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PARAMETRIC STUDY ON EFFICIENCY OF ARCHIMEDES SCREW TURBINE

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ABSTRACT
Production of electrical power through the use of the gravitational force and flowing water or electricity generated by power derived from the potential energy and running water is called hydroelectricity. The subject study is conducted to identify the potential parameters and desirable design for Archimedes Screw Turbine that has high power efficiency. Therefore, computational fluid dynamics (CFD) methods are used. By applying some boundaries condition such as steady state flow condition, isentropic flow and isothermal temperature, the simulation of water flow in the screw turbine can be shown and can be analyzed. This study shows that the higher number of helixes will decrease the efficiency of the screw turbine. Any modification in the design of the screw runner blade can be analyze for further study.

Keywords: Archimedes Screw Turbine ・ Hydroelectricity ・ Computational Fluid Dynamics (CFD) ・ Efficiency

INTRODUCTION

Electric energy is considered to be the most important route of power consumed right now. This electricity can be generated from many types of fuel. Coal is the main fuel for more than half of the electricity generated. This type of fuel have their own disadvantages while using it to produce electricity like the burning of coal will give out large quantities of gases like carbon dioxide, nitrogen oxide and sulfur dioxide that can cause climate change, global heating and any other contamination.

Now, many technologies were introduced to make environmentally friendly electricity and one of them by using an Archimedes Screw turbine at the hydro power plants because it can be fish friendly. As its name, Archimedes Screw was credited to Archimedes and was originally used for irrigation in the Nile delta and for pumping out ships. In modern times, this screw can be applied as flood-detention, wastewater treatment facilities and also use as hydro turbine in electricity production.

The original design of Archimedes screw allows it to be used as hydro pump to generate electricity with high efficiencies. Brada (1996b) experiments in the years 1993-1995 at the University of Prague showed that as much as 80% of the hydraulic energy available in elevated water can be converted to mechanical energy at the beam of the Archimedes screw with a rather small screw, and afterwards proved by Kleemann and Helmann (2003) that even higher efficiencies could be made for larger screws.

In a paper of (Lubitz et al., 2014) showed that with the present of leakage, decreasing in the slope will cause the head difference between the buckets decreases due to the reducing amount of leakage flow rate that is driven by the pressure difference. As a result, the efficiency of the Archimedes screw will increase when the slope is set up low (decrease).

METHODOLOGY

Parameters

Archimedes Screw Turbine parameters consist of two types of parameters. The external and the internal parameters. There are three types of external parameters which is the radius of the screw's outer cylinder turbine, R_o; the total length of the screw turbine, L and the slope or angle of the screw turbine, α (Rorres, 2000). All of the external parameters have been fixed for all designs.

There are also three types of internal parameters that can be study for this type of turbine which is the inner radius of screw's turbine, R_i; the pitch or the period of one blade; and the number of the blade (Rorres, 2000).

This paper will focus on the internal parameters by studying on the effect of the efficiency of the screw turbine by manipulating the number of blades, M; and the helix turns,m.

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Designing stage

Using SolidWorks 2014 version which is one of Computational Aided Design (CAD) software, the basic design of the Archimedes screw blade has been drawn. Table 1 below indicates the parameter and dimension used.

Table 1: Parameters and Dimension.

Parameters	Dimension
Length, L	1140m
Slope or angle, α	35°
Outer radius, R_o	110mm
Inner radius, R_i	100mm
Shaft diameter	108mm

All of above parameter is using 1:5 ratio to the previous researcher dimension and is kept constant while the number of blades and the helix turns,m as the manipulated variable in this study.

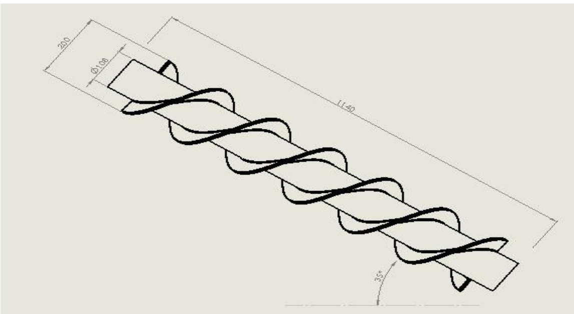

Figure 1 : Screw dimension

Computational setup and boundary conditions

The simulation of fluid motion can be developed in Computational Fluid Dynamics (CFD). Fluid flow or fluid motion can be solved and analyze using numerical methods and algorithms that have been already set up in CFD. With high speed and high specification of digital computers, CFD can provide a better simulation which is more precise and at high quality.

Steady state flow has been used in this simulation as its boundary conditions. The inlet velocity is set at 2.47 m/s and no-slip wall is applied at the blade and the casing of the screw while the outlet pressure is set to 0 Pa. Besides that, there is some parameter are kept constant. Table 2 shows all the constant parameter design obtained from Mutasim, 2014.

Table 2 : Constant Parameter Design

Variables	Specifications
Material	Water
Pressure	0 Pa
Domain motion	Stationary
Heat transfer	Isothermal
Fluid temperature	25°C
Turbulence model	Standard k-ε model
Turbulence intensity	5%
Inlet velocity	2.47 m/s
Density	997 kg/m³
Dynamic viscosity	8.8990e-04 kg/m.s
Screw's ability	Static

After setting up the solution of the simulation up to 100 iterations which is to ensure the simulation is converged up to tolerance of $1e^{-6}$, then, by manipulating the displays (velocity streamlines, contour pressure, vector plots, and etc.) of the final element of CFD which is post processor, the results of the fluid flow simulation which is one of the project's objectives will be shown.

Theoretical Efficiency

To come to a conclusion which of the design has the potential parameter, the theoretical efficiency should be calculated. Efficiency measures the turbine's effectiveness in transforming the energy and power from any sources. Using the formula from (Fiardi et al., 2014);

Water depth increases;

$$\Delta d = \frac{L}{m} \tan \alpha \tag{1}$$

Hydrostatic force;

$$F_{hyd} = \frac{(d_o + \Delta d)^2}{2} \rho g \tag{2}$$

Outflow velocity;

$$v_1 = \frac{d_o}{d_o + \Delta d} v_o \tag{3}$$

Blade power;

$$P_{blade} = F_{hyd} \cdot v_1 \tag{4}$$

Total power;

$$P = m . P_{blade} \tag{5}$$

Hydraulic power;

$$P_{hyd} = \rho . g . d_o . v_o . m . \Delta d \tag{6}$$

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Finally, the theoretical efficiency;

$$\eta_{th} = \frac{P}{P_{hyd}} = \frac{2n+1}{2n+2} \quad (7)$$

Where;

L	Total length of the screw
m	Turns of the helix
d_o	Water entry depth
v_o	Water entry velocity
M	Number of blades
ρ	Water density
g	Gravitational acceleration
n	$d_o/\Delta d$

RESULTS AND DISCUSSION

The result produced which is the water flow simulation (as shown in Figure??) in the form of velocity streamline. All design will have different velocity streamline due to their blade design. And the results of calculated performance of every turbine show which turbine has the best combination of potential parameters.

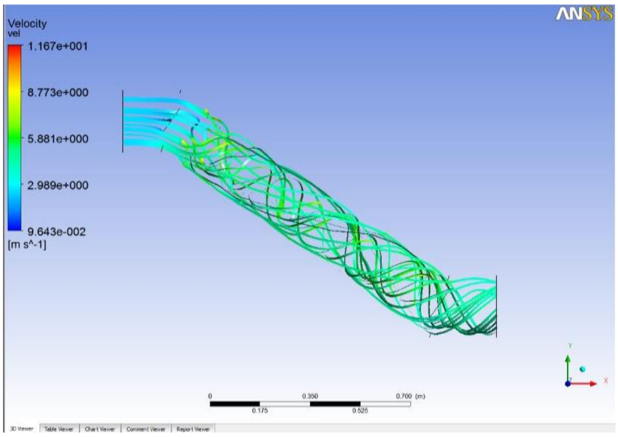

Figure 2 : Simulation of water flow in three helixes with three blades of Archimedes Screw turbine

By applying the theoretical efficiency formula; the potential parameter and desirable design for Archimedes Screw turbine can be determined. Table 3 shows calculated theoretical efficiency of the screw blade.

Table 3 : Theoretical outlet velocity, v_1 and theoretical efficiency.

M	2			3		
m	3	6	9	3	6	9
v_1	1.12	1.54	1.76	1.12	1.54	1.76
η_{th}	0.61	0.44	0.39	0.91	0.66	0.58

For each variation of number of turns and blades, ANSYS simulations produced a different value of the outlet velocity, as a result, different value of numerical efficiencies were calculated based on the result obtained from ANSYS simulations.

Table 4 : Numerical outlet velocity, v_1 and numerical efficiency.

M	2			3		
m	3	6	9	3	6	9
v_1	3.06	3.92	4.08	2.99	3.59	4.03
η_{th}	0.83	0.56	0.45	0.81	0.52	0.44

Below shows the number of turns vs efficiency achieved by the screw.

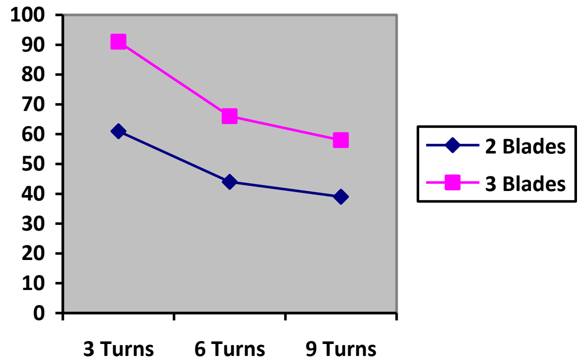

Figure 3 : Theoretical Efficiency (%) with number of turns

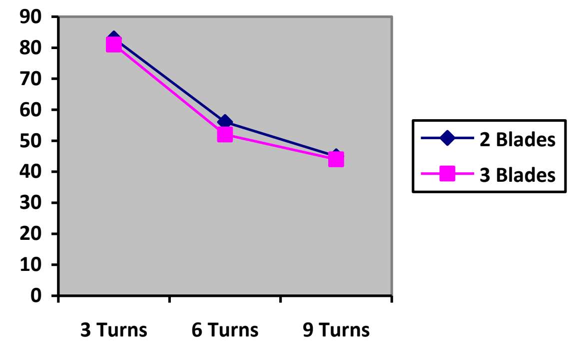

Figure 4 : Numerical efficiency (%) with number of turns

Both graphs show that an Archimedes Screw turbine with lower number of helixes or turns which is three; achieved highest efficiency.

From the simulation, for all of Archimedes Screw turbine blades, the velocity streamlines are lowest and smooth at the inlet because the water flow is not being disturbed by the blade. The velocity begins to increase as water flow approaching the center of the screw turbine. The conservation of momentum in the fluid flow has remained the same as the kinetic energy increases as the water flow going down while the potential energy will decrease. Due to the instability of the flow and the increase number of helixes, the velocity streamlines is

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messy at the center of the blade as seen in the above figures. The velocity streamlines also show that the velocity decreases as the fluid flow approaching the ground of the screw turbine where the maximum angle, which is 35^o placed.

CONCLUSIONS AND RECOMMENDATION

This study is mainly focused to identify potential parameters for an Archimedes Screw turbine that can increase its power efficiency. In order to reduce the cost while conducting the project, Computational Aided Design software, which are SolidWorks 2014 for designing stage and ANSYS 2014 for the simulation and analysis stage were used. The computational method was used to analyze a complex geometry and reduce the costs to conduct an experiment. The analysis and simulation using ANSYS will show the physical characteristics of the water flow in the Archimedes Screw turbine. The formula of theoretical efficiency also was used to determine theoretically which design has the potential parameters and the best performance. From the calculated theoretical efficiency, the efficiency of the screw turbine will increase when the number of blades increases while the efficiency will decrease when the number of helixes increase.

There are few recommendations that can be applied to next screw turbine research. In terms of design, nest researcher can increase the number of blade, but, must decrease the number of turns to check trend of the efficiency. They also can add another outlet in the center of the screw to extract the power produced because from the analysis that has been done, the center of the screw turbine has the highest velocity due to the kinetic energy. In terms of simulation, change the ANSYS setup from static blade to rotating blade to differentiate the efficiency between two types of motion.

REFERENCE

Stergiopoulou, A., Stergiopoulos, V., Kalkani, E. Chronopoulos, C., & Papadopoulou, D. (2013). Back to the future: Rediscovering the Archimedean screws as modern turbines for harnessing Greek small hydropower potential.*Fresenius Environmental Bulletin, PSP Volume 22*, (6a).

Williamson, S. J., Stark, B. H., & Booker, J. D. (2014). Low head pico hydro turbine selection using a multi-criteria analysis. *Renewable Energy*, *61*, 43-50.

Lyons, M., & Lubitz, W. D. (2013, July). Archimedes screws for microhydro power generation. In *ASME 2013 7th International Conference on Energy Sustainability collocated with the ASME 2013 Heat Transfer Summer Conference and the ASME 2013 11th International Conference on Fuel Cell Science, Engineering and Technology* (pp.V001T15A003-V001T15A003). American Society of Mechanical Engineers.

Lashofer, A., Hawle, W., & Pelikan, B. (2012). State of technology and design guidelines for the Archimedes screw turbine. *Hydro 2012*.

Stergiopoulou, A., & Stergiopoulos, V. (2009, June). From the old Archimedean screw pumps to the new Archimedean screw turbines for hydropower production in Greece. In *Proceedings of the 2nd International Conference on Environmental Management, Engineering, Planning & Economics (CEMEPE 2009)*.

Stergiopoulou, A., & Kalkani, E. (2013). Investigating the hydrodynamic behavior of innovative Archimedean Hydropower Turbines. *International Journal of Research and Reviews in Applied Sciences*, *17*(1).

Erinofiardi, E. (2014). Preliminary design of Archimedean screw turbine prototype for remote area power supply. *Journal of Ocean Mechanical and Aerospace Science and Engineering-*, *5*(03), 1-12.

Lubitz, W. D., Lyons, M., & Simmons, S. (2014). Performance Model of Archimedes Screw Hydro Turbines with Variable Fill Level. *Journal of Hydraulic Engineering*, *140*(10).

Nuernbergk, D. M., & Rorres, C. (2012). Analytical Model for Water Inflow of an Archimedes Screw Used in Hydropower Generation. *Journal of Hydraulic Engineering*, *139*(2), 213-220.

Rorres, C. (2000). The turn of the screw: optimal design of an Archimedes screw. *Journal of Hydraulic Engineering*, *126*(1), 72-80.

Mutasim, M. A. N., Azahari, N. S., & Adam, A. A. A. (2014). Prediction of Particle Impact on an Archimedes Screw Runner Blade for Micro Hydro Turbine. *Applied Mechanics and Materials*, *465*, 552-556.

Stergiopoulou, A., Stergiopoulos, V., & Kalkani, E. (2014). Computational Fluid Dynamics Study On A 3d Graphic Solid Model Of Archimedean Screw Turbines. *Fresenius Environmental Bulletin*, *23*(11), 2700-2706.

Santos, D., Chhabra, S., Dixon, D., Cummings, W., Porcari, S., & Marongelli, S. R. (2006). An Analysis of Archimedes Screw Design Parameters and their Influence on Dispensing Quality for Electronics Assembly Applications. *State University of New York at Binghamton*, (1-5).

Rorres, C. (2007). Archimedes Screw-Optimal Design. *Courant Institute of Mathematical Sciences. Consultado el*, 23-07.

Lin, C. L., Vitrant, G., Bouriau, M., Casalegno, R., & Baldeck, P. L. (2011). Optically driven Archimedes micro-screws for micropump application. *Optics express*, *19*(9), 8267-8276.