Pump as Turbine for Micro Hydro Power

by

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8063

Dissertation submitted in partial fulfilment of
the requirements for the
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(Mechanical Engineering)

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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have on been undertaken or done by unspecified sources or persons.

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NOR AZEANTY MOHD ADZAN

ABSTRACT

Using pump as turbine and induction motor as generator has numerous benefits for remote area hydro project in term of cost saving. The objectives of this project are to determine the head and flow rate of a centrifugal pump in turbine mode, to design pump as turbine test rig and to test a centrifugal pump as a turbine and induction motor as generator to develop turbine characteristic at various head and flow rate. People who live in rural area are hard to get electrical source from grid connection. Using a centrifugal pump as turbine instead of conventional turbine can reduce the installation cost. Unfortunately it is difficult to find turbine characteristics that are needed to select the correct pump at site. Methodology involved in this study includes the initial prediction of centrifugal pump as hydro turbine, designing the pump as turbine test rig and performs a testing in order to find the characteristic of the pump in turbine mode. The tested result shows that the value of head, hydraulic power and voltage output increase with the increasing of flow rate. This project has could help to understand more on the application of centrifugal pump as turbine for generating small scale hydro power.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Micro hydro power is relatively small power source from flowing water that appropriate to supply power from 5kW up to 100kW. This power is converted into electricity using an electric generator. It can be simplified as moving water from stream flows through penstock and turns a turbine, turbine spins a generator and electricity is produced.

Micro hydro system is usually applicable for remote area community where is failed to get electricity connection from national grid. The areas with available of flowing water all over the year are the most suitable for micro hydro application.

In some cases centrifugal pump is more appropriate to replace the turbine and run it in reverse in some cases in micro hydro power system. Using pump as turbine and induction motor as generator has numerous benefits for remote area hydro project in term of cost saving. Pumps also are easy to install because are manufactured to operate under a wide range conditions.

A main problem using centrifugal pump as turbine is the difficulty of finding the turbine characteristics that are needed to select the correct pump for a particular site. It is recommended that after initial selection, the pump is tested as a turbine to find out what power will be produced at the available head and flow.

1.2 Problem Statement

Nowadays, electrical power is important in developing socio-economic status. People who live in rural area are hard to get electrical source from grid connection. Diesel and gasoline generators are currently cheaper to buy but due to the increasing the cost of fuel oil and maintenance has made them expensive to operate. Installing dams to produce electricity at rural area requires high cost of construction reservoir and maintenance and also has environmental effects. Using a centrifugal pump as turbine instead of conventional turbine can reduce the installation cost. Unfortunately it is difficult to find turbine characteristics that are needed to select the correct pump at site. A specific centrifugal pump will be converted to a turbine at required head and flow rate and will be tested to find its turbine characteristics.

1.3 Objectives of Study

Upon completing the project, a few objectives need to be achieved. The objectives of the study are as follows:

1. To determine the head and flow rate of a centrifugal pump in turbine mode.
2. To design pump as turbine test rig.
3. To test a centrifugal pump as a turbine and induction motor as generator to develop turbine characteristic at various head and flow rate.

1.4 Scope of Study

The scope of study is to conduct study on the current use of pump as turbine and motor as generator for Micro hydro system which has been applied as source of electrical energy. The design, applications and principle of micro hydro system is reviewed. An initial estimation of suitable head and flow rate of a pump at turbine mode will be determined. Engineering calculations is carried out to determine all the parameters required in setting up the pump as turbine test rig. A specific centrifugal pump will be tested as a turbine to analyze the required head of flow rates at maximum produced. The result of the test will show the turbine characteristic of a centrifugal pump.

1.5 Significance of Study

A specific centrifugal pump will be converted as a turbine for hydro electric generation. Initial calculation is made to determine the appropriate head and flow rate in turbine mode. The pump as turbine test rig will be designed in order to test the pump as turbine to find turbine characteristic. The result produced will give the actual best efficiency point of a turbine at maximum power produced. Result obtained from this study will be used to recommend the installation of standalone power generation system for domestic use in Malaysia. This study could help remote area communities to have access to alternative energy supplies by using other type of hydro turbine.

1.6 The Relevancy of the Project

Malaysia has many water sources such as river and waterfall that can be used as renewable sources to generate electricity. Micro hydro system can be used in remote area in order to reduce problems occur in current micro hydro system. Using centrifugal pump as turbine can reduce the installation cost.

CHAPTER 2

LITERATURE REVIEW

2.1 Case Studies

The project of pump as turbine for pico hydro system at the village of Thima in Kenya was installed by Micro Hydro Centre at Nottingham Trent University in collaboration with ITDG East Africa and the report was prepared by P.Maher, N.P.A. Smith and A.A Williams (2003). It used pump as turbine directly coupled to induction motor as generator. The system was designed to provide 2.2 kW of electrical output to be supplied to 110 households in the village by 20 watts per house. The water source is from small river with natural fall 20 meters and normal flow rate at 100 l/s. A head of 20 m and flow rate of 28 l/s were chosen to produce adequate power output by considering the reasonable head loss which was about 10%. 90m long of low-pressure PVC penstock was supported on soil bags and covers to prevent damage by sunlight. By using the value of head and flow rate of the pump as turbine, the pump data was estimated with 10.96m of head and 20.6 l/s of flow rate at best efficiency point (BEP). The 3.7 kW induction motor KDS 515+ centrifugal pumps with end suction type with rated head of 12.5m and flow rate of 22 l/s at BEP of 75% was chosen which was close to the required site head and flow. The turbine power output to generator was approximately 3214 watts. By assuming a generator efficiency of 75%, the electrical power output was 2.4kW. [1] However, testing of pump as turbine had been done before installation of the system. It is proven that the disadvantage of relying on the calculated prediction of turbine prediction. The satisfactory solution was found after testing the pump and the scheme can provide basic but reliable power to more than 100 households

The second project is in Huai Kra Thing village in Thailand. According to Chris Greacen (2006), one of the people who got involved in installation an off-the-shelf centrifugal pump running backwards as a turbine and running the pump's induction motor backwards as a generator. The system can generate up to 3kW, but in order to keep more water in the stream, it was throttled back to about 1.6kW by providing 10 l/s. The penstock was set up with 5 meters deep trench about 30 meters of hillside and extended pipe elevation section for 50 meters that also crossed over the stream in order provide sufficient head to the turbine. 4kW induction motor run as generator was provided excitation by using two capacitors in a "C-2C" wiring arrangement and used 3 kW ballast load. The electricity was transformed by a custom-made 380 volt-to-235 volt 3 kW transformer and 220 volt power was transmitted throughout the village to the clinic, school, community centre, two churches and village headman's house. [11]

Shahram Derakhshan and Ahmad Nourbakhsh (2007) from deparment of Mechanical Engineering, Faculty of Enineering, University of Tehran did an experimental study of characteristic curves of centrifugal pumps working as turbines in different specific speeds. This is because pumps manufacturers do not normally provide the characteristic curves of their pumps working as turbines. Several centrifugal pumps with range N_s 14 to 56 (m,m^3/s) were tested as turbines. It used two pumps which is one running as feed pump to provide flow rate and head to pump as turbine (PAT) in order to generate proper power. PAT, a feed pump, several pipes, an orifice, a generator and some ballast loads were selected and installed in the test rig. The experiment showed that PAT worked in higher head and flow rate than those of the pump mode at the same rotational speed and the efficiencies are almost the same on both pump and turbine modes. [12]

2.2 Micro Hydro System

Hydro power is power that is derived from the force of energy of flowing water and can be harnessed for useful purpose. Hydropower plants capture the energy of falling water to generate electricity. A turbine converts the kinetic energy of falling water into mechanical energy. Then a generator converts the mechanical energy from the turbine into electrical energy to become hydroelectricity. Micro hydro power is small hydropower system that can generate electricity less than 5kW.

Water from river is directed to intake which is the highest point and can be simple as screened pipe dropped into a pool of water. Water flows through the penstock will enter the turbine and convert the energy of flowing water into mechanical energy. Generator is connected to turbine by using set of gears, belts or chain converts mechanical energy from the turbine to electrical energy.

Micro hydro system has three components which are:

1. A water turbine is a heart of this system that converts the energy of flowing water into mechanical energy that drives the generator to generate electrical power.
2. A control panel to produce stable electrical power.
3. Electrical transmission line to deliver the power to users [2].

This project focuses on the first component which is how to convert flowing water at available site into mechanical energy at turbine to run the generator and produce small electricity that can be used at remote area.

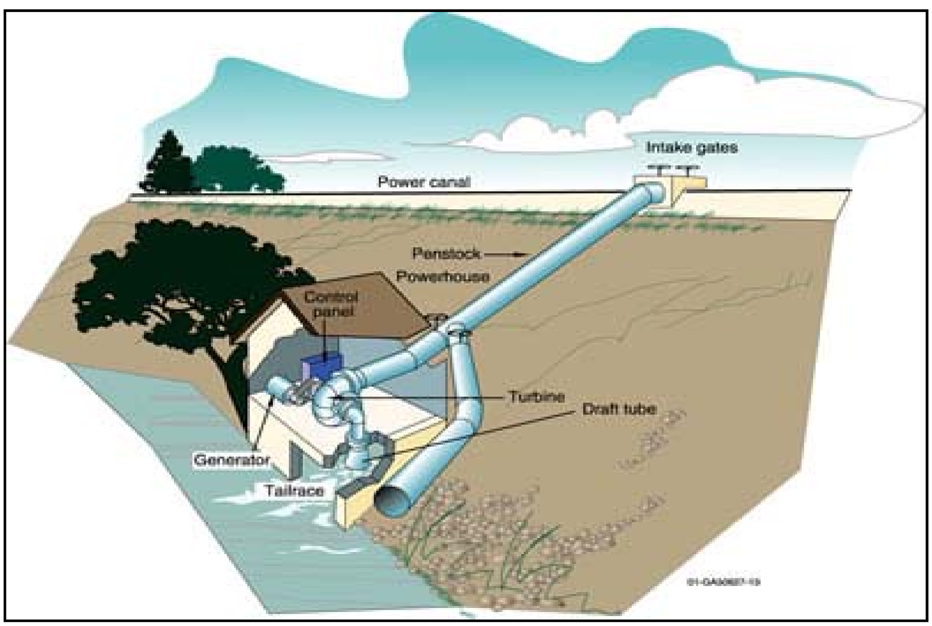


Figure 1: Micro Hydro System

Below are the functions of major components of Micro hydro system:

a. **Intake:** intake can be as simple as screened box submerged in the watercourse, to divert debris and air free water into pipeline.
b. **Penstock (Pipeline):** Penstock is not only used to allow water to flow to the turbine, but an enclosure that create head pressure as the vertical drop increase.
c. **Turbine:** The force falling water from penstock pushes against turbine's blades and cause the turbine to spin. The turbine converts the kinetic energy of falling water into mechanical (rotating) energy. The choice of turbine will depend mainly on the pressure head available and the design flow for the proposed hydropower installation.
d. **Generator:** Generator can be connected by shaft and gears or chain or belt, so that it will spin when the turbine spins. It converts the mechanical energy to electrical energy.

2.3 Hydro Turbines

Turbine is the part of the system which harnesses the hydro power and turns it into mechanical (rotating) power.

Hydro turbine is categorized under two main types which are reaction and impulse.

2.2.1 Reaction Turbine

Energy of the water is converted from pressure to velocity within the guide vanes and the turbine wheel itself. They spin themselves around as a reaction to the action of the water squirting from the nozzles in the arms of the rotor. Propeller and Francis turbines are the example of reaction turbines [3].

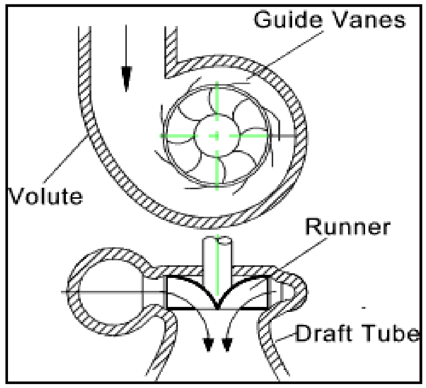


Figure 2: Reaction Turbine

2.2.1 Impulse Turbine

This turbine uses a nozzle at the end of the pipeline that converts the water under pressure into a fast moving jet and then directed at the turbine wheel which is called runner. It is designed to convert as much of the jet's kinetic energy as possible into shaft power. Pelton, turgo and cross-flow are the example of impulse turbine [3].

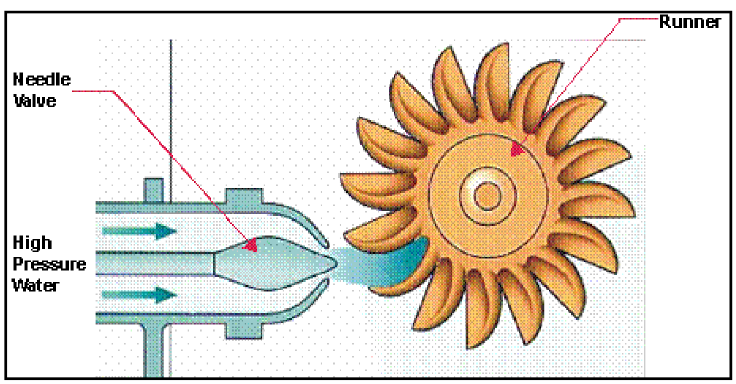


Figure 3: Impulse Turbine

2.4 Pumps as Turbines for Micro Hydro Power

Typical hydropower systems convert the energy of falling water to mechanical energy with a turbine. In some cases, it may be more appropriate to replace the turbine with a centrifugal water pump, and run it in reverse. The words 'pump' and 'turbine' are used interchangeably in this manual, as are the words 'motor' and 'generator'. Using a pump as a turbine has numerous benefits for rural micro hydro projects in the developing world. Pumps are manufactured to operate under a wide range of conditions, are easy to install, and spare parts for these pumps are easy to find. [4]

Centrifugal pumps run pretty well backward. Their capacity suffers somewhat and their head generation is off, but they run smoothly. Since many pumps are oversized for both head and capacity anyway, the process generally does not suffer. [5]

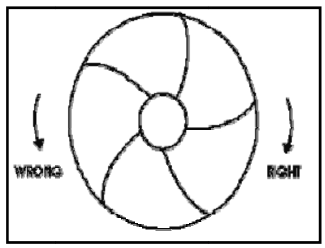


Figure 4: Rotation of Centrifugal Pump

In general, all centrifugal pumps classified as Radial, Mixed Flow and Axial Flow types closely resemble reaction turbines. Thus, it may be said that

a. A radial pump is just reverse of a radially inflow reaction turbine.
b. A mixed flow pump is just a reverse of mixed flow type of turbine such as Francis Turbine.
c. An axial flow pump is just reverse of a propeller or Kaplan Turbine.

Arthur Williams in the book “Pumps as Turbines: A user Guide” stated using the standard centrifugal pump unit with end suction has a number of advantages over conventional turbines for micro hydro power generation. The main advantages are as follows:

a. Integral pump and motor can be purchased for use as a turbine and generator set.
b. Available for a wide range of head and flows.
c. Available in a large number of standard sizes.

d. Low cost.
e. Short delivery time.
f. Spare parts such as seals and bearings are easily available.
g. Easy installation – uses standard pipe fittings.

Pump as turbine requires fixed flow rate. Therefore it is only suitable for sites where there is a sufficient supply of water throughout the year. The main disadvantages of using a pump as turbine is the difficulty of finding the turbine characteristics that are needed to select the correct pump for a particular site. Therefore, it is recommended that after initial selection, the pump is tested as a turbine to find out what power will be produced at the available head and flow [1].

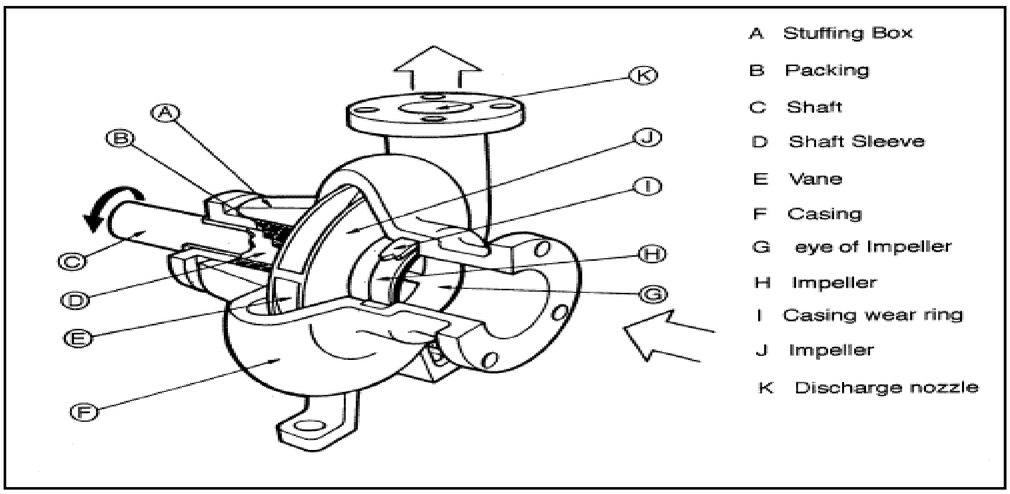


Figure 5: Centrifugal Pump

During CEEX 2007 Conference, using standard pumps as turbines can help reducing the total cost of small-scale hydropower schemes. Pumps as turbines can be used in village schemes in developing countries where the main electric requirement is lighting. The important advantages of pumps over conventional turbines are integral pump and motor can be purchased and can be used as a turbine-generator unit. It is also available for wide range of heads and flows, available in large number of sizes, low cost, short delivery time and easy to install. However there are some limitations of using pumps as turbines which is the range of flow rates over which a unit can operate. It is much smaller than in a conventional turbine.

In this project, specific centrifugal pump will be tested at various ranges of head and flow rate in order to determine the performance of the pump works as turbine and analyze the maximum power output the pump can produce to suit the electricity need at one house at remote areas, specifically in lighting purpose.

2.5 Pumps as Turbines Performances

2.3.1 Normal Operation of Centrifugal Pump

Centrifugal pump works by employing centrifugal force to lift liquids from low position to high position. Impeller is fitted into shaft and rotates in volute casing. Water is pumped into centre impeller is pickup by vanes of impeller and accelerated to a high velocity by the rotation of impeller and then is discharged b centrifugal force into the casing and then out to discharge pipe. Vacuum is created at the centre to allow more flow in. [6]

Performance curve is a relationship between head and flow rate of the pump. When flow is increased, the head delivery head is decreased. The maximum value of efficiency varies accordingly to the type and size of the pump, usually in between 40% to 80%. [7]. Figure 6 shows the performance curve of centrifugal pump.

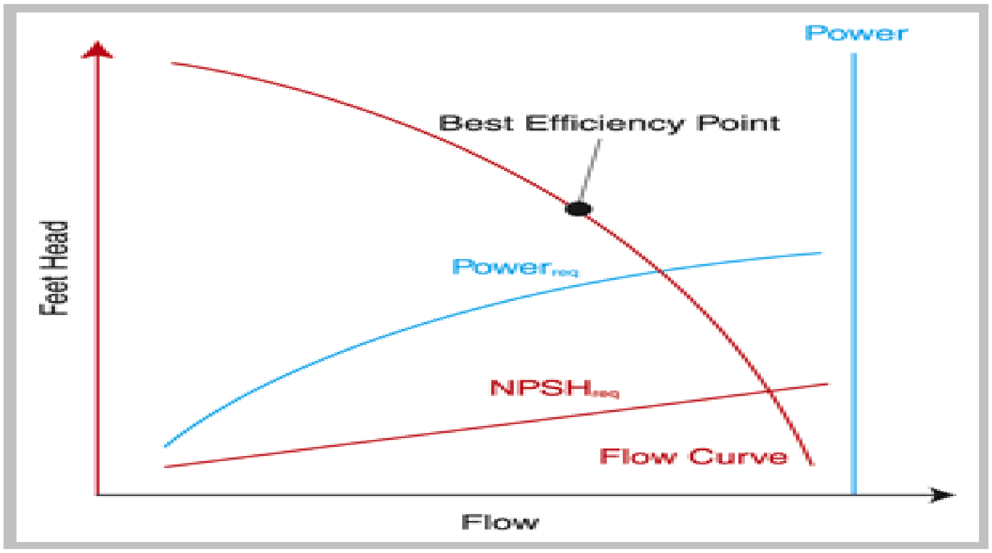


Figure 6: Centrifugal Pump Performance Curve. [8]

Hydraulic Power is the power output produced during pumping activity.

$$P_o = \rho \times g \times H \times Q \qquad \text{(Eq. 1)}$$

Where,

P_o is hydraulic power (watt)
ρ is the density fluid (kg/m^3)
g is the gravity (9.81 m/s^2)
H is delivery head (m)
Q is flow rate (m^3/s)

Power input is the power required to transfer from the motor to the shaft of the pump. It is depends on the efficiency of the pump and can be calculated as,

$$P_{in} = P_o / \eta \qquad \text{(Eq. 2)}$$

Where,

P_{in} is input power (watt)
P_o is output Power (watt)
η is pump efficiency

2.3.2 Pumps as Turbine Performance

Pumps as turbine can be used over the range covered by Pelton and small Francis turbines. However, for high head, low flow application, a Pelton turbine has a greater efficiency than a pump, at the same cost. Figure 5 show the head-flow range for various turbine options. This range of pumps as turbines is based on standard centrifugal pumps produced by major UK manufacturer.

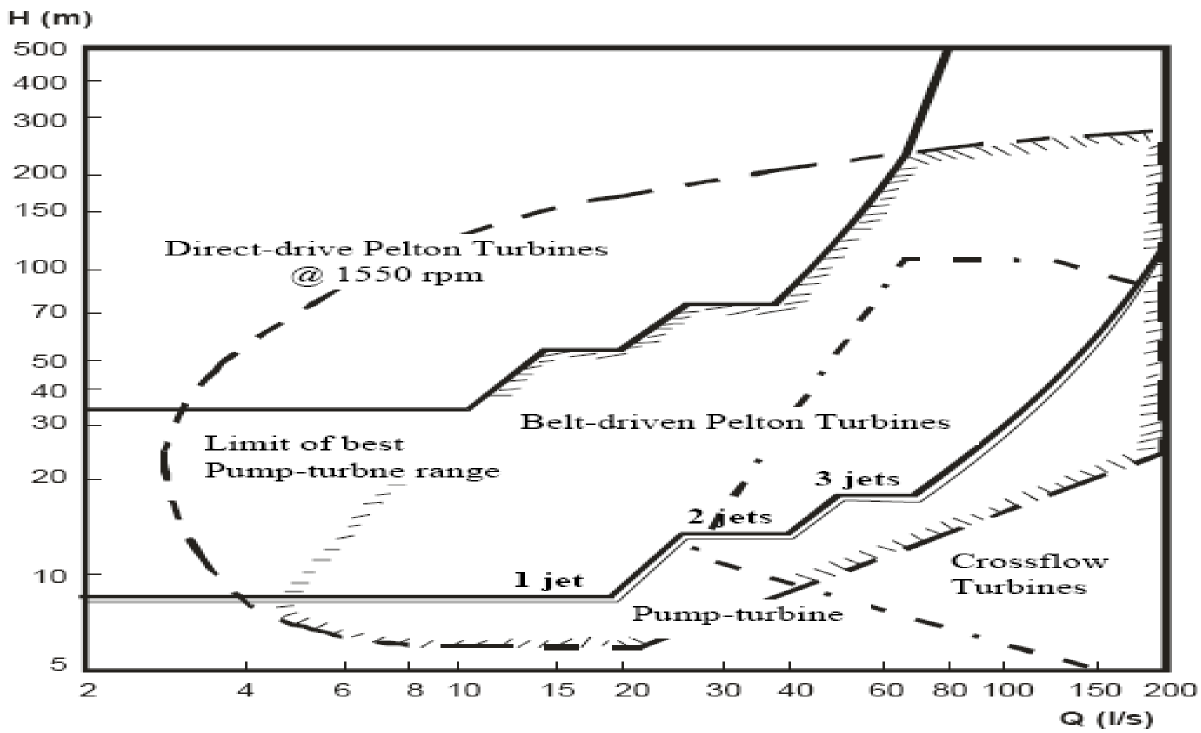


Figure 7: Head-flow range for various turbine options

In turbine mode, the flow increases with increasing head. The head available at the turbine is equal to the vertical height between the intake from the stream and the turbine outlet. Operating point is the intersection between H=H (Q), gives the head and flow at which the turbine will operate.

In Bernoulli’s equation the mechanical energy of a unit weight of liquid can be expressed by its specific value H:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + H_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + H_2 \qquad \text{(Eq. 4)}$$

Where

z is elevation (m)
g is gravity (9.81 m/s^2)
v is velocity of liquid (m/s)
p is pressure (N/m^2)
ρ is liquid density (kg/m^3)

To calculate hydropower produce, Eq. 1 is applied.

2.6 Motor as Generator

In order to make centrifugal pump works at normal operation as well as reverse operation, the selection of motor type is very important. Motor type can be used to run the pump and the other time operates as generator when pump works as a turbine. Induction motors that have dual rotation, which can operate as generator, are cheaper than synchronous generators, particularly for sizes up to 30kw. They are also more robust because a standard induction machine has cast bars instead of winding on the rotating part. [9] According to Arthur Williams, the advantage of an induction generator is that is cannot be burnt out through overloading, since it simply loses excitation and stops generating under these condition.

Most pump units, even for powers of less than 1 kW, are supplied with three-phase induction motors. Fortunately, it is possible to use a three-phase induction motor as a single-phase generator and this is the preferred approach to providing a single-phase supply. [10] CEEX 2007 Conference stated the induction motor needs to be ensured not be overload when running as generator. The induction motor needs to de-rate with approximately 20% of rate power. Maximum power output of the generator is 80% of the rated power and the voltage efficiency is around 2% lower than its rated motor efficiency.

2.7 Pump as Turbine Test Procedure

It is recommended that a centrifugal pump is tested after making initial selection in order to find its turbine characteristics. The pump as turbine is tested over a range of heads and flows. According to Arthur Williams, a feed pump will be required which must capable of producing a greater head and flow than the predicted pump as turbine best efficiency point conditions. There are two methods of pump as turbine testing:

1. Using a measuring tank
   This method required 2 different size of tank that is connected using pipe and hand valve. The flow rate is measured by timing the pump as turbine discharge into known volume. The value of head is calculated from pressure gauge reading.

2. Using a flow meters
   This method is only required one tank that will operate as close loop system. The value of flow rate is determined from an orifice plate, venture meter or other accurate flow measuring device. Same as method 1, the value of head is obtained from the pressure gauge reading.

CHAPTER 3

METHODOLOGY

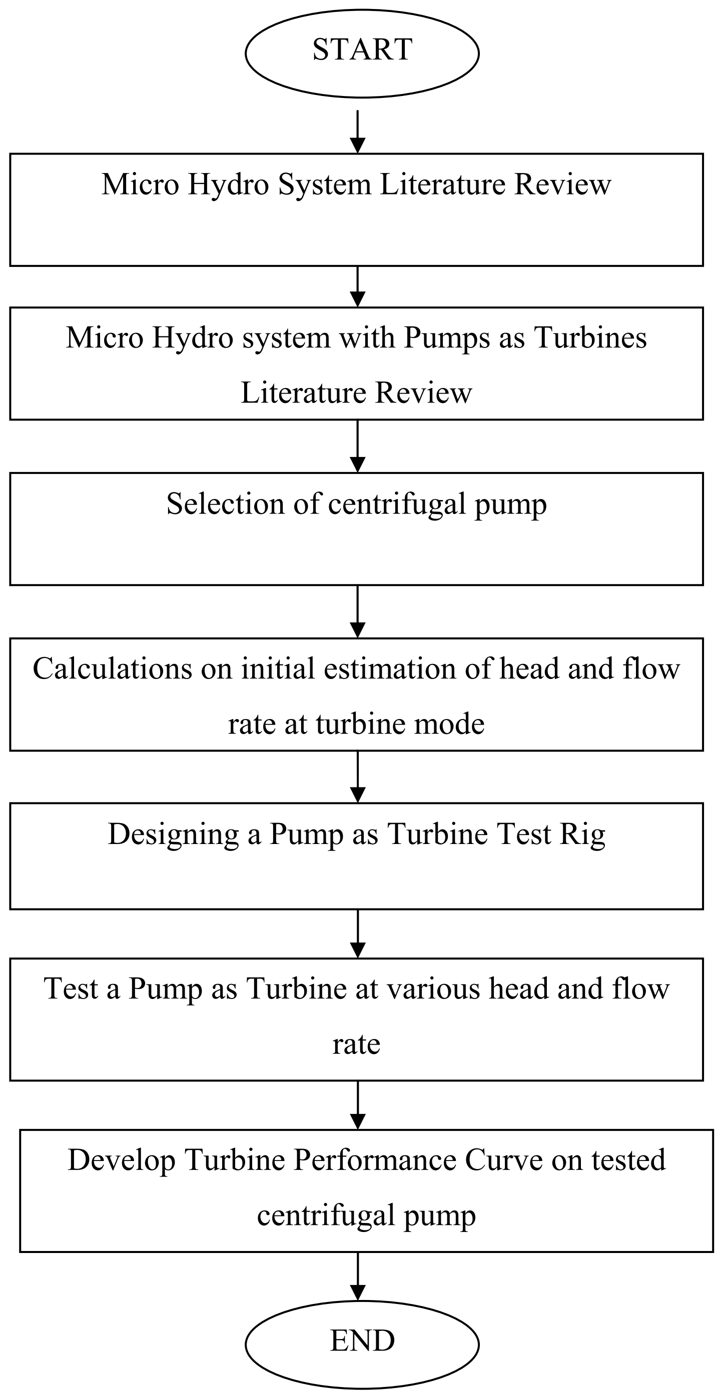


Figure 8: Project Process Flow Diagram

3.1 Literature Review

During literature review, research and study on the micro hydro system is done. Further research on the application of centrifugal pump as turbine for micro hydro system is done. Working principle pump as turbine are reviewed. This is important to give direction to understand the current used and application of micro hydro system. Related micro hydro projects by using pump as turbine is reviewed. The information is gathering and referring to respective books, journals and thesis which are developed by internal and external parties.

3.2 Pump as Turbine Test Procedure

a. Selection of centrifugal pumps

The specific centrifugal is chosen that is suitable for working in reverse as turbine. Centrifugal pump performance curve is analyzed to make initial selection when it works as turbine.

b. Design on pump as turbine test rig

Another pump is chosen as a feed pump for pump as turbine test which is greater power than pump as turbine. Method of testing is chosen based on availability of the equipment. Selection of piping system on size and material is chosen based on head loss calculations. Pressure gauge is connected to the specific side on the piping system to determine the pump as turbine head. Two pumps is connected using piping and storage tank.

c. Constraints

In order to test pump as turbine, the range of head and flow rate has been set up. Whenever a constraint is applied, the solution possibilities are reduced.

d. Pump as turbine test

After pump as turbine test rig has been setup, pump as turbine test is ran under a range head and flow rate based on initial calculation. The electrical power produced is determined by voltmeter and ammeter that is connected to pump's motor. The pump as turbine performance curve is developed and the required head and flow rate at best efficiency point is determined.

3.3 Develop Turbine Characteristic of a Pump

The tested centrifugal pump works as turbine is matched with suitable site and applications based on required head and flow rate. Flow rate of flowing water at specific place in Malaysia is determined whether the tested centrifugal pump is suitable to the site or not.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Selection of Centrifugal Pump

First of all the centrifugal is selected to be tested as a turbine. Pedrollo CP 130 Water Pump with 3 phase induction motor is chosen to be worked as turbine. Based on pump's datasheet in Appendix 2, it is shown that:

Table 1: Pedrollo CP 130 Water Pump Specification

H_{max}	22 m
Q_{max}	80 l/min
Power Input	0.37 kW
Frequency	50 Hz
Maximum Speed	2900 rpm
Voltage	240 V
Current	1.8 A

Since the pump performance curve does not show the power input, an approximation for the best efficiency point (BEP) conditions is made by using:

$$Q_{bep} = 0.75Q_{max}$$

$$Q_{bep} = 0.75 \times 80 \text{ l/min}$$

$$= 60 \text{ l/min}$$

$$H_{bep} = 0.75H_{max}$$

$$H_{bep} = 0.75 \times 22$$

$$= 16.5\text{m}$$

The pump efficiency can be obtained from table in Appendix 3, by interpolation,

$$\frac{75\% - 70\%}{1.1 - 0.55} = \frac{75\% - \eta}{1.1 - 0.37}$$

$$\eta = 68.36\%$$

4.2 Initial Selection of Pump as Turbine Head and Flow Rate

The Affinity Laws relate the head, flow and power of the pump or turbine to its speed, where:

- Flow (Q) is proportional to speed (N)
- Head (H) is proportional to N^2
- Power (P) is proportional to N^3

The speed given in pump's plate is synchronous speed and the motor speed is always greater than synchronous speed. Thus, the speed of the motor can be obtained by:

$$N_m = \frac{120}{p} \times f\,(1 - s)$$

Where p = 2 (Appendix 3)

f=50Hz

s= 0.02-0.05 (small fraction)

Therefore,

$$N_m = \frac{120}{2} \times 50\ (1 - 0.03)$$

$$= 2910 \text{ rpm} > 2900 \text{ rpm (synchronous speed)}$$

When it is running as generator,

$$N_{gen} = \frac{120}{p} \times f(1 + s)$$

$$N_{gen} = \frac{120}{p} \times 50(1 + 0.03)$$

$$= 3090 \text{ rpm}$$

The relationship of Affinity Laws can be used to determine the best efficiency point of the pump when it running as turbine by:

$$Q_t = \frac{N_t}{N_p} \times \frac{Q_{bep}}{\eta_{max}{}^{0.8}}$$

$$Q_t = \frac{3090\text{rpm}}{2910\text{rpm}} \times \frac{1\ {}^{l}/_{s}}{0.6836^{0.8}}$$

$$= \mathbf{1.43}\ {}^{\mathbf{l}}/_{\mathbf{s}}\ @\ \mathbf{86.37}\ {}^{\mathbf{l}}/_{\mathbf{min}}$$

$$H_t = \left(\frac{N_t}{N_p}\right)^2 \times \frac{H_{bep}}{\eta_{max}{}^{1.2}}$$

$$H_t = \left(\frac{3090\text{rpm}}{2910\text{rpm}}\right)^2 \times \frac{16.5\text{m}}{0.6836^{1.2}}$$

$$= \mathbf{29.37}\boldsymbol{m}$$

Available Hydro Power,

$$P_{hydro} = \rho \times g \times Q \times H$$

$$= 1000\ {}^{kg}/_{m^3} \times 9.81\ {}^{m}/_{s^2} \times 0.00143\ {}^{m^3}/_{s} \times 29.37\text{m}$$

$$= \mathbf{412.01\ watts}$$

4.3 Pump as Turbine Test Rig

The value of Q_t and H_t in the above section is not the actual value of the best efficiency point of pump as turbine. Those values give $\pm$20% of the predicted value for the best efficiency point. Therefore, after initial selection, pump will be tested to find out the range of power it can produce at certain range of head and flow rate.

The method of using a measuring tank is chosen for pump as turbine test. Feed pump is selected to give greater head and flow rate than the predicted pump as turbine best efficiency point condition. For pipeline design, it is suggested that the length of pipeline is at least 10 times the pipe diameter. It this experiment:

Vertical Length: 0.037m x 10 = 0.37m ~ 0.4 m.

Horizontal length should be 3 times more than vertical length = 1.2 m

4.3.1 Test Procedure

Below is the layout of pump as turbine test rig. Feed pump and pump as turbine are connected together using set of pipeline with pressure gauge and hand valve. Hand valve is used to control the flow rate while the pressure gauge is used to predict the value of head across the test rig. Measuring tank is used to measure the flow rate by timing the water discharge into a known volume. 3 phase induction motor of pump as turbine is modified by adding the capacitor using C-2C connection to produce single phase voltage output. The steps on how to sizing the capacitor to 3 phase induction motor is discussed in next section. For the water supply, it is should be at least 20 times of the Q_t.

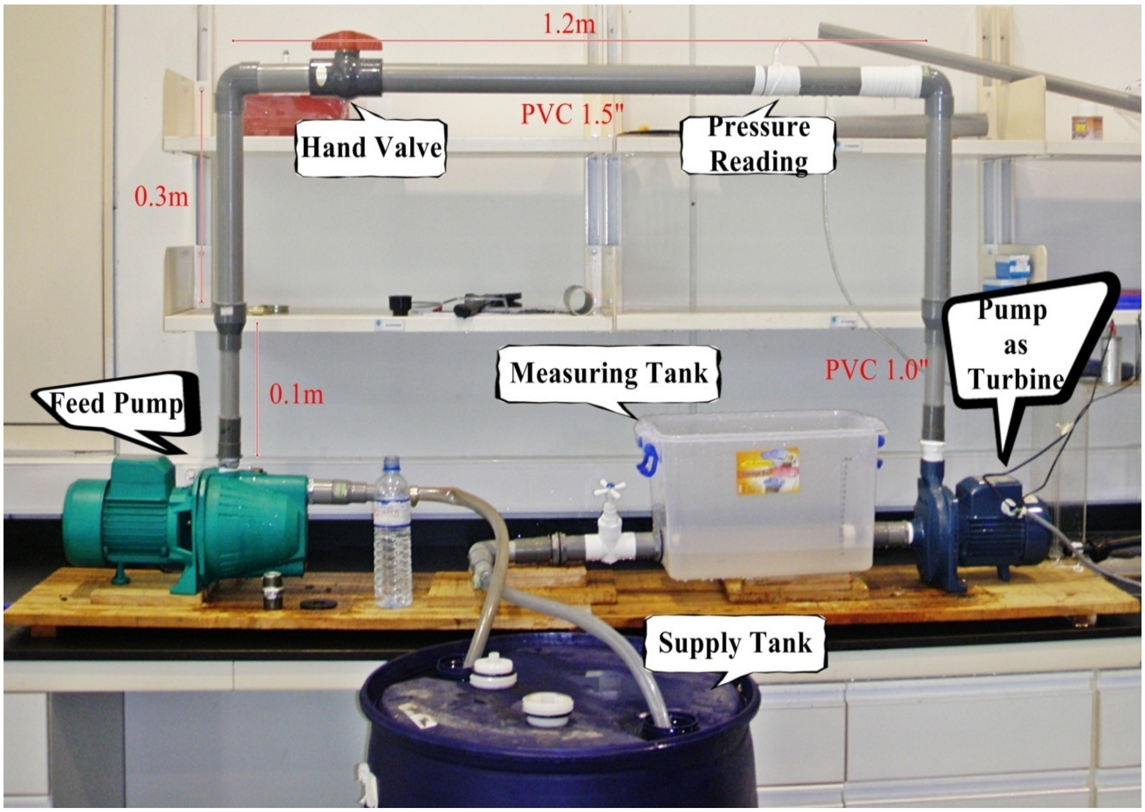


Figure 9: Pump as Turbine Test Rig Prototype

<u>Procedure:</u>

1. The test rig is set up as in Figure 9.
2. The hand valve at pipeline is open fully.
3. The test rig is switched on.
4. First reading of pressure gauge at fully opens of the valve.
5. The rate of flow being measure using volume of received tank and the stop watch.
6. The value of voltage and current is taken at the induction motor.
7. The steps 4 to 6 are repeated by adjusting the valve manually.
8. The pump as turbine performance graph is developed.

4.4 Head Loss Calculation

Head loss in pipe is due to the frictional forces and is dissipated as turbulence. There two categories of losses which are major losses and minor losses. Major losses are associated with energy loss per length of pipe while minor losses are associated with bends, fittings and valves. The most common way to calculate the losses is using the Darcy-Weisbach equation or by obtaining using the appropriate head loss table. In this project, the major losses along the pipe are determined by using the head loss table. When designing the pipeline system, it is necessary to choose the criteria that will give the minimum of losses. This will prevent the energy loss during operation. The Polyvinyl Chloride (PVC) pipe is chosen for the piping system of the test rig. Figure 11 shows the dimension of the pipeline system.

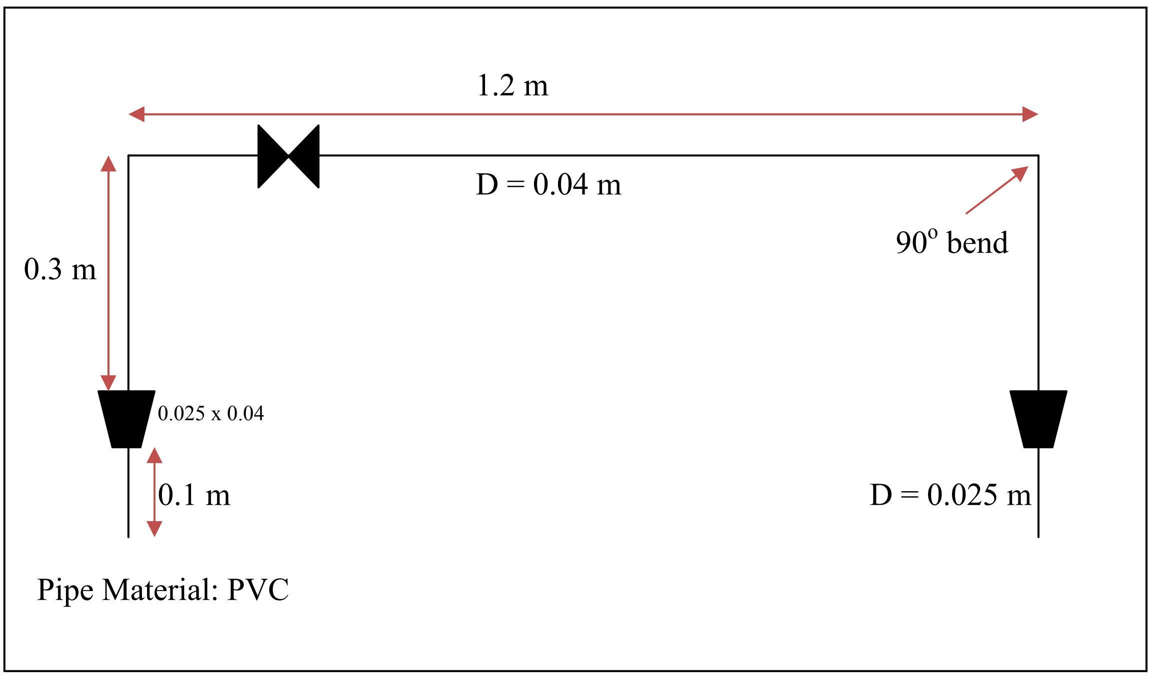


Figure 10: Pump as Turbine Test Rig Pipeline

4.4.1 Major Losses

The pressure loss in pipes and tubes depends on the flow velocity, pipe or duct length, pipe or duct diameter, and a friction factor based on the roughness of the pipe or duct, and whether the flow is turbulent or laminar. The selection of pipe size is based on the friction loss characteristic of PVC pipe which can be referred at Appendix 4. This table provides the recommendation for the pipe sizing that is related to velocity and friction loss of the pipe.

The water flow rate = 1.43 l/s (22.69 GPM)

From Hunter: Friction Loss Table in Appendix 4,

At 0.04 m (1.57 inch) diameter of pipe, the friction loss per 100 ft is = 1.81 psi.

1. <u>1.2 m (3.97 ft) length,</u>

$$= \frac{1.81\text{psi}}{100\text{ft}} \times 3.97\text{ft}$$

$= 0.072$ psi (0.49 kPa)

Converting to head in meter,

$$0.49 \text{ kPa} = \rho.g.H$$

$$0.49\text{kPa} = 1000 \ {}^{\text{kg}}/_{\text{m}^3} \times 9.81 \ {}^{\text{m}}/_{\text{s}^2} \times \text{H}$$

$$\mathbf{H = 0.049m}$$

2. <u>2 x 0.3 m (0.984 ft) length,</u>

$$= \frac{1.81\text{psi}}{100\text{ft}} \times 0.984\text{ft}$$

$= 0.0178$ psi (0.122 kPa)

Converting to head in meter,

$$0.122 \text{ kPa} = \rho.g.H$$

$$0.122 \text{ kPa} = 1000 \ {}^{kg}/_{m^3} \times 9.81 \ {}^{m}/_{s^2} \times H$$

$$\mathbf{H = 0.0124m \times 2 = 0.0248m}$$

At 0.025 m (1 inch) diameter of pipe, the friction loss per 100 ft is = 16.15 psi.

1. <u>2 x 0.1 m (0.328 ft) length</u>

$$= \frac{16.15\text{psi}}{100\text{ft}} \times 0.3284\text{ft}$$

$$= 0.053 \ (0.365 \text{ kPa})$$

Converting to head in meter,

$$0.365 \text{ kPa} = \rho.g.H$$

$$0.365 \text{ kPa} = 1000 \ {}^{kg}/_{m^3} \times 9.81 \ {}^{m}/_{s^2} \times H$$

$$\mathbf{H = 0.0372m \times 2 = 0.0744m}$$

Total major losses in PVC pipe is = 0.049m + 0.0248m + 0.0744m

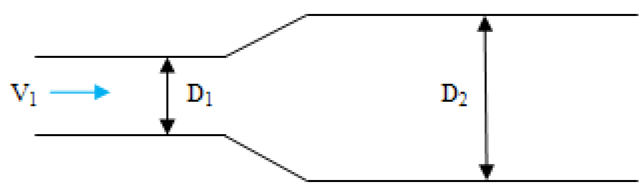
= **<u>0.1482 m.</u>**

4.4.2 Minor Losses

Referring to Figure 10, there are two 90° bends, two reducers and a valve along the piping system of the pump as turbine test rig. Below is the detail calculation on the minor losses:

1. Loss at Fitting

   a. Expansion



D1 = 0.025m, D2 = 0.04m

V_1 is determined by dividing the flow rate and area of the pipe:

$$V_1 = \frac{Q}{A_1}$$

$$= \frac{0.00143 \, ^{m^3}/_{2}}{\pi \times 0.0125^2}$$

$$= 2.91 \text{ m/s}$$

$$\frac{D_2}{D_1} = \frac{0.04\text{m}}{0.025\text{m}} = 1.6$$

From expansion table in Appendix 4, by interpolation,

$$\frac{0.35 - 0.38}{3 \, ^{m}/_{s} - 1.2 \, ^{m}/_{s}} = \frac{0.35 - k}{3 \, ^{m}/_{s} - 2.91 \, ^{m}/_{s}}$$

$$k = 0.3515$$

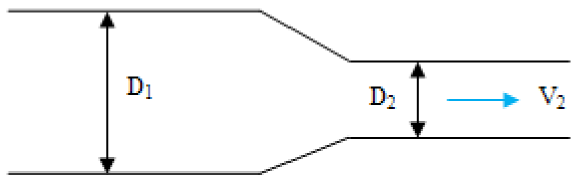
So the head loss at expansion fitting is,

$$h_L = k\frac{{V_1}^2}{2g}$$

$$= 0.3515\frac{2.91\, {m/_s}^2}{2\times 9.81\, {m/_{s^2}}}$$

$$= \mathbf{0.152m}$$

b. Contraction



D1 = 0.04m, D2 = 0.025m

V_2 is determined by dividing the flow rate and area of the pipe:

$$V_2 = \frac{Q}{A_2}$$

$$= \frac{0.00143\, {m^3/_2}}{\pi \times 0.0125^2}$$

$$= 2.91\ m/s$$

$$\frac{D_1}{D_2} = \frac{0.04m}{0.025m} = 1.6$$

From contraction table in Appendix 4, the k value is = 0.26

So the head loss at contraction fitting is,

$$h_L = k\frac{{V_1}^2}{2g}$$

$$= 0.26 \frac{2.91 \, ^{m}/_{s}{}^{2}}{2 \times 9.81 \, ^{m}/_{s^2}}$$

$$= \mathbf{0.112\ m}$$

2. <u>Loss at Bend</u>

The velocity of the liquid at 0.04m diameter pipe is,

$$V = \frac{Q}{A}$$

$$= \frac{0.00143 \, ^{m^3}/_{2}}{\pi \times 0.02^2}$$

$$= 1.138 \text{ m/s}$$

For elbow, flanged regular 90°, k = 0.3

So the head loss at 90° elbow is,

$$h_L = k\frac{V^2}{2g}$$

$$= 0.3 \frac{1.138 \, ^{m}/_{s}{}^{2}}{2 \times 9.81 \, ^{m}/_{s^2}}$$

$$= \mathbf{0.019\ m}$$

Since the quantity of 90° elbow is two, the total loss at bend is = 0.038 m

3. Losses at Valve

Ball valve is used to regulate the flow rate of water during testing.

For fully open ball valve, the k value is = 0.05

So the head loss at fully open ball valve is,

$$h_L = k\frac{V^2}{2g}$$

$$= 0.05\,\frac{1.138\,{}^{m}/_{s}{}^{2}}{2 \times 9.81\,{}^{m}/_{s^2}}$$

$$= \mathbf{0.0033\ m}$$

Total minor losses are = 0.152m + 0.112m + 0.019m + 0.0033m

= **0.2863m**

4.4.3 Total Head Loss

The total head loss is determined by adding all the major and minor losses along pipe.

Major Losses + Minor Losses

= 0.1482m + 0.2863m

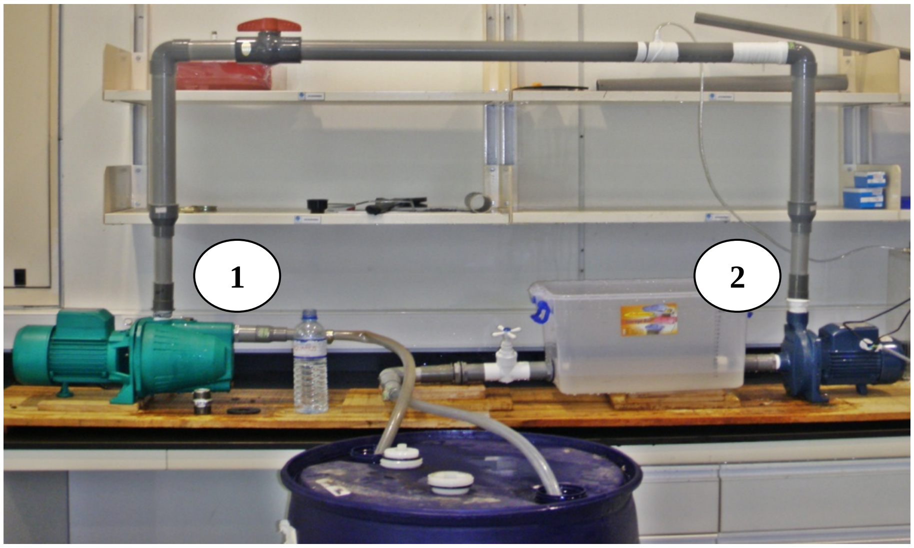
= **0.4345m**

4.5 Selection of Feed Pump

A feed pump is required for pump as turbine testing to provide head and flow rate to the pump being tested. The feed pump must be capable of producing a greater head and flow rate and the predicted pump as turbine best efficiency point (bep) conditions that has been shown in section 4.2.

A selection of feed pump is determined by using Energy equation. The flow rate of the feed pump must be greater or equal to the predicted flow rate of pump as turbine. Using energy equation:

$$\frac{P_1}{g} + \frac{v_1^{\ 2}}{2g} + Z_1 + H_p = \frac{P_2}{g} + \frac{v_2^{\ 2}}{2g} + Z_2 + H_L + H_T$$



The elevation point is equal at point 1 and point 2.

$$Z_1 = Z_2 = 0.4\text{m}$$

The velocity of the liquid is assuming equal along the system since it will give the same flow rate along the pipe at fully open ball valve. So,

$V_1 = V_2$

Since the same pressure is applied throughout the pipeline, the pressure at point 1 and point 2 is equal:

$P_1 = P_2$

Hence, the head of the feed pump is:

$$\mathrm{H_p} = \mathrm{H_L} + \mathrm{H_T}$$
$$= 0.4345\ \mathrm{m} + 29.37\ \mathrm{m}$$
$$\mathbf{H_p \geq 29.9\ m}$$

$$\mathbf{Q_p \geq 1.43\ {}^{l}\!/\!_{s}}$$

Based on calculation above, Precision JET-355(A) Water Pump is chosen as a feed pump. From the equipment datasheet in Appendix 2, the summary of this pump is:

Table 2: Precision JET-355(A) Water Pump Specification

H_{max}	40 m
Q_{max}	50 l/min
Power Input	0.75 kW
Frequency	50 Hz
Maximum Speed	2850 rpm
Voltage	230-240 V
Current	4.0 A

From Table 2, the maximum flow rate of this pump is lower than the predicted flow rate of pump as turbine. Because of unavailable of other pump it UTP, it is expected that the value of maximum power produce will be lower than the predicted. It can be enhanced by using the stronger pump as a feed pump for the testing.

4.6 Capacitor Sizing

As discussed in section 4.3, the induction motor with 3 phase connection should be modified by adding a set of capacitor to the connection circuit. The modification is used to produce one phase load and to balance the current in the generator. The size of capacitors determines the voltage and speeds at which generator will run. The connection of capacitors is shown in Figure 12:

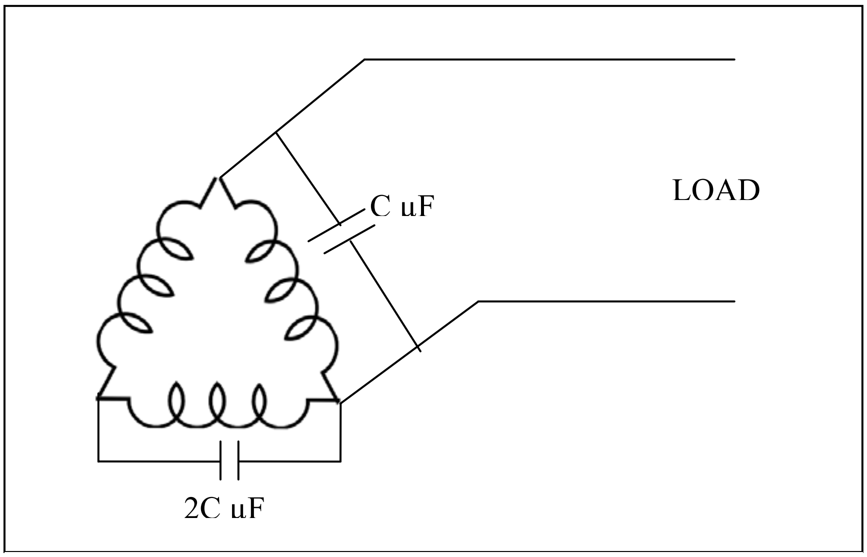


Figure 11: Single Phase Output from 3 Phase Induction Motor

Motor per phase current at full load, 240 V = 1.8 A

In generator mode for delta connection, 1.8A x $\sqrt{3}\ =\ 3.114$ A

The motor power factor = 0.75

Reactive current is perpendicular to total current (1), hence by using Theorem Pythagoras,

$= \sqrt{1^2 - 0.75^2}$

$= 0.611$

$= 0.661\ \times 3.114$

$= 2.05\text{ A} =\ \text{I}_c$ (current is supplied by capacitors) where $I_c = 2\pi VfC$

rearrange the equation, $C = \frac{I_c}{2\pi Vf}$

$$C = \frac{2.05}{2\pi \times 240 \times 50}$$

$$= \mathbf{27.19\ \mu F}$$

$$2C = 2 \times 27.19\mu F$$

$$= \mathbf{54.38\ \mu F}$$

The values of capacitor should be added at delta connection of induction motor by using C-2C connection as shown in Figure 12. Since there is no exact value of the capacitor in the market, capacitor with 20µF and 45µF are chosen.

Figure 12: 20µF and 45µF Capacitors

4.7 Pump as Turbine Test Result

The characteristics of the pump as turbine in this experiment are obtain from the head, hydraulic power and voltage output versus the flow rate of the water. The efficiency of the pump in turbine mode cannot be obtained since unavailability the equipment to determine the torque of the pump. So the efficiency of the pump is assumed to be same in pump mode which has been discussed in section 4.1. The pump is tested with the range of flow rate of 0.4l/s to 0.9l/s which is below the theoretical flow rate that had been calculated in section 4.2. This is due to the size of feed pump is smaller than the required. Below is the result of the pump as turbine test:

Table 3: Pump as Turbine Test Result

No	Pressure (kPa)	Head (m)	Volume (m^3)	Time (s)	Flow Rate (m^3/s)	Hydraulic Power (watts)	Voltage (V)
1	15.17	1.5	0.0162	39	0.00042	6.3	0.48
2	18.62	1.9	0.0162	35	0.00046	8.6	0.62
3	27.57	2.8	0.0162	31	0.00052	14.4	0.65
4	39.99	4.1	0.0162	27	0.00060	24.0	0.8
5	44.81	4.6	0.0162	23	0.00070	31.6	1.9
6	53.02	5.4	0.0162	19	0.00085	45.2	2.5

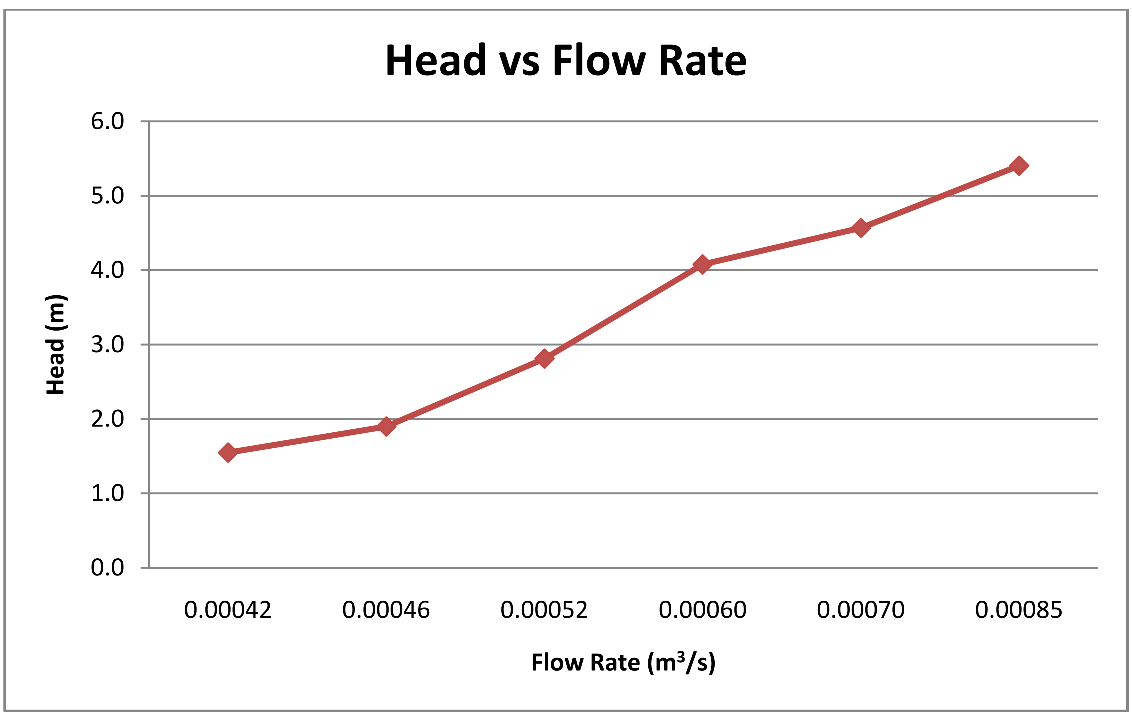


Figure 13: Graph of Head versus Flow Rate

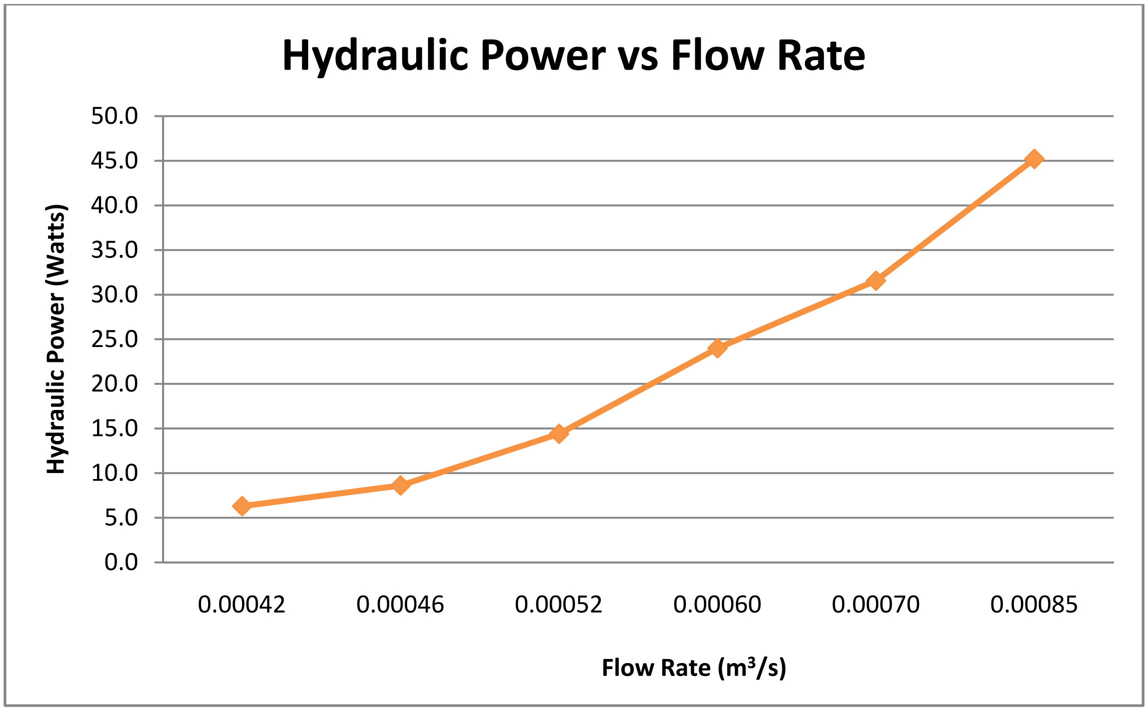


Figure 14: Graph of Hydraulic Power versus Flow Rate

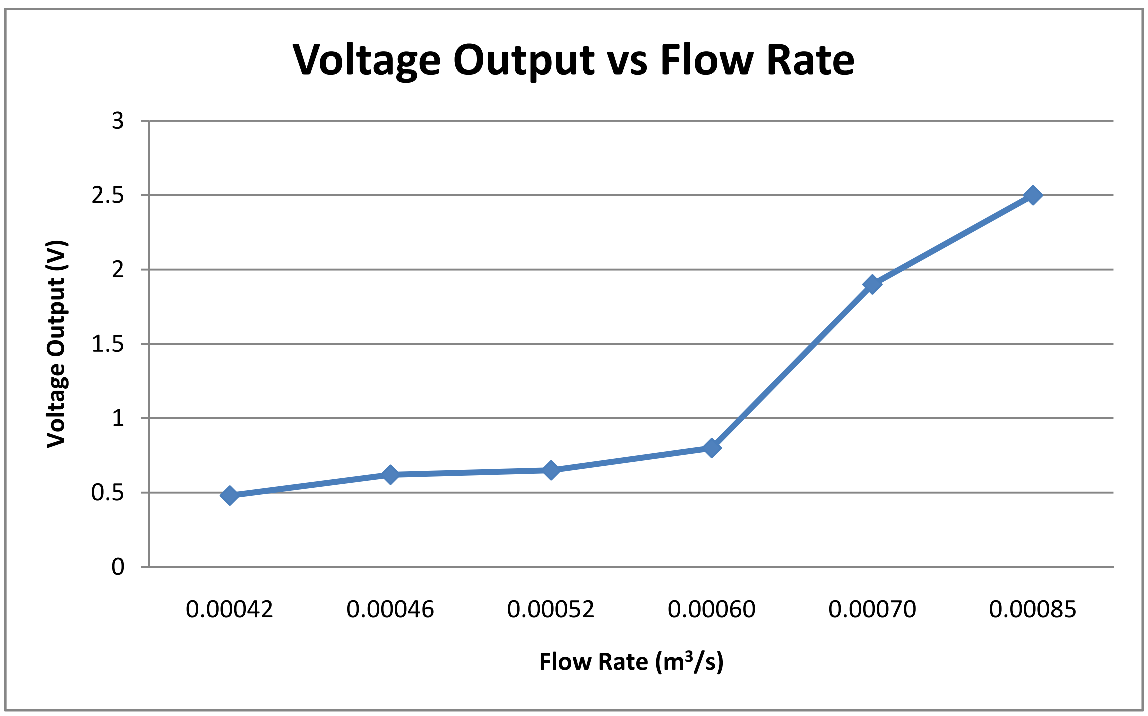


Figure15: Graph of Voltage Output versus Flow Rate

Discussions:

1. From the test result, it is proven that centrifugal pump can be used as a turbine to generate electricity.
2. From graphs, it is shows values of head, hydraulic power and voltage output are increasing when the flow rate is increased.
3. From the initial prediction of the pump as turbine, the required flow rate and head at best efficiency point are 1.43 l/s and 29.37 m. Due to the size of the feed pump is smaller in flow rate than required, the flow rate during the test only can be obtained from the range of 0.41 l/s and 0.9 l/s only. The accurate value can be obtained by using the bigger size of feed pump that will give the higher value of flow rate.
4. From the graph of head versus flow rate, the range value of head supplied to the pump as turbine is smaller than the prediction value of the pump as turbine at best efficiency point. This is due the length of the pipeline is smaller compare to the predicted head of pump as turbine. This real value can be obtained by multiplied with the 40m (head of the feed pump) and divided with 12 (scale of predicted head over length of pipeline).
5. The value of hydraulic power is calculated as follows:
   $= \text{Head (m)} \times \text{flow rate}(\text{m}^3/\text{s}) \times 9.81\ \text{m/s}^2$ (KW)
   It is shown that the value of hydraulic power is depending on the value of head and flow rate of water.
6. The value of voltage output is obtained at the induction motor that has been changed to generator. Fixed electrical load is considered which is with fix speed of the generator.
7. During the experiment, there are several errors that need to be considered. Those errors will give the inaccuracy on the result that has been taken from experiment. The possible errors are:
   a. <u>Equipment error:</u> This error occurs due to wrong calibration of the equipment. During the experiment, there were some leakage occurred at the inlet and outlet of the pump as turbine. This is due to improper handling during setting up of the test rig. This value will cause more losses to the overall system.
   b. <u>Human Error:</u> The possible human error occurred during this experiment is failing to measure the required accurately such as the volume of water in order to calculate the water flow rate. It happened because of using improper measurement equipment and this can be avoided by using proper equipment and measure the value several times in order to get relatively accurate values.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Using a centrifugal pump as a turbine is another way to provide stand alone electricity for remote area community. The testing of centrifugal pump works in reverse as a turbine can determine the turbine characteristics of the pump in turbine mode. The initial estimation of the head and flow rate of the pump in turbine mode is already calculated. The preliminary design of the pump as turbine test rig is already done. The selection of piping system and feed pump are determined. The size of capacitor will determine the voltage and speed of the motor will run as generator. The installation of test rig of pump as turbine is complete. Pump as turbine has been tested in order to find the range of head and flow rate available from the selected feed pump. This project has enabled me to understand more on the application of centrifugal pump as turbine for generating small scale hydro power. It can be concluded that this project is a success and completed within agreed time frame.

5.2 Recommendations

For future works, since the test result does not give the accurate value as expected, it is strongly recommended to replace the feed pump with the larger size that can comply with the predicted value of pump in turbine mode. Proper installation of the test rig is recommended in order to eliminate errors during experiment thus will improve the accuracy of the result. The size and length of the pipeline can be enlarged in order to reduce the total losses in pipe.

REFERENCES

[1] Arthur Williams (2003), "Pumps as Turbines: A User Guide", YTDG Publishing.

[2] (2004) *"Micro Hydro Power System: A Buyer's Guide",* Natural Resources Canada.

[3] *"Microhydro Turbine Generator".* www.alternative-heating-info/microhydro_part1

[4] Chris Greacen and Megan Kerins, *"A Guide to Pump-as-Turbine Pico-Hydropower System".*

[5] *"Reverse Rotation of Centrifugal Pump",* www.jhwright.com/topics/reverse.htm.

[6] G.K Sahu (2000), *"Pumps",* New Age International Publisher.

[7] Eugen Constantin Isbăşoiu, Diana Maria Bucur, Călin Mihail Ghergu Georgiana Dunca (2007), *"Using Standard Pumps as Turbines",* CEEX 2007 Conference.

[8] *"How to Read Pump Curve",* http://www.coleparmer.com/techinfo/techinfo.asp.

[9] Dr. A A Williams (1996), "*Pumps as Turbines for Low Cost Micro Hydro Power"*, Nottingham Trent University, UK.

[10] Arthur Williams & Hugh Piggott, *"Pumps as Turbine for Pico Hydro Power",* http://www.pumpsasturbines.org.uk/

[11] Chris Greacen (19th Feb 2006), *"Project report – Huai Kra Thing Micro-hydro project"*

[12] Shahram Derakhshan, Ahmad Nourbakhsh (2007), *"Experimental study of characteristics curve of centrifugal pumps working as turbines in different specific speeds"*, University of Tehran, Iran.

[13] Clayton T. Crowe, Donald F. Elger, John Roberson (2005), *"Engineering Fluid Mechanics"*, Wiley International.

[14] Robert L. Mott (2006), *"Applied Fluid Mechanics"*, Pearson, Prentice Hall.

APPENDIX 1

Gantt Chart

First Semester

No	Detail.Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Awarded	■													
2	Preliminary Report (Research)		■	■											
3	Submission of Preliminary Report				●										
4	Design Process (Preliminary Design)					■	■	■	■						
5	Submission of Progress Report and Seminar								●						
6	Design Calculation (Preliminary Stage)									■	■	■			
7	Result Gathering												■	■	
8	Submission of Interim Report													●	
9	Oral Presentation														●

Second Semester

No	Detail.Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Centrifugal Pump	■	■	■	■										
2	Submission of Progress Report I				●										
3	Design Calculation (Final Stage)					■	■	■	■						
4	Submission of Progress Report II								●						
5	Seminar									●					
6	Pump as Turbine Testing									■	■				
7	Poster Exhibition											●			
8	Project Work Continue												■		
9	Submission of Dissertation (softbound)													●	
10	Oral Presentation													●	
11	Submission of Dissertation (hard bound)														●

■ Process

● Suggested Milestone

APPENDIX 2

Equipment Datasheet

1. Pedrollo CP 130 Water Pump (Italy)

RANGE OF PERFORMANCE

Flow rate up to 160 l/min (9.6 m^3/h)
Head up to 58 m

LIMITS OF USE

Manometric suction height up to 7 m
Liquid temperature up to + 90°C
Liquid temperature up to + 40°C in the CPX version (with technopolymer impeller)
Environment temperature up to + 40°C

EXECUTION AND SAFETY STANDARDS

EN 60034-1
IEC 34-1
CEI 2-3
CE

USES AND INSTALLATIONS

They are recommended for pumping clean water and liquids that are chemically non aggressive for the materials of which the pump is made.
FOR THEIR RELIABILITY AND ABSENCE OF MAINTENANCE THEY ARE WIDELY USED IN THE DOMESTIC AND CIVIL SECTOR, IN PARTICULAR FOR DISTRIBUTION WATER IN COMBINATION WITH SMALL OR MEDIUM AUTOCLAVES, FOR TRANSFER IN GENERAL, FOR IRRIGATING GARDENS.
The pumps must be installed in enclosed places, or at least protected against inclement weather.

GUARANTEE 1 YEAR subject to our general terms of sale.

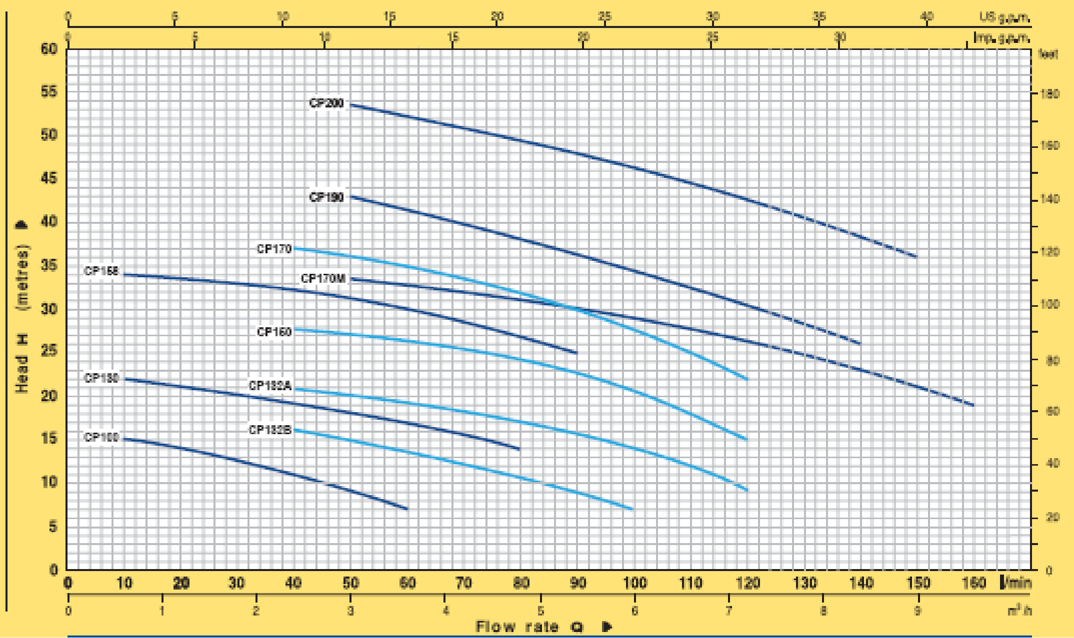
CONSTRUCTION CHARACTERISTICS

- **PUMP BODY:** **cast iron**, with threaded inlets ISO 228/1.
- **PUMP BODY COVER:** **stainless steel AISI 304** or **cast iron** on higher powered models.
- **BRASS IMPELLER:**
  CP 100-CP 132-CP 150-CP 170-CP 190-CP 200
- **STAINLESS STEEL IMPELLER:**
  CP 130-CP 158
- **MOTOR SHAFT: stainless steel EN 10088-3 - 1.4104.**
- **MECHANICAL SEAL: ceramic - graphite - NBR.**
- **ELECTRIC MOTOR:** the pumps are coupled to a PEDROLLO electric motor with specially calculated dimensions, silent-running, closed, with external ventilation, suitable for continuous duty.
  CPm: single-phase 230 V - 50 Hz with condenser and thermal overload protector built into the winding.
  CP: three-phase230/400 V - 50 Hz.
- **INSULATION:** class F. • **PROTECTION:** IP 44.
- **REGISTERED MODEL n° 72753.**

EXECUTIONS ON REQUEST

⇒ electropump with impeller in **technopolymer** (CPm...X - CP...X)
⇒ special mechanical seal
⇒ other voltages or frequency 60 Hz

CURVES AND PERFORMANCE DATA AT n= 2900 1/min

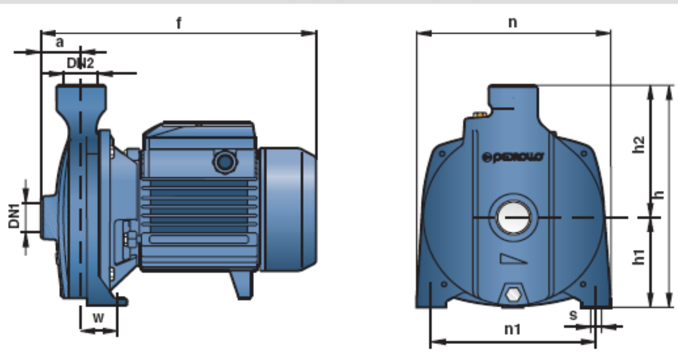


TYPE		POWER		Q m³/h	0	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	7.8	8.4	9.0	9.6
Single-phase	Three-phase	kW	HP	l/min	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
CPm 100	CP 100	0.25	0.33	H metres	16	15	14	12.5	11	9	7										
CPm 130	CP 130	0.37	0.50		23	22	21	20	19	18	17	15.5	14								
CPm 132B	CP 132B	0.45	0.60		20	—	18	17	16	15	13.5	12	10.5	9	7						
CPm 132A	CP 132A	0.60	0.85		23	—	22	21.5	21	20	19	18	17	16	14	12	9				
CPm 150	CP 150	0.75	1		29.5	—	29	28.5	28	27.5	26.5	26	24.5	23	21	18	15				
CPm 158	CP 158	0.75	1		36	34	33.5	33	32.5	31.5	30	28.5	27	25							
CPm 170	CP 170	1.1	1.5		41	—	—	38	37	36	35	33.5	32	30	27.5	25	22				
CPm 170M	CP 170M	1.1	1.5		36	—	—	35	34.5	33.5	33	32	31	30	29	28	26.5	25	23	21	19
CPm 190	CP 190	1.5	2		50	—	—	46	44.5	43	41.5	40	38	36	34.5	32.5	30.5	28	26		
——	CP 200	2.2	3		58	—	—	55	54.5	53.5	52	51	49.5	48	46	44.5	42.5	40.5	38.5	36	

Q = Flow rate H = Total manometric head

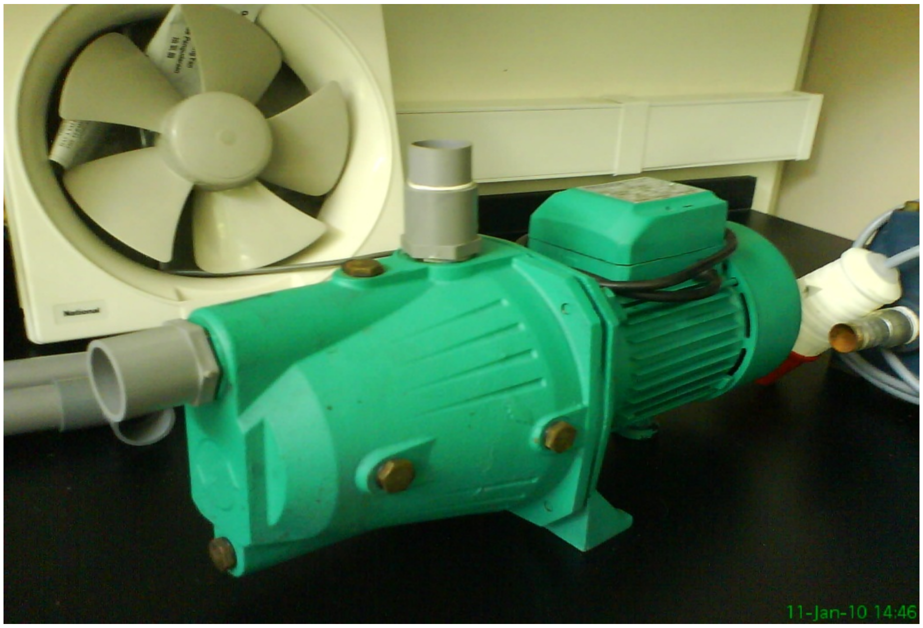
Tolerance of the performance curves according to EN ISO 9906 App. A.

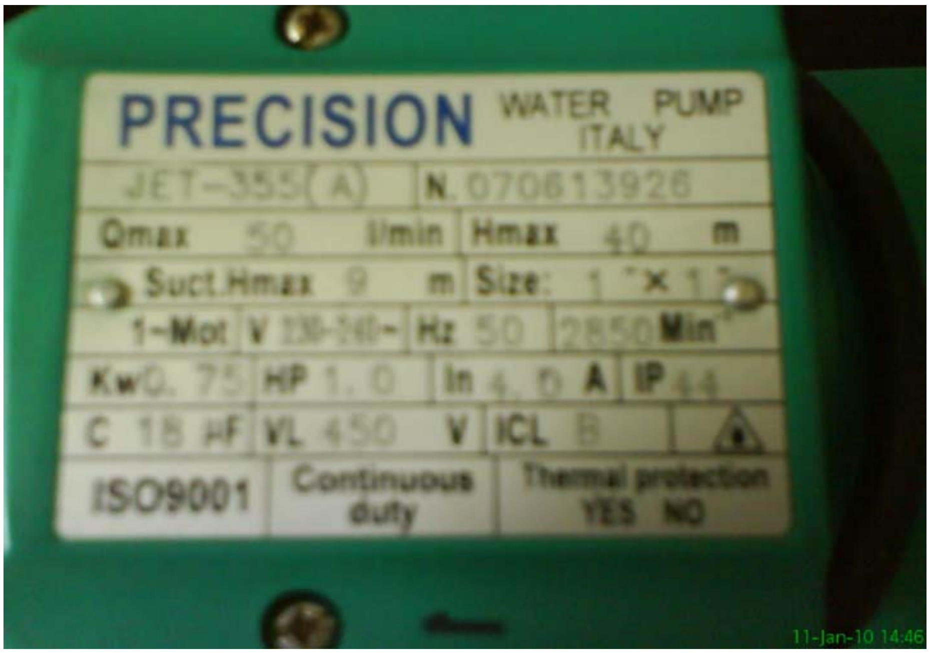
DIMENSIONS AND WEIGHTS



TYPE		INLETS		DIMENSIONS mm									kg	
Single-phase	Three-phase	DN1	DN2	a	f	h	h1	h2	n	n1	w	s	1~	3~
CPm 100	CP 100			34	247	187	77	110	148	118	45		6.8	6.9
CPm 130	CP 130				259								7.8	7.6
CPm 132B	CP 132B					205	82	123	165	135	41		8.0	7.5
CPm 132A	CP 132A	1"	1"	42	266/259							10	8.4	8.1
CPm 150	CP 150				285	240	92	148	190	160	38		12.5	11.3
CPm 158	CP 158												12.1	11.6
CPm 170-170M	CP 170-170M				367	260	110	150	206	165	44.5		19.2	18.5
CPm 190	CP 190	11/4"	1"	51	364	290	115	175	242	206	32.5	11	25.0	24.2
——	CP 200												-	25.5

2. Precision JET-355(A) Water Pump (Italy)





APPENDIX 3

Pump and Motor

1. Typical Efficiencies of Induction Motor

A. Three Phase Induction Motors:

Rated Power (kW)	0.55	1.1	2.2	4.0	11.0
Motor Efficiency (%)	70	75	79	82	87

B. Single Phase Induction Motors:

Rated Power (kW)	0.55	1.1	2.2 (2-pole)	2.2 (4-pole)
Motor Efficiency (%)	70	75	79	82

Note 1. When the motor is used as induction generator efficiency for the same voltage and frequency (240V, 50Hz) is likely to be approximately 2% less than the motor efficiency.

Note 2. The efficiency values for single-phase motors are quoted for the capacitor-start, induction run type.

Source: Arthur Williams, 2003. Pumps as Turbines: A User's Guide. ITDG Publishing

2. Typical Induction Motors and Generator Running Speed (rpm)

Poles	50Hz Motor	50Hz Generator	60Hz Motor	60Hz Generator
2	2900	3100	3500	3700
4	1450	1550	1750	1850
6	950	1050	1150	1250

Source: Arthur Williams, 2003. Pumps as Turbines: A User's Guide. ITDG Publishing

APPENDIX 4

Head Loss

1. Pipe Relative Roughness

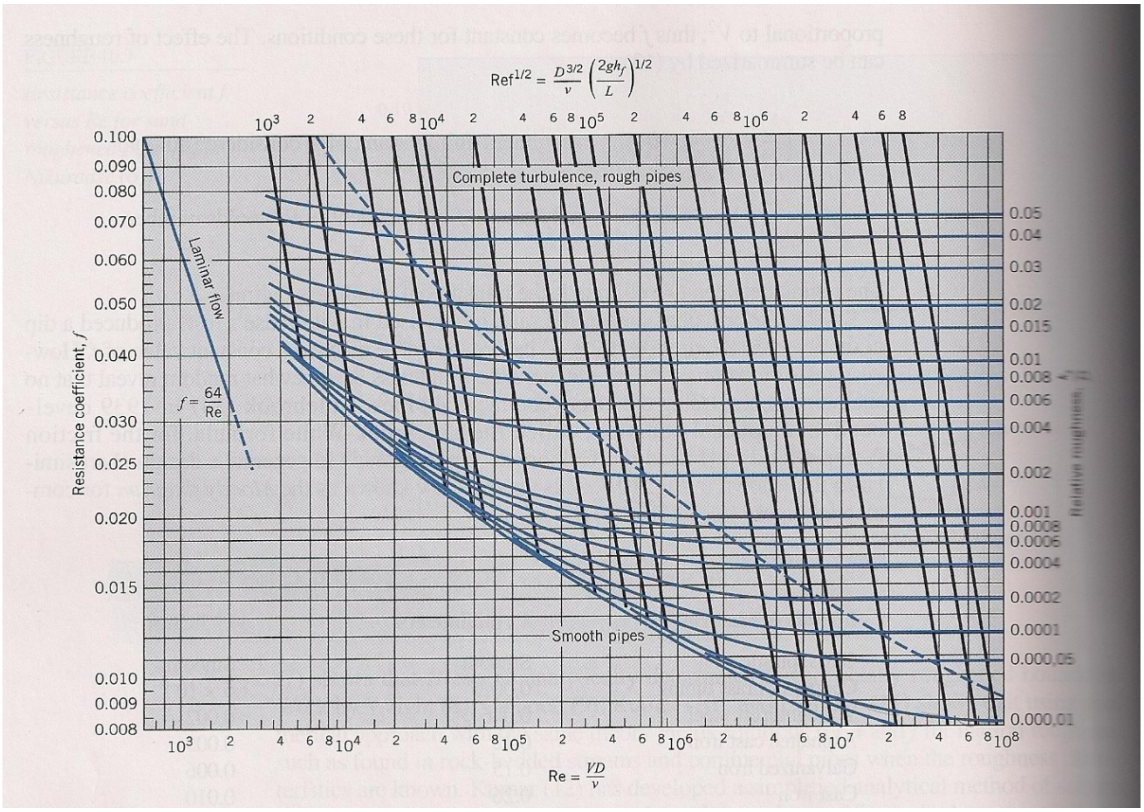
For turbulent flow the friction coefficient depends on the Reynolds Number and the roughness of the duct or pipe wall. Roughness for different materials can be determined by experiments.

Absolute roughness - *k* - for some common materials can be found in the table below:

Surface	**Absolute Roughness Coefficient - *k* -**	
	(m) 10^{-3}	*(feet)*
Copper, Lead, Brass, Aluminum (new)	0.001 - 0.002	3.33 - 6.7 10^{-6}
PVC and Plastic Pipes	0.0015 - 0.007	0.5 - 2.33 10^{-5}
Stainless steel	0.015	5 10^{-5}
Steel commercial pipe	0.045 - 0.09	1.5 - 3 10^{-4}
Stretched steel	0.015	5 10^{-5}
Weld steel	0.045	1.5 10^{-4}
Galvanized steel	0.15	5 10^{-4}
Rusted steel (corrosion)	0.15 - 4	5 - 133 10^{-4}
New cast iron	0.25 - 0.8	8 - 27 10^{-4}
Worn cast iron	0.8 - 1.5	2.7 - 5 10^{-3}
Rusty cast iron	1.5 - 2.5	5 - 8.3 10^{-3}
Sheet or asphalted cast iron	0.01 - 0.015	3.33 - 5 10^{-5}
Smoothed cement	0.3	1 10^{-3}
Ordinary concrete	0.3 - 1	1 - 3.33 10^{-3}
Coarse concrete	0.3 - 5	1 - 16.7 10^{-3}
Well planed wood	0.18 - 0,9	6 - 30 10^{-4}
Ordinary wood	5	16.7 10^{-3}

Source*: http://www.engineeringtoolbox.com/surface-roughness-ventilation-ducts-d_209.html*

2. Friction Factor Chart (Moody Chart)



Source: *Clayton T. Crowe, Donald F.Elger, John A.Roberson, 2005. Engineering Fluid Mechanics: Wiley, Figure 10.8*

Laminar flow (Re < 2300), $f = \frac{64}{Re}$

Turbulent flow (Re > 2300), $f = \frac{0.25}{[\log_{10}(\frac{\epsilon}{3.7D}+\frac{5.74}{Re^{0.9}})]^2}$

3. Friction Loss Characteristic of PVC Pipe

Hunter

FRICTION LOSS CHARACTERISTICS PVC SCHEDULE 80 IPS PLASTIC PIPE

(1120, 1220) C = 150
PSI loss per 100 feet of tube (PSI/100 FT)

Sizes 1/2" thru 6"
Flow GPM 1 thru 600

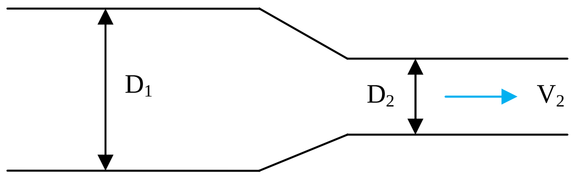
SIZE	1/2"		3/4"		1"		1 1/4"		1 1/2"		2"		2 1/2"		3"		4"		6"		SIZE
OD	0.840		1.050		1.315		1.660		1.900		2.375		2.875		3.500		4.500		6.625		OD
ID	0.546		0.742		0.957		1.278		1.500		1.939		2.323		2.900		3.826		5.761		ID
WALL THK	0.147		0.154		0.179		0.191		0.200		0.218		0.276		0.300		0.337		0.432		WALL THK
FLOW G.P.M.	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	VELOCITY F.P.S.	P.S.I. LOSS	FLOW G.P.M.
1	1.38	0.81	0.74	0.18	0.44	0.05	0.24	0.01	0.18	0.01	0.10	0.00									1
2	2.73	2.92	1.48	0.66	0.89	0.19	0.49	0.05	0.36	0.02	0.21	0.01	0.15	0.00							2
3	4.10	6.19	2.22	1.39	1.33	0.40	0.74	0.10	0.54	0.05	0.32	0.01	0.22	0.01							3
4	5.47	10.54	2.96	2.37	1.78	0.69	0.99	0.17	0.72	0.08	0.43	0.02	0.30	0.01							4
5	6.84	15.93	3.70	3.58	2.22	1.04	1.24	0.25	0.90	0.12	0.54	0.03	0.37	0.01	0.24	0.00					5
6	8.21	22.33	4.44	5.02	2.67	1.46	1.49	0.36	1.08	0.16	0.65	0.05	0.45	0.02	0.29	0.01					6
7	9.58	29.71	5.18	6.68	3.11	1.94	1.74	0.47	1.26	0.22	0.75	0.06	0.52	0.03	0.33	0.01					7
8	10.94	38.05	5.92	8.56	3.56	2.48	1.99	0.61	1.45	0.28	0.86	0.08	0.60	0.03	0.38	0.01					8
9	12.31	47.33	6.66	10.64	4.00	3.09	2.24	0.76	1.63	0.35	0.97	0.10	0.68	0.04	0.43	0.01					9
10	13.68	57.52	7.41	12.93	4.45	3.75	2.49	0.92	1.81	0.42	1.08	0.12	0.75	0.05	0.48	0.02	0.27	0.00			10
11	15.05	68.63	8.15	15.43	4.90	4.47	2.74	1.10	1.99	0.50	1.19	0.14	0.83	0.06	0.53	0.02	0.30	0.01			11
12	16.42	80.63	8.89	18.13	5.34	5.26	2.99	1.29	2.17	0.59	1.30	0.17	0.90	0.07	0.58	0.02	0.33	0.01			12
14			10.37	24.12	6.23	6.99	3.49	1.71	2.53	0.79	1.51	0.23	1.05	0.09	0.67	0.03	0.39	0.01			14
16			11.85	30.88	7.12	8.95	3.99	2.19	2.90	1.01	1.73	0.29	1.20	1.12	0.77	0.04	0.44	0.01			16
18			13.33	38.41	8.01	11.14	4.49	2.73	3.26	1.26	1.95	0.36	1.36	0.15	0.87	0.05	0.50	0.01			18
20			14.82	46.69	8.90	13.54	4.99	3.31	3.62	1.52	2.17	0.44	1.51	0.18	0.97	0.06	0.55	0.02			20
22			16.30	55.70	9.80	16.15	5.49	3.95	3.98	1.81	2.38	0.52	1.66	0.22	1.06	0.07	0.61	0.02			22
24			17.78	65.44	10.69	18.97	5.99	4.64	4.35	2.13	2.60	0.61	1.81	0.25	1.16	0.09	0.66	0.02			24
26			19.26	75.90	11.58	22.01	6.49	5.39	4.71	2.47	2.82	0.71	1.96	0.29	1.26	0.10	0.72	0.03			26
28					12.47	25.24	6.99	6.18	5.07	2.83	3.03	0.81	2.11	0.34	1.35	0.11	0.78	0.03			28
30					13.36	28.69	7.49	7.02	5.43	3.22	3.25	0.92	2.26	0.38	1.45	0.13	0.83	0.03	0.36	0.00	30
35					15.59	38.16	8.74	9.34	6.34	4.29	3.79	1.23	2.64	0.51	1.69	0.17	0.97	0.05	0.43	0.01	35
40					17.81	48.87	9.99	11.96	7.25	5.49	4.34	1.57	3.02	0.65	1.94	0.22	1.11	0.06	0.49	0.01	40
45							11.24	14.88	8.16	6.83	4.88	1.96	3.40	0.81	2.18	0.28	1.25	0.07	0.55	0.01	45
50							12.49	18.09	9.06	8.30	5.42	2.38	3.78	0.99	2.42	0.34	1.39	0.09	0.61	0.01	50
55							13.73	21.58	9.97	9.90	5.96	2.84	4.15	1.18	2.66	0.40	1.53	0.10	0.67	0.01	55
60							14.98	25.35	10.87	11.63	6.51	3.33	4.53	1.38	2.91	0.47	1.67	0.12	0.73	0.02	60
65							16.23	29.40	11.78	13.49	7.05	3.87	4.91	1.61	3.15	0.55	1.81	0.14	0.79	0.02	65
70							17.48	33.72	12.69	15.47	7.59	4.44	5.29	1.84	3.39	0.63	1.95	0.16	0.86	0.02	70
75							18.73	38.32	13.59	17.58	8.13	5.04	5.67	2.09	3.63	0.71	2.09	0.18	0.92	0.03	75
80							19.98	43.19	14.50	19.81	8.68	5.66	6.04	2.35	3.88	0.80	2.22	0.21	0.98	0.03	80
85									15.41	22.16	9.22	6.36	6.42	2.63	4.12	0.90	2.36	0.23	1.04	0.03	85
90									16.32	24.64	9.76	7.07	6.80	2.93	4.36	1.00	2.50	0.26	1.10	0.04	90
95									17.22	27.23	10.30	7.81	7.18	3.24	4.60	1.10	2.64	0.29	1.16	0.04	95
100									18.13	29.95	10.85	8.59	7.56	3.57	4.85	1.21	2.78	0.31	1.22	0.04	100
110									19.94	35.73	11.93	10.25	8.31	4.25	5.33	1.45	3.06	0.38	1.35	0.05	110
120											13.02	12.04	9.07	5.00	5.82	1.70	3.34	0.44	1.47	0.06	120
130											14.10	13.96	9.82	5.80	6.30	1.97	3.62	0.51	1.59	0.07	130
140											15.19	16.02	10.58	6.65	6.79	2.27	3.90	0.59	1.72	0.08	140
150											16.27	18.20	11.34	7.56	7.27	2.57	4.18	0.67	1.84	0.09	150
160											17.36	20.51	12.09	8.51	7.76	2.89	4.46	0.75	1.96	0.10	160
170											18.44	22.95	12.85	9.53	8.24	3.24	4.73	0.84	2.08	0.11	170
180											19.53	25.51	13.60	10.59	8.73	3.60	5.01	0.93	2.21	0.13	180
190													14.36	11.71	9.21	3.98	5.29	1.03	2.33	0.14	190
200													15.12	12.87	9.70	4.37	5.57	1.14	2.45	0.16	200
225													17.01	16.01	10.91	5.44	6.27	1.41	2.76	0.19	225
250													18.90	19.46	12.12	6.61	6.96	1.72	3.07	0.23	250
275															13.34	7.89	7.66	2.05	3.38	0.28	275
300															14.55	9.27	8.36	2.41	3.68	0.33	300
325															15.76	10.75	9.05	2.79	3.99	0.38	325
350															16.97	12.33	9.75	3.20	4.30	0.44	350
375															18.19	14.01	10.45	3.64	4.60	0.50	375
400															19.40	15.79	11.14	4.10	4.91	0.56	400
425																	11.84	4.59	5.22	0.63	425
450																	12.54	5.10	5.53	0.70	450
475																	13.23	5.64	5.83	0.77	475
500																	13.93	6.20	6.14	0.85	500
550																	15.32	7.40	6.76	1.01	550
600																	16.72	8.69	7.37	1.19	600

Note: Shaded areas of chart indicate velocities over 5' per second. Use with Caution.

***Source**: Hunter: Friction Loss Table.*
http://www.hunterindustries.com/resources/pdfs/Technical/Domestic/LIT091w.pdf

4. Losses from Fittings

a) Contraction

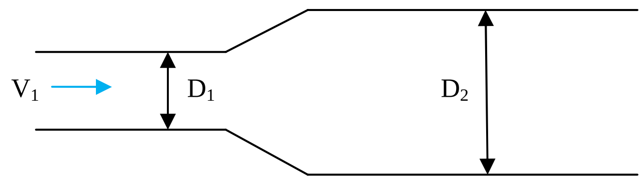


$$h_L = K\frac{{V_2}^2}{2g}$$

$\frac{D_1}{D_2}$	**Velocity, V_2 (m/s)**								
	0.6	**1.2**	**1.8**	**2.4**	**3**	**4.5**	**6**	**9**	**12**
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.06
1.2	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.10	0.11
1.4	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.20
1.6	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.24
1.8	0.34	0.34	0.34	0.33	0.33	0.32	0.31	0.29	0.27
2.0	0.38	0.37	0.37	0.36	0.36	0.34	0.33	0.31	0.29
2.2	0.40	0.40	0.39	0.39	0.38	0.37	0.35	0.33	0.30
2.5	0.42	0.42	0.41	0.40	0.40	0.38	0.37	0.34	0.31
3.0	0.44	0.44	0.43	0.42	0.42	0.40	0.39	0.36	0.33
4.0	0.47	0.46	0.45	0.45	0.44	0.42	0.41	0.37	0.34
5.0	0.48	0.47	0.47	0.46	0.45	0.44	0.42	0.38	0.35
10.0	0.49	0.48	0.48	0.47	0.46	0.45	0.43	0.40	0.36
∞	0.49	0.48	0.48	0.47	0.47	0.45	0.44	0.41	0.38

Source: *King, H.W., E.F Brater. 1963. Handbook of Hydraulics, 5th Edition. New York: McGraw-Hill. Table 6-9*

b) Expansion



$$h_L = K\frac{{V_1}^2}{2g}$$

$\frac{D_1}{D_2}$	**Velocity, V_2 (m/s)**						
	0.6	**1.2**	**3**	**4.5**	**6**	**9**	**12**
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2	0.11	0.10	0.09	0.09	0.09	0.09	0.08
1.4	0.26	0.25	0.23	0.22	0.22	0.21	0.20
1.6	0.40	0.38	0.35	0.34	0.33	0.32	0.32
1.8	0.51	0.48	0.45	0.43	0.42	0.41	0.40
2.0	0.60	0.56	0.52	0.51	0.50	0.48	0.47
2.5	0.74	0.70	0.65	0.63	0.62	0.60	0.58
3.0	0.83	0.78	0.73	0.70	0.69	0.67	0.65
4.0	0.92	0.87	0.80	0.78	0.76	0.74	0.72
5.0	0.96	0.91	0.84	0.82	0.80	0.77	0.75
10.0	1.00	0.96	0.89	0.86	0.84	0.82	0.80
∞	1.00	0.98	0.91	0.88	0.86	0.83	0.81

Source: *King, H.W., E.F Brater. 1963. Handbook of Hydraulics, 5th Edition. New York: McGraw-Hill.*

Table 6-7

c) Threaded Pipe Fitting

Minor loss coefficients for some of the most common used components in pipe and tube systems.

Type of Component or Fitting	**Minor Loss Coefficient -k-**
Tee, Flanged, Line Flow	0.2
Tee, Threaded, Line Flow	0.9
Tee, Flanged, Branched Flow	1.0
Tee, Threaded , Branch Flow	2.0
Union, Threaded	0.08
Elbow, Flanged Regular 90^o	0.3
Elbow, Threaded Regular 90^o	1.5
Elbow, Threaded Regular 45^o	0.4
Elbow, Flanged Long Radius 90^o	0.2
Elbow, Threaded Long Radius 90^o	0.7
Elbow, Flanged Long Radius 45^o	0.2
Return Bend, Flanged 180^o	0.2
Return Bend, Threaded 180^o	1.5
Globe Valve, Fully Open	10
Angle Valve, Fully Open	2
Gate Valve, Fully Open	0.15
Gate Valve, 1/4 Closed	0.26
Gate Valve, 1/2 Closed	2.1
Gate Valve, 3/4 Closed	17
Swing Check Valve, Forward Flow	2
Ball Valve, Fully Open	0.05
Ball Valve, 1/3 Closed	5.5
Ball Valve, 2/3 Closed	200
Diaphragm Valve, Open	2.3
Diaphragm Valve, Half Open	4.3
Diaphragm Valve, 1/4 Open	21
Water meter	7

Source: Minor Loss Coefficients in Pipes and Tubes Components
http://www.engineeringtoolbox.com/minor-loss-coefficients-pipes-d_626.html