

Analysis of pipe diameter variation in axial pumps for reducing head loss

E Widodo and R Y Pradhana

Universitas Muhammadiyah Sidoarjo, Indonesia

ediwidodo@umsida.ac.id

Abstract. Axial type water pumps are widely used in daily activities. The size of the output pipe has a significant influence on the efficiency and performance of the pump performance. By changing the size of the pump will cause changes in flow velocity and fluid pressure on the pipe. The PVC pipe used in this test is 1, 1/2', 1', 3/4', 1/2' inches. By varying the pipe press carried out measurements of flow speed generated, as well as the flow of the water in the pipe. The length of the pipe causes the loss of the head, because the friction of fluid with the pipe surface is wider. While the pipe size change that will cause fluid flow change. From the test results obtained fluid flow that occurs is turbulent flow with Reynold numbers 17.050 up to 59.884. The lowest head loss value occurs on the 1.5 "pipe size of 2.504, with a water debit of 41×10^{-5} m³ / s. The water flow through the pipeline causes the Reynolds' to be lower, if the water flow is low. The tendency of the liquid stream to be laminar, and the flow rate becomes lower.

1. Introduction

The axial pump is a positive displacement pump with rotary components such as lobes, gears, threads, vanes, and rollers. The way it works is to pump the liquids to the suction side, and push it into the gap or the press room between the pumping components, then pressed so that the smaller the gap further liquid is removed through the side of the exhaust. The fall in pump performance suddenly and instability in the operation would be a problem, an indication of the cause of the decline in the performance of the pump is one caused by cavitation [1]

The problem raised in this study was to find out whether there was any effect on the size of the rotary PVC pump pipe on the speed of the water thrust. There is also this study discussing the size of PVC pipe with a variety of diameters (1½", 1", ¾", ½") discusses the rotational force of the pump on the PVC pipe and discusses the speed of water pressure in each variation of PVC pipe diameter, but this research except the discussion about the rotary pump components of the machine.

This study was conducted with the aim of knowing on the size of PVC pipe required for a rotary pump speed of water thrust, knowing the thrust on the tested rotary pump and for knowing the value of the water compressive velocity on a predetermined PVC pipe. The benefit of this research to know about the size of PVC pipe with the use of rotary pump, to know the speed of water coming out with various sizes of PVC pipe and know the thrust of the rotary pump.



2. Methodology

PVC pipe used with diameter variation (1½", 1", ¾", ½"). The research steps on the pump which is assembled starting from the planning of PVC pipe installation, installation of PVC pipe, data collection, data processing, discussion and conclusion. Data analysis performed using SPSS for Windows 10 software.

2.1. Fluid flow in the pipe

In the drainage process inside the pipe there is a loss of the pump pressure which is often called head losses. The flow type in the pipe is a turbulent type, since the value of the Reynolds number [2] and [3]. There are several fluid streams in the pipeline that are steady flow and flow on a straight pipe. On straight pipeline flow is classified into laminar and turbulent flow. To determine whether a flow is laminar or turbulent a Reynold number as in table 1 can be used using equation (1).

$$Re = \frac{V.D}{\nu} \quad (1)$$

Where:

Re = Reynold number.

V = average of velocity of flow in pipe (m/s).

D = inner diameter of pipe (m).

ν = kinetic viscosity (m²/s).

Table 1. Reynold number.

Reynold number	Characteristics
< 2000	Laminar flow
> 4000	Turbulent Flow

2.2. Regression

Regression in the modern sense [4, 5] is the study of the dependence of a variable, which is variables depend on one or more other variables or it called explanatory variables in order to make estimates and / or prediction about the average population or the mean value. Variable values are dependent in relation to know the values of their explanatory variables. According to [6] and [5], the regression is used to determine the nature and strength of the relationship between two unknown variables and the view on past observations of the variables and other variables. Since Levin & Rubin in defining the regression also use the term "correlation analysis", it is preferable in this section that the authors need to explain the difference between regression and correlation. According to [4] and [5] correlation analysis aims to measure the strength or degree of linear association between two variables.

2.3. Head losses

The compressive height is the height of the rising fluid column to obtain an amount of energy equal to that of one unit of fluid weight under the same conditions. A compressive loss is one of the unavoidable losses in a fluid flow in the form of reduced pressure on a stream, and the results on reduced flow velocity. One of the most common and irreversible disadvantages of piped water flow is compressive losses due to friction and cross-sectional change or pipe bends that interfere with normal flow. This causes the water flow to become weaker and smaller [3, 7]. Head Losses is obtained by using equation (2).

$$hl = f \frac{LV^2}{D2g} \quad (2)$$

Where

D = pipe diameter (m).

V = velocity average of flow in pipes (m/s).

- L = pipe length (m).
 G = acceleration of gravity (9.81 m/s²).

2.4. Coefficient of losses

In a stream through a pipe system or installation there is a flow resistance. These barriers are caused by form-installation factors. These barriers can cause a decrease in energy from a fluid that is often called a head loss or pressure drop caused by the influence of friction losses and changes in flow patterns. In the laminar flow conditions, the frictional resistance is only affected by the viscosity of the fluid. However, in the turbulent flow the resistance is affected by the viscosity of the fluid and the pipe surface roughness. The effect of pipe surface roughness was first researched widely by Nikuradse. The results of his experiments show that surface roughness greatly affects the flow of high Reynolds, the coefficient of friction depends on the Reynolds number. Von Karman lowered the formula for turbulent flow by including surface roughness. The result of the decrease is shown in equation (3).

$$\frac{1}{\sqrt{f}} = 1.14 + 2 \log \frac{D}{e} \quad (3)$$

Blasius equation also describes the coefficient of friction for turbulent flow as shown in equation (4).

$$f = 0.3164 Re^{-\frac{1}{4}} \quad (4)$$

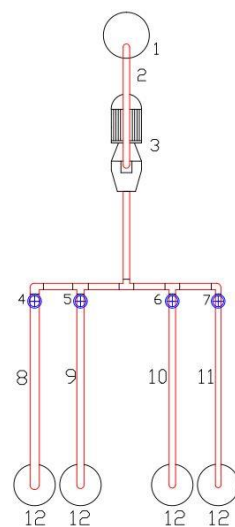
According to [8], Moody developed the experimental results of Nikurades into a mathematical model and succeeded in plotting a graph of friction coefficient relation with the Reynold number of turbulent flow with surface hardness variation. In this study as for materials and equipment used are as follows:

- a) Centrifugal pump.
- b) PVC pipe with variation diameter 1½", 1", ¾" and ½".
- c) Knee.
- d) Chainsaw saws.
- e) Meter.
- f) Lock pipe.
- g) Glue pipe.
- h) Stopwatch.
- i) Glass measuring cup.
- j) Stop the faucet.
- k) Tee.
- l) Sok.
- m) Water union.
- n) Water reservoir.

After preparing the tools and starting materials with the installation of the pump installation, testing the flow velocity of the water fluid, the measurement of the flow of water flow until the calculation of thrust that can release water quickly. The operational procedure are:

- a) Provide tools and materials needed in research.
- b) Install the rotary pump used.
- c) Install PVC pipe to know the thrust of the water.
- d) Turn on the prepared pump.
- e) Begin research with a comparison of PVC pipe with various sizes by opening the lid of the faucet.
- f) Data retrieval and data processing required.

Figure 1 shows the research installation design.



Where:

1. Water container
2. Suction pipe $\frac{3}{4}$ "
3. Pump
4. Valve 1
5. Valve 2
6. Valve 3
7. Valve 4
8. Pipe $1\frac{1}{2}$ "
9. Pipe 1"
10. Pipe $\frac{3}{4}$ "
11. Pipe $\frac{1}{2}$ "
12. Water reservoir

Figure 1. Research installation design.

3. Result and discussion

Average data time required to move 5 liters of water from tub A to tub B PVC press pipe on rotary pump with diameter $\frac{1}{2}$ " is 10.361 s, diameter $\frac{3}{4}$ " is 10.695 s, diameter 1" is 10.944 s, and the diameter of $1\frac{1}{2}$ " is 19.931 s. Then from the obtained average it is continued with regression analysis using SPSS 20. The correlation is shown in table 2, regression is shown in table 3 and hypothesis is shown in table 4.

Table 2. Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.990 ^a	0.980	0.970	0.116739

a. Predictors: (Constant), X1

b. Dependent Variable: Y1

Table 3. Anova^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.343	1	1.343	98.532	0.010 ^b
	Residual	0.027	2	0.014		
	Total	1.370	3			

a. Dependent Variable: Y1

b. Predictors: (Constant), X1

Table 4. Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	9.514	0.159		59.801	0.000
	X1	1.567	0.158	0.990	9.926	0.010

a. Dependent Variable: Y1

In the coefficients in table 4, the column B Constant (a) is 9.514, while the value (b) 1.567, so the regression can be written as $Y = a + bX$ or $Y = 9.514 + 1.567X$.

3.1. Debit calculation

Obtained Q (discharge) with known volume of 5 liters which was first converted to 0.005 m^3 and to obtain the discharge calculated by using an equation (5).

$$\text{If } V = Q \cdot t \text{ then } Q = \frac{V}{t} \quad (5)$$

Where:

V = Volume (m^3)

Q = Debit (m^3/s)

T = Time (s)

Then the average of 5 liters discharge is obtained, followed by manual calculation to know the head losses.

3.2. Calculation of cross-sectional area

Calculate the flow velocity (v) by using the formula $Q = v \cdot A$, since the cross-sectional area is not known then, look for the cross-sectional area using the formula $A = \pi r^2$ or $A = \frac{1}{4} \pi D^2$ [6], where D is the diameter of pipe 1 inch = 0.0254 m.

3.3. Calculation of flow velocity

The flow velocity (v) is calculated using equation (6).

$$v = \frac{Q}{A} \quad (6)$$

Where:

Q = Debit (m^3/s)

V = flow velocity (ms)

A = Area of cross section (m^2)

3.4. Calculation of Reynolds number

There are several fluid streams pipe that is steady flow and flow on straight pipe. In straight stream pipes are classified into laminar flow, transition stream, and turbulent flow. To determine whether the flow is laminar or turbulent can be used Reynolds number

$$\text{Re} = \frac{V \cdot D}{\nu} \quad (7)$$

Where:

Re = Reynold number

V = average velocity of flow in pipe (m/s)

D = inner diameter of pipe (m)

V = kinetic viscosity (for temperature $30^\circ = 0.804 \times 10^{-6} \text{ m}^2/\text{s}$)

3.5. Calculation of coefficient losses

When calculating the losses head using turbulent flow because all of $\text{Re} > 4000$ which includes turbulent flow. The calculation of coefficient losses is shown in equation (8).

$$f = 0.3164 \text{ Re}^{-\frac{1}{4}} \quad (8)$$

Head Losses are obtained using equation (9) and the result of head loss calculation is shown in table 5 and figure 2.

$$hl = f \frac{LV^2}{D^5g} \quad (9)$$

Where:

- D = pipe diameter (m)
- V = average velocity of flow in pipes (m/s)
- L = pipe length (m)
- G = acceleration of gravity (9.81 m/s²)

Table 5. Calculation of head losses.

Diameter of Pipe	Head Losses	Debit (m ³ /s)	Velocity of flow (m/s)	Coeff Losses (f)	Reynold number
½"	1,141.957	48×10 ⁻⁵	3.791	20×10 ⁻³	59,884.139
¾"	123.476	46×10 ⁻⁵	1.615	22×10 ⁻³	38,259.311
1"	6.488	45×10 ⁻⁵	0.889	24×10 ⁻³	28,070.690
1 ½"	2.504	41×10 ⁻⁵	0.359	28×10 ⁻³	17,050.345

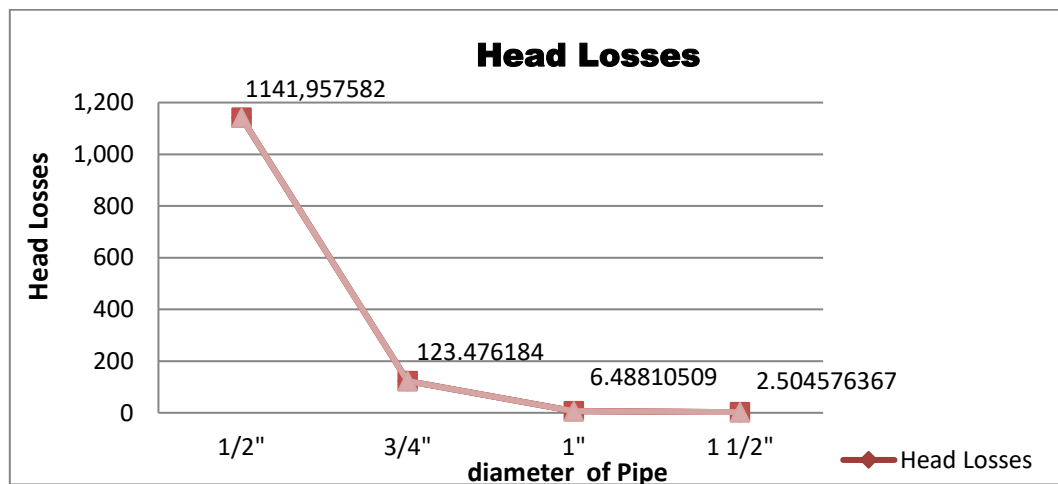


Figure 2. Graph of head losses.

Figure 2 shows the graph of data collection diameter PVC pipe with a variety of pipe size ½", ¾", 1", 1 ½". The graph in figure 2 explains the highest value of Head Losses has a value of 1,141.957582 with ½" diameter pipe and the lowest value has a value of 2.504576367 with a diameter of 1 ½" pipe. In the graph above shows the higher the value of Head Losses, the higher the thrust force in the pipe and the thrust force it is in the ½" diameter pipe.

Figure 3 shows that the highest point of water discharge on a ½" PVC pipe with a value of 48 × 10⁻⁵ m³/s and the lowest point of PVC pipe water discharge on a 1 ½" pipe size with a value of 41 × 10⁻⁵ m³/s. Graph in figure 3 shows that the PVC pipe size ½" is higher or faster in moving water from tub A to tub B while the PVC pipe is 1 ½" slower, this is because PVC pipe diameter is very influential in the soon or later the water is flowing.

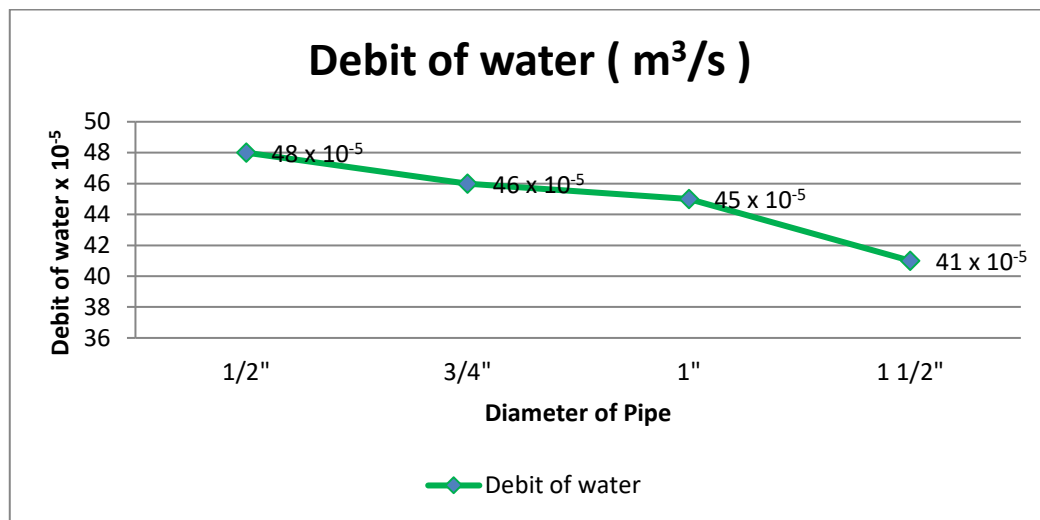


Figure 3. Graph of debit of water.

In figure 4, the comparison of the graph of the water discharge data to the Reynolds number explains that the smaller the diameter of the PVC pipe then the water debit value will be large and comparable with the Reynold number value the smaller the size of the PVC pipe then the Reynold number will be greater, The larger the diameter of PVC pipe then the smaller the value of the water debit and the value of the Reynold number.

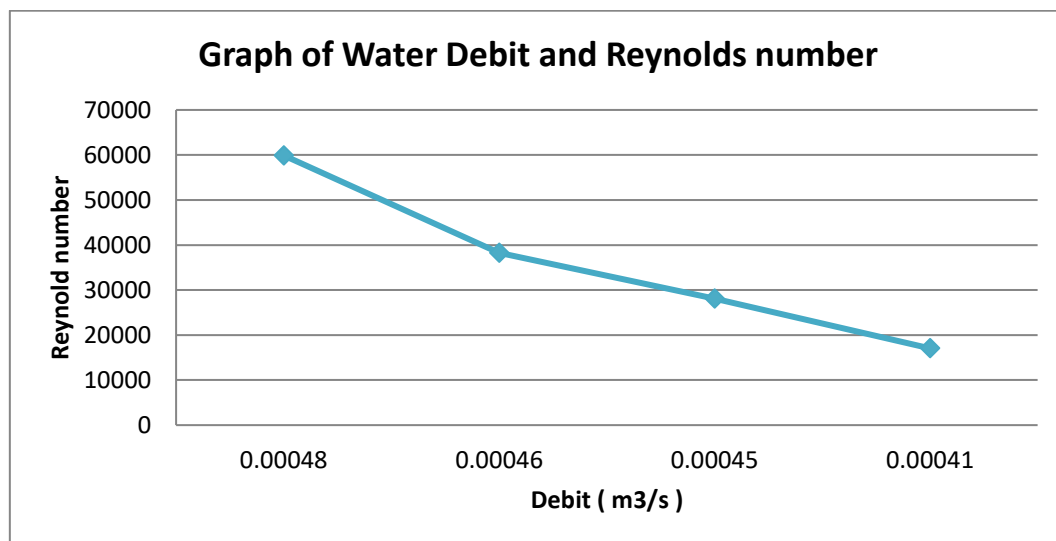


Figure 4. Graph of water debit and Reynolds number.

4. Conclusion

Based on the data obtained, the pipeline further accelerates the water push force on the rotary pump with the diameter of the pipe 1/2". In this research can be obtained data showing that PVC pipe diameter pipe 1/2" can accelerate the water push force of the rotary pump with the last time. This water-push acceleration study using PVC pipe with different variations in the rotary pump can be a good reference for the use of pvc pipe on rotary pumps. The smaller the size of the PVC pipe taken, the faster the resulting thrust force. The thrust energy generated on the PVC pipe diameter of 1/2" pipe in

this study can be used to save the cost and time required to drive water using a rotary pump as a vacuum.

References

- [1] Alfayez L, D Mba D and Dyson G 2005 The application of acoustic emission for detecting incipient cavitation and the best efficiency point of a 60kW centrifugal pump: Case study *Ndt & E International* vol 38 no 5 pp 354-8
- [2] Ozbayoglu E M and Sorgun M 2010 Frictional pressure loss estimation of non-newtonian fluids in realistic annulus with pipe rotation *Journal of Canadian Petroleum Technology* vol 49 no 12 pp 57-64
- [3] Chiaramonti D, Prussi M, Casini D, Tredici M R, Rodolfi L, Bassi N, Zittelli G C and Bondioli P 2013 Review of energy balance in raceway ponds for microalgae cultivation: re-thinking a traditional system is possible *Applied Energy* vol 102 pp 101-11
- [4] Juana L, guez-Sinobas L R and Losada A 2004 Closure to “Determining Minor Head Losses in Drip Irrigation Laterals. I: Methodology” by Luis Juana, Leonor Rodr ı́ guez-Sinobas, and Alberto Losada *Journal of irrigation and Drainage Engineering* vol 130 no 3 pp 255-6
- [5] Provenzano G, Pumo D and Dio P D 2005 Simplified procedure to evaluate head losses in drip irrigation laterals *Journal of irrigation and drainage engineering* vol 131 no 6 pp 525-32
- [6] Geem Z W, Kim J H and Loganathan G V 2002 Harmony search optimization: application to pipe network design *International Journal of Modelling and Simulation* vol 22 no 2 pp 125-33
- [7] Romeo E, Royo C and Monzón A 2002 Improved explicit equations for estimation of the friction factor in rough and smooth pipes *Chemical engineering journal* vol 86 no 3 pp 369-74
- [8] Fang X, Xu Y and Zhou Z 2011 New correlations of single-phase friction factor for turbulent pipe flow and evaluation of existing single-phase friction factor correlations *Nuclear Engineering and Design* vol 241 no 3 pp 897-902