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Analysis of Pipe Diameter Variation and Lamp Load on Centrifugal Pump Performance as a Generator Driving Turbine

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ABSTRACT

As the population grows, the demand for energy increases, especially from non-renewable resources. Many countries are turning to renewable energy sources such as water to meet this demand. Water from a certain height can drive a turbine generator by converting potential energy into mechanical energy in the form of shaft rotation, which is transmitted to the generator and then converted into electrical energy. This study aims to analyse variations in pipe diameter and lamp load on the performance of a centrifugal pump as a turbine driving a generator. The research method was an experiment in which the pipe diameter was varied as 1/2, ¾, 1, and 1.5 inches, and the lamp load was varied as 5, 10, 15, and 20 W. Pump performance includes specific speed, rotor power, and shaft power. The results of this study show that the performance of the centrifugal pump as a driving turbine, the highest is at a pipe diameter of 1.5 inches, which produces a specific speed of 207.59 rpm at a power load of 5 W, rotor power of 2002 watts at a load of 20 W, and shaft power of 9509.50 watts at a load of 20 W. By regression analysis, the highest specific speed was obtained by the formula y=223.16-2.9063x with a correlation coefficient of r=0.989. The rotor power formula was y=57.093+98.045x with a correlation coefficient of r=0.999, while the resulting shaft power formula was y=271.19+465.72x with a correlation coefficient of r=0.999. Thus, a strong positive relationship exists between diameter and lamp load on specific speed, rotor power, and shaft power to generate electrical energy sources in turbine axle pumps.

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1. Introduction

As the population increases, energy requirements increase. Energy is currently produced chiefly from non-renewable natural resources, such as coal. If there is sufficient coal, power plants will produce enough energy. Clean energy is increasingly becoming a priority worldwide through the development of renewable energy technologies [1]. Substitutes for non-renewable energy must be found. Several countries are now switching to renewable energy; for example, water is used to drive turbine generators. Turbines connected to generators use potential energy from water to produce electrical power. Several turbine modifications have been used and developed to provide the ability to rotate generators. For minor hydropower generation, one of the better options is to use a pump in reverse mode as a hydraulic turbine[1]. Utilising hydrodynamic pumps in reverse mode offers a cost-effective substitute for traditional water turbines in small-scale hydropower applications [2]. One tool for converting energy is the pump as a turbine [3]. The broad usage of turbines and pumps is very beneficial for both energy use and conservation [4]. One well-known application of Pumps as Turbines (PATs) in small-scale/micro hydropower facilities is the replacement of traditional turbines [5]. The PAT system is economically viable and cost-effective, and it utilises water as the primary supply, making it a valuable hydraulic technology through multiple tests. The rotation speed of the turbine and pump determines the best efficiency point (BEP) characteristics (head, discharge, and power) of the turbine model connected to the pump model [6]. In general, the centrifugal pump impeller exhibits a greater degree of reactivity than the hydraulic turbine impeller. This suggests that longer pump blade channels translate into more pressure energy being transferred while converting less kinetic energy [7]. Specific speed characteristics depend on the input value. Sensitivity analysis shows a weak correlation between input parameters and pump performance. Two different mathematical approaches gave consistent results [8]. Regression modelling is a popular statistical technique in research, especially for observational studies [9]. Correlation and linear regression methods determine the relationship between two or more variables. When two variables have a linear relationship, correlation can measure the strength of the relationship, while regression represents the relationship as an equation [10]. The strength and direction of the linear relationship between pairs of continuous variables are evaluated using the correlation coefficient. High-impact research based on regression can benefit from optimisation models. Powerful real-time and predictive analysis of large data requires less computational processing [11]. Therefore, this study will analyse the relationship between variations in pipe diameter and lamp load on the performance of a centrifugal pump as a generator turbine drive using the regression method.

2. Method

This research was conducted at the Energy Conversion Laboratory, Sekolah Tinggi Teknologi "Warga" Surakarta. The research flowchart on using centrifugal pumps as turbines to drive generators is presented in Fig. 1.

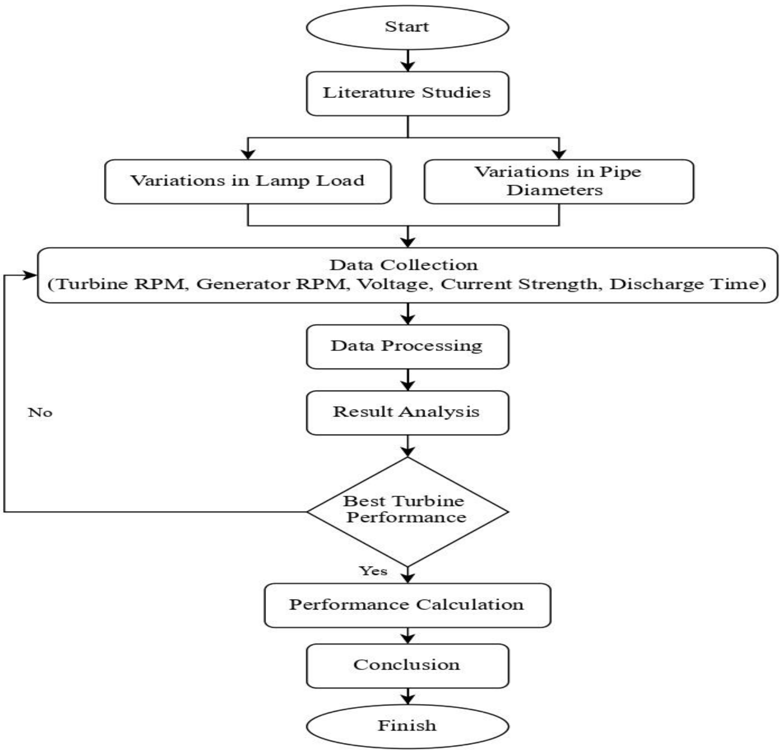

Fig. 1. Flowchart of research

The test device is shown in Fig. 2, which depicts the centrifugal pump as a turbine, along with a water tank, test pipe, centrifugal pump, generator, and wastewater storage tank.The experimental procedure began with the installation of all necessary components, including a ½ inch pipe, a centrifugal pump configured to operate as a turbine, a generator mechanically coupled to the pump, and a loading board equipped with voltage and current measurement instruments. Each test pipe was precisely measured to a length of 1.55 meters to ensure consistency across different diameters. The upper tank was then filled with water, after which a valve was opened to initiate flow through the pipe and rotate the turbine.

Fig. 2. Experimental setup

Once the turbine achieved steady rotation, light loads were applied incrementally at 5W, 10W, 15W, and 20W, during which the rotational speeds of both the turbine and the generator were recorded using a tachometer. Simultaneously, voltage and current readings were observed on the voltmeter and ammeter of the loading board. This entire procedure, from component installation to data collection, was repeated using pipes of increasing diameters—¾ inch, 1 inch, and 1.5 inches. Following data collection, the performance of the centrifugal pump operating as a turbine was analysed in terms of rotational speed, electrical output, and efficiency. Finally, correlation and regression analysis were employed to investigate and quantify the relationship between pipe diameter, applied light load, and the overall performance of the centrifugal pump as a turbine.

2.1 Turbine Performance

The specific speed was calculated by equation (1).

$$Ns = \frac{n\sqrt{Q}}{H^{\frac{3}{4}}} \tag{1}$$

where Ns is specific speed, n is turbine rotation (rpm), Q is flow rate of design point (100 L/m), and H is head of design point (20.5 m). The rotor power was calculated by equation (2).

$$Rotor\ Power = (V \times I) \times \left(\frac{Turbine}{Generator} \times 100\%\right) \tag{2}$$

where V is Voltage (V) and I is Current (A). The shaft power was calculated by equation (3).

$$Shaft\ Power = \frac{\eta transmission \times Protor}{1 \times \alpha} \tag{3}$$

where $\eta_{transmission}$ is 0.95 and α is 0.2.

2.2 Regression Analysis

A regression method was used to determine the relationship between variations in pipe diameter and a light load on the performance of centrifugal pumps as generator-driving turbines. Linear regression is included in the time series model, which uses quantitative methods using time as the basis for forecasting[9]–[11]. Linear regression has the following basic equations (4), (5), and (6).

$$Y = a + bx \tag{4}$$

where Y is the forecast value for the t^{th} period, a is the intercept,b is the slope of the trend line (the rate of change), x is the time index (t=1, 2, 3, ..., n); n is the number of periods.

There are three components in linear regression, namely a as intercept, b as slope and x as a time index. To get the values a and b equations (5) and (6) were used.

$$a = \frac{(\sum X^2)(\sum Y) - (\sum XY)(\sum X)}{n(\sum X^2) - (\sum X)^2} \tag{5}$$

$$b = \frac{n(\sum XY) - (\sum X)(\sum Y)}{n(\sum X^2) - (\sum X)^2} \tag{6}$$

3. Results and Discussion

The experimental data on variations in pipe diameters (½, ¾, 1, and 1.5 inches) and lamp loads (5, 10, 15, and 20 Watts) on the performance of centrifugal pumps as turbine driving generators are presented in Table 1. The performance of centrifugal pumps as turbine generators is reviewed based on specific speed, rotor power, and shaft power produced. Each variation was carried out three times during the test replication to minimise errors, and the average data were taken for each variation.

Table 1. Experimental Result Data

Pipe Diameter (inch)	Power Load (watt)	Rpm Generator	Rpm Turbin	Voltage (V)	Current (A)	Filling Time (second)	Discharge Time (second)	Specific Speed Ns (rpm)	Rotor Power (Watt)	Shaft Power (Watt)
1/2	5	147	114	8.0	0.63	187	213	118.33	390.86	1856.57
	10	124	98	7.7	1.30			101.72	791.11	3757.79
	15	120	91	7.2	2.08			94.46	1135.68	5394.48
	20	105	84	6.8	2.94			87.19	1599.36	7596.96
3/4	5	151	115	9.0	0.56	187	193	119.37	383.84	1823.25
	10	145	114	8.6	1.16			118.33	784.32	3725.52
	15	139	108	8.2	1.83			112.10	1165.93	5538.19
	20	137	106	7.7	2.60			110.02	1548.99	7357.72
1	5	190	175	11.0	0.45	187	155	181.64	455.92	2165.63
	10	170	160	10.4	0.96			166.08	939.67	4463.44
	15	160	150	9.7	1.55			155.70	1409.53	6695.27
	20	160	150	8.9	2.25			155.70	1877.34	8917.38
1.5	5	190	200	11.2	0.45	187	142	207.59	530.53	2520.00
	10	180	190	10.2	0.98			197.21	1055.13	5011.88
	15	165	170	9.6	1,56			176.45	1542.98	7329.16
	20	160	160	9.1	2,20			166.08	2002.00	9509.50

The larger the pipe diameter, the greater the specific speed produced, and vice versa. If the diameter is small, the specific speed will also be small. A higher specific speed indicates that the turbine or pump performs better at higher discharge and lower head. A comparison between pipe diameters and lamp load to specific speeds is seen in Fig. 3.

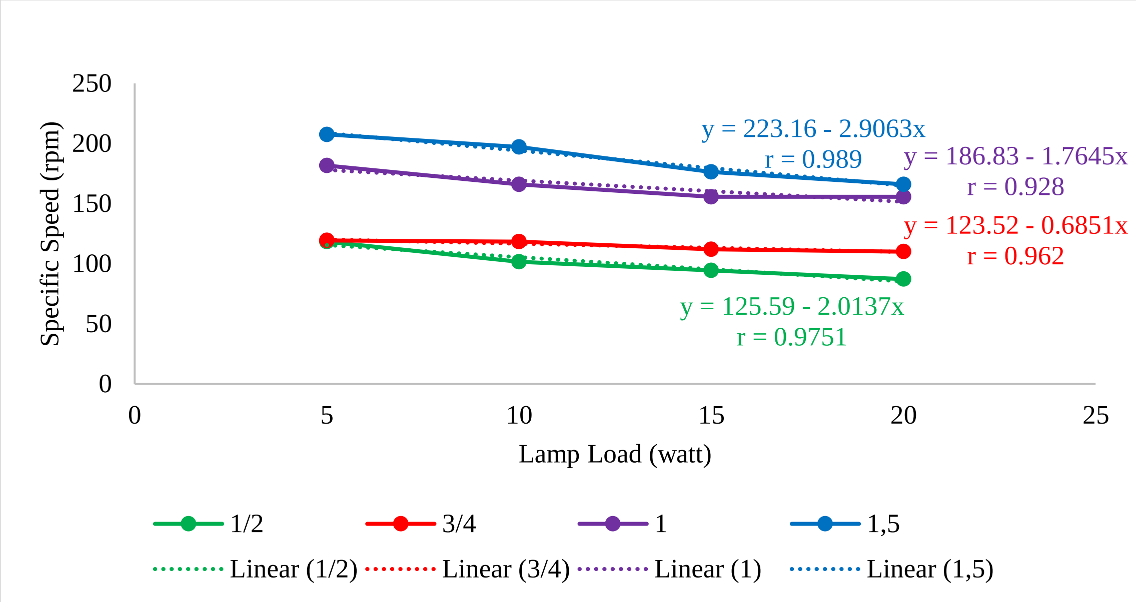

Fig. 3. Comparison between Pipe Diameters and Lamp Load to Specific Speed

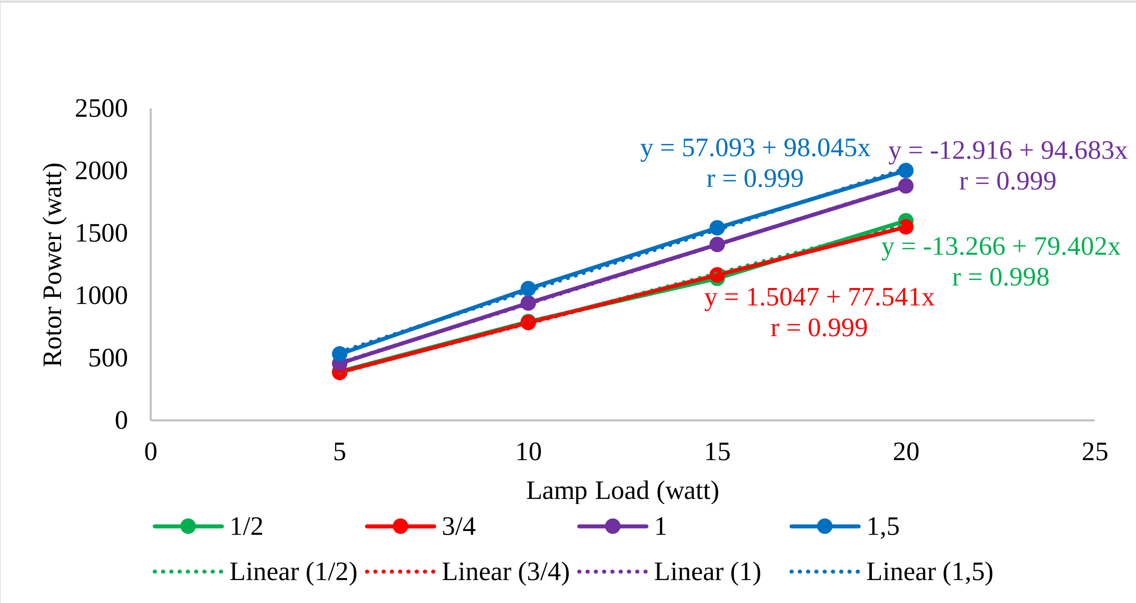

Fig. 4. Comparison between Pipe Diameters and Lamp Load to Rotor Power

Fig. 3 shows that the test's highest specific speed value is 207.59 rpm at a diameter of 1.5 inches with a lamp load of 5W. Furthermore, at the same pipe diameter, if the lamp load increases, the specific speed generated by the turbine will decrease. This study's results align with previous research [7], which explains that specific speed is one of the categories of pump performance prediction as a turbine. A similar research was also conducted, which explained that the positive and reverse characteristics of centrifugal pumps are present at different flow rates [12]. According to a previous work [13], who states that the flow rate increases, the hydrodynamic force on the impeller, and the pressure fluctuation amplitude in the volute decreases and then increases. Another research [14] also explains that speed control using an inverter is carried out because it is high. The regression equation and its correlation value can be analysed in Fig. 3. The regression equation obtained is linear y = 223.16 - 2.9063x with a correlation value of r = 0.989. The correlation coefficient shows a strong positive relationship between pipe diameter and lamp load on the specific speed generated. This study's results align with previous research [11], [17], which examined new methods for linear regression analysis and computationally efficacious polynomials for big data in the field of medicine. Results stated that regression-based models greatly impacted and benefited greatly from optimization models.

Based on Fig.4, the highest rotor power value of the test is 2002 watts at a pipe diameter of 1.5 inches with a light load of 20W. It shows that the larger the pipe diameter, the higher the rotor power generated due to increased power requirements. The large diameter causes lower back pressure. Thus, it can reduce the load on the pump as a turbine to flow more significant water discharge quickly. These results align with previous a finding which explains that rotor power affects the performance and efficiency of the pump as a turbine [16]. Another similar research states that centrifugal pumps can be operated in turbine mode without mechanical damage [17]. In Fig. 4, the regression equation obtained is linear, y = 57.093 + 98.045x with a value of r = 0.999. The correlation coefficient shows a strong positive relationship between pipe diameter and lamp load to the rotor power generated. The results of this study are supported by another finding on a comprehensive linear regression review on machine learning [9]. This study results in that the simple linear regression model works well with data that shows the relationship between two variables.

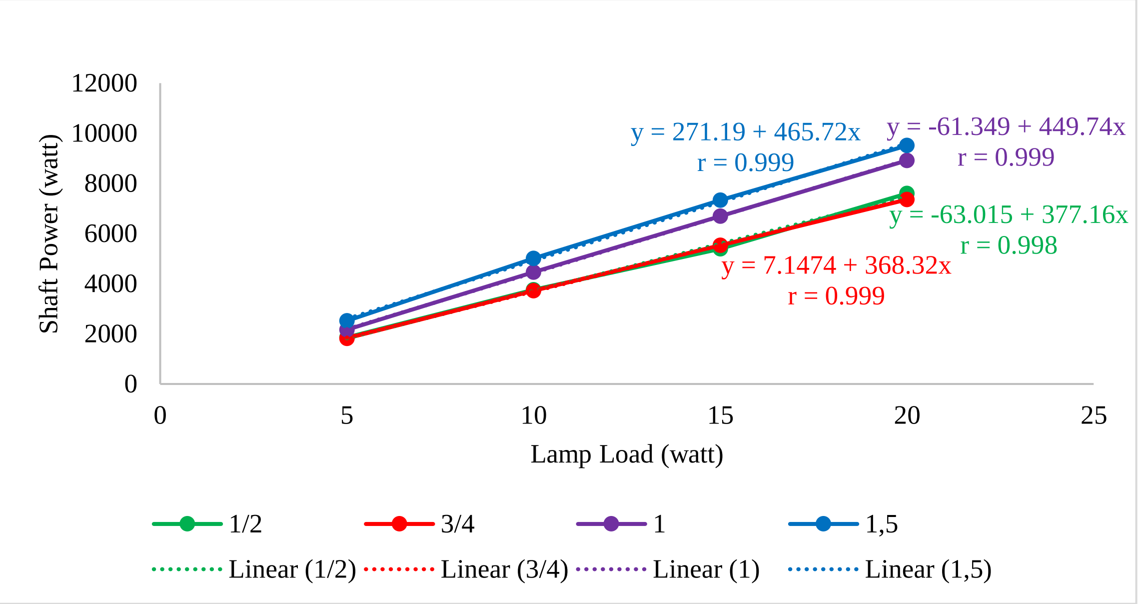

Fig. 5. Comparison between Pipe Diameters and Lamp Load to Shaft Power

Fig. 5. shows that the best shaft power is 9509.5 Watts at a diameter of 1.5 inches with a light load of 20W. The larger the pipe diameter, the higher the shaft power produced due to the increased shaft power generated. If the water discharge increases due to the larger pipe diameter, the kinetic energy absorbed by the turbine also increases. The shaft power generated by the turbine will also increase. The results of this research align with some findings, that explain that shaft power can influence the performance and efficiency of the pump and the turbine [1], [18], [20]. In Fig. 5, the regression equation

obtained is linear, y = 271.19 + 465.72x with a correlation value of r = 0.999. The correlation coefficient shows a strong positive relationship between pipe diameter and lamp load on the resulting shaft power.

4. Conclusion

Based on the analysis of the results, it can be concluded that the highest performance of the centrifugal pump as a generator driving turbine is found in a pipe diameter of 1.5 inches, which produces a specific speed of 207.59 rpm at a power load of 5W; rotor power of 2002 watts with 20W loading, and shaft power of 9509.50 watts 20W load. The correlation coefficients for specific speed, rotor power, and centrifugal pump shaft power are 0.989, respectively, 0.999, and 0.999. This shows a strong positive relationship between pipe diameter and power load on specific speed, rotor power, and centrifugal pump shaft power.

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