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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 potentially generate the highest power efficiency. The study focused on varying two design parameters which are the number of helix turns and the blades of the turbine. Thus, to simulate the best turbine design based on these two parameters, computational fluid dynamics (CFD) methods with constant boundaries condition such as steady state flow condition, isentropic flow and isothermal temperature were applied. The simulation of water streamlines in the screw turbine were obtained to determine the turbine efficiency numerically and theoretically. Overall, decreasing the number of helix turns will enhance the turbine efficiency where results showed that the highest turbine efficiency that can be obtained numerically is 81% with 3 helix turns and 3 blades. However, this study is considered as preliminary parametric study where in the future the number of helix turns and blades should be varied in a larger range to elicit the trend in terms of turbine efficiency. Potentially, varying the other design parameters such as length and slope of the screw runner blade should also be considered to obtain the highest turbine efficiency. Also, further investigation is needed as the turbine is assumed to be in steady state condition instead of in rotating motion as it is more practical and realistic.

Keywords: archimedes screw turbine, helix turn, blade, ccomputational fluid dynamics, 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 (Khurana and Kumar, 2011) (Kusakana, Munda, & Jimoh, 2008).

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 (Lisdiyanti, Hizhar, & Yulistiyanto, 2012)(Lubitz, 2014) . 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 (Rorres, 2000).

The original design of Archimedes screw allows it to be used as hydro pump to generate electricity with high efficiencies. (Brada and Radlik, 1996) 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, Lyons, and Simmons, 2014) (Lubitz, 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).

The computational fluid dynamics (CFD) approaches help researcher to investigate the flow pattern characteristics that save the operational cost and time. It is also considered as a powerful design tools in industry equally in research and development convention (Jain, Saini, & Kumar, 2010) (Shukla *et al.*, 2011) .

Currently there is no literature on Archimedes screw blade turbine has been found so far in the aspect of number of blades by using numerical analysis. Hence, the objective of this paper is to simulate the blade design numerically and to investigate the impact of number of blades and number of turns towards the efficiency of turbine.

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

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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.

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 constant parameter and dimension used in designing the Archimedes screw blade turbine while Figure-1 illustrates the screw runner blade.

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.

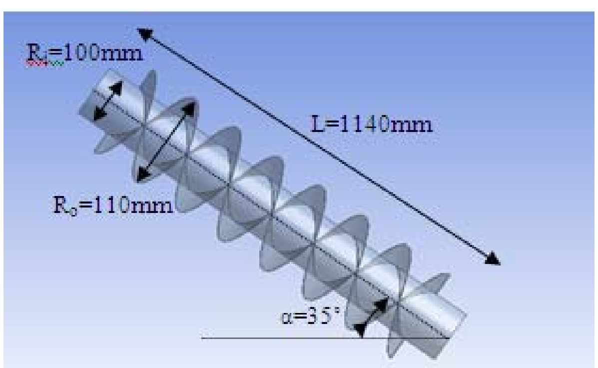

Figure-1. Screw dimension.

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, Azahari, and Adam, 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/m^3
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. For a start, the blade is considered as stationary blade due to the complexity of the software setting perhaps it might require different boundary conditions in the future study.

For repeatability study to find the optimum parameter that effect the efficiency of the turbine, the simulation was repeated using the same boundary conditions as mentioned earlier in Table-1 and 2. However, the number of helix turns,m of the turbine was modified into 3 turns, 6 turns and 9 turns for 2 blades and 3 blades designs.

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, 2014)(Müller and Senior, 2009);

Water depth increases;

$$\Delta d = \frac{L}{m} \tan \alpha \qquad (1)$$

Hydrostatic force;

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$$F_{hyd} = \frac{(d_0 + \Delta d)^2}{2}.\rho.g \quad (2)$$

Outflow velocity;

$$v_1 = \frac{d_0}{d_0 + \Delta d}.v_0 \quad (3)$$

Blade power;

$$P_{blade} = F_{hyd}.v_1 \quad (4)$$

Total power;

$$P = m.P_{blade} \quad (5)$$

Hydraulic power;

$$P_{hyd} = \rho.g.d_0.v_0.m.\Delta d \quad (6)$$

Finally, the theoretical efficiency was determined using the equation;

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

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 DISCUSSIONS

The result produced which is the water flow simulation (as shown in Figure-2) in the form of velocity streamline. All presented designs have different velocity streamline due to blade design changes in the aspects of number of helix turns and blades. Hence, the results of calculated performance for every turbine design will elicit the best combination of potential parameters that will enhance the efficiency of this type of turbine.

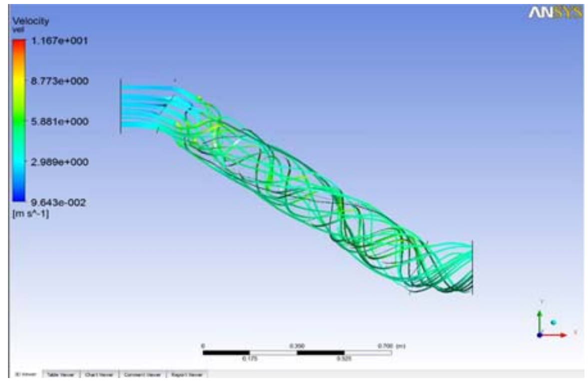

Figure-2. Simulation of water flow in three helixes with three blades of Archimedes Screw turbine.

Based on the simulation (as shown in Figure-2), for all of Archimedes Screw turbine blades, the velocity streamlines are lowest and smooth at the inlet because the water flow is not 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 chaotic at the center of the blade as seen in the above Figure-2. 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° placed.

For each variation of number of turns and blades, ANSYS simulations produced a different value of the outlet velocity, and as a result, different value of numerical efficiencies were calculate based on the result obtained from ANSYS simulations as demonstrated in Table-3.

Table-3. 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

By applying the theoretical efficiency formula, the potential parameter and desirable design for Archimedes Screw turbine can be determined. Table 4 indicates the calculated theoretical efficiency of the screw blade.

ARPN Journal of Engineering and Applied Sciences

Table-4. 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

Figure-3 indicates the theoretical efficiency and number of helix turns where the Archimedes screw blade was remodeled with different number of blades. The nature of turbine efficiency is drops from 2 blades and 3 blades, but in terms of the feature of the efficiency percentage, the screw with 3 blades is considered efficient compared to 2 blades. However, 3 helix turns is preferably compared to 9 helix turns. Overall, these results showed that turbine with low number of helix turns but high number of blades enhances the turbine efficiency.

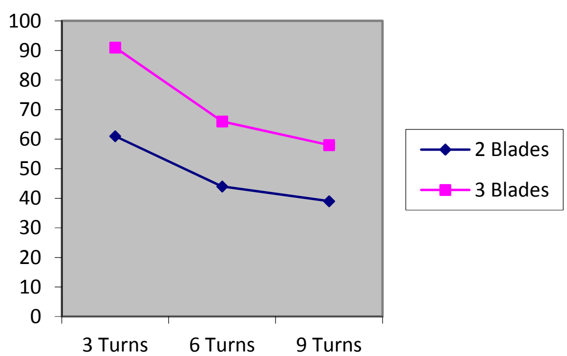

Figure-3. Theoretical efficiency (%) with number of turns.

Figure-4 shows the numerical efficiency with 2 blades and 3 blades with the modification of various number of helix turns. Generally, turbine with less number of helix turns is categorized as a competent turbine. In addition, the maximum turbine efficiency obtained based on the simulation is 81% based on the turbine design with 2 blades and 3 helix turns.

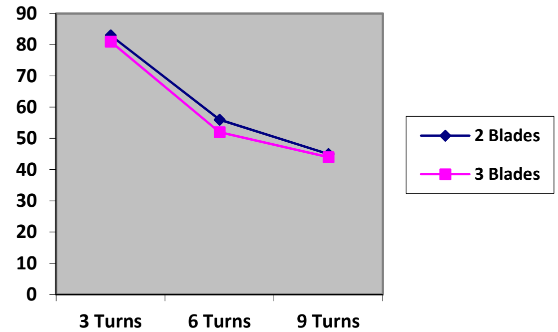

Figure-4. Numerical efficiency (%) with number of turns.

Both graphs show that an Archimedes Screw turbine with lower number of helixes or turns which is three; achieved the highest efficiency. The contradiction results between both methods in aspect of blade numbers maybe due to the boundary conditions applied in numerical methods as the blade is assumed in a steady state condition instead of in rotating form dynamically.

CONCLUSIONS AND RECOMMENDATION

This study is mainly focused to identify potential parameters for an Archimedes Screw turbine that can increase its power efficiency. Computational Aided Design software such as SolidWorks 2014 and ANSYS 2014 were used in this study to simulate the blade design in order to find the best parameter combination in terms of number of helix turns and blades which will enhance the efficiency of the turbine. The design process is essential to analyze the complexity of the turbine's geometry that reduces the costs to fabricate and conduct an experiment. The analysis and simulation using ANSYS will show the physical characteristics of the water streamlines in the Archimedes Screw turbine that gives the overall view when experiment is conducted later on. The formula of theoretical efficiency also was used to determine the best turbine design that produced the highest performance and efficiency.

Based on the calculated theoretical efficiency, the combination of 3 blades with 3 helix enhanced the overall turbine efficiency. However, by numerical simulation it can be concluded that the best combination to obtain the highest efficiency of 81% is by designing the turbine with 2 blades and 3 helix turns. Thus, the study concluded that the critical parameter that affect the turbine efficiency is the number of helix turns instead of number of blades.

For future study, few recommendations need to be considered in designing Archimedes screw blade. A water outlet can be added at the centre of the screw to extract the power generation as the centre of the screw turbine is identified to have the highest velocity due to the conservation of kinetic energy. In terms of simulation, changing the ANSYS setup from static blade to rotating blade will give the real circumstances of blade turbine application in generating electricity.

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