ICAST-1

By Tinneke Saroinsong

Performance Of Three-Bladed Archimedes Screw Turbine Using Response Surface Methodology

Tineke Saroinsong, Adelbert Thomas,
Alfred N Mekel
dept. of Mechanical Engineering
Politeknik Negeri Manado
Manado, Indonesia
tinekesaroinsong@gmail.com,
adl.thomas@yahoo.com,
alfrednoufiemekel75@gmail.com

***Abstract*—**

Experimental study of Archimedes screw turbine had been done in laboratory scale. Performance of Archimedes screw turbine was influenced by goemetric and fluid characteristic that flow in screw turbine. The aim of this research is to compare the performace of Archimedes screw turbine with using response surface methodology. The screw turbine model was made of acrylic. Performance testing of screw turbines is carried out with independent variables of flow rate, depth of turbine inlet flow and turbine shaft slope. While the dependent variable is the power and efficiency of the turbine.

The results of this study are the screw turbines obtained maximum power and efficiency of 10.28 watts and 82.72% respectively with a shaft slope of 51.82 degrees, depth of turbine inlet flow of 0.064 m, and speed of inlet flow of 0.6 m/s.

Keywords—screw turbine, response surface methodology, performance, power, efficiency.

I. INTRODUCTION

The study of Archimedes screw turbine is being developed including the numerical optimization of screw thread geometry (Rorres 2000) that the optimum range ratio depends on the number of blades and the radius ratio (R_1/R_0) equal to 0.54. Then (Müeller Gerald 2009) simplified Archimedes's screw theory based on geometric parameters and the ideal energy conversion process for one helical turn. The results of this research stated that the efficiency of screw turbines was influenced by geometry and flow losses. Furthermore (Nuembergk Dirk M., Rorres 2013) introduced the analytical model of screw turbine inflow by calculating the possibility of leakage flow in the gap between the thread and the outer cylinder (casing) and also the excess water in the center of the pipe. MATLAB simulation of screw turbines for hydropower plants at low head has been carried out (Ali Raza et al 2013). Models and theories from (Müeller Gerald 2009), (Nuembergk Dirk M., Rorres 2013), and (Ali Raza et al. 2013) they compare this with experiments from Brada (1996a) and Brada (1996b). Subsequent research was conducted by Havendry Adly and Hendro Lius (2010) regarding the determination of the optimum screw angle in screw turbines with 23^0, 26^0 and 29^0 screw angle variations. In his report explained that the 29^0 screw angle produces better power and efficiency compared to 23^0 and 26^0 screw angles. Then Hizhar Yul (2011) examined the effect of the difference in pitch and the slope of the axis on the performance of the two-blade screw turbine model at low head flow. The result of the research was that the 2Ro range results in a rotating speed higher than 1.6Ro and 1.2Ro. And the greatest power wasvproduced at a slope angle of 35^0 from the slope of the other turbine shaft 25^0, 30^0, 40^0.

The study of fluid flow on the performance of the screw turbine Archimedes by Saroinsong Tineke et al (2015) and (2016), reported in his study that the froude number increasingly reduced the efficiency of the turbine because of the vortex between the blades which reduced the momentum of the blade and absorbed the kinetic energy of water. Experimental results The performance of maximum turbines occurs at a slope of 25^0 from 35^0 and 45^0. From several studies on the variable slope of the turbine shaft which still produces the maximum difference in yield, it is necessary to analyze the screw turbine performance using response surface methodology. Montgomery, D.C (2003) states that Response Surface Methodology is a set of mathematical and statistical methods used to see between one or more form treatment variables with a response in an experiment. According to Berger and Maurer (2002) research is an investigation in which the investigator selects levels from one or more inputs or independent variables and observes the response values or dependent variables.

II. RESEARCH METHODS

A. The experimental equipment diagram

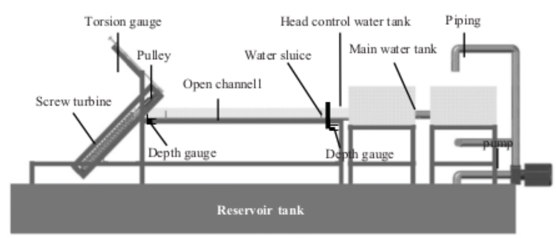
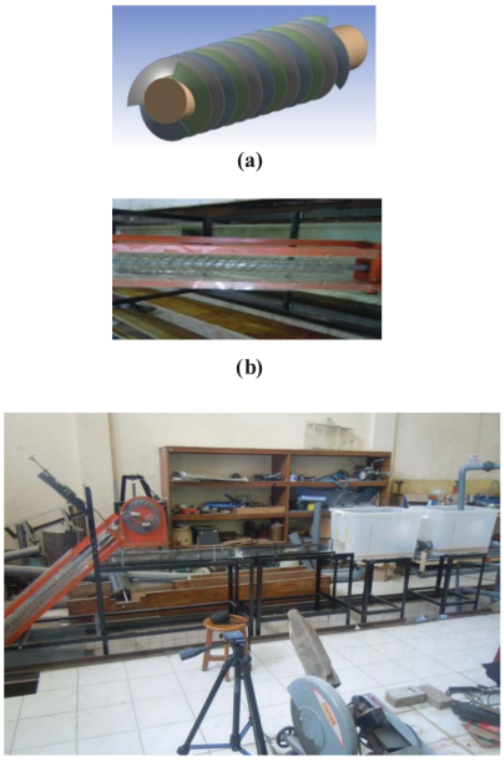


Fig. 1. The screw turbine Installation [13]

Screw turbine model parameters :

Parameter	Value	Description
R_o	0.055 m	Outer radius
R_i	0.030 m	Inner radius
S	0.132 m	Pitch
N	3	Number of blades
m	21	number of helix turns
β	30°	thread angle
λv	0.059	Normalized volume/turn
α	25°, 35°, 45°	turbine shaft slope

h_o	$1/2R_o$, $2/3R_o$, $1R_o$	Inflow head
c_o	(0.3, 0.4, 0.5) m/s	inflow velocity



(a)

(b)

(c)

Fig. 2. Three bladed Archimedes screw,
a) the model, b) experimental photo, (c) experimental setup

Performance tests for screw turbines are as follows: Water is flowed using a pump and accommodated in container 1 connected to container 2 for steady flow conditions. Flow velocity can be adjusted through the water level in reservoir 2 which is connected to the channel. Water is flowed on the Archimedes screw turbine. Screw blades receive hydrostatic pressure of the water so that the screw turbine rotates. Turbine rotation is measured using a tachometer. Torque is measured through round braking using pulleys and belts that are connected to the spring balance. Inlet water depth, flow velocity and shaft slope are the independent variable. While the power and efficiency of the turbine becomes the response variable.

The equation used in data analysis is :

Hydraulic power of screw turbine,

$$P_{hyd} = \rho \,.\, g.\, Q.\, H \qquad (1)$$

Where ρ is the density of water, g the acceleration of gravity, Q the flow rate, m the number of threads and Δy the head difference between blades. The power of the screw turbine P is T torque proportional to the angular velocity ω, whose equation is:

$$P = T.\, \omega \qquad (2)$$

The efficiency of screw turbines is calculated by the equation:

$$\eta = \frac{P_{output}}{P_{input}}.100\,\% \qquad (3)$$

B. Experimental Design

In order to obtain the first-order and second-order empirical models, a 2k factorial experiment design was added with observations several times at the center point and points on the axial axis with α = 2k/4 in the form of Central Composite Design (CCD). The 2k CCD factorial design was used for experiments consisting of k factorial with each factor having a low level (coded -1), high level (code +1), middle level (code 0), and level on the axial axis (given the code -α and + α). For k = 3, the value of α = 1.682. Table 1. shows the level of the independent variable.

Table 1 Level of independent variable

Variabel Name	Shaft Slope (^{0})	Head of inlet flow (m)	Flow velocity (m/s)
LowLevel (-1)	25	0,033	0,3
MiddleLevel (0)	35	0,042	0,4
HighLevel (+1)	45	0,055	0,5

The response variable is the dependent variable, which is a variable that is influenced by a factor level or a combination of factors. The response variable in this study is the power and efficiency of Archimedes three-blade screw turbine.

III. RESULT AND DISCUSSION

Based on screw turbine testing, the design of the research experiment can be determined as shown in table 2.

Table 2 Design of research experiment

No.	X_1 Shaft Slope (°)	X_2 Head of Inlet Flow (m)	X_3 Flow rate (m/s)	Power (Watt)	Efficiency (%)
1	-1 (25)	-1 (0,033)	-1 (0,3)	0,40	32
2	1 (45)	-1 (0,033)	-1 (0,3)	1,42	27
3	-1 (25)	1 (0,055)	-1 (0,3)	1,75	60
4	1 (45)	1 (0,055)	-1 (0,3)	3,85	43
5	-1 (25)	-1 (0,033)	1 (0,5)	0,72	24
6	1 (45)	-1 (0,033)	1 (0,5)	1,18	33
7	-1 (25)	1 (0,055)	1 (0,5)	2,16	51
8	1 (45)	1 (0,055)	1 (0,5)	5,01	72
9	-1.682 (18,18)	0 (0,042)	0 (0,4)	0,87	63
10	1.682 (51,82)	0 (0,042)	0 (0,4)	4,45	82
11	0 (35)	-1.682 (0,027)	0 (0,4)	0,71	62
12	0 (35)	1.682 (0,064)	0 (0,4)	3,24	68
13	0 (35)	0 (0,042)	-1.682 (0,2)	0,43	38
14	0 (35)	0 (0,042)	1.682 (0,6)	3,70	69
15	0 (35)	0 (0,042)	0 (0,4)	0,93	64
16	0 (35)	0 (0,042)	0 (0,4)	0,90	62, 08
17	0 (35)	0 (0,042)	0 (0,4)	0,95	65,28
18	0 (35)	0 (0,042)	0 (0,4)	0,94	64,7
19	0 (35)	0 (0,042)	0 (0,4)	0,92	63,04
20	0 (35)	0 (0,042)	0 (0,4)	0,91	62,7

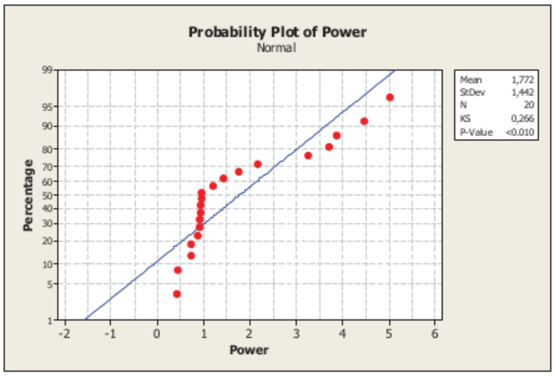


Figure 3. Residual Normality Test of Hypotesis

Figure 3 produces the mean information and the standard deviation of 1.722 and 1.442, respectively

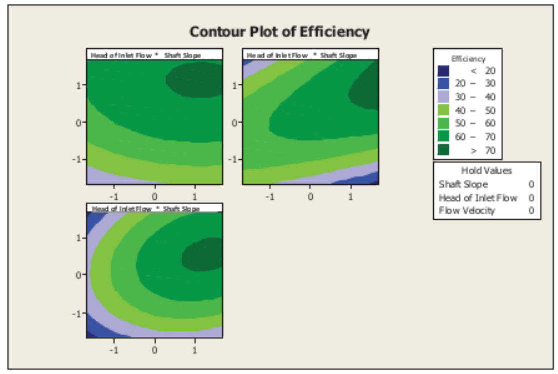


Figure 4 Contour Plot of the screw turbine power value

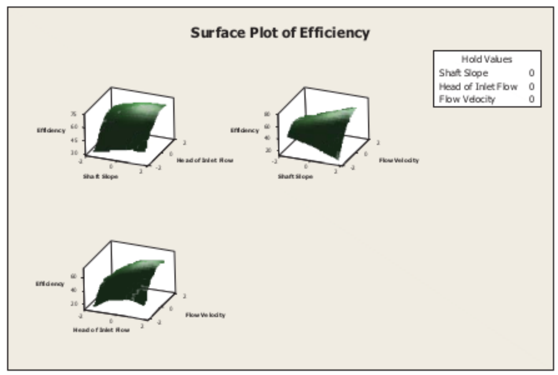


Figure 5 Surface plot of the screw turbine power value

Empirical Model

The empirical model of the average power values and efficiency of Archimedes screw turbines based on the surface response analysis method can be formulated as follows:
The empirical model of Power value predictions based on RSM is:

The empirical model of Power value predictions based on RSM is:

$$Y = 0.933 + 0.911(X_1) + 0.974(X_2) + 0.523(X_3) + 0.560(X_1)^2 + 0.318(X_2)^2 + 0.349(X_3)^2 + 0.433(X_1)(X_2) + 0.023(X_1)(X_3) + 0.186(X_2)(X_3)$$

Where Y is Power of screw turbine, X_1 the turbine shaft slope, X_2 the head of inlet flow and X_3 the inlet flow rate.

The empirical model of Efficiency value prediction based on RSM is :

$$Y = 64.308 + 2.925(X_1) + 8.793(X_2) + 5.135(X_3) - 1.279(X_1)^2 - 3.931(X_2)^2 - 7.997(X_3)^2 + 0.000(X_1)(X_2) + 6.500(X_1)(X_3) + 2.750(X_2)(X_3)$$

Where Y is Efficiency of screw turbine, while X_1, X_2, and X_3 is independent variable on empirical model of Power. Based on the mathematical model obtained, the three independent variables have an effect on the average value of the Power and the efficiency of the screw turbine..

Countour Plots and Surface Plot

Based on the results of RSM analysis, the contour plot and surface power of Archimedes screw turbine obtained as shown in Figures 4 and 5, while the contour plot and surface plot of Archimedes screw turbine efficiency are shown in Figures 6 and 7.

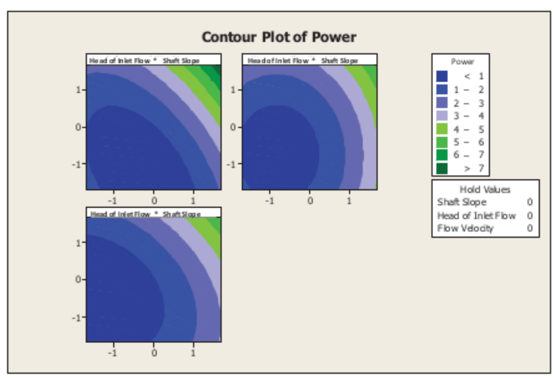


Figure 6 Contour Plot of screw turbine efficiency value

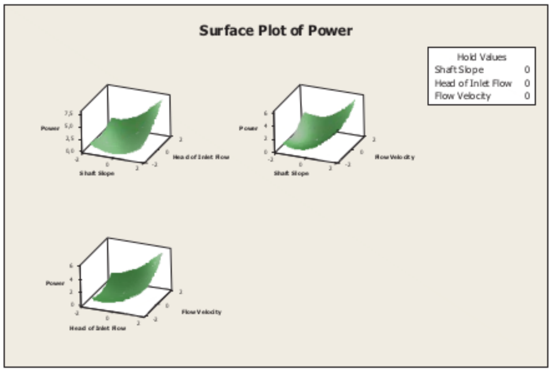


Figure 7 Surface plot of screw turbine efficiency value

Analysis with Desirability Function Approach

From the known model, the value of the power and efficiency of the Archimedes screw turbine can be determined. The optimization method used is the desirability function approach with MINITAB version 16. The desirability function criteria used are "smaller the better". This criterion is conducted to determine the power value and efficiency of Archimedes screw turbines with variable turbine shaft slope testing, turbine inlet head and turbine inlet velocity. Analysis of the desirability function approach first includes the response limit value. The target to be achieved is the power and efficiency of the Archimedes screw turbine. Tables 3 and 4 show the results of the power or efficiency of the largest or maximum screw turbine obtained at 10,2822 watt and 82,7153 %.

Table 3 Desirability function approach analysis for Archimedes screw turbine power

Response Optimization					
Parameters					
Goal	Lower	Target	Upper	Weight	Import
Max. Power	0.4	5.01	5.01	1	1
Global Solution					
Shaft slope	= 1.682				
Inlet Flow Head	= 1.682				
Flow rate	= 1.682				
Predicted Responses					
Power = 10.2822 , desirability = 1.000000					
Composite Desirability = 1.000000					

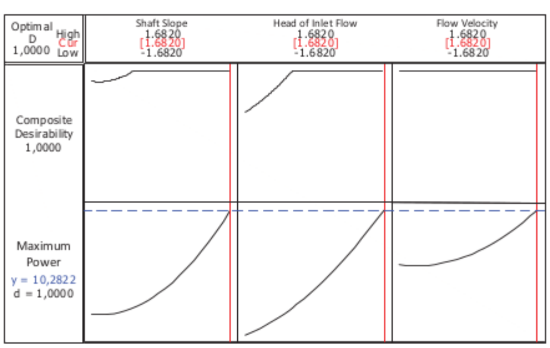
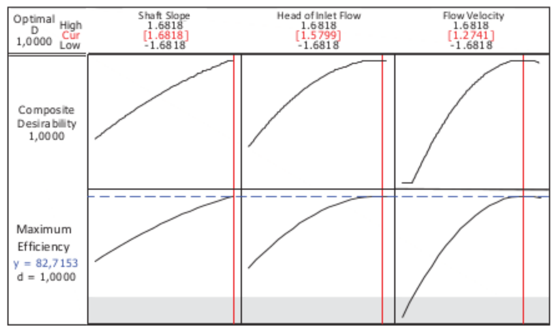


Table 4 Desirability function approach analysis for Archimedes screw turbine efficiency

Response Optimization					
Parameters					
Goal	Lower	Target	Upper	Weight	Import
Max. Efficiency	24	82	82	1	1
Global Solution					
Shaft Slope	= 1.68179				
Inlet Flow Head	= 1.57987				
Flow rate	= 1.27409				
Predicted Responses					
Efficiency = 82.7153, desirability = 1.000000					
Composite Desirability = 1.000000					



The results of the analysis of the desirability function approach of the power value and the biggest or maximum screw turbine efficiency is obtained at 10,2822 watts and 82,7153%. The maximum axle tilt is 51, 82 °; the maximum inlet flow head is 0.064 m and the maximum speed of the turbine inlet is 0.6 m / s. When compared with the results of laboratory-scale screw turbine performance tests reported by Saroinsong Tineke, et al (2016), the lower the slope of the turbine shaft, the higher the efficiency. If the slope of the shaft is enlarged, there will be a vortex between the screw turbine blades which reduces turbine efficiency. However the turbine power will increase if the shaft slope is enlarged. The best efficiency of Archimedes steam turbine occurs at 25° shaft slope, 0.055 m inlet head and 0.5 m/s flow velocity produces 1.35 Watt power and 89% efficiency. While the highest turbine power of 5.01 watts occurs on a 45° axle slope with an efficiency of 72%.

Thus, in order to obtain the optimum performance of Archimedes screw turbine, a combination of independent variables and response variables is needed through RSM (response surface methodology) analysis.

IV. Conclusion

According to the optimization approach with response surface methodology it can be concluded as follows:

1. The empirical model of the predicted value of Power is:
   $Y = 0.933 + 0.911(X_1) + 0.974(X_2) + 0.523(X_3) + 0.560(X_1)^2 + 0.318(X_2)^2 + 0.349(X_3)^2 + 0.433(X_1)(X_2) + 0.023(X_1)(X_3) + 0.186(X_2)(X_3)$
   The empirical model of the predicted value of efficiency is :

$$Y = 64.308 + 2.925(X_1) + 8.793(X_2) + 5.135(X_3) - 1.279(X_1)^2 - 3.931(X_2)^2 - 7.997(X_3)^2 + 0.000(X_1)(X_2) + 6.500(X_1)(X_3) + 2.750(X_2)(X_3)$$

2. Based on the results of the analysis of the desirability function approach the power value and efficiency of the largest or maximum screw turbine is obtained at 10.2822 watts and 82.7153%. The maximum axle tilt is 51.82^0; the maximum inlet flow head is 0.064 m and the maximum flow rate is 0.6 m / s respectively.

3. RSM (response surface methodology) is an effective experimental plan used in optimizing Archimedes screw turbine performance so that the combination of independent variables and response variables can be determined precisely.

ACKNOWLEDGMENT

The authors thank to Ristekdikti Ministry and Manado State Polytechnic which was supported by the research grant.

REFERENCES

[1]. Waters Shaun., Aggidis George A. (2015) Over 2000 Years In Review : Revival of the Archimedes Screw From Pump To Turbine. Renewable and Sustanable Energy Review. 51 (2015) 497-505. Elsevier

[2]. David Kilama Okot, 2013. Review of Small Hydropower Technology.Journal of Renewable and Sustainable Energy Reviews, vol 26 (2013) 515-520. Elsevier.

[3]. Elbatran A.H, et al. (2015). Operation, Performance and Economic Analysis of Low Head Micro-Hydropower Turbines for Rural and Remote Areas : A Review. Journal Renewable and Sustainable Energy Reviews. 43 (2015) 40-50. Elsevier

[4]. Müeller. G (2009). Simplyfied theory of Archimedean screw, Journal of Hydraulic. Vol 47, pp. 666-669. University of Southamton, UK.

[5]. Rorres, C (2000). The turnoff the screw: Optimal design of the Archimedean screw. Journal of Hydraulic. 126(1), 72-80

[6]. Nuembergk Dirk. M and Chris Rorres (2013). Analytical Model for Water Inflow of an Archimedes Screw Used in Hydropower Generation. Journal of Hydraulic Engineering, vol. 139, no. 2.

[7]. Raza Ali, at al (2013). Modeling of Archimedes Turbine for Low Head Hydro Power Plant in Simulink MATLAB. International Journal of Engineering Research & Technology (IJERT). Vol. 2 Issue 7.

[8]. Brada, K (1996a). Schneckentrogpump als Mikroturbine, in Wasserkraftanlagen-Klien-und Klienstraftwerke, 1st Ed., expert-Verlag, Malsheim

[9]. Brada, K (1996b). Wasserkraftschnecke-Eigenschaften und Verwendung. Proc.,Sixth Int. Symp. On Heat Exchange and Renewable Energi, Szczecin, 43-52.

[10]. Munson R. Bruce, et all. Fundamentals of Fluid Mechanics. 4th. Ed, Wiley, 2004.

[11]. Nagel, G., Radlik, K.-A. (1988). Wasserförderschnecken [Water lifting screws] Bauverlag,Wiesbaden/Berlin [in German].

[12]. Saroinsong Tineke, at al.(2015) The Effect of Head Inflow and Turbine Axis Angle Towards The Three Row Bladed Screw Turbine Efficiency. International Journal of Applied Engineering Research. Vol.10, no 7, pp 16977-16984.

[13]. Saroinsong Tineke, at al (2016). Fluid Flow Phenomenon in a Three-Bladed Power Generating Archimedes Screw Turbine. Journal of Engineering Science and Technology Review. Vol.9, no 2, pp. 72-79. Kavala Institute of Technology, Greece (Yunani)..

[14]. Saroinsong Tineke, at al (2016). Performance of Three-Bladed Archimedes Screw Turbine. ARPN journal of Engineering and Applied Sciences. Vol.11, No 15, pp 9491-9495. ARPN Journals, Pakistan.

[15]. Mongomery, D.C (2013). Design and Analysis of Experimens, John Willey & Sons. Singapure

[16]. Berger, P.D., and Meurer, R.E. (2002). Experimental Design with Application in Management, Engineering, and the Sciences, Duxburry, Thomson Learning, USA.

ICAST-1

ORIGINALITY REPORT

0%

SIMILARITY INDEX

PRIMARY SOURCES

EXCLUDE QUOTES	OFF	EXCLUDE SOURCES	OFF
EXCLUDE BIBLIOGRAPHY	OFF	EXCLUDE MATCHES	OFF