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Performance of a Centrifugal Pump as a Pico Hydro Scale Turbine

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Abstract: Utilization of the potential energy of water scale piko hydro is still very small, one of the challenges is that water turbines are not sold freely on the market, to get it must be ordered in advance to certain shops or workshops so that the price of turbines becomes expensive. The purpose of this experimental research is to analyze the performance of alternative fluid engines that can function as water turbines, namely pumps as turbines (PAT). Tests were carried out on three sizes of centrifugal pumps, namely 1 inch, 1.5 inches and 2 inches. using the same test equipment. The test results found that centrifugal pumps can be used as a good alternative as a water turbine. The larger pump size results in a lower head, power and efficiency. The results of testing at constant rotation and head, PAT 1 inch superior to PAT 1.5 inches, and PAT 2 inches. The maximum power and efficiency of 1 inch PAT is 235 W and 38% occur at a constant head of 15 m, 4.1 L/s discharge and 850 rpm rotation. This data inspired the researchers to create head and discharge standards suitable for each PAT size. Furthermore, many centrifugal pumps are sold in the market, it is necessary to do further research to get the right recommendations about the type, brand and size of the ideal pump used as a pico hydro scale water turbine in accordance with the potential for water and head discharge in the community.

Keywords: Pump as Turbine, Centrifugal Pump, Pump, Turbine, Water Turbine, Pico Hydro

1. Introduction

Renewable energy is an important choice in meeting global energy, especially water energy [1]. Water energy generators are divided into two groups, namely large-scale and small-scale (micro and pico hydro) energy energy plants. In its development, small-scale water energy generation is increasingly popular because of its simple design and operation, less environmental impact, easier installation, and does not require heavy construction [2-4]. One obstacle to the development of small-scale hydropower plants, especially piko hydro, is that the prime movers or water turbines are not sold freely in the market, the public must order in advance so that the price per turbine unit becomes expensive plus the survey and planning costs borne by the community, as a result the investment of piko hydro is sufficient expensive around 5000 US $/kW [5].

The problem of developing hydro-power plants is of concern to researchers such as [6-9] who each explained the development of hydro pico in Malaysia, Rwanda, Laos and Kenya. Several other researchers have succeeded in designing a practical, easy and inexpensive piko hydro distribution system. Gaiser succeeded in designing a cost-effective turgo turbine that can be optimized for piko hydro plants at an optimum speed ratio of 0.425, 25 blades, 15.4 mm jet diameter, and nozzle diameter ratio with the distance between blades (d/s) = 0,94. The best turbine performance can be achieved when the ratio (d/s) is greater than 0.45 and when the jet is directed to the center of the blade at an angle of 300. Another challenge that is of interest to the researchers is the alternative to several types of pico hydro turbines [10] such as research conducted by Haidar and Senan [11] who created aturbine model that is different from other conventional turbines and made steps to modify the turbine runner to improve efficiency.

The optimization of the pump as a turbine was observed by several researchers including Jain [12] which explains optimization is designed to find out the optimal diameter and rotation of the PAT impeller which can produce maximum efficiency. Reduced impeller diameter causes increased efficiency normal load operating conditions. PAT performance is known to be better at lower rotation compared to normal rotation. The effect of rounding/leveling the surface of the original impeller blade causes an increase in efficiency of around 3% to 4% which occurs at normal speed. Maximum efficiency is obtained at 76.93% with impeller d = 225 mm reduced by 10% at 1100 rpm as shown in figure 1.

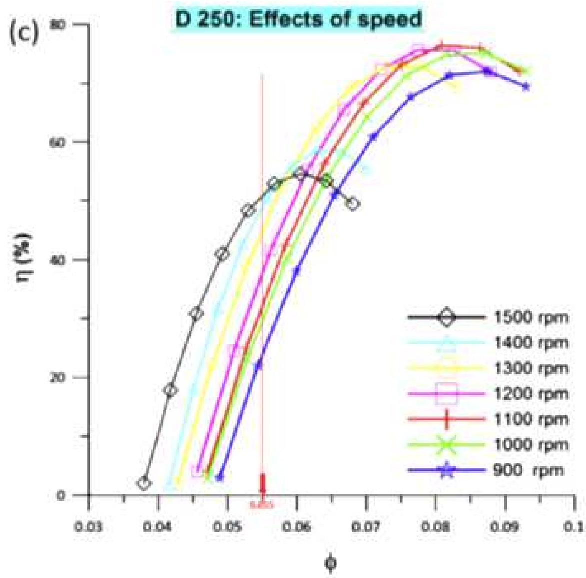
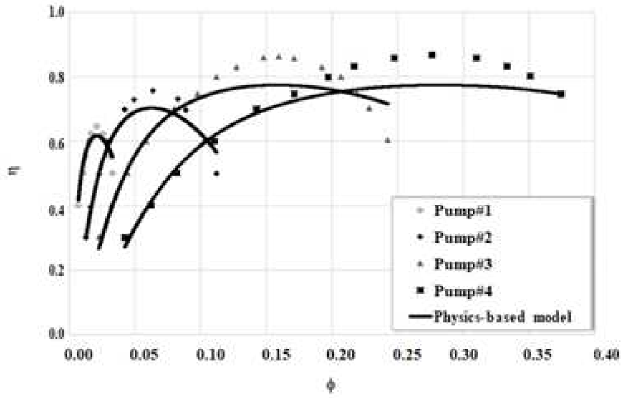
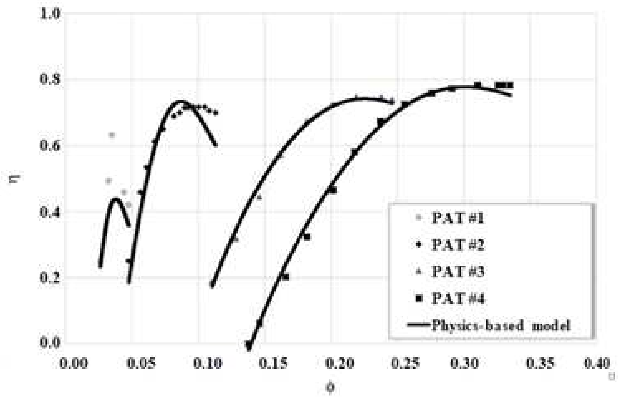


Figure 1. *Effciency Vs non dimensional volume flowrate for a10% reduction pump impeller.*

Venturini successfully developed a simulation model to predict pump and PAT performance curves. The simulation model is calibrated with experimental data obtained from the literature. The variables shown by the pump and PAT performance curves are the head, power and efficiency of four fluid engines (pumps) with specific speed values between 1.53 - 5.82. The simulation results as shown in Figure 2. The analysis results show all the performance curves of the simulation results are consistent for all operating intervals. Relative deviations occur when compared to field data but the head and power are still within tolerance limits. Deviations can be accepted when compared using other methods in the literature [13].



(a)



(b)

Figure 2. *Efficiency Vs.non dimensional volume flowrate for pump(a) and PAT(b).*

Other researchers, Yang, who explained the experimental and numerical tests of the effect of reducing the diameter of a centrifugal pump impeller as a turbine on efficiency. The results showed that the PAT water discharge at the best efficiency point (BEP) position shifted from 95.23 m^3/hour to 86.14 m^3/hour and then moved back to 93.63 m^3/hour. Efficiency in the BEP position decreased 4.11% for impellers with a diameter reduced from 255 mm to 215 mm [14]. Optimization of other PAT has been carried out by many researchers among them Zhu conducted a complete study to optimize the medium-high PAT head by considering interactions between blades, water and channel shape [15]. Rezghi concluded that the efficiency achieved by PAT at the best efficiency point (BEP) was the same as that achieved in pumps operating at the same head and discharge. This formula speed and cut the diameter to 80% of its initial size to increase efficiency at moderate loads [16]. Bozorgi compared the results obtained with CFD simulations using NUMECA software, with those obtained from laboratory tests to validate the simulated results [17]. Tan and Angeda present the prediction of PAT performance referring to the nine previous methods contained in the literature and taking into account the speed and diameter of the impeller as the main parameters [18]. Giosio studied the design and performance of PAT that matched the village environment with the plant installation to be built [19]. Finally, Barbarelli conducted a one-dimensional numerical analysis that can predict the design characteristics and performance of PAT used in applications in the field [20].

Noting the results of the literature study, research on the phenomenon of centrifugal pumps as water turbines is a research material that is still open to be explored and there are still quite a lot of secrets that can be revealed. This study will test the achievement and characteristics of three PAT measures in one research package so that alternative turbines offered to the community are more varied. The performance parameters of the three pump sizes when they function as water turbines are torque, power and efficiency at three constant head variations and ten variations of rotation which will be explained by curves. Some of the advantages of the application of pumps as turbines are as a mass product, pumps are easily obtained with a variety of head and discharge, available in various brands, types and sizes, easy to install, relatively inexpensive prices, and spare parts easily obtained. The community is expected to be easier in building piko hydro power plants in accordance with their financial capabilities, water potential and the potential of solutive fluid engines in their environment.

2. Material and Methods

PAT testing takes place at four constant head variations that can be seen from the pressure gauge installed at the end of the inlet pipe. The variables involved in the test are turbine inlet flow (Q), turbine rotation (n), turbine torque (T), turbine power (N_t), potential power (N_p), and turbine efficiency (η_t). The stages that were passed in the study were the procurement of materials and tools to be used, PAT modification, PAT assembly at the test installation, testing and analysis stages. The test will identify the turbine head and rotation which will produce maximum turbine efficiency, the test will also identify the PAT size that is capable of producing the best turbine efficiency. Research will recommend a solutive fluid engine that is feasible to be developed in the countryside.

2.1. Procurement of Tools and Materials

Experimental research was carried out at the Fluid Dynamics Laboratory, Department of Engineering, Andalas University, Indonesia, the installation of the test equipment used was shown in figure 3. The main ingredients used for the study were three 1-inch, 1.5-inches, and 2-inches centrifugal pump units as shown figure 4.

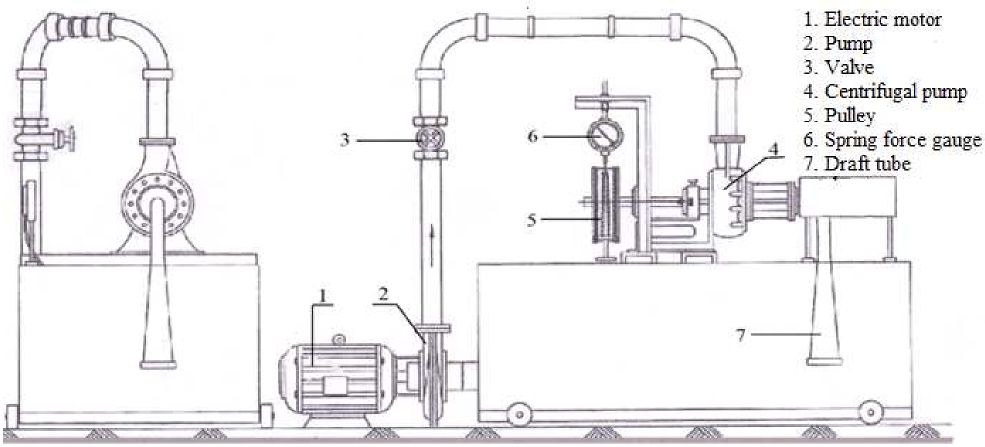


Figure 3. *Centrifugal pump test installation as a turbine.*

Figure 4. *Centrifugal pumps measuring 1 inch, 1.5 inches, and 2 inches.*

2.2. Modification Stage

The modification stage is adjusting the Pump to a turbine which involves several sizes of elbow and reduser. Modifications to the pump are relatively simple because the position of the driving motor is separate from the position of the pump. After adjustments and modifications, the pump stand is built and prepared for PAT testing as shown in figure 5.

The next step after the modification stage is the testing stage as shown in figure 6. Testing of each pump size is carried out at four variations of the constant head and ten variations of the PAT 1 inch rotation as the test results are described in Table 1.

Figure 5. *Centrifugal pump mounted on the stand.*

Figure 6. *Position of the centrifugal pump when testing.*

Table 1. *Testing Data of 1 Inch Pump Head Constant 15 m.*

Head (m)	Discharge (L/s)	Rotational Speed (rpm)	Torque (N. m)	Turbine Power (W)	Potential Power (W)	PAT Efficiency (%)
15	6.0	0	6.00	0	882.90	0
15	5.7	180	5.79	109.03	838.75	13.0
15	5.4	370	5.05	195.47	794.61	24.6
15	5.1	500	4.39	230.00	750.46	30.5
15	4.6	720	3.27	246.39	676.89	36.4
15	4.1	850	2.64	235.00	603.31	38.0
15	3.6	1060	1.78	197.06	529.74	37.2
15	3.0	1330	0.99	137.73	441.45	31.2
15	2.6	1490	0.59	92.70	382.59	24.3
15	2.4	1610	0.36	61.45	353.16	17.4
15	2.0	1800	0	0	294.30	0

2.3. Turbine Head Analysis

The turbine head (H) is the effective head of the generating system which can be seen from the static pressure measured at the pressure gauge installed in the inlet pipe near the turbine. The pressure gauge used in this test is a wet pressure gauge which is a pressure gauge equipped with liquid oil contained in the glass circle. This liquid is useful to reduce the vibration of the pointer so that the pressure reading becomes easier and more accurate. Wet pressure gauge used has the largest pressure scale up to 2.5 atm or equivalent to a 25 m head in water because 1 atm is equivalent to 10 m head in water [26].

2.4. Testing Stage

Torque testing is carried out with a braking mechanism as shown in figure 7. In the braking process, the tension at the tight side (F_t) and the slack side of the band (F_s) will arise, the difference between F_t and F_s is the braking force (F_b). The torque that occurs can be searched by equation (1) [27].

$$T=F_b\times r \tag{1}$$

Where, r is a pulley radius of 20 inches (r = 26 cm).

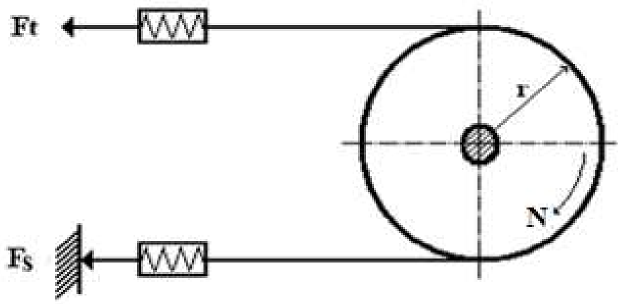


Figure 7. *Torque measurement system using turbine pulley breaking.*

Real power W2KDS (P_w) and potential power (P_p) can be known from equations (2) and (3) [26].

$$P_w=2\times\pi\times N\times T/60 \tag{2}$$

$$p_p=\rho\times g\times Q\times H_t \tag{3}$$

ρ is the dencity of water (1000 kg/m^3). The efficiency of the water wheel (η_w) can be seen from equation (4) [26].

$$\eta_w=(P_w/P_p)\times 100\% \tag{4}$$

The discharge of water into the waterwheel (Q) is known from the characteristics of the water through the triangular weir. The data variable in measuring this water discharge is the height of water in the calming bath (h) and the width of the door triangle (B=0.6 m) which is then entered into the empirical equation (5) [28].

$$Q=k\times h^{5/2} \quad (5)$$

k is the discharge coefficient which can be known from the empirical equation (6) [28].

$$k=81,2+(0,24/h)+\{(43,08\ (h/B-0,09)\}^2 \quad (6)$$

2.5. PAT Achievement Curve Analysis

Trend of torque curve, turbine power and efficiency of each PAT can be seen from the influence curve between ten variations of turbine rotation (N) and three variations of constant head (H) to the value of torque (T), turbine power (P_t), and efficiency turbine (η_t) that occurs. To get a competitive trend curve, the interval between revolutions ranges from 80 rpm to 150 rpm. From the curves formed it can be seen starting from the rotation position of the turbine how much rpm the rising trend and the downward trend will occur at once can be known at what position the highest efficiency obtained as a measure of performance of the PAT being tested. The final output of this prestigious analysis is that recommendations can be made about which solutive fluid engines are feasible to be developed in rural areas as the initial driving force for pico hydro electric power generation.

3. Result and Discussion

The PAT achievement test is carried out in four variations of influence relationships namely.

3.1. Effect of Rotational Variation (n) on PAT (T) Rising Torque in Four Constant Head Variations

This test aims to analyze the four torque curves that occur and to find out the maximum torque size and optimum turbine rotation. Torque data that occur for each spin is known from the results of the braking test which is then plotted into a curve, as shown in figure 8, figure 9, and figure 10.

Figure 8, figure 9, and figure 10 explains that there is an inverse relationship between pump size with rising torque and constant head, so that a 1-inch PAT produces torque and constant head variations that are greater than the torque generated by a 1.5 inch PATand PAT 2 inches.

The four curves of each image have slopes or slopes that are relatively equal, symmetrical, regular and each other is not crossing each other. Technically, this situation shows that the three pumps have the same reaction characteristics, that is, the three pumps can continue to operate stable as a turbine despite the constant rotation and head variations. The maximum torque achieved by PAT 1 inch, PAT 1.5 inches, and PAT 2 inches respectively are 6.3 N-m, 6.0 N-m and 5.4 N-m and it occurs at a constant head position of 15 m, 12 m, and 10 m, an average maximum torque decrease of around 7.3%. 1 inch PAT has better rise torque performance than the other two PAT sizes, four linear curves formed from figure 8 show that at constant head 15 m, 12 m, 9 m and 8 m the maximum torque of 6.3 N-m is produced respectively, 5 N-m, 4.2 N-m and 3.5 N-m. From this finding it is recommended that the community who will build a piko hydro plant be able to make the highest possible actual head in the field to produce maximum torque and power.

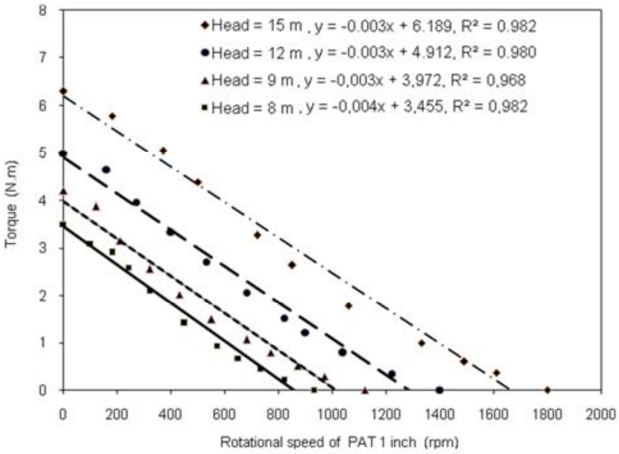


Figure 8. *Curve effect of rotation variation on 1 inch PAT torque.*

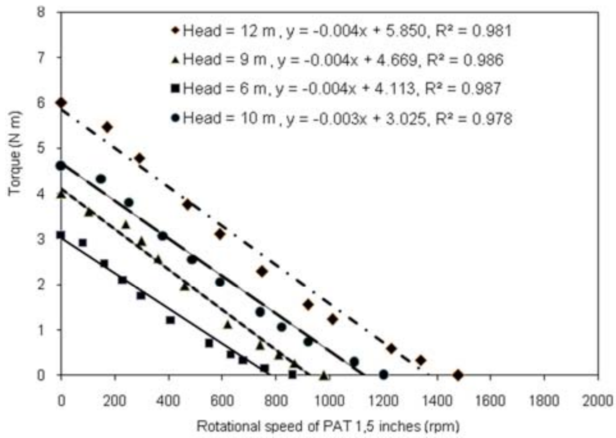


Figure 9. *Curve effect of rotation variation on 1.5 inches PAT torque.*

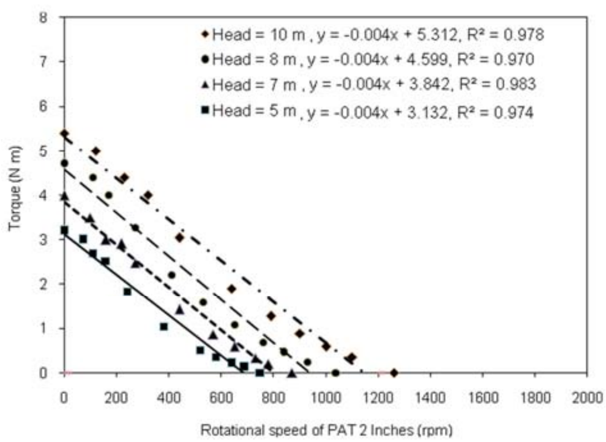


Figure 10. *Curve effect of rotation variation on 2 inches PAT Torque.*

3.2. Effects of Rotation Variations (n) on the PAT Resurrection Power (N_t) in the Four Constant Head Variations

The purpose of the test is to analyze the power curve that is formed in accordance with the addition of rotation and constant head variation. Another thing you want to know is the maximum PAT power at the optimum rotation. After the torque data for ten variations of rotation are obtained, through equation (2) PAT power can be known, figure 11, figure 12, and figure 13 shows the trend of the PAT curve of 1 inch, PAT 1.5 inches, and PAT 2 inches for ten variations of rotation and four variations of constant head.

Figure 11, figure 12, and figure 13 shows the inverse relationship between the size of PAT and the achievement of power, the greater the size of PAT, the achievement of PAT power gets smaller. These findings indicate that each PAT size requires support for different potential head and water discharge. The larger PAT size will require a greater potential for discharge and head so that it is expected that the performance of power and rotation generated by the turbine will be greater.

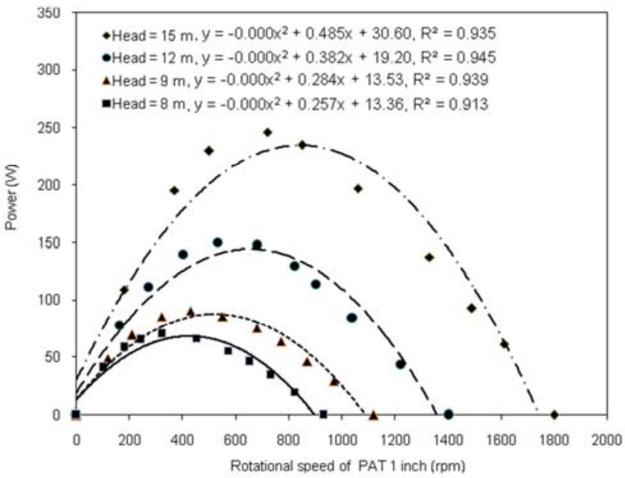


Figure 11. *Curve effect of rotation variation on 1 inch PAT power.*

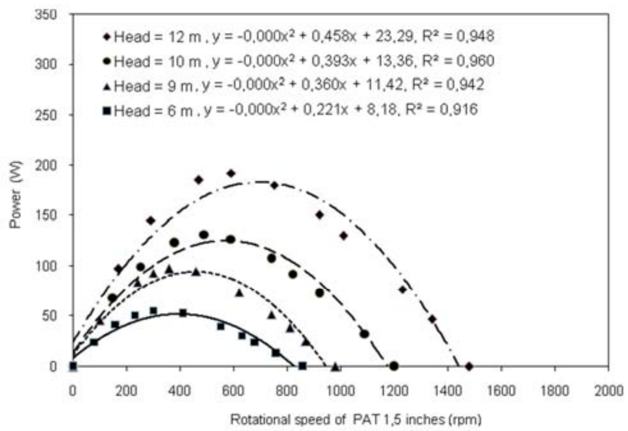


Figure 12. *Curve effect of rotation variation on 1.5 inches PAT power.*

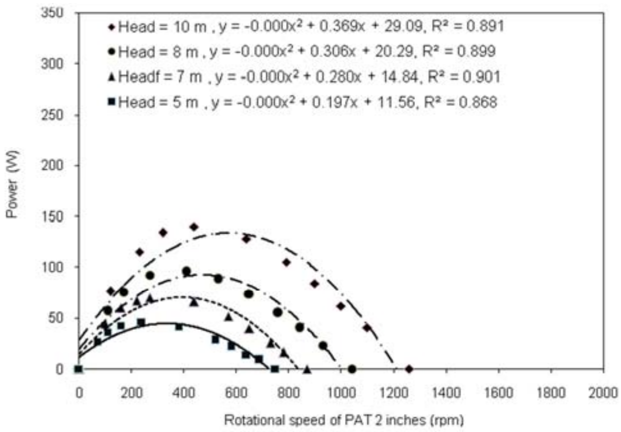


Figure 13. *Curve effect of rotation variation on 2 inches PAT power.*

From this test it is known that 1-inch PAT has better performance in power, head and rotation than other size PATs. The four parabolic curves in each PAT image have relatively the same curvilinear direction pattern that starts from the center of the coordinates, the second curve covers the first curve, the third curve covers the second curve and the fourth curve covers the third curve, the difference lies in its size. Curve trends that occur produce a parabolic curve with a simple equation that is sufficiently solved by a quadratic equation but still produces a convincing coefficient of determination (R^2), approaching the value of 1. Rotation variation and constant head variation significantly affect the power rise from the beginning to the end of the round. In each of the images seen, there is a drastic increase in rising power at the largest constant head. A 1-inch PAT produces a maximum rise power of 246.39 W which occurs at a constant head of 15 m and turbine rotation of 850 rpm. A 1.5-inch PAT produces a maximum rising power of 191.87 W which occurs at a constant head of 12 m and turbine rotation of 590 rpm, while a 2-inch PAT produces a maximum rising power of 140.15 W which occurs at a constant head of 10 m and at rotation 440 rpm turbine. Percentage of maximum rise in power from PAT 1 inch to PAT 2 inches is around 24%. Especially for 1-inch PAT, from figure 9 it is known that the highest maximum power of 246.39 W occurs at a constant head of 15 m and rotation of 850 rpm. The next maximum power is 150.27 W occurs at a constant head of 12 m and 530 rpm rotation. Maximum power of 90.87 W occurs at 9 m constant head and 430 rpm rotation, and maximum power of 70.32 W occurs at 8 m constant head and 320 rpm rotation.

3.3. Effect of Rotational Variation (n) on PAT Efficiency (η_t) in Four Constant Head Variations

This test aims to determine the efficiency curve that is formed in accordance with the addition of variations in rotation and constant head variations. This test will also identify the optimum rotation that can produce maximum PAT efficiency. Efficiency can be seen from the comparison between turbine power and potential power as explained in equation (4). Figure 14, figure 15, and figure 16 shows the efficiency trend of PAT 1 inch, PAT 1.5 inches and PAT 2 inches due to ten variations of rotation and four variations of constant head.

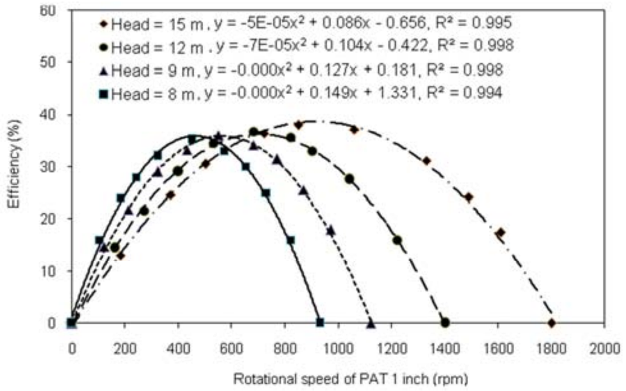


Figure 14. *Curve effect of rotation variation on the efficiency of PAT 1 inch.*

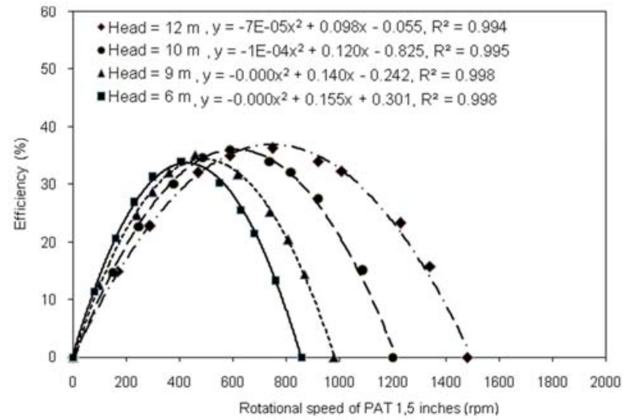


Figure 15. *Curve effect of rotation variation on the efficiency of PAT 1.5 inches.*

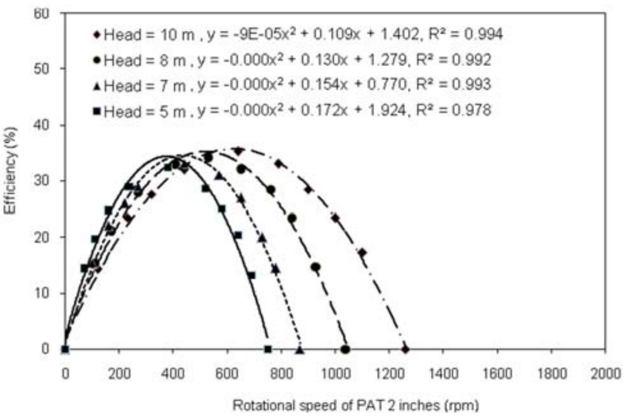


Figure 16. *Curve effect of rotation variation on the efficiency of PAT 2 inches.*

The curves in figure 14, figure 15, and figure 16 provide information that there is an inverse relationship between the size of PAT and achievement efficiency. Curve one with the next curve does not close to each other, this shows that the efficiency of the turbine in addition to being influenced by variations in rotation is also influenced by constant head variations. The efficiency curve produces a parabolic curve with a coefficient of determination (R^2) close to 1, meaning that the variation in the efficiency values corresponds to the variation in the rotation value. Each curve shows a trend of increasing efficiency that is different, that is, at a constant high head, an increase in efficiency occurs gradually seen from the up and down ramps. While the lower the constant head, the increase in efficiency occurs drastically as evident from the steep rising curve at the beginning of the round and steep decline at the end of the round. This shows that the lower the constant head, the effect of rotation on turbine efficiency is increasingly limited. Furthermore the high rotation does not show as the optimum rotation because the data prove the highest efficiency is obtained at the rotation position around half the rotation period.

The maximum efficiency of 1 inch PAT of 38.00% is obtained at an optimum rotation of 850 rpm and a constant head of 15 m. The next maximum efficiency occurs at PAT 1.5 inches by 36.2% at 750 rpm optimum rotation and 12 m constant head and at 2 inches PAT, maximum efficiency of 35.2% occurs at 640 rpm rotation and 10 m constant head. The maximum efficiency increase of the three PAT sizes is around 7.5% as the trend explained curve figure 17. PAT 1 inch has the highest efficiency achievement compared to other PAT sizes ie at a constant head of 15 m and a rotation of 850 rpm obtained a maximum efficiency of 38.00%, at a constant head of 12 m and a rotation of 680 rpm a maximum efficiency of 36.80% was obtained, at a constant head of 9 m and a rotation of 550 rpm a maximum efficiency of 36.00% was obtained and at a constant head of 8 m and a rotation of 450 rpm a maximum efficiency of 35.20% was obtained.

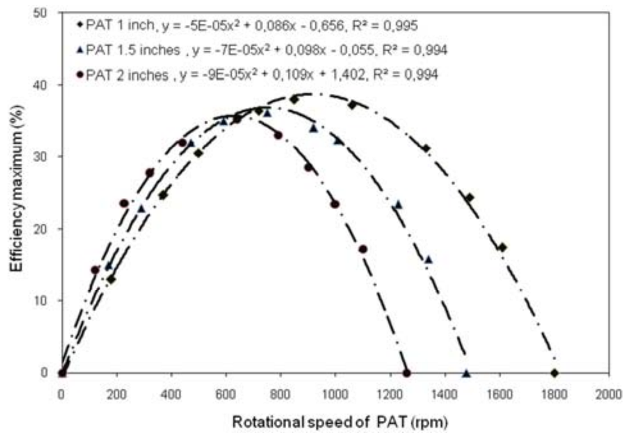


Figure 17. *Curve effect of rotation variation on efficiency maximum PAT.*

3.4. Effect of Rotational Variations (n) on PAT (Q) Inlet Discharge in Four Constant Head Variations

PAT inlet discharge is known from the water level data in the weirmeter tank which is installed at the end of the sedation tank and entered into equation (5). This test aims to analyze the effect of rotation variations on turbine inlet flow and how four discharge curves are formed. Rotation variation data and discharge variation data are plotted into a curve and the results are shown in figure 18, figure 19 and figure 20.

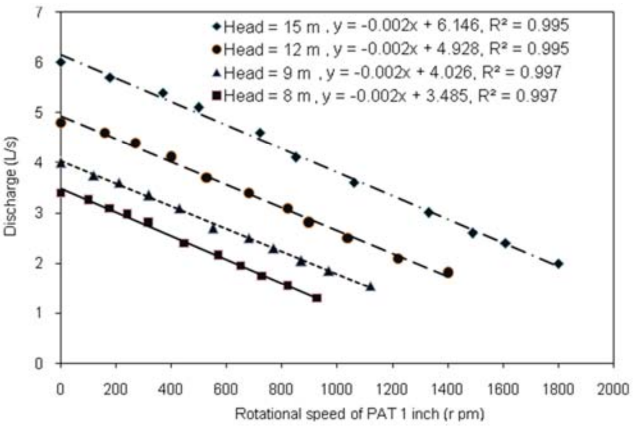


Figure 18. *Curve effect of rotational variations on the discharge of PAT 1 inch.*

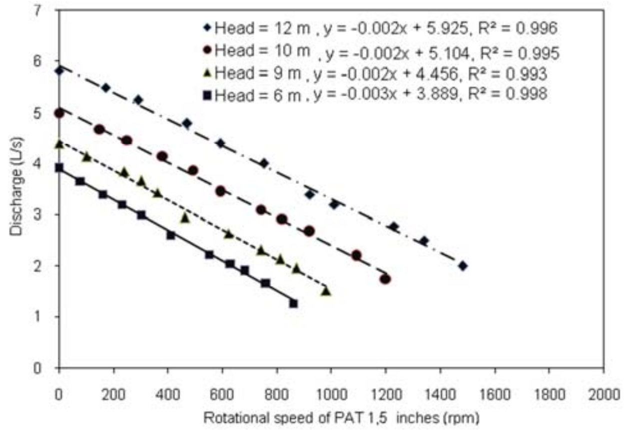


Figure 19. *Curve effect of rotational variations on the discharge of PAT 1.5 inches.*

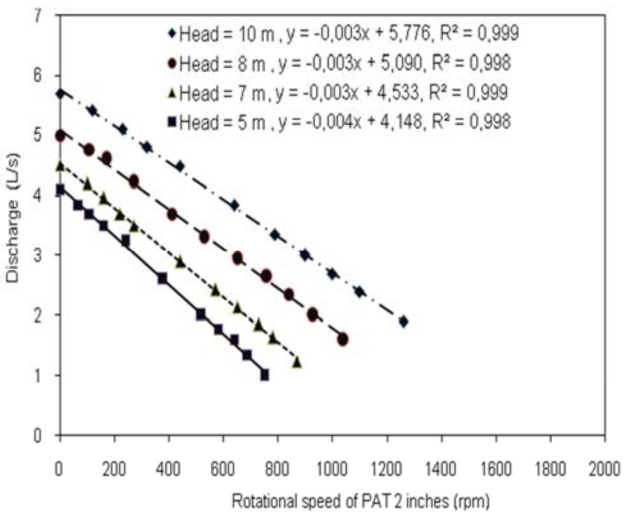


Figure 20. *Curve effect of rotational variations on the discharge of PAT 2 inches.*

Taking into account the curves in figure 18, figure 19, and figure 20, it can be explained that the larger the PAT size, the smaller the potential for water discharge, the head and the rotation seen from the shorter linear discharge curve length, there is an inverse relationship between the two. Besides that the larger the PAT size, the slope or slope of each curve is more steep or steep, this shows the greater the PAT size, the effect of the addition of rotation on the addition of water discharge becomes less sensitive.

The maximum water discharge for each PAT sie occurs at the lowest spin. The maximum discharge for PAT 1 inch, PAT 1.5 inches, and PAT 2 inches respectively are 6.0 L/s, 5.8 L/s, 5.7 L/s which occurs at a constant head of 15 m, 12 m, and 10 m. From this analysis it can be stressed that each PAT size requires a test installation with a different discharge bed supply. The larger PAT size requires greater potential for constant discharge and head so that PAT can generate optimum power. Specifically in this test, 1-inch PAT has better performance and characteristics than other PAT measures. Curve effect of variation of rotation (n) on PAT 1 inch inlet discharge as shown in figure 16. All four curves have relatively equal slopes and are quite gentle, none of which crosses each other, technically this shows rotation variations do not affect turbine operations, PAT can still operate stable and normal, especially in terms of supplying water discharge. Between the variations in rotation with variations in water discharge there is a significant inverse relationship to regular order. Specifically for 1 inch PAT, the maximum water discharge for the four curves occurs at the lowest rotation and the maximum water discharge of 6.0 L/s occurs at a constant head of 15 m, the next maximum water discharge is 4.8 L/s, 4.0 L/s and 3,4 L/s that occur at constant head 12 m, 9 m and 8 m.

4. Conclusion

Test results prove that centrifugal pumps can function as water turbines. The maximum efficiency achievement of PAT 1 inch, PAT 1.5 inches, and PAT 2 inches respectively are 38%, 36.2%, and 35.2% which occur at constant heads of 15 m, 12 m, and 10 m respectively, with optimum rotation of 850 rpm, 750 rpm and 640 rpm, respectively. This finding explains that each PAT measure requires its own discharge and head supply to obtain greater maximum efficiency achievements. 1 inch PAT has better efficiency performance compared to other PAT sizes namely at a constant head of 15 m and 850 rpm rotation obtained a maximum efficiency of 38.00%, at a constant head of 12 m and 680 rpm rotation obtained a maximum efficiency of 36.80%, at the head a constant of 9 m and a rotation of 550 rpm obtained a maximum efficiency of 36.00% and at a constant head of 8 m and a rotation of 450 rpm obtained a maximum efficiency of 35.20%. Centrifugal pumps are sold in the market with various brands, types and sizes, so it is necessary to do further research to get the right recommendations about brands, types and sizes. The most superior centrifugal pumps as solutive fluid machines are worthy of being socialized and applied to the public.

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