Effect of Head Variations on Performance Four Sizes of Blowers as Turbines (BAT)

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Received: 27.01.2020 Accepted:27.02.2020

Abstract- Pico hydro power plant construction using water turbines is still small. One of the challenges is that water turbines are not sold freely in the market, to get them people must order in advance so that the price of turbines becomes expensive. The purpose of this experimental study is to analyze the performance of blowers as turbines (BAT). The research results are known, that centrifugal blowers was successfully functioned as a water turbine. The smaller the size of the blower results in better performance. The performance of 2-inch blowers is superior compared to 2.5-inch, 3-inch and 4-inch blowers. The maximum power and efficiency of a 2-inch BAT is 583.02 Watt and 50.90% occurs at 14 m head, 8.34 L/s discharge, 800 rpm rotation and discharge ratio of 0.9. Water discharge below 2.6 L/s is called starting discharge while water discharge above 2.6 L/s to 8.34 L/s is called effective discharge. The mathematical equation of the BAT efficiency curve is $y = 105.1x^3 - 363.6x^2 + 398.5x - 89.72$, $R^2 = 1.0$. BAT applicative research in the community needs to be carried out by subsequent researchers to find out the challenges and ease of using centrifugal blowers as turbines.

Keywords-Blower, Pump, Turbine, Pico hydro, Centrifugal, Blower as turbine (BAT), Pump as turbine (PAT).

1. Introduction

The future of developed and developing countries in the world depends on the availability and sustainability of energy, which in the near future world energy consumption continues to grow [1]. The effort to get energy is a fundamental problem for human life. The development of energy systems through the exploitation of various natural resources such as coal and petroleum has been carried out in recent years, this phenomenon has brought about an increase in harmful pollutants in the atmosphere [2]. The use of renewable energy systems is the best alternative to achieve reduction of the high cost of energy supply and carbon emissions [3]. Many challenges in meeting the demand for electricity by the community caused by an increase in population. In addition, the operation of conventional energy plants is not able to meet all consumer demands. In this case, the use of renewable energy is very suitable and economical to meet the demands of the community [4]. Future plans to be able to meet the needs of the community with 100% renewable energy will be realized if it involves new technologies in building power systems [5]. Although the demand and demand for new and renewable energy continues to increase, there are still unresolved issues related to unstable power supply and relatively low generation efficiency. Settlement steps can be taken including the efficient use of energy through the expansion of energy storage systems, energy management systems and energy generation innovations [6].

In recent years, renewable energy sources such as solar, hydrogen, water, and wind have become more popular due to global warming and the depletion of fossil fuels [7]. The potential of hydro, geothermal and bioenergy energy is quite large, so in 2050 the target of using new and renewable energy can reach around 31% [8]. Innovation of the generator system continues to be carried out by researchers including the generator system built more simple, more compact, not noisy and versatile utilization [9]. For example, renewable energy has been proven to be utilized for the procurement and distribution of water in the Adrar region, Algerian Sahara as one of the world heritage sites [10]. Renewable energy sources are being investigated, especially the potential for small-scale water energy (pico hydro and micro hydro) that is widely available in villages. Hydroelectric power plants have several advantages so that attractive hydroelectric power plants are researched and developed [11]. The development of the pico hydro power plant is interesting to study because there are three fluid engines namely pumps, blowers and centrifugal compressors which can be converted into water turbines [12]. IJRER accepts submissions in three styles that are defined as Research Papers, Technical Notes and Letter, and Review paper. The requirements of paper are as listed below:

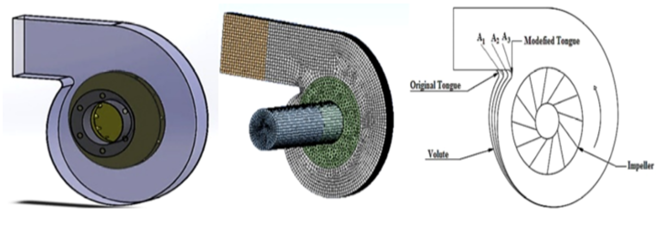
This research requires the support of academic motivation in addition to practical motivation, namely research journals related to the pico hydro power generation system. The interesting challenge for the researchers is to design alternative turbines that are different from conventional turbines and are suitable for application in pico hydro plants. Initial research has been carried out by researchers by modifying turbine runners so that turbine efficiency can be increased. [13]. Efforts to improve the performance of pico hydro plants are carried out using cross flow turbines and it is known that water velocity has a positive effect on the performance of pico hydro plants [14]. Another idea to improve efficiency is to modify the turbine impeller. The number of blades impeller the Banki mitchell turbine or cross flow turbine affects the performance of the pico hydro generator [15]. A simple Pico hydro plant can be built using a pump as a turbine (PAT) as a prime mover because of its low cost [16]. Table 1 explains the price comparison in Indonesia between the price of a francis turbine as a conventional pico hydro power plant driver and a centrifugal pump / blower as an alternative pico hydro power generator with the same impeller diameter size [17].Through experimental research it was concluded, the maximum efficiency of PAT is 76% can be achieved at a specific speed of 57 [18]. PAT technology is suitable for pico hydro power plants but the obstacle in using PAT technology is that when pumps are used as turbines, turbines do not have a certain speed interval. The specific speed of PAT is generally smaller than 60 and to produce competitive PAT efficiency it is recommended that the specific speed be between 60-150 [19]. PAT is the optimal solution for hydropower scale pico hydroelectric power. The results of the analysis revealed that pico hydro investment is considered feasible if the electric power capacity is greater than 380 kWH / month [20]. PAT size and PAT performance have an inversely related relationship, thus in planning the pico hydro plant must pay attention to the harmony between the size of the PAT with the potential head and discharge in the field [21].

Table 1. Price comparison of centrifugal pumps, centrifugal blowers and francis turbine

No	Prime Mover	Price (USD$) 6-inch Impeller	8-inch Impeller
1	Centrifugal pump	300	460
2	Centrifugal blower	230	300
3	Francis turbine	920	1150

Furthermore, the use of pumps into turbines is one of the solutions offered by researchers so that people can more easily get the initial drive from the pump turbine. The maximum PAT efficiency can be achieved at a specific speed of 57 rpm and PAT is capable of generating power up to 19.18 kW with 338.11 kWH of electricity production per day [22]. Achievement of pump efficiency as a turbine reaches 65% at 8.4 m head and turbine inlet water discharge 18 L/s [23]. Centrifugal PAT is proven to be an effective alternative to electricity generation because it is able to produce high efficiency at large discharges. Conversely, turbine performance will decrease drastically if it is under an unstable discharge (24). Tip clereance affects the characteristics of a centrifugal pump as a turbine. With an increase in tip clearance, there is a decrease in head potential and pump efficiency [25]. High viscosity fluids have a positive lubrication effect, this effect can significantly change the efficiency of the PAT system. Experimental results data show the effect of lubrication with higher viscosity liquids will reduce mechanical losses resulting in higher efficiency [26].

The results of the literature study are known, quite a lot of research journals that discuss the performance of PAT, but conversely research on blowers as turbines (BAT) is still limited. Indeed, quite a lot of research addresses blowers as the topic of their observations, but researchers discuss different aspects. Research on centrifugal blowers aims to predict air mass flow using the Computational Fluid Dynamics (CFD) program. The results of numerical analysis are compared with the characteristic curves issued by the manufacturer [27]. Research on the effect of variations in the distance of the volute tongue to the performance of centrifugal blowers was carried out by a researcher as shown in Figure 1. Four centrifugal blowers with different volute tongue distances, namely 6%, 8%, 10%, and 12.5% of the diameter of the impeller used for numerical and experimental analysis. The results showed that the narrowing of the volute tongue had a significant effect on the performance of centrifugal blowers and this parameter increased with a decrease in the distance of the tongue volute [28].

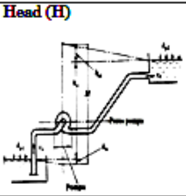
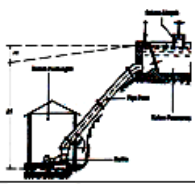
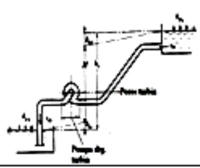
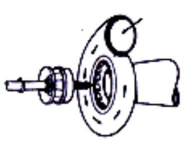
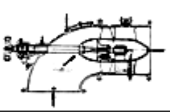
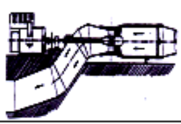
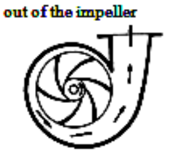


(a) (b) (c)

Fig. 1.(a) Tested centrifugal blowers, (b) mesh models and (c) volute tongue modification stages

Subsequent literature studies succeeded in summarizing the similarity of the characteristics of blowers/pumps, BAT/PAT with turbines so as to further strengthen academic motivation as previously explained. Between BAT/PAT and francis turbines have relatively the same characteristics in terms of construction and process work as shown in Table 2 column 3.

Table 2. Comparison of blower/pump, turbine and BAT/ PAT characteristics

No	Blower/ Pump	Turbine	BAT/PAT
1	Head (H)		
			
2	Casing construction a) Radial flow	Francis turbines	
			
	b) Axial flow	Propeller turbines	
			
3	The flow of water in / out of the impeller		
			

For example, the construction of BAT/PAT volutes with Francis turbines volute is relatively similar so that the flow of water when entering into in BAT/PAT and in Francis turbines do not have different characters. Likewise, the analysis of the water velocity triangle on the blower/pump and BAT/PAT is relatively similar, the difference is the direction of the water velocity when heading and leaving the impeller. This finding strengthens the researcher's hypothesis that blowers and pumps can function as water turbines. This finding strengthens the researcher's hypothesis that blowers can function as water turbines. Theoretically centrifugal blowers can function as water turbines, thus testing and analysis is needed to reveal the extent of the blower's performance as a turbine. Testing is carried out on a laboratry scale with testing variables including rotation, discharge, torque, power, and BAT efficiency.

2. Research Methodology

The initial stage of the research is the procurement of materials, measuring instruments and testing support tools. The next step is to modify the blower into a turbine (BAT), install the BAT on the test installation, do the testing and analysis. The test is carried out on four constant head variations, in each head there are ten variations of rotation and 10 variations of discharge. The test result variables are discharge (Q), head (H), rotation (N), potential power (P_p), BAT power (P_t), and BAT efficiency (η_t). The purpose of the test is to identify the rotation, discharge and head optimization that results in maximum efficiency.

2.1. Test Location

Blower testing site as a turbine in the laboratory with a test installation as shown in Figure 2. The main components of the test installation consist of pumps as a source of pressure and discharge, piping and reservoirs. Alternative fluid machines that function as water turbines are four sizes of centrifugal blowers as shown in Figure 3.

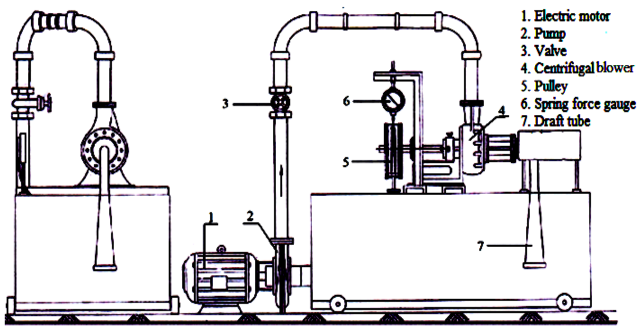
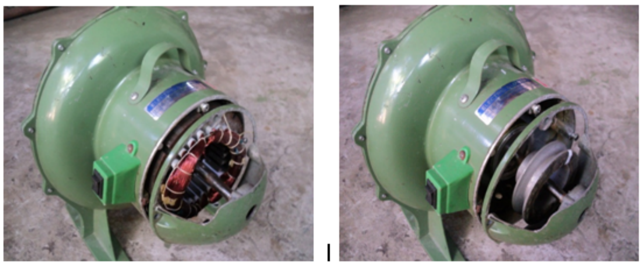


Fig. 2. Installation of a centrifugal blower test as a turbine

Fig. 3. Centrifugal blowers of size 4-inch, 3-inch, 2.5-inch, and 2-inch

2.2. Modification Stage

Blowers on the market cannot be directly functioned as turbines, it needs to be modified into BAT. The stator from the electric motor inside the blower is removed, and half of the blower cap is removed to facilitate the installation of 3-inch pulleys on the blower shaft as shown in Figure 4. The rotor attached to the shaft is difficult to remove and is left fixed to the shaft which can be used as a flywheel . When the blower functions as a turbine, the impeller, rotor, and 3-inch pulleys will be installed as shown in Figure 5.



(a) (b)

Fig. 4. (a) Close the blower split, visible motor stator, (b) the stator is removed and replaced with a 3-inch pulley

Fig. 5. Impeller, rotor, and pulleys mounted on the blower shaft

The next modification stage is installing inlet and outlet pipes. The inlet pipe is made from a spiral pipe of the size according to the diameter of the inlet hole. Connecting the inlet pipe with a body blower using a ring clamp, at the end of the inlet pipe a pressure gauge is installed to measure the turbine head. The outlet pipe functions as a draft tube made of PVC pipe equipped with elbow 90^0. Connecting the outlet pipe with the blower body using plastic steel as the result shown in Figure 6.

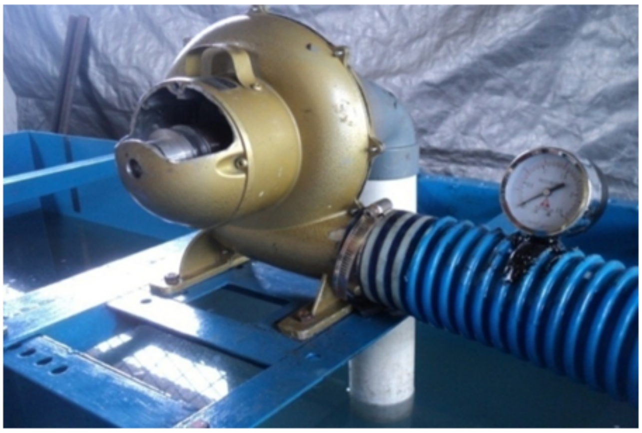


Fig. 6. Position of the inlet pipe, outlet pipe, and pressure gauge

2.3. Constant head analysis

BAT testing is carried out on four constant head variations. The constant head can be seen from the pressure on the pressure gauge mounted at the end of the inlet pipe. Four constant head variations are obtained by adjusting the valve opening until the desired constant head position is reached. The pressure gauge used has a maximum scale of 2.5 atm. Unit conversion from pressure units (atm) to head units (m) is referring to the equation that 10 m high water is equal to 1 atm, then a maximum pressure of 2.5 atm is equivalent to a head of 25 m [29].

2.4. Testing Stage

Figure 7 shows the technical testing of turbine torque with a loading mechanism consisting of a band and pulley turbine. In the braking process, the tension on the tight side (F_t) and the slack side of the band (F_s) will arise, braking force (F_b) is the difference between F_t and F_s. Furthermore, the turbine torque can be determined by equation 1 [30]. Measurement of torque when testing in the laboratory is shown in Figure 8.

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

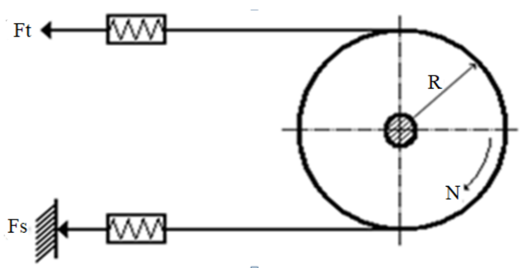


Fig. 7. Tubin torque measurement scheme

Fig. 8. BAT torque measurement

Potential power (P_p) and BAT power (P_t) can be analyzed by equations (2) and (3) [29].

$$P_t = 0.10466 \times N \times T \quad (2)$$

$$p_p = Q \times H_t \times \rho \times g \quad (3)$$

g and ρ are constants, the efficiency of the BAT (η_t) can be seen from equation (4) [29].

$$\eta_t = (P_t/P_p) \times 100\ \% \quad (4)$$

Turbine discharge (Q) is the same as water flowing out through the triangle door which is one of the components of the weirmeter. The variables that determine the size of the discharge are the height of the water in the reservoir (h_w) and the width of the triangle door (b: 0.6 m) which are then analyzed by equation (5) [31].

$$Q = c \times h_w^{5/2} \quad (5)$$

c is the coefficient of discharge that can be found by equation (6) [31].

$$c = 81.2 + (0.24/h_w) + \{(43.08\ (h_w/b - 0.09)\}^2 \quad (6)$$

3. Results and Discussion

BAT performance testing involves four types of blower sizes, namely 2-inch, 2.5-inch, 3-inch and 4-inch centrifugal blowers as shown in Figure 3. This laboratory test was carried out in three variations of the relationship of influence, namely the effect of variations of rotation on the power and efficiency of BAT, the effect of variations of discharge on the efficiency of the BAT at a constant head and the effect of the discharge on the power and efficiency of the BAT at a constant rotation. Recapitulation of test data for 2-inch blowers and their analysis, as an example shown in Table 3. Table 3 is an example of test data that explains the 2-inch BAT performance data with a constant head of 14 m. The torque, power, and efficiency data of each BAT are then plotted into a curve, then the output can be known for the trend of the torque, power and efficiency curve of the BAT.

Table 3. Data from the 2-inch BAT test results with a constant head of 14 m

No	Discharge, Q (L/s)	Rotational Speed, N (rpm)	Torque, T (N m)	BAT Power, P_t (W)	Potential Power, P_p (W)	BAT Efficiency, η_t (%)
1	11.00	0	15.00	0.00	1510.74	0.0
2	10.82	160	13.37	223.97	1483.27	15.1
3	10.61	260	12.20	331.92	1455.80	22.8
4	10.33	380	11.45	455.50	1414.60	32.2
5	9.52	610	9.38	598.87	1304.73	45.9
6	8.34	800	6.96	583.02	1145.54	50.9
7	7.33	970	4.66	473.16	1002.58	47.2
8	6.71	1100	3.30	380.58	920.18	41.3
9	6.32	1210	2.42	307.20	865.24	35.5
10	5.62	1400	1.12	164.07	769.10	21.3
11	5.00	1600	0.00	0.00	686.70	0.0

3.1. BAT Power (P_t) Due to the Effect of Variation in Rotation Speed (N)

This test aims to find out how the BAT power curve, another thing that needs to be revealed, is the optimum rotation at what rpm the maximum BAT power is obtained. The BAT power can be directly known through the equation (2), and the results of the analysis are listed in column 6 of Table 3. Figure 9-12 illustrates the trend of the BAT power curve of 2-inch, 2.5-inch, 3-inch and 4-inch.

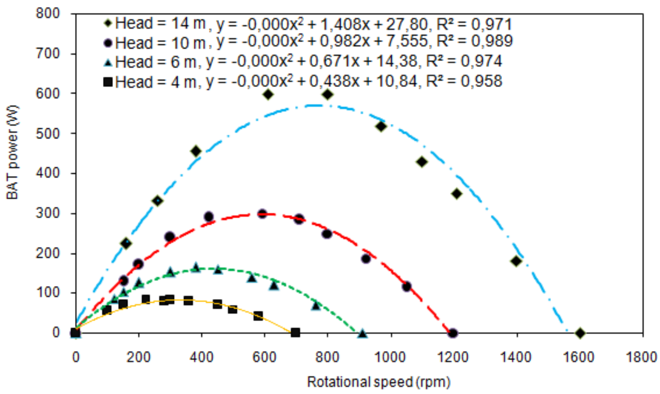


Fig. 9. BAT power curve of 2 inches due to the influence of rotation variations

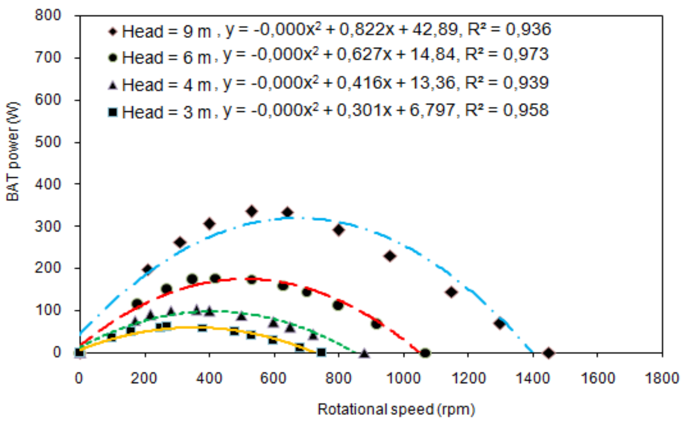


Fig. 10. BAT power curve of 2,5 inches due to the influence of rotation variations

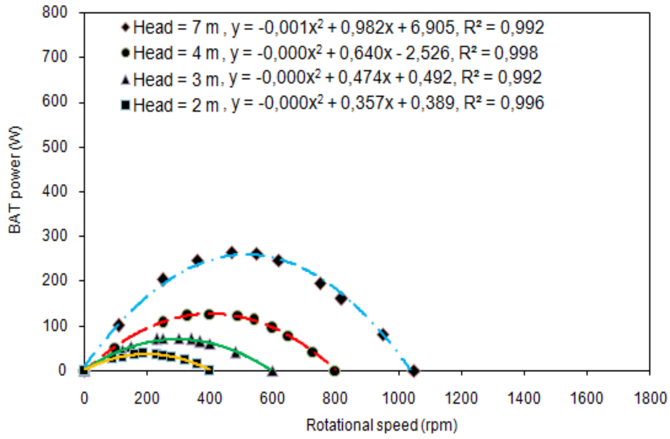


Fig.11. BAT power curve of 3 inches due to the influence of rotation variations

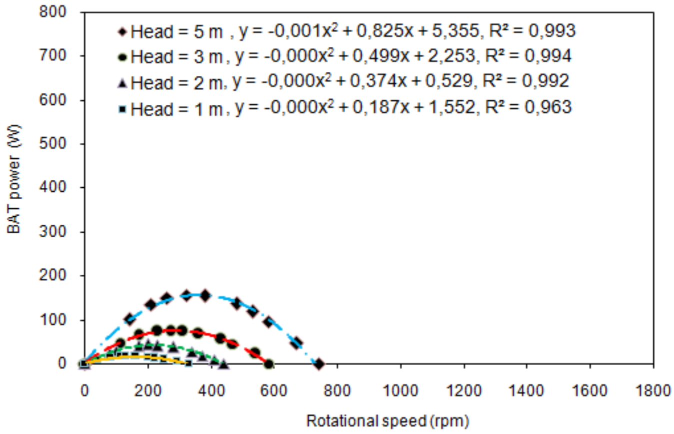


Fig. 12. BAT power curve of 4 inches due to the influence of rotation variations

Figure 9-12 explain, that 2-inch BAT performance is better than other BAT proven there is an inverse relationship between power (P_t), head (H), and BAT rotation (N) to BAT size. Each of the pictures shows that at the greatest constant head there is a drastic increase in turbine power. At 700 rpm turbine rotation and a constant head of 14 m, the maximum power of 2-inch BAT is 563 W. At turbine rotation 640 rpm and constant head 9 m, 2.5 inch BAT produces maximum power 340 W. At 360 rpm turbine rotation and constant head 7 m, 3-inch BAT produces a maximum power of 264 W. At 320 rpm turbine rotation and a constant head of 5 m, 4-inch BAT produces a maximum power of 155 W. The maximum power reduction of 2-inch BAT to 4-inch BAT is around 35%.

3.2. BAT Efficiency (η_t) Due to the Effect of Variation in Rotation Speed (N)

This test aims to analyze the effect of constant head variations and rotation variations on the BAT efficiency trend. This test will also identify the maximum BAT efficiency and how many optimum rpm occur. BAT efficiency can be determined by equation 4, the results of which are shown in column 7 of Table 3. Furthermore, the rotation and efficiency data in columns 3 and 7 are plotted into a curve, then the trend of the effect of variation of rotation on BAT efficiency is shown in Figure 13-16.

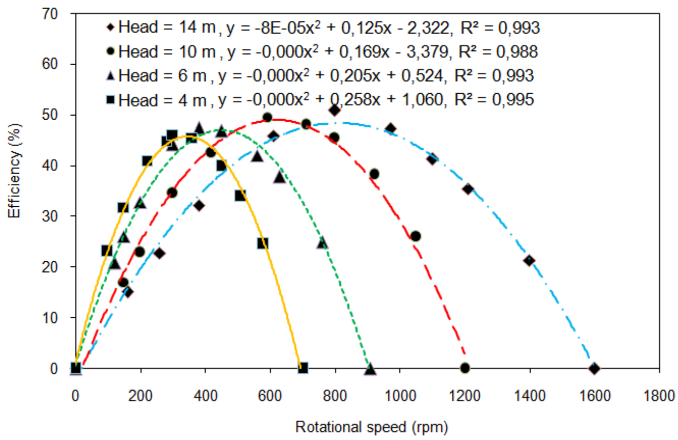


Fig. 13. BAT efficiency curve of 2 inches due to the influence of rotation variations

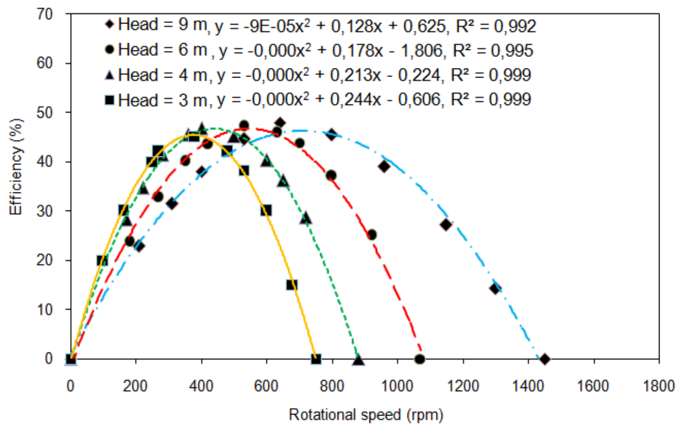


Fig. 14. BAT efficiency curve of 2.5 inches due to the influence of rotation variations

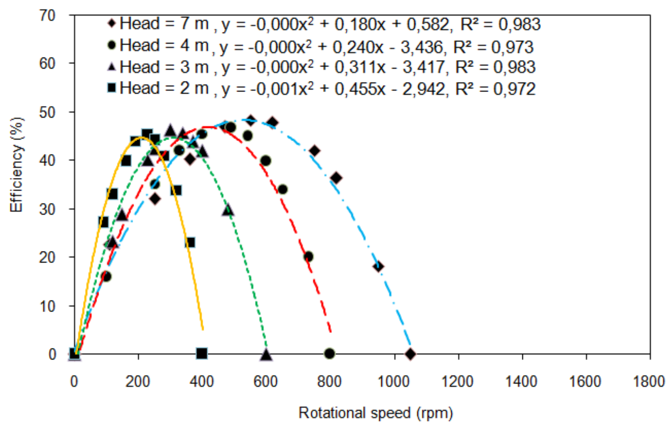


Fig. 15. BAT efficiency curve of 3 inches due to the influence of rotation variations

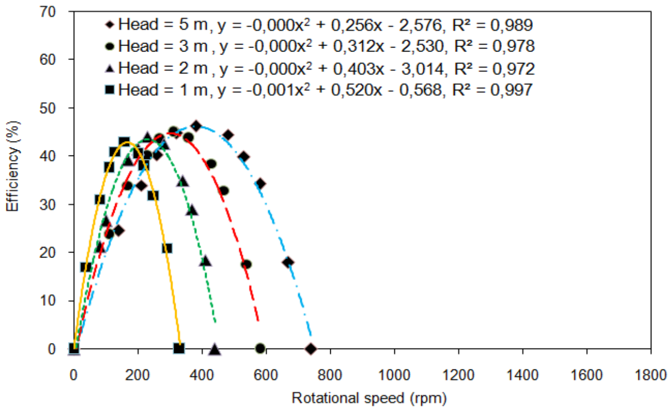


Fig. 16. BAT efficiency curve of 4 inches due to the influence of rotation variations

The curves in Figure 13-16 shows the BAT size with efficiency, rotation range and head there is an inverse relationship. The bigger the BAT size the lower the efficiency achievement and the rotation range. The data prove, the highest BAT efficiency is obtained at half the rotation interval, this shows that the high rotation is not the optimum rotation. At a constant 14 m head and 800 rpm rotation, the maximum 2-inch BAT efficiency is 50.89%. At a constant head of 9 m and rotation of 640 rpm, the maximum efficiency of 2.5-inch BAT is 49%. At 7 m constant head and 550 rpm rotation, the maximum 3-inch BAT efficiency is 48.3%. At a 5 m constant head and 380 rpm rotation, the maximum 4-inch BAT efficiency is 46.3%. The average reduction in maximum efficiency of the four BAT sizes is around 1%. Furthermore, the lowest efficiency at each of the largest constant heads occurs at 1600 rpm turbine rotation for 2-inch BAT, 1450 rpm for 2.5-inch BAT, 1050 rpm for 3-inch BAT and 740 rpm for 4-inch BAT.

3.3. BAT Efficiency (η_t) Due to the Effect of Variation in Discharge (Q)

The data in Table 3 is interesting to continue to analyze, especially how the influence of discharge variations on BAT efficiency. This study aims to determine the trend of the efficiency curve of four BAT sizes with ten variations of discharge and four variations of constant head. Another goal is to determine the optimum discharge that can produce maximum efficiency and start discharge from each BAT size. Furthermore, the discharge and efficiency data as shown in columns 2 and 7 in Table 3 are plotted into a curve, and the results are as described in Figure 17-20.

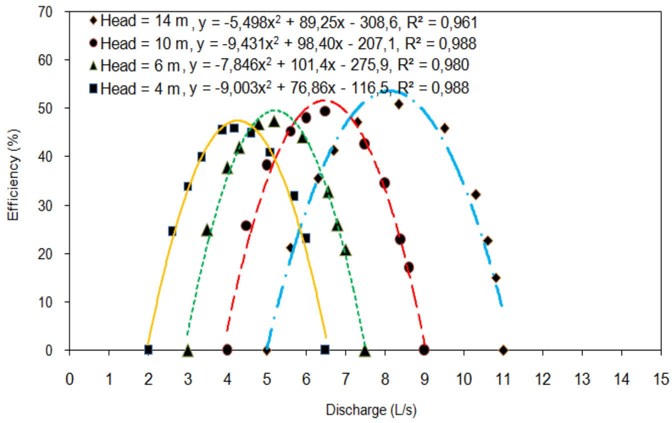


Fig. 17. BAT efficiency curve of 2 inches (η_t) due to variations in discharge (Q)

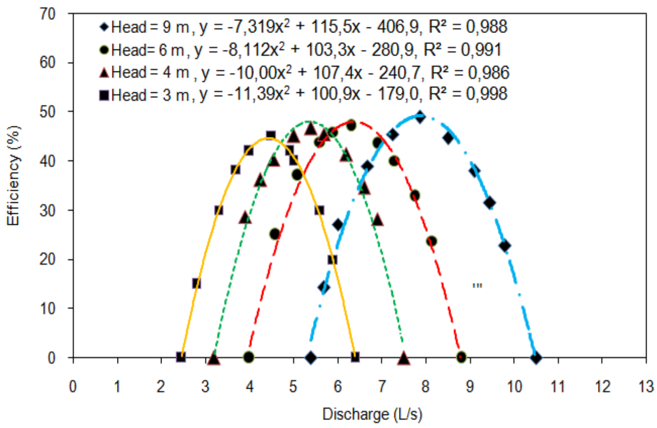


Fig. 18. BAT efficiency curve of 2.5 inches (η_t) due to variations in discharge (Q)

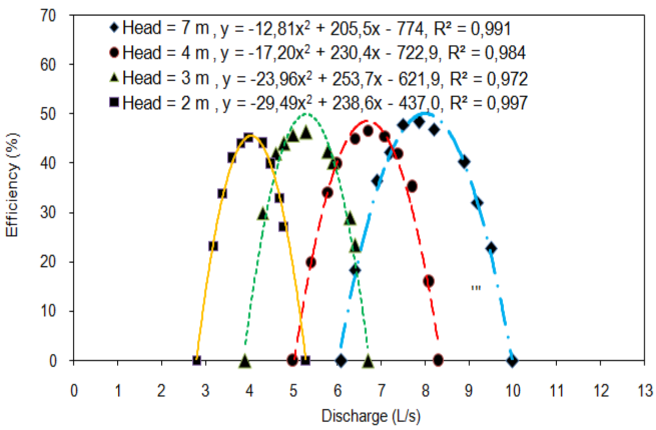


Fig. 19. BAT efficiency curve of 3 inches (η_t) due to variations in discharge (Q)

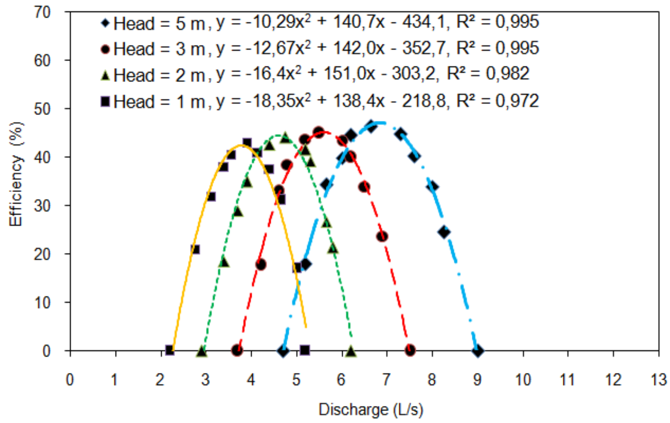


Fig. 20. BAT efficiency curve of 4 inches (η_t) due to variations in discharge (Q)

The curves in Figure 17-20 explain, that the efficiency patterns of the four curves of each figure have a relatively similar shape but only have different sizes. BAT size has an inverse relationship with maximum efficiency, maximum constant head, optimum discharge, and with start discharge. The greater the BAT size, the lower the values of maximum efficiency, maximum constant head, optimum discharge, and start discharge. At 2-inch BAT, 2.5-inch BAT, 3-inch BAT, and 4-inch BAT, the maximum efficiencies were 50.89%, 49%, 48.4%, and 46.3% at a 14 m constant head, 9 m, 7 m, and 5 m with optimum discharge respectively 8.34 L/s, 7.86 L/s, 7.8 L/s, and 6.65 L/s. The starting discharge of each BAT is 5 L/s, 5.4 L/s, 6.1 L/s, and 4.7 L/s, at a position below each start discharge each BAT size has not been able to produce power. From the above analysis it is concluded that the 2-inch BAT has better efficiency and water discharge compared to other BAT sizes.

3.4. Power (P_t) and Efficiency (η_t) 2-inch BAT Due to Variation in Discharge (Q) at Constant Rotation Speed

The results of the analysis revealed that 2-inch BAT has better characteristics and achievements compared to the other three BAT sizes, as evidenced by the higher efficiency and constant head variations. Subsequent analysis focused on the 2-inch BAT to determine the effect of variations in discharge on turbine power and efficiency. From the four tables of analysis of 2-inch BAT, there is one value of the same rotation that is 800 rpm. This analysis is focused on a constant rotation of 800 rpm as the rotation which produces the greatest efficiency. Recapitulation of data related to this analysis as shown in Table 4.

Table 4. Power and efficiency of 2-inch BAT due to variations in discharge (Q) at a constant rotation of 800 rpm

No	Head, H_t (m)	Discharge, Q (L/s)	BAT Power, P_t (W)	Discharge Ratio, Q/Q_{max}	BAT Efficiency, η_t (%)
1	4	2.60	0.0	0.312	0.00
2	6	3.37	37.76	0.404	18.30
3	10	5.60	250.16	0.671	45.39
4	14	8.34	583.02	1.000	50.90

Furthermore, the discharge, power and efficiency data in Table 4 are plotted into the curve then the turbine rise power trend information and efficiency are obtained due to the influence of discharge variations as shown in the curve in Figure 21.

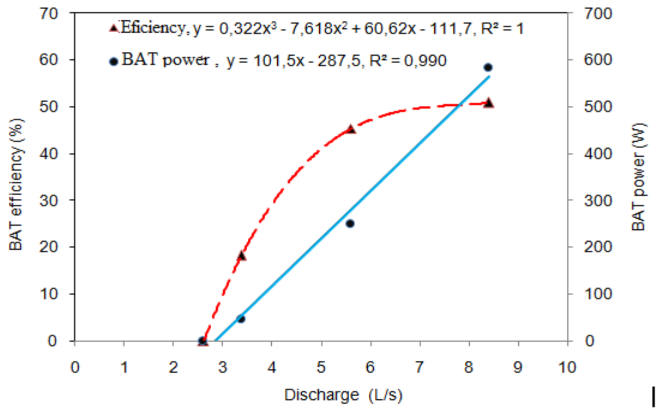


Fig. 21. Power (P_t) and efficiency (η_t) 2-inch BAT due to variations in discharge (Q) and constant rotation

Figure 21 explains that discharge has a consistent effect on increasing turbine power as seen from the power trends that form a linear curve. This is in accordance with the turbine power equation that is $P_t = Q \times H_t \times \rho \times g \times \eta_t$, turbine head ($H_t$) and turbine discharge (Q) as variables and ρ and g are constants. From the linear curve, it is known that the maximum turbine power of 583.02 W occurs at an optimum discharge of 8.34 L/s with a maximum efficiency of 50.90%, turbine rotation 800 rpm and 14 m head. While the efficiency curve forms a polynomial line, it means that water discharge is not the only factor that affects the BAT efficiency value. Other variables that affect efficiency include the construction quality of the BAT, especially the impeller components which are starting to saturate at certain test positions. In the discharge interval from 2.6 L/s to 5.6 L/s, the efficiency trend increases dramatically, this shows that in this discharge range BAT is very sensitive to changes in discharge. At a discharge interval of 5.6 L/s to 8.34 L/s turbine operations begin to saturate or are less sensitive to changes in water flow that occur. At a discharge position of less than 2.6 L/s, BAT has not been able to produce power to the lowest efficiency achievement. Discharges below 2.6 L/s are called start discharges while water discharges above 2.6 L/s to 8.34 L/s are referred to as effective discharges.

3.5. BAT efficiency of 2 inches (η_t) due to the Effect of Discharge Ratio (Q/Q_{max})

The discussion continues to determine the efficiency trend due to the effect of variations in the discharge ratio at a constant rotation of 800 rpm. Curves of the results of the analysis generally apply that can be used to determine the trend of BAT efficiency without being limited by the size of the discharge system generator. Figure 22 is the result of plotting the data of the discharge ratio and efficiency in columns 5 and 6 of Table 4 into the curve.

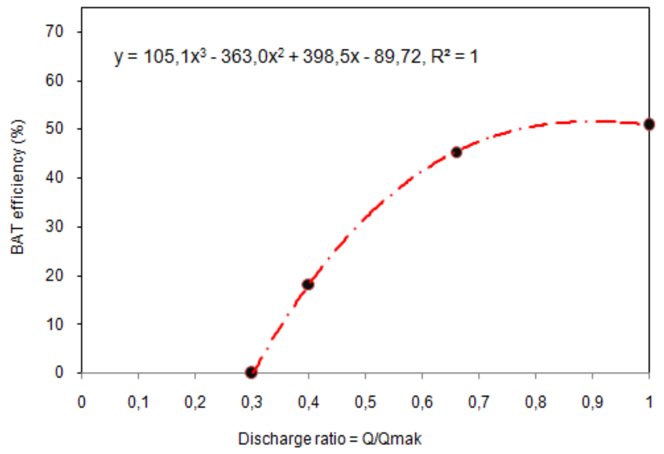


Fig. 22. Efficiency curve (η_t) of 2-inch BAT due to the effect of variations in the discharge ratio (Q/Q_{max})

Figure 22 curve can be analyzed that at a discharge ratio below 0.3, turbine efficiency reaches the lowest point, meaning that at this interval BAT has not been able to produce power. But the discharge ratio between 0.3 to 0.9 increases the turbine efficiency significantly. The formed efficiency trend produces a polynomial curve with a mathematical equation $y = 105.1x^3 - 363.6x^2 + 398.5x - 89.72$, $R^2 = 1$. Furthermore, a discharge ratio of 0.9 to 1.0 produces a relatively constant efficiency trend. This situation explains that BAT is getting saturated or less sensitive to changes in the discharge ratio above 0.9. This is due to the construction of the impeller or house volute can not compensate or adjust to the addition of water discharge. Thus the highest efficiency of the 2-inch BAT of 50.89% occurs at a discharge ratio of 0.9, which is a finding that can be used as a performance measure of centrifugal blowers as turbines.

3.6. BAT Efficiency Curves with Conventional Turbines for Comparison

Figure 23 explains, that the BAT efficiency curve has a trend of increasing efficiency similar to the trend of increasing efficiency of a francis turbine. The trend of the efficiency curve that occurs is an orderly rise that is consistent from the minimum efficiency to reach maximum efficiency. This is very possible because the construction of volute and centrifugal blower impeller resembles the volute and the francis turbine impeller. BAT has the highest efficiency achievement reaching 50.89% at a discharge ratio of 0.9. At a discharge ratio below 0.3, BAT has not been able to produce visible power from its low efficiency value. Furthermore, by looking at the curve of Figure 23, it is known that the BAT efficiency achievement is lower than that of all conventional turbines, especially with a Francis turbine, this is due to the curvature of the BAT blade backing towards the impeller inlet water as shown in Table 2. In the Francis turbine, the curvature of the impeller blade faces or challenges the direction of water enter the impeller so that the efficiency of a Francis turbine is better than BAT. In addition, the Francis turbine impeller is technically different from a centrifugal blower impeller, the Francis turbine impeller is designed as a turbine and the BAT impeller is designed as a blower.

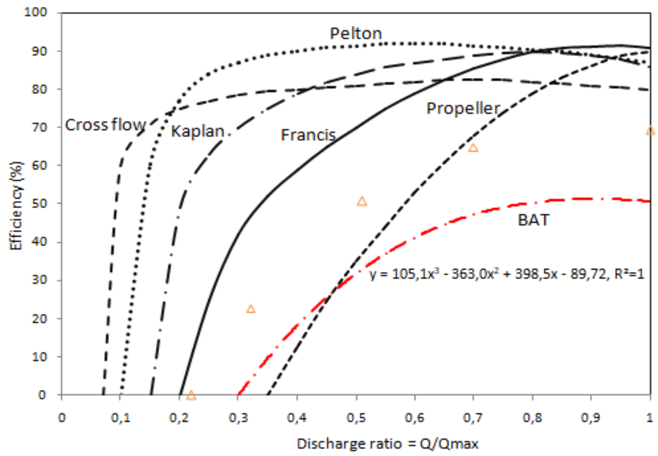


Fig. 23. BAT efficiency curve compared to five conventional turbines

4. Conclusion

BAT test results are in accordance with the test installation used, it is known that the smaller the size of the blower results in better performance. 2-inch blowers produce performance that is superior to the size of the centrifugal blowers above. Performance of 2-inch BAT at a discharge of 8.34 L/s and constant head of 14 m produces torque of 8.3 N m, power of 583 W, and maximum efficiency of 50.90% at 800 rpm. Discharge of turbine inlet is less than 2.6 L/s, BAT has not been able to produce power so that the lowest performance. Water discharge below 2.6 L/s is called starting discharge while water discharge above 2.60 L/s to 8.34 L/s is called effective discharge. The highest efficiency of 2-inch BAT of 50.90% occurs at a discharge ratio of 0.9 and the formed efficiency curve produces a mathematical equation $y = 105.1x^3 - 363.6x^2 + 398.5x - 89.72$, $R^2 = 1.0$. Testing at a constant rotation of 800 rpm, it is known that the discharge ratio is below 0.3, the efficiency of 2-inch BAT reaches the lowest point, meaning that at this interval BAT has not been able to produce power. Starting from the discharge ratio of 0.3 to 0.9 the increase in turbine efficiency has increased significantly, this shows that BAT is quite sensitive in terms of increasing power changes due to the addition of water discharge. Furthermore, from changes in the discharge ratio of 0.9 to 1.0 resulting in a slightly decreasing efficiency trend, this situation explains that the BAT is starting to saturate or is less sensitive to changes in the discharge ratio above 0.9. This is due to the construction of the impeller or volut house which cannot compensate or adjust to the addition of discharge. The efficiency of 2-inch BAT efficiency can be improved by modifying the impeller, namely by improving the curvature of the blades so that they approach the curvature of the francis turbine blade.

Acknowledgments

Thank you to all parties, especially Fluid Dynamics Laboratory assistants, Andalas University, who have contributed in testing the performance of centrifugal blowers as turbines.

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