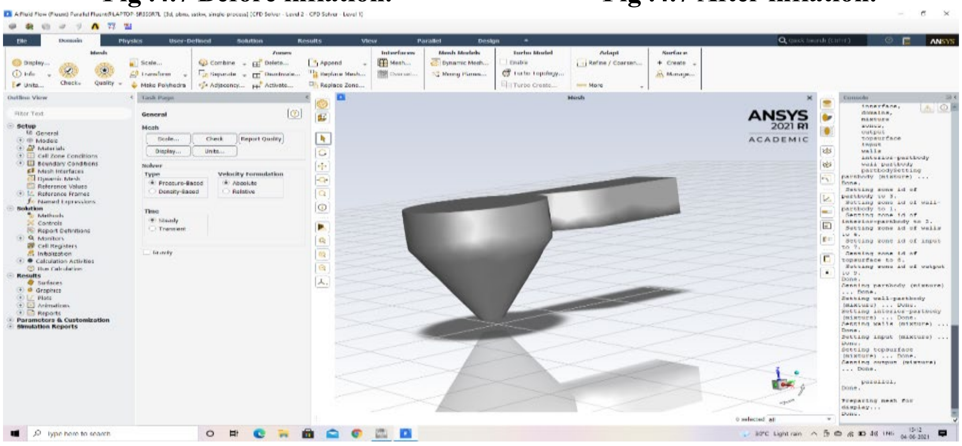


Fig .4.8 Main setup in ANSYS

5.RESULTS:

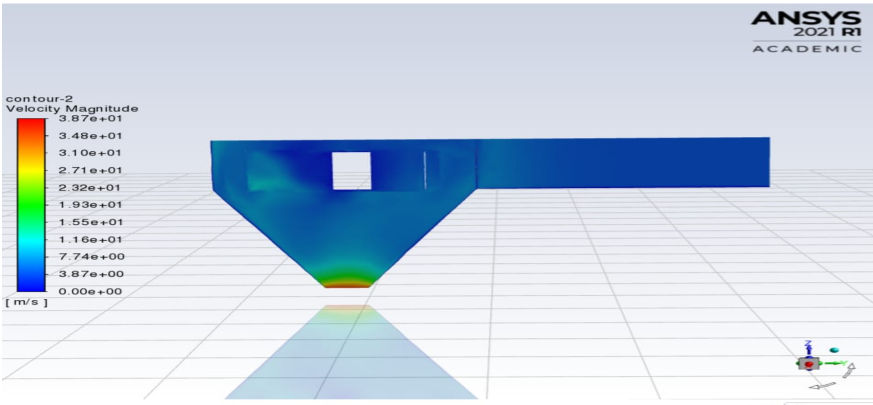


Fig: 5.1 velocity contour.

From the above velocity contour we can say that the water flowing from the inlet to outlet is different and at inlet, the water is almost still and when it enters into the turbine basin, due to the shape of the basin and tangential flow of water through out the basin will generate vortex, then the formed vortex hits the turbine blades and rotation of the blades takes place, therefore in the above figure 4.1 we can observe how the velocity varies at different points.

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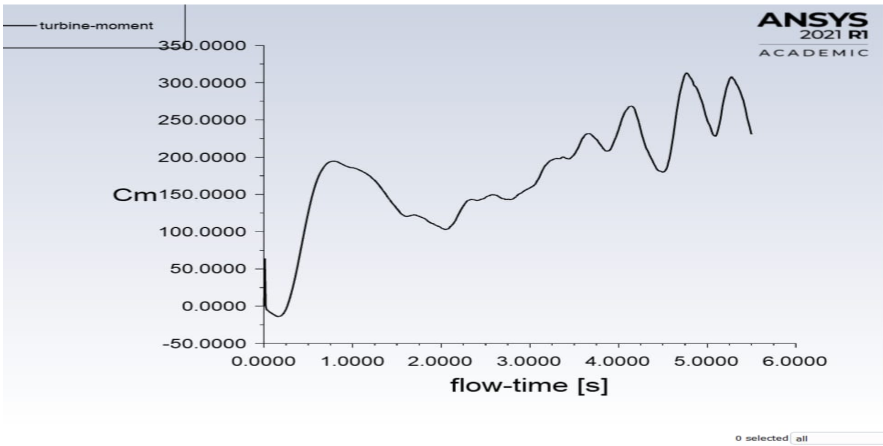

Fig .5.Torquevs Time graph

5.1 EFFICIENCY CALCULATIONS:

from the analysis, we get. $v = 9.91\ {}^{m}/_{s}$

$u = 6.8\ {}^{m}/_{s}$

$\theta = 90°$

Now, efficiency is $\eta = \frac{2u(v-u)(1+\cos\theta)}{v^2}$

$= \frac{2(6.8)(9.91-6.8)(1+\cos 90°)}{9.91^2}$

$= 0.430677$

$\eta = 43.067\%$

6. CONCLUSIONS

We used CATIA V5 to model the Gravitational Water Vortex Turbine and ANSYS R21 student version to simulate the model.

i. An increase of flow velocity or mass flow rate into the basin causes a rise in the height of water level with an increase in the tangential velocity.
ii. The velocity increase in the vortex is maximum when a full air core is formed.
iii. The air core and vortex height cannot be directly related to each other since the air-core formation depends upon many other factors as well.
iv. Increasing the flow rate by increasing the inlet depth is a better option as compared to the inlet width.
v. Air core can be formed by increasing the outlet diameter keeping all other parameters constant.
vi. When the basin diameter is reduced, the water level in the basin slightly increases. But the reduction of basin diameter causes the air core to decrease till the air-core eventually dies.
vii. As the basin diameter is increased from the optimum value, the vortex height decreases, and thus the strength of the vortex.

viii. When a basin of larger diameter is used, the vortex height drops and almost all the water glides along the floor of the basin. This causes a great frictional loss in the velocity of the water.
ix. Optimum torque lies in the mid of the whole rpm range i.e. between no load condition and maximum load condition. Best efficiency point also lies in the mid of the rpm range.
x. Heavier blades result in lower rpms.
xi. When the load on the turbine is increased, it decreases the height of the vortex.

The efficiency of the turbine varies from 42% to 82% depending upon the blades used. The efficiency is generally high for the curved plates. The blades we used is flat blades with baffle plates, The efficiency for the model which we created is **ŋ= 43.067%**

REFERNCES:

[1]. Pongsakorn Wichian and Ratchaphon Suntivarakorn :The Effects of Turbine Baffle Plates on the Efficiency of Water Free Vortex Turbines, ELSEVIER, Energy Procedia 100 (2016) 198 – 202 CPESE 2016, 8-12 September 2016, Kitakyushu, Japan.

[2].P Sritram and R Suntivarakorn:The effects of blade number and turbine baffle plates on the efficiency of free-vortex water turbines, IOP Conf. Series: Earth and Environmental Science 257 (2019) 012040.

[3]. Haryadi and Adri Maldi Subarjah Sugianto: Experimental study on 3D vortex gravitational turbine runner, AIP Conference Proceedings 2296, 020025 (2020); Published Online: 16 November 2020.

[4]. Sagar Dhakal, Ashesh B. Timilsina, Rabin Dhakal,Dinesh Fuyal, Tri R. Bajracharyaa, Hari P. Pandit, Nagendra Amatya:"Mathematical modeling, design optimisation and experimental verification of conical basin: Gravitational water vortex power plant".

[5].R. Dhakal, T.R Bajracharya, S.R Shakya, B. Kumal:"Computational and Experimental Investigation of Runner for Gravitational Water Vortex Power Plant".

[6]Alejandro Ruiz Sánchez , Jorge Andrés Sierra Del Rio , Angie Judith Guevara Muñoz , José Alejandro Posada Montoya:Numerical and Experimental Evaluation of Concave and Convex Designs for Gravitational Water Vortex Turbine, ISSN: 2289-7879.

[7]Gheorghe-Marius MARIAN, Tudor SAJIN, Iulian FLORESCU,Dragos-Iulian NEDELCU, Constantin-Narcis OSTAHIE,Cătalin BÎRSAN: "The concept and theoretical study of micro hydro power plant with gravitational vortex and turbines with radpidity steps", WORLDENERGY SYSTEM COFERENCE (WESC), Buletinul AGIR nr. 3/2012 ● iunie-august.

[8]V. Naderi, S. Gaskin: A 3D Study of An Intake Air-Core Vortex Structure Using PIV & Flow Visualization, 7th International Symposium on Hydraulic Structures Aachen, Germany, 15-18 May 2018, ISBN: 978-0-692-13277-7 DOI: 10.15142/T3K93V

[9]M. M. Rahman, J. H. Tan, M. T. Fadzlita, A. R. Wan Khairul Muzammil: A Review on the Development of Gravitational Water Vortex Power Plant as Alternative Renewable Energy Resources, IOP Conf. Series: Materials Science and Engineering 217 (2017) 012007 doi:10.1088/1757-899X/217/1/012007

[10] SujateWanchat, RatchaphonSuntivarakorn, SujinWanchat, KitipongTonmit and PongpunKayanyiem: A paramentric study of a Gravitation Vortex Power Plant, Advanced

Materials Research Vols. 805-806 (2013) pp 811-817 (2013) Trans Tech Publications, Switzerland, doi:10.4028/www.scientific.net/AMR.805-806.811

[11] K.Satyanarayana, Vinodh Kumar Padala, T.V.Hanumantha Rao, S.V.Umamaheswararao "Variable Compression Ratio Diesel Engine Performance Analysis", International Journal of Engineering Trends and Technology (IJETT), V28(1),6-12 October 2015. ISSN:2231-5381.

[12] Satyanarayana K, Naik RT, Uma-Maheswara Rao SV (2016) Performance and Emissions Characteristics of Variable Compression Ignition Engine. Adv Automob Eng 5: 146. doi:10.4172/2167-7670.1000146

[13] Aditya Kolakoti and B V Appa Rao, "A comprehensive review of biodiesel application in IDI engines with property improving additives," I-manager's J Mech Eng,5(4), pp.35–45, 2015.

[14] Aditya Kolakoti and B V Appa Rao, "Effect of fatty acid composition on the performance and emission characteristics of an IDI supercharged engine using neat palm biodiesel and coconut biodiesel as an additive",Biofuels, 2017.DOI: 10.1080/17597269.2017.1332293

[15] K. Satyanarayana, P. V. J. Mohan Rao, I. N. Niranjan Kumar " **Some studies on Mathematical Modeling and Dynamic** stress analysis of a Variable Compression Ratio Diesel Engine Crankshaft" JVE INTERNATIONAL LTD. ISSN PRINT 2351-5279, ISSN ONLINE 2424-4627, KAUNAS, LITHUANIA , vol 4.1 March 2018 ,(Pages1- 10), DOI:https://doi.org/10.21595/mme.2018.19616

[16] LankaTata Rao , Katakam Satyanarayana , M.S.S.Srinivasa Rao, T.V. Hanumanta Rao, S.V.UmamaheswaraRao, "stress analysis of 4stroke diesel engine piston " IJCESR ISSN (print): 2393-8374, (online): 2394-0697,volume-2,issue-2,2015

[17]Satyanarayana, K., Viswanath, A.K., Rao, T.H. and Rao, S.U.M., 2017. Investigation of the Stresses Induced in Crank Shaft AISI E4340 Forged Steel. *Procedia Engineering*, *173*, pp.1672-1677.

[18]T. V. Hanumantha Rao • M. S. S. Srinivasa Rao • B. V. Apparao • K. Satyanarayana "A Study on Design and Analysis of Hybrid Vibration Damper with Energy Harvesting and Optimal Damping Effect" J. Inst. Eng. India Ser. C (April–June 2014) 95(2):97–102.

[19] K. Snarayana, P.V.J. Mohan Rao, I.N.Niranjan Kumar, V.V.S. Prasad, T.V. Hanumantha Rao,"Some Studies On Stress Analysis Of A Sundry Variable Compression Ratio Diesel Engine Piston"Materials Today: Proceedings,Volume 5, Issue 9, Part 3,2018,Pages 18251-18259,ISSN 2214-7853,https://doi.org/10.1016/j.matpr.2018.06.162.

[20] K .Satyanarayana, T.V. Hanumantha Rao, I Niranjan Kumar, P.V.J Mohan Rao, V.V.S. Prasad,"Response optimization of four stroke variable compression ratio diesel engine cylinder head with stress analysis"Materials Today: Proceedings, Volume 5, Issue 9, Part 3, 2018,Pages 19497-19506,ISSN 2214-7853,

[21] Ajay Kumar Jha, Deepa Upadhyaya Subedi, Ashesh Babu Timilsina "ASSESSMENT OF GRAVITATIONAL WATER VORTEX HYDROPOWER PLANT IN NEPAL, International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 05 Issue: 07 | July 2018 www.irjet.net p-ISSN: 2395-0072

[22] Suman Acharya , Subodh Kumar Ghimire, Hari Bahadur Dura: Design Study of Runner for Gravitational Water Vortex Power Plant with Conical Basin, Proceedings of IOE Graduate Conference, 2019-Summer Peer Reviewed Year: 2019 Month: May Volume: 6 ISSN: 2350-8914 (Online), 2350-8906

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