CERTIFICATION OF APPROVAL

Comparison of Performance between Centrifugal and Positive Displacement Pump at Low Flow Rate

by

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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 acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(NOORAZREEN BINTI SUHAIMI)

ABSTRACT

In general, centrifugal pump is more preferable to industrial applications. When a centrifugal pump operates at its off-design condition; operating at low capacity and require high pressure conditions, pump will experience some unfavorable condition such as temperature rise effect. Positive displacement pump is more suitable to be used when low capacity and high pressure are necessary. Thus, this project is carried out to make a comparison between centrifugal and positive displacement pumps at low flow rate. The objectives of the project are to determine the best efficiency points for both centrifugal and positive displacement pump by using data obtained from the experiments, to suggest the suitable pump used at low flow rates and to monitor the temperature rise effects of both pumps when they are running at low flow rates for several hours.

Experiments on single stage centrifugal pump and a gear pump are conducted. The objective of the experiments is to determine the efficiency of centrifugal and gear pump at low flow rate with four different types of liquids; water, heavy, medium and light crude and two different conditions; constant and variable speeds. From the experiments for both centrifugal and gear pump, the efficiency of centrifugal pump is nearly 0% as pump operates at low flow rate. As the viscosity of liquid increases, the efficiency decreases and temperature increases at constant speed. When the speed increases, the efficiency also increases whereas the viscosity of liquid is decreased. When gear pump operates at low flow rate, its efficiency value is higher than the centrifugal pump. As the viscosity of liquid increase, the efficiency increases and temperature increases at constant speed. If the speed of the pumps increases, the efficiency increases.

Positive displacement creates flow and centrifugal pump creates pressure. Thus, positive displacement pump such as gear pump is more preferable when the system runs at low capacity.

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NOMENCLATURE

h_t = Total head (m)

h_s = Static head (m)

h_f = Friction head (m)

h_p = Pressure head (m)

h_v = Velocity head (m)

μ = dynamic viscosity (N.s/m^2 or kg/s.m)

L = length of the pipe (m)

V = velocity of the fluid (m/s)

ν = kinematics viscosity (m^2/s)

g = acceleration due to gravity, 9.81m/s^2

f = resistance coefficient

D = diameter of pipe (m)

k_s = equivalent sand grain roughness (mm)

Re = Reynolds Number

K = resistance coefficient for particular valve or fitting

P = pressure (kPa)

H = Head (m)

N = pump speed (rpm)

Q = flow rate (m^3/s)

η = pump efficiency

NPHSr = net positive suction head required (m)

NPSHa = net positive suction head available (m)

ATM = the atmospheric pressure at the elevation of the installation (kPa)

Pg_s = the suction pressure gauge reading taken at the pump centerline (kPa)

H_{vp} = the vapor pressure (m)

ρ = density (kg/m^3)

m = mass (kg)

γ = specific gravity

CHAPTER 1

INTRODUCTION

1.1 Project Background

A pump is a kinetic device used to transfer liquid from one place to another by using several energy transformations. There are many types of pumps available in the market according to their function and are designed for different types of fluids such as water, crude oil, diesel, gasoline and others.

Basically, centrifugal pump is more widely used in industrial application compared to the other pumps available. For a centrifugal pump, theoretically, as long as the net positive suction available is greater than the required net positive suction head, a centrifugal pump is capable in operating over a wide range of capacities. [1]
When low capacity and high pressure are considered, positive displacement pump is more preferable. In this project, type of positive displacement pump used is a gear pump. Gear pump is a most commonly manufactured rotary positive displacement pumps. Besides, gear pump has conquered a wide market due to its simple design and possibility of economical production.

This project carries out the comparison of performance between single stage centrifugal pump and positive displacement gear pump. Different types of liquids will be used as flowing liquid with two different conditions; constant and different speeds. By the end of this project, the efficiency of the centrifugal and gear pump can be determined and compared when low flow rate and high pressure are considered. Other than that, the effect of temperature rise also monitored during the experiments when the pump operates out of the ideal range.

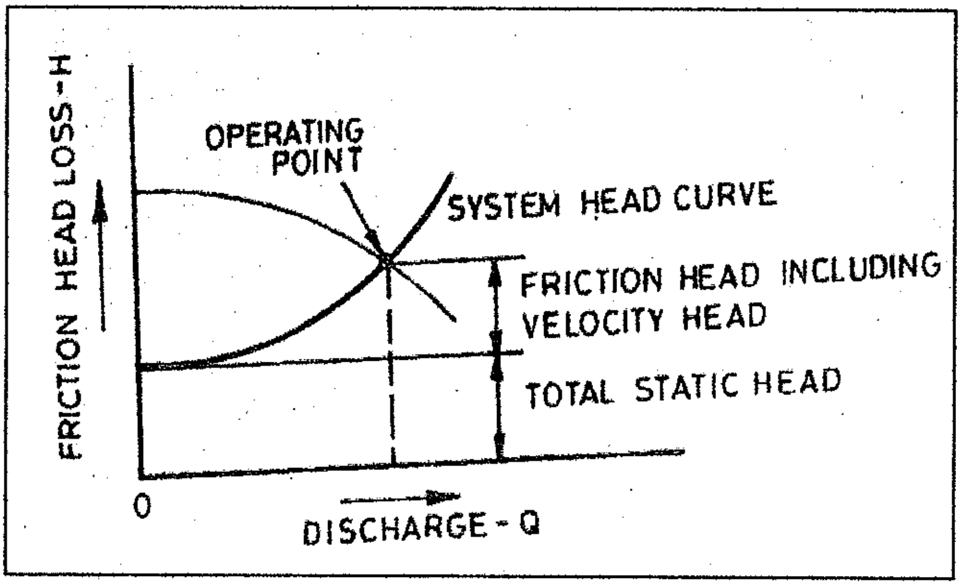


Figure 1.1: System head curve of centrifugal pump. (From *Pump,* G.K.Sahu, 2000)

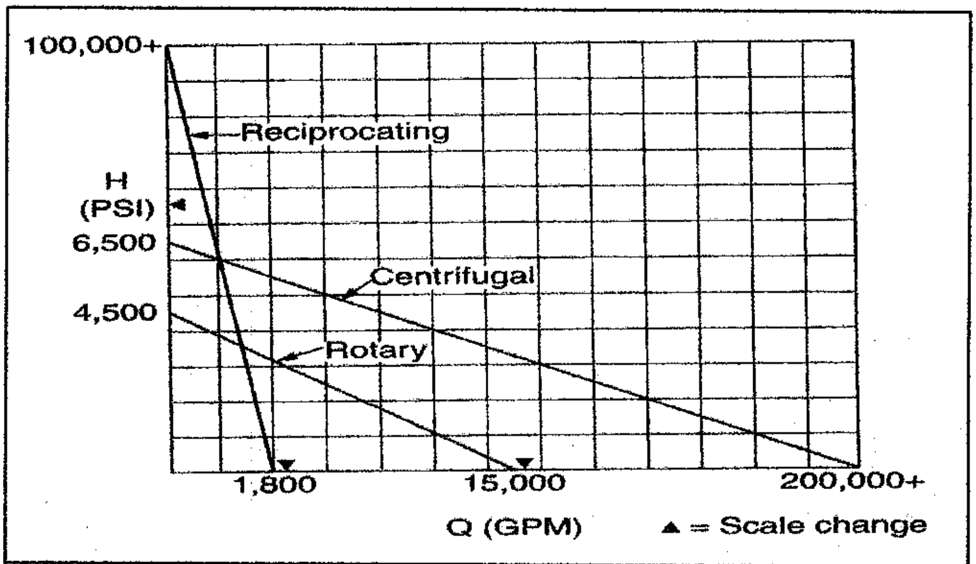


Figure 1.2: Head versus flow for centrifugal, rotary and reciprocating pump. (From, *Pumps Characteristics and Applications,* Michael Volk, 2005)

1.2 Problem Statement

When a centrifugal pump is operating at off-design condition which is a condition where the pump is required by the force of circumstances to deliver flows either in excess of or below the capacity of best efficiency. There are two types of conditions for pump to be operated at off-design conditions which are operation at high flow rates and operation at low flow rates. Operation at high flows occurs when a pump has been oversized by specifying excessive margin on total head. In this condition, the head – flow curve intersects the system-head curve at capacity much in excess of the real required flow.[5] Centrifugal pump that operates at low flow rates when there is a reduction in demand of the process can lead to a number of unfavorable conditions that may take place separately or simultaneously such as temperature rise effect, vibration, noise and etc.

When high pressure and low flow criteria are considered together, it is impossible to find a centrifugal pump that produces several thousands pounds of pressure (psi) with low flow rate. So, positive displacement pump is used to meet the criteria for both high pressure and low flow.

The project is carried out to do a comparison of performance between centrifugal pump and positive displacement pump and to determine the efficiencies for both pumps that operate at low flow and high pressure.

1.3 Objectives and Scope of Study

The main objectives aimed at the completion of this project are:

1. To determine the best efficiency points for both centrifugal and positive displacement pumps by using data obtained from the experiments.
2. To suggest the suitable pump (either centrifugal pump or gear pump) used at low flow rates.

The project specifically focused on a single stage centrifugal pump and positive displacement gear pump.

CHAPTER 2

LITERATURE REVIEW

2.1 Pump Classification

There are many different types of pumps available in the market depending on its function. Pumps are classified as shown in the Figure 2.1 below:

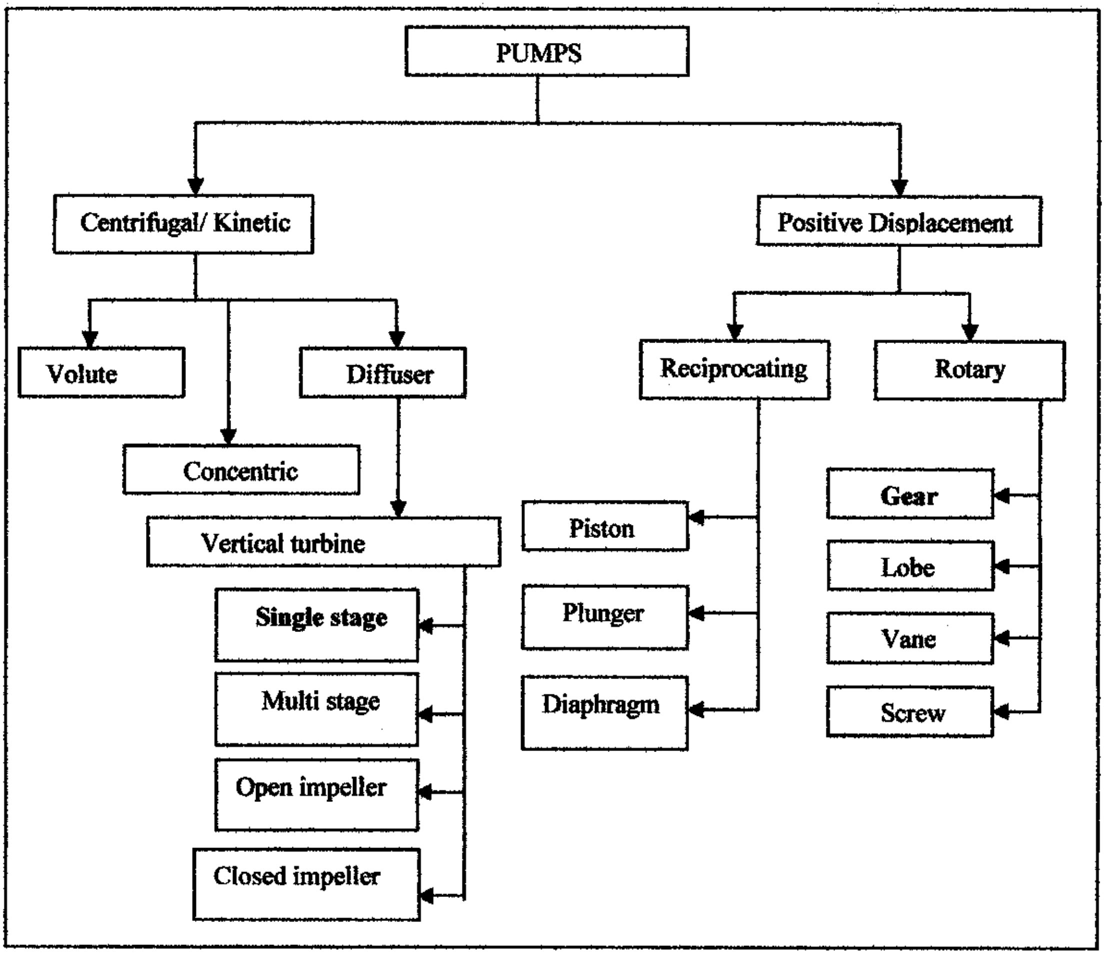


Figure 2.1: Classification of two families of pumps.

2.2 Working Principle of Centrifugal Pump and Positive Displacement Pump

A centrifugal pump converts energy of prime mover either electric motor or turbine to kinetic energy by using rotating impeller. Liquid is forced into the inlet side of the pump casing. As the impeller rotates, liquid will be pumped outward from the vanes and produces centrifugal acceleration. The liquid experiences high pressure when being pumped and leaving the eye of the impeller and flows towards discharge. Since the impeller blades are curved, fluid is pushed in a tangential and radial direction by centrifugal force.

The amount of energy is proportional to the velocity at the edge or vane tip of the impeller. The faster the impeller revolves, the bigger the size of the impeller, the higher will be the velocity of liquid at vane tip and the greater energy imparted.

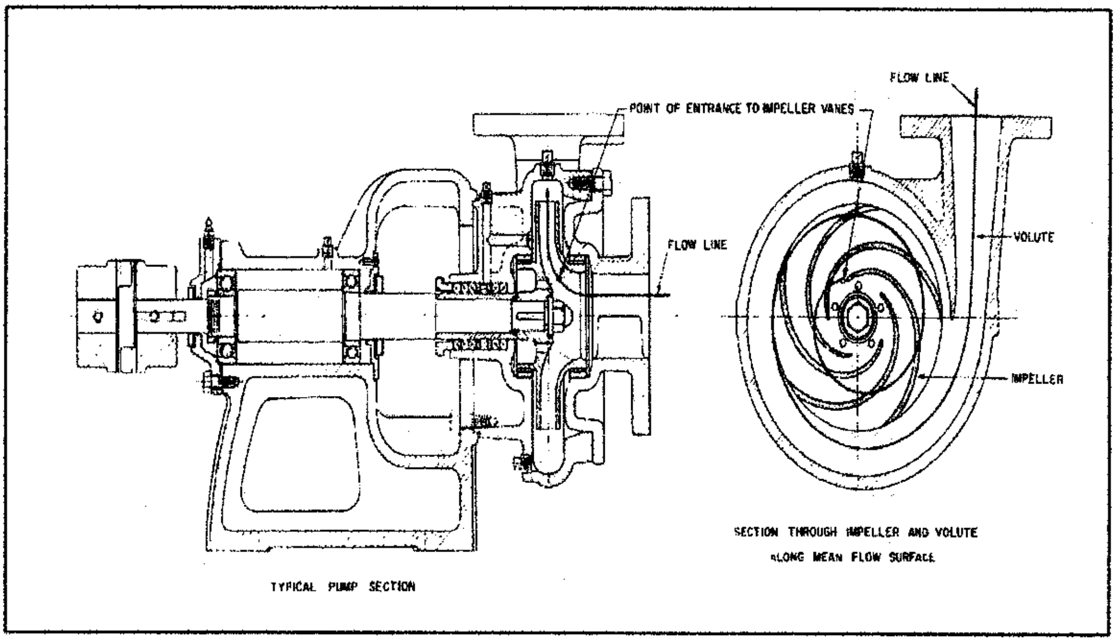


Figure 2.2: Working principle of a centrifugal pump. (From *Centrifugal Pumps,* I.J Karassik, 2000)

According to S Ilango and V Soundararajan (2007)

The principle of operation of gear pump lies in meshing and rotating of two gears as shown in Figure 2.3 below. One gear which is mostly driven by an electric motor is called the driver gear and the other one meshing with this gear is called the driven gear. These two gears are housed in a closely – fitted housing.

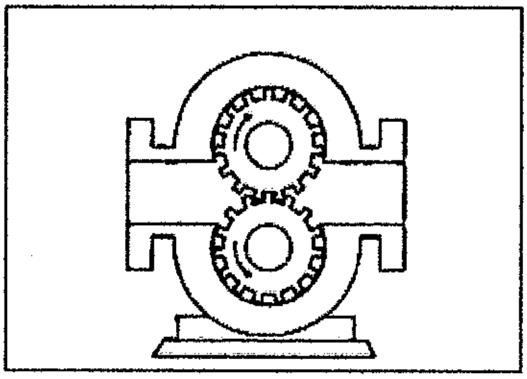


Figure 2.3: Engaging of gears in a gear pump (From *Introduction to Hydraulics and Pneumatics,* Ilango S & Soundararajan V, 2007)

Two gears rotate in the opposite directions. The meshing of the gears start as the engaging pair of teeth approaches the discharge side of the pump and starts disengaging as the engaged pair of gear teeth reaches the path of suction side of the pump. When the teeth start disengaging, the pressure at the suction side drop and this makes liquid to be sucked up into the pump. As the gears continue to rotate, liquid is entrapped between the gear space and the wall of the housing is carried forward and delivered at the discharge side. As teeth of the driver and driven gears start meshing again, the pressure builds up at the discharge side and because of that liquid is pushed outside the pump. The working of the external gear pump as illustrated in Figure 2.4 below:

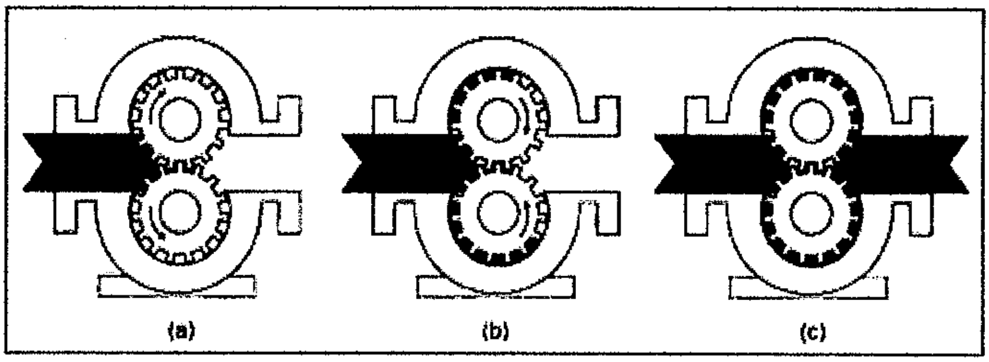
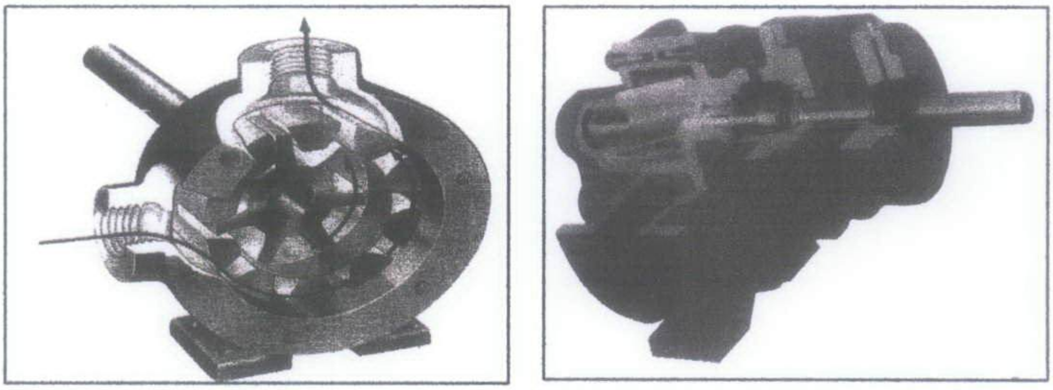


Figure 2.4: Working of the external gear pump: (a) Suction, (b) Transport, (c) Discharge. (From *Introduction to Hydraulics and Pneumatics,* Ilango S & Soundararajan V, 2007)

The delivery of the liquid at the discharge takes place in discrete quantities and depending on the number of teeth the smoothness of flow will vary. The more the number of teeth, the better will be the continuous delivery of the liquid.

Positive displacement pump creates flow and centrifugal pump creates pressure. Flow is created by enclosing a volume at suction, moving it to discharge and releasing it. Pressure is created by the system's response to flow. If there are no connections to the discharge flange, the flow would exit the pump at atmospheric pressure. Positive displacement supplies a steady source of power.



(a) (b)

Figure 2.5: (a) Internal gear pump (b) External gear pump (From *Pumps Characteristics and Applications*, Michael Volk, 2005)

2.3 Performance Curve of Pump

There are four curves relating to each other in performance curve on a common graph:

1. The Head – Flow Curve
2. The Energy Curve
3. The Efficiency Curve
4. The Net Positive Suction Head required (NPSHr) Curve

2.3.1 The Head – Flow Curve

There are four separates components of total system head. The four components are static head, friction head, pressure head and velocity head. Total system head can be simply expressed in the equation below:

$$h_t = h_s + h_f + h_p + h_v$$

Static head is the difference in elevation between discharge and suction liquid level. Three types of static head considered in calculating static head are static discharge head, static suction head and static suction lift. Static discharge head is the difference in elevation between discharge liquid level and centerline of pump. Static suction head is the difference in elevation between suction liquid level and centerline of pump. Static suction lift is the suction liquid level below the centerline. Refer to Appendix A.

Friction head is the head necessary to overcome the friction losses in the piping expressed in meters (feet) of liquid pumped. The value of friction head varies with the quantity of flow, size, type and condition of piping and fittings and also characteristic of liquid pumped. The smaller the size of the pipe, valves and fittings of the given flow rate, the greater the friction head loss. In theory, friction losses that occur as liquid flows through the piping system must be calculated by using complicated formulae and factors such as liquid density and viscosity and pipe inside diameter and materials used are taking into account. The friction head loss in a given length of pipe can be expressed by either of the following formula according to the value of Reynolds number, Re:

1) If Re < 2000, the flow in a pipe is laminar flow

   Thus, friction head loss of laminar flow is calculated by the following equation:

   $$h_f = \frac{32\mu LV}{\gamma D}$$

   Here, $\mu / \gamma = v / g$

2) If Re > 3000, the flow in a pipe is turbulent flow

   Thus, friction head loss of turbulent flow is calculated by the following the Darcy-Weisbach equation:

   $h_f = f(LV^2 / D2g)$

   where f is derived from the following equation:

   $$f = \frac{0.25}{[\log_{10}((k_s/3.7D) + (5.74/Re^{0.9}))]^2}$$

   The value ok equivalent sand grain roughness, k_s can be obtained from Appendix B. Besides, the value of f can also be determined by using Moody diagram. Refer to Appendix C.

The friction loss in valves and fittings is given by the formula:

$h_f = K x (V^2 / 2g)$

Refer to Appendix D.

The value for $(V^2/2g)$ for different flow rates and different valve/fitting diameters is found in the pipe friction.

Pressure head is the head required to overcome a pressure in the pump's system. Pressure head is normally measured at the liquid surface in the supply and delivery system. If the pressure in the supply vessel and the delivery system is same, then there is no additional head in total head. Likewise, the additional head is required in calculating the total head of the pump's system. The pressure must be converted to feet by following equation:

$$P = \frac{H x \gamma}{2.31}$$

Velocity head is the kinetic energy in liquid at any point can be expressed in the equation below:

$$h_v = (V^2) / (2g)$$

The velocity at the impeller tip can also be expressed as:

$$V = (N x D) / 229$$

It is necessary to add velocity head at pressure gauge reading to determine the additional suction at discharge head whereas the gauge only indicates pressure energy.

2.3.2 The Energy Curve

The amount of energy that must be supplied to operate a pump is called horsepower. Interpretation of horsepower data on the pump performance curve is necessary in order to choose the correct size of driver for the pump. Two commonly designated expression for horsepower are water horsepower and brake horsepower. Water horsepower (WHP) is the output of the pump handling a liquid of a given specific gravity, flow rate and head. WHP can be expressed by the following formula:

$$WHP = \frac{Q \, x \, H \, x \, \gamma}{3960}$$

The constant, 3960 is obtained by dividing 33,000 (the number of ft-lb/min in one horsepower) by 8.34 (the number of pounds per gallon of water).

Brake horsepower (BHP) is the actual amount of power that must be supplied to the pump to obtain a particular flow and head. The formula for BHP is:

$$BHP = \frac{Q \, x \, H \, x \, \gamma}{3960 \, x \, \eta}$$

2.3.3 The Efficiency Curve

According to Michael Volk (2005)

> The relative importance of the four losses varies from one type of pump to another. Actual efficiencies for various types of centrifugal pumps can vary widely, over a range from less than 30% to over 90%. Therefore the pump efficiency is equal to the ratio of the two:
>
> $$\eta = \frac{WHP}{BHP}$$

2.3.4 The Net Positive Suction Head (NPSH) Curve

According to Larry Bachus and Angel Custodio (2003)

> Net Positive Suction Head required is the energy required to overcome the friction losses from the suction nozzle to the eye of the impeller without causing vaporization. The value of the NPSHr varies by design, size and operating conditions. NPSHr increases at high flow rates due to the increased amount of friction loss inside the pump inlet before the liquid reaches the impeller.

NPSHr can be determined by using the following formula:

$$NPHSr = P_{atm} + Pg_s + H_v - H_{vp}$$

Vapor pressure of a liquid is a pressure when a liquid turns into vapor when heat is added to the liquid.

Net Positive Suction Head available (NPSHa) is the energy in the fluid at the suction connection of the pump over and above liquid's vapor pressure. NPSHa should be greater than NPSHr.

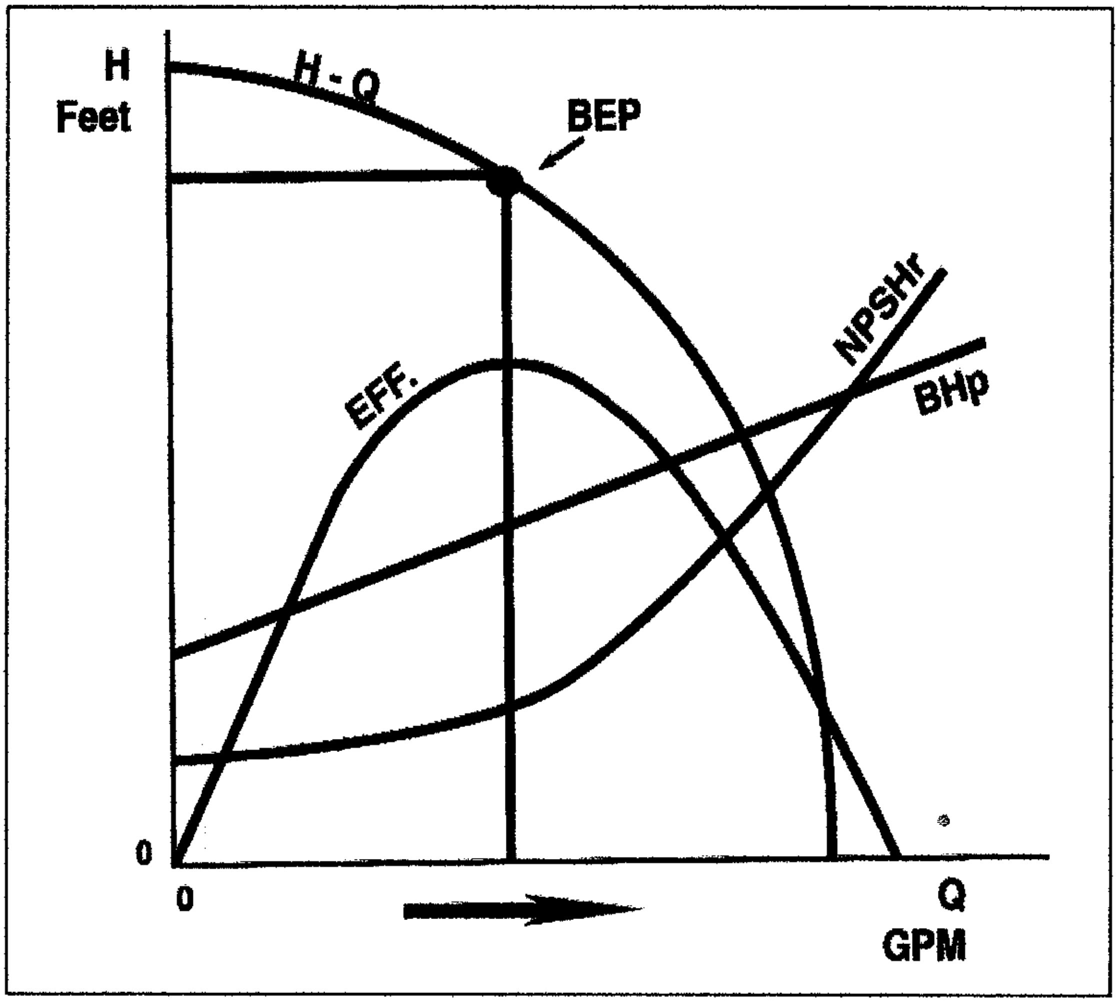


Figure 2.6: The four curves of centrifugal pump as they appear on the same graph. (From *Know and Understand Centrifugal Pumps,* L.Bachus, A. Custodio, 2003)

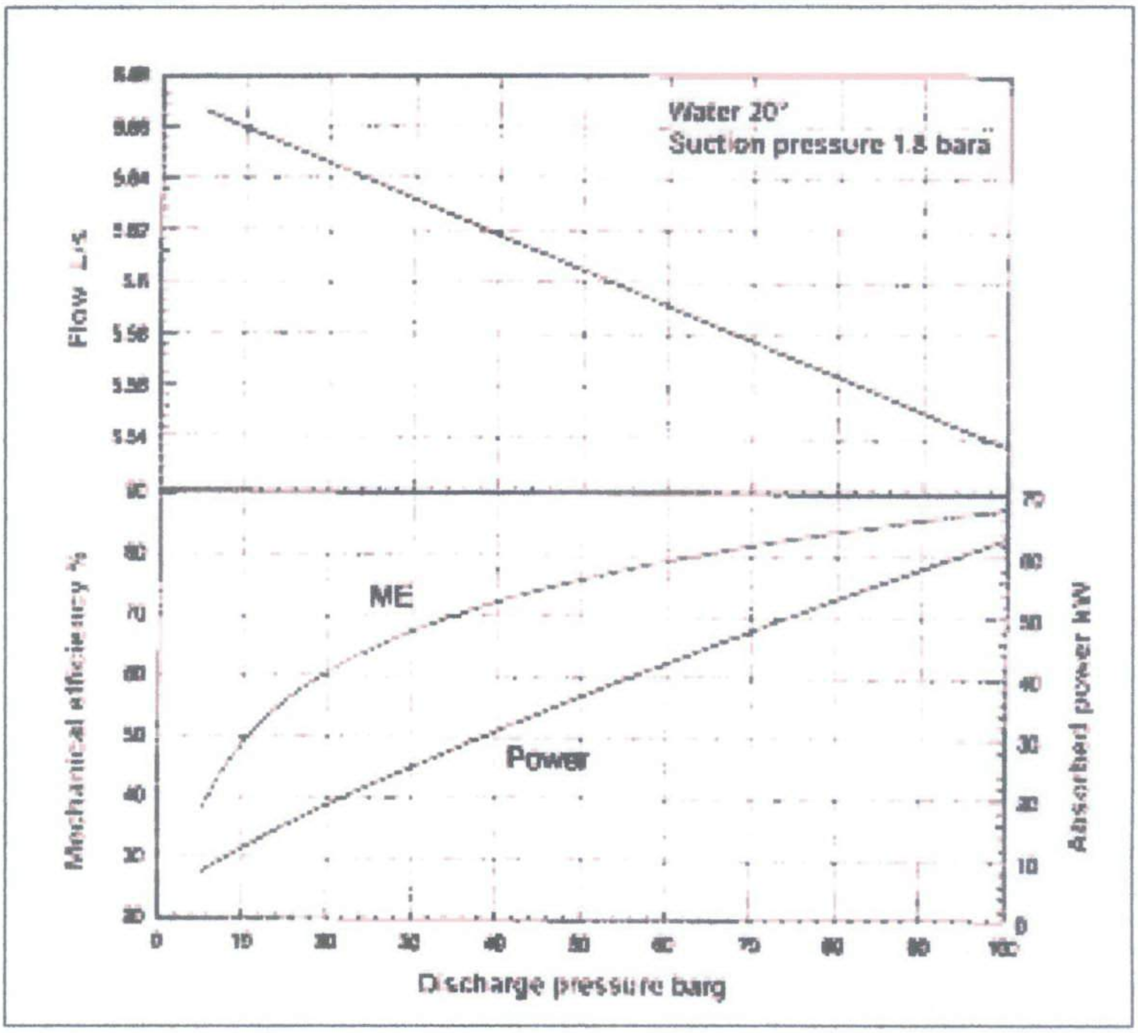


Figure 2.7: The typical performance curves of gear pump (From *Handbook of Pump and Pumping*, Brian Nestbitt, 2006)

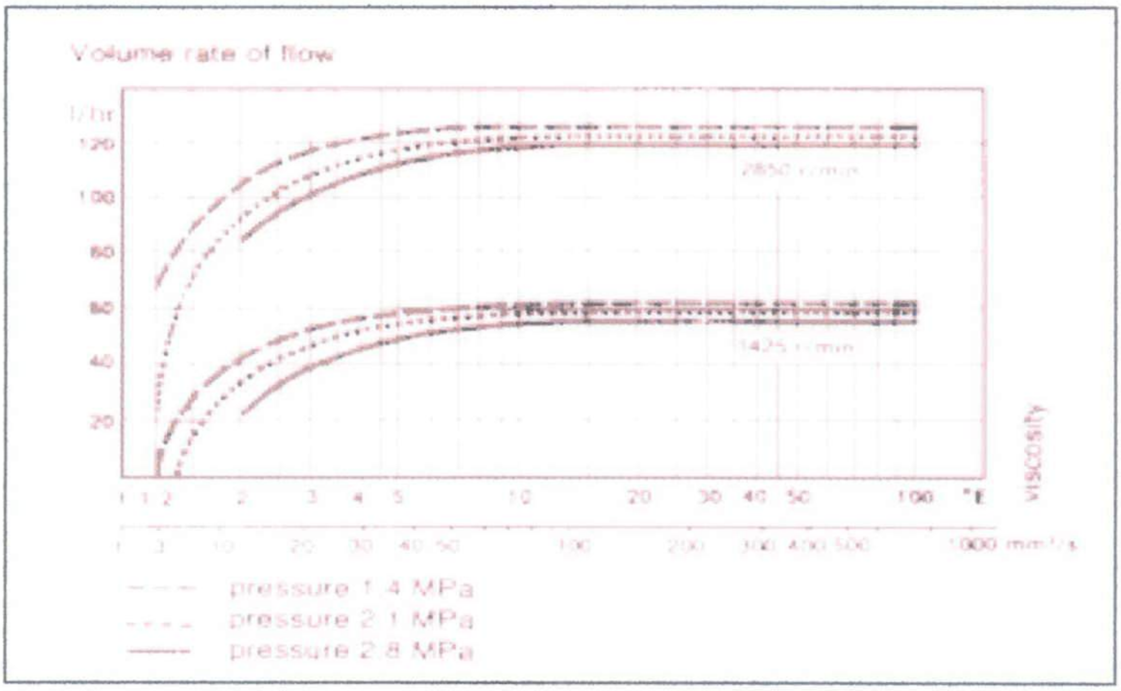


Figure 2.8: The effect of speed and pressure on a small gear pump (From *Handbook of Pump and Pumping,* Brian Nestbitt, 2006)

Below are the viscosity values for all liquids used in the experiment:

Table 2.1: Viscosity values for all the liquids used in the experiment.

Types of liquids	Theoretical viscosity, cp	Experimental viscosity, cp
Water	1.00	0.890
Light Crude Oil (TCOT)	1.60 – 3.80	1.620
Medium Crude Oil (Angsi)	3.50 – 9.70	3.966
Heavy Crude Oil (Penara)	4.90 – 17.80	4.934

(From *Progress Report FYP 2,* Yusoff N S, 2010)

CHAPTER 3

METHODOLOGY

3.1 Problem Definition and Literature Review

Primarily, feasible study is conducted in order to understand the basic concept and working principle of a centrifugal pump and positive displacement pump. A thorough literature review is conducted by referring to reference books, journals and internet websites for a better understanding.

3.2 Centrifugal Pump and Positive Displacement Pump (Gear Pump) Laboratory Test

There are two experiments conducted in this project. The experiments are on characteristic curves of centrifugal pump by using centrifugal pump demonstration unit FM20 and characteristics curves of positive displacement pump (gear pump) by using gear pump demonstration unit FM22. The focus for both experiments is primarily on the pump's performance at low flow rates. Experiments involve taking the measurement reading of pump's flow rates, total head, efficiency and power consumption of each operating pump. Based on both experiments data, the performance curve can be plotted and the efficiency of the pump at respective flow rate can be determined.

3.2.1 Objective of the Experiments

The objective of the experiments is to determine the efficiency of the centrifugal and gear pump at low flow rate.

3.2.2 Description of the Experiments

The equipment comprises of a centrifugal pump/gear pump driven by an electric motor which is mounted on a support plinth together with a clear acrylic reservoir and associated pipework for continuous circulation. Liquid (water, TCOT, Penara and Angsi crude oil) are used as the operating fluid and a drain valve at the base of the reservoir allows the liquid to be drained after use.

Appropriate sensors are incorporated on the unit to facilitate analysis of the pump performance when connected to a suitable computer via an Armfield interface device. In addition to the tapping required by the pressure sensors, additional tapping are included in the pipework to allow appropriate calibration instruments to be connected. The flow of the water through the centrifugal pump is regulated by a flow control valve installed in the discharge pipework of the pump. Adjustment of this valve allows the head/flow produced by the pump to be varied. A valve in the inlet pipework of the pump allows the effect of the suction losses to be investigated. The following sensors are used to monitor the performance of the centrifugal pump/gear pump:

i. Differential pressure sensor – This differential pressure sensor comprises of a pressure sensitive piezoresistive device with appropriate signal conditioning all contained in a protective case. This sensor is used to measure pressure developed across orifice plate installed in the discharge pipework of the pump. The volume flow rate of the water through the pump can be calculated using this measurement.
ii. Differential pressure sensor – This sensor comprises of a pressure sensitive piezoresistive device use to measure the difference in pressure between the inlet and outlet of the centrifugal pump/gear pump. The head developed by the pump can be calculated from this measurement.
iii. Rotational speed sensor – This rotational speed sensor comprises a reflective infra-red opto switch on a remote lead with appropriate signal conditioning in a protective case and is used to measure the rotational speed of the motor/pump impeller.

iv. Temperature sensor – The temperature sensor consists of a temperature sensitive semiconductor device which is used to measure the temperature of the liquid entering the centrifugal pump/gear pump. [18]

The experiment set up of the centrifugal and gear pump demonstration units are shown in the Figure 3.1 and Figure 3.2 respectively:

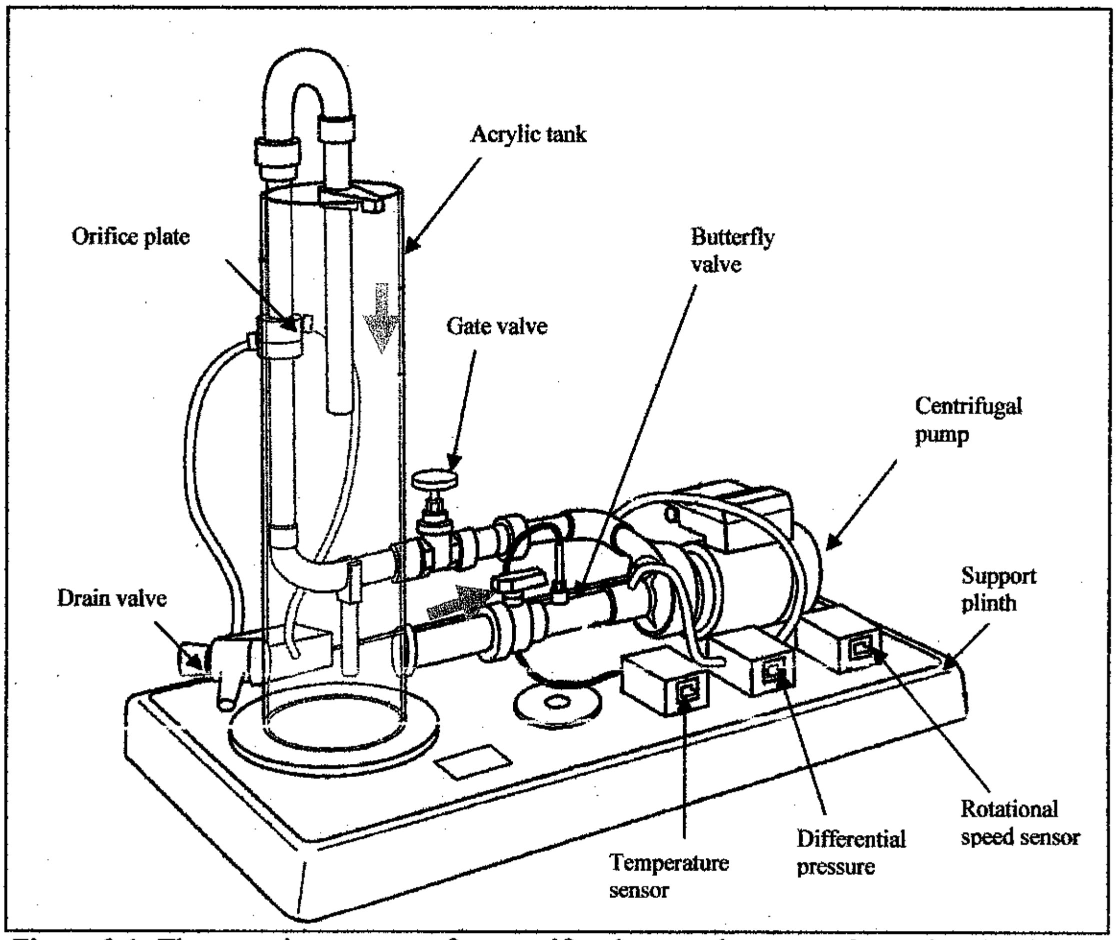


Figure 3.1: The experiment set up for centrifugal pump demonstration unit (FM20)

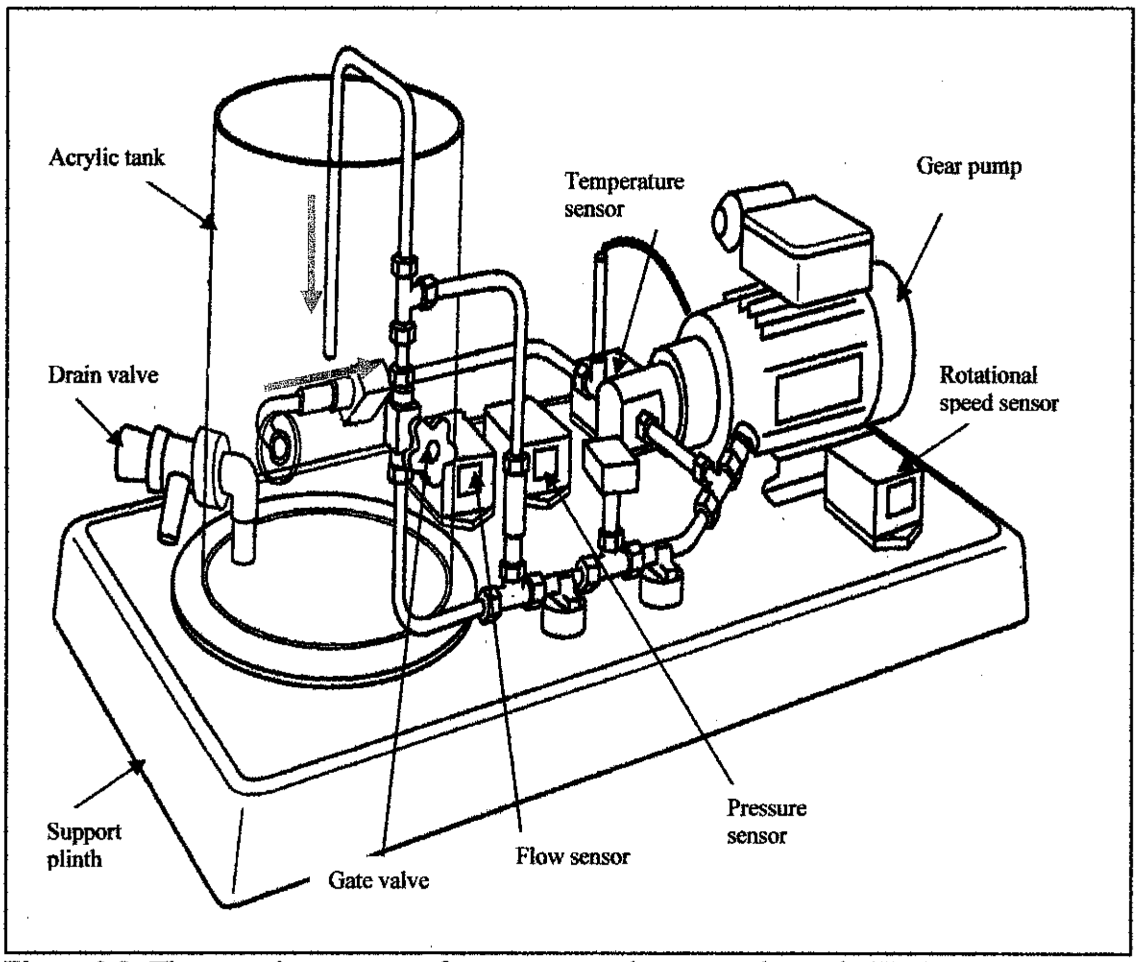


Figure 3.2: The experiment set up for gear pump demonstration unit (FM22)

Refer to Appendix E for the procedures of the experiments for both centrifugal and gear pump.

3.4 Governing Equation in Experiments

The basic terms used to define and measure the pump performance include discharge, head, power input and efficiencies.

The discharge or flow rate or capacity of the pump is the volume of the fluid pumped per unit time. In SI units, this is expressed in cubic meters per second (m^3/s) or for convenience with small flows, in cubic decimeters per second (dm^3/s). The Armfield FM20 unit employs an orifice plate in the pump discharge pipeline to measure flow rate according to the conventional relationship between the measured pressure drops across the orifice. The equation of the flow rate is as follow:

$$Q = \frac{Cd x \Pi x d^2 \sqrt{2 x \rho x \Delta P}}{4 \rho}$$

The power consumed by the fluid in producing the total dynamic head at a discharge can be calculated by the equation below:

$$P = \rho x g x Q x H$$

The Armfield FM 20 and FM 22 pump unit do not include the direct measurement of mechanical power Pm for cost reasons but instead measures electrical power Pgr to the pump motor. Thus, the overall efficiency can be calculated as follow:

$$Egr = \frac{P}{Pgr}$$

3.5 Project Work Flow

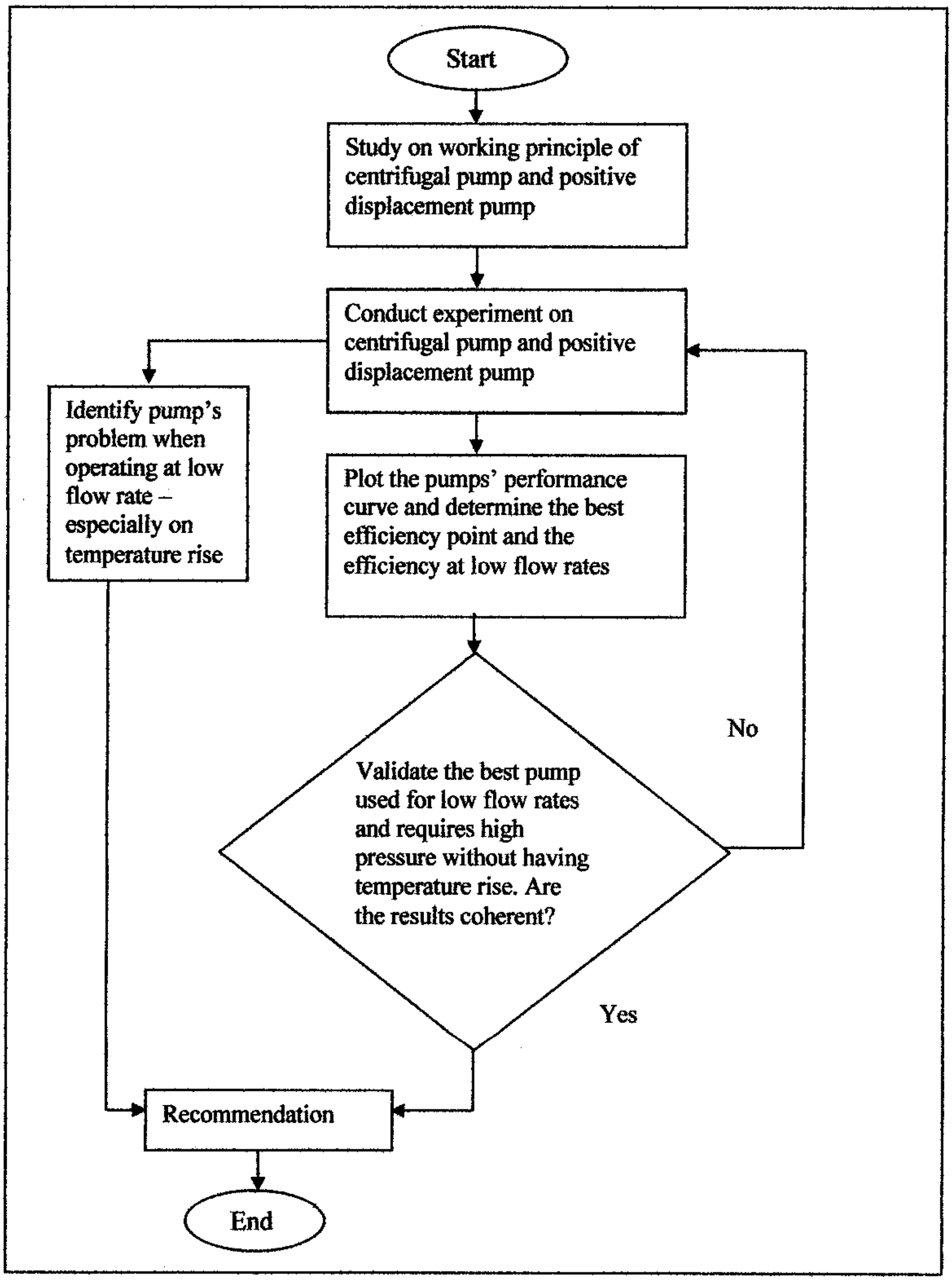


Figure 3.3: The process flow of the project

Refer to Appendix F for the Gantt chart of the project.

3.6 Tools

Tools used in the project are:

1. FM 20 equipment set up
2. FM 22 equipment set up
3. Data logging software
4. Microsoft excel

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results

4.1.1 Experiment on Centrifugal Pump Demonstration Unit

Experiments are conducted on centrifugal pump demonstration unit (FM 20) to investigate the relationship between pressure head, power consumption and efficiency of a centrifugal pump at low flow rates based on two conditions which are different speeds and constant speed. In these experiments, four different types of liquids are used. The liquids used are water, light (TCOT) crude oil, medium (Angsi) crude oil and heavy (Penara) crude oil. Refer to Appendix E for the procedures of the experiment.

Below are the data obtained from the experiments:

Table 4.1: Data tabulated on centrifugal pump at constant speed for water

No	Flow rate (dm^3/s)	Head (m)	Power Input (W)	Efficiency (%)
1	0.000	9.566	0	0.000
2	0.160	9.499	15	0.000
3	0.201	9.109	18	9.177
4	0.318	8.970	28	28.514
5	0.417	8.772	36	36.561
6	0.507	8.824	44	89.530
7	0.610	8.324	50	22.568
8	0.709	7.943	55	11.252
9	0.822	7.451	60	0.000
10	0.976	6.677	64	0.000

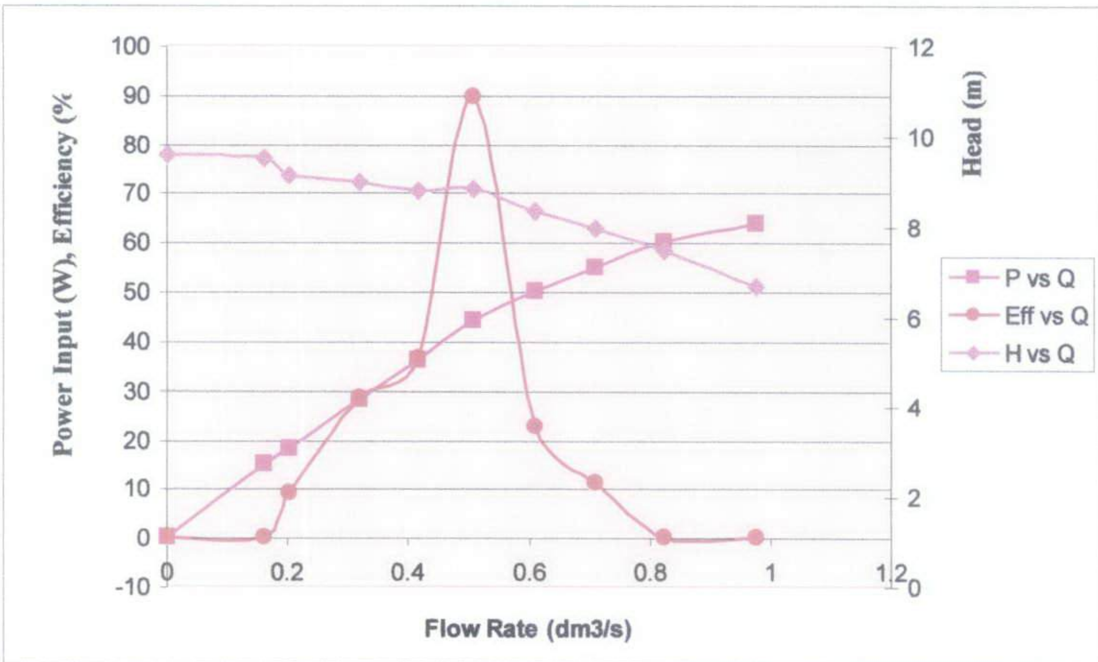


Figure 4.1: Performance curves of centrifugal pump at constant speed for water

Based on the graph plotted in Figure 4.1, the highest efficiency can be obtained by the centrifugal pump at constant speed, 3600 rpm for water as liquid used is 89.53% at 0.507 dm^3/s of flow rate. When the flow rate is as low as 0 – 0.160 dm^3/s, the efficiency of the pump is 0%.As the flow rate increases from 0.160 dm^3/s, the efficiency of the pump also increase. After reaching best efficiency point at 89.53%, the efficiency of the pump decreases as the flow rate increases. As the flow rates increase, the total heads decrease. When the flow rates increase, the power inputs also increase.

Table 4.2: Data tabulated on centrifugal pump at different speeds for water

No	Speed (rpm)	Flow rate (dm^3/s)	Head (m)	Power Input (W)	Efficiency (%)
1	0	0.000	9.600	0	0.000
2	60	0.000	9.490	0	0.000
3	1200	0.000	9.450	0	0.000
4	1800	0.050	9.434	10	0.010
5	2400	0.179	9.277	17	0.021
6	3000	0.506	8.560	43	88.356
7	3600	0.968	6.687	65	0.040

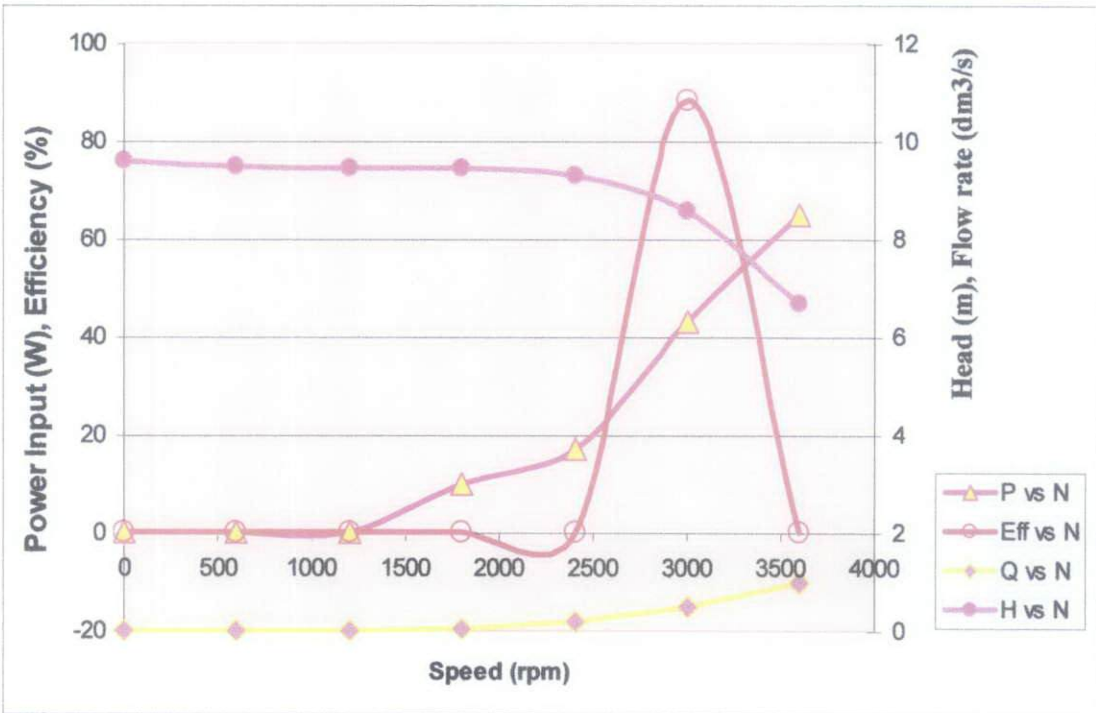


Figure 4.2: Performance curves of centrifugal pump at different speeds for water.

From Figure 4.2, when the speed of the motor is 0 rpm, the flow rate is 0dm^3/s. The total head when the flow rate 0 dm^3/s is 9.6m. The highest efficiency of the centrifugal pump can be obtained is 88.356% at 3000 rpm. As the speed of the pump increase, the power inputs also increase.

Table 4.3: Data tabulated on centrifugal pump at constant speed for TCOT crude oil

No	Flow Rate (dm^3/s)	Head (m)	Power Input (W)	Efficiency (%)
1	0.000	7.453	0.0	0.0
2	0.025	7.310	1.0	13.0
3	0.050	7.180	2.0	68.0
4	0.073	5.790	2.4	75.0
5	0.108	3.879	3.0	84.0
6	0.125	3.156	3.0	81.0
7	0.152	2.889	4.0	80.0
8	0.170	1.783	3.0	73.0
9	0.180	1.391	3.0	61.0
10	0.193	1.402	4.0	69.0

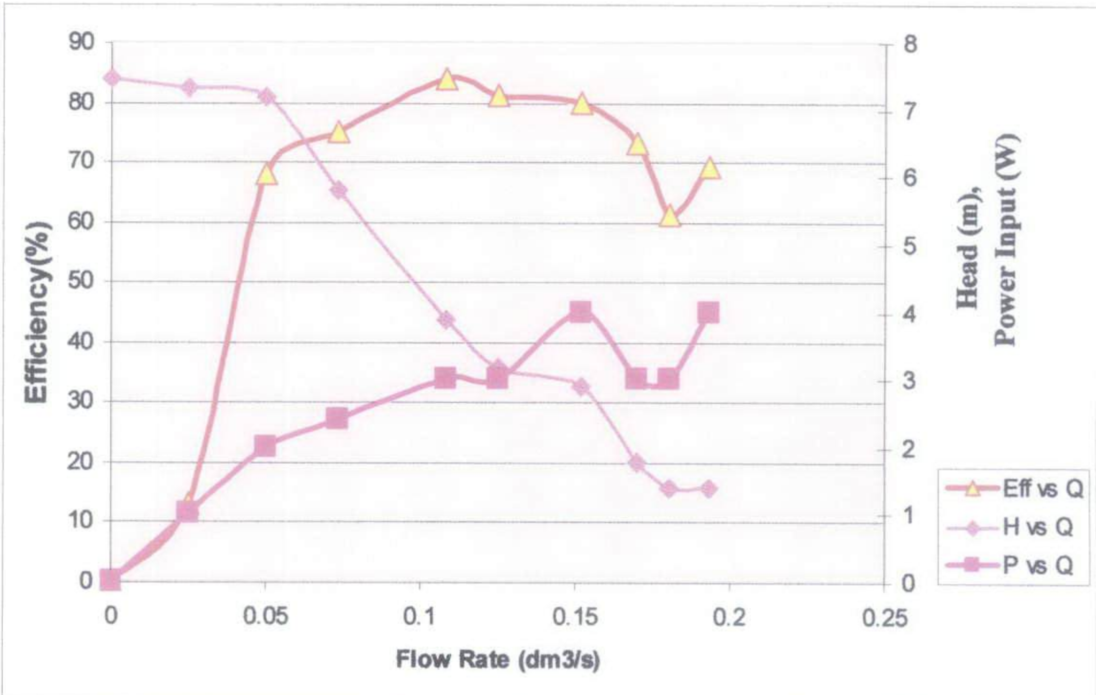


Figure 4.3: Performance curves of centrifugal pump at constant speed for TCOT crude oil

The graph plotted in Figure 4.3 shows that the highest efficiency of the pump is 84% when the flow rate is 0.108 dm^3/s. When TCOT crude oil is used, the best efficiency point is slightly lower compared to the value of the best efficiency point when the water is used instead.

Table 4.4: Data tabulated on centrifugal pump at different speeds for TCOT crude oil

No	Speed (rpm)	Flow rate (dm^3/s)	Head (m)	Power Input (W)	Efficiency (%)
1	0	0.000	0.807	0	0.0
2	60	0.000	0.839	0	0.0
3	1200	0.000	0.852	0	0.0
4	1800	0.000	0.861	0	0.0
5	2400	0.095	0.870	1	1.1
6	3000	0.132	0.873	1	1.5
7	3600	0.199	0.961	2	2.2

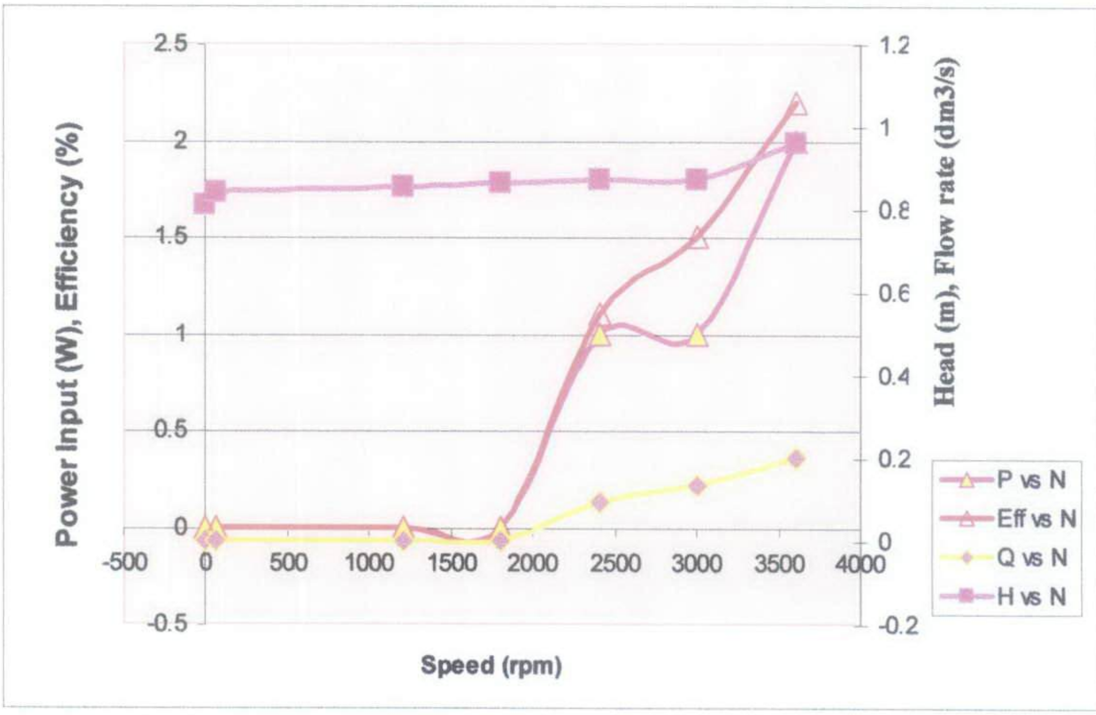


Figure 4.4: Performance curves of centrifugal pump at different speeds for TCOT crude oil

The above graph shows that when the speed of the motor increases, flow rates and power inputs increase. The best efficiency that can be obtained by the pump when TCOT crude oil is used as liquid is 2.2%.

Table 4.5: Data tabulated on centrifugal pump at constant speed for Angsi crude oil.

No	Flow rate (dm^3/s)	Head (m)	Power Input (W)	Efficiency (%)
1	0.000	1.335	0	0
2	0.025	1.295	1	15
3	0.050	1.181	1	36
4	0.071	1.123	1	36
5	0.100	1.114	1	37
6	0.144	1.104	2	58
7	0.152	1.104	2	72
8	0.169	1.107	2	54
9	0.180	1.094	2	47
10	0.199	1.081	2	36

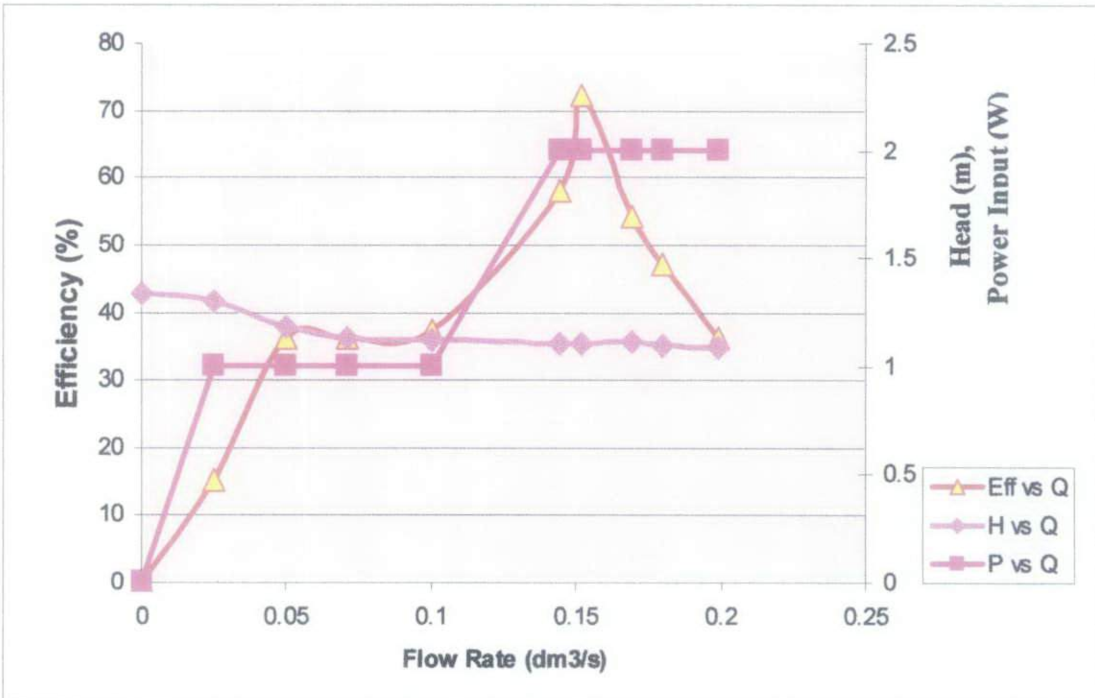


Figure 4.5: Performance curves of centrifugal pump at constant speed for Angsi crude oil

The performance curve of centrifugal pump at constant speed for Angsi crude oil shows that the highest efficiency can be obtained is 72% when the flow rate is 0.152 dm^3/s. The total head obtained when $0 dm^3/s$ is 1.335 m. The value is lower than the value of the total head for water and TCOT crude oil.

Table 4.6: Data tabulated on centrifugal pump at different speeds for Angsi crude oil

No	Speed (rpm)	Flow rate (dm^3/s)	Head (m)	Power Input (W)	Efficiency (%)
1	0	0.000	1.027	0	0.0
2	60	0.000	1.049	0	0.0
3	1200	0.050	1.071	1	1.1
4	1800	0.129	1.203	2	2.1
5	2400	0.147	1.225	2	2.0
6	3000	0.165	1.269	2	2.1
7	3600	0.205	1.324	3	2.5

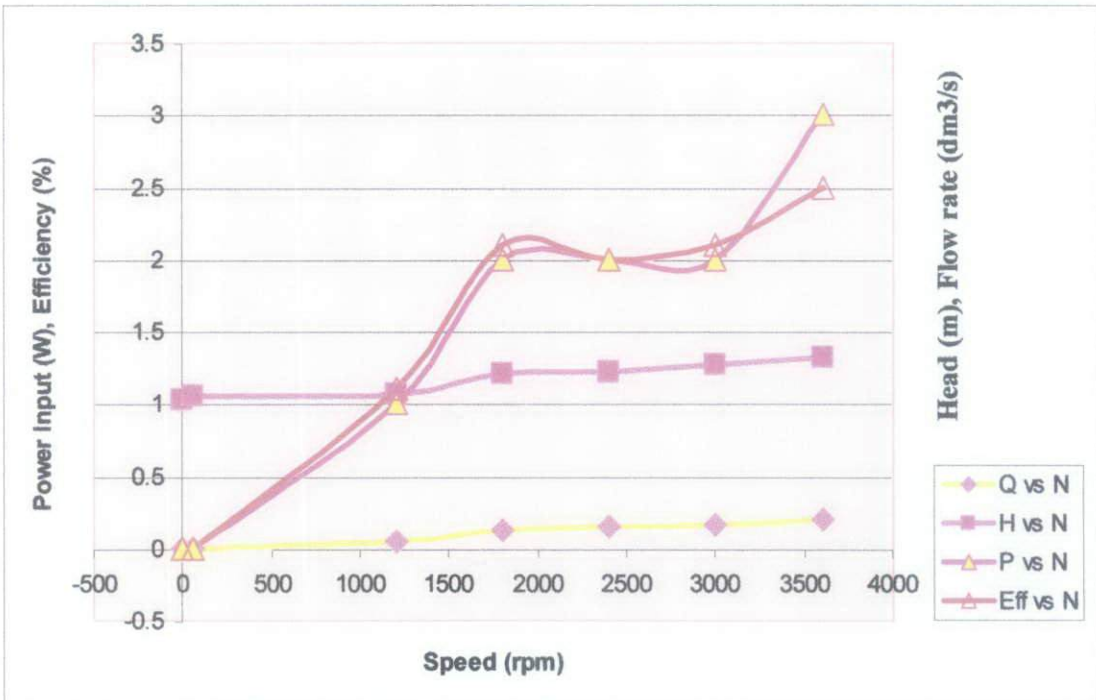


Figure 4.6: Performance curves of centrifugal pump at different speeds for Angsi crude oil

Based on the Figure 4.6, the highest speed of motor which is 3600 rpm obtains the highest efficiency, 2.5%. As the speeds of the motor increase, the flow rates, power inputs and temperature also increase. The total heads of the pump decrease as the flow rates and speeds of the pump increase. When the speed of the motor is 0 rpm and flow rate is 0 dm^3/s, the efficiency of the pump is 0%.

Table 4.7: Data tabulated on centrifugal pump at constant speed for Penara crude oil

No	Flow rate (dm^3/s)	Head (m)	Power Input (W)	Efficiency (%)
1	0.000	1.493	0	0.0
2	0.024	1.454	1	7.3
3	0.058	1.367	1	18.0
4	0.071	1.333	1	19.4
5	0.104	1.316	1	27.0
6	0.126	1.299	2	34.0
7	0.150	1.292	2	46.0
8	0.171	1.280	3	46.0
9	0.191	1.249	3	50.0
10	0.204	1.248	3	56.0

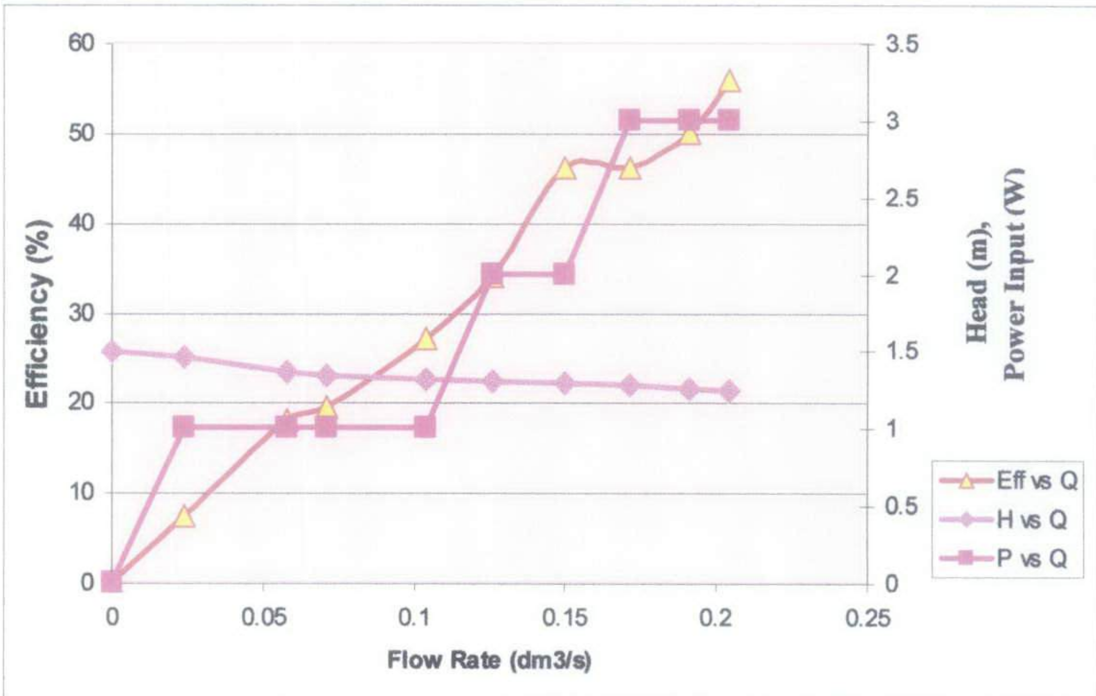


Figure 4.7: Performance curves of centrifugal pump at constant speed for Penara crude oil

The above graph shows that the highest efficiency can be obtained is 56% when Penara crude oil is used as liquid. If the flow rates increase, the power inputs also increase. From the graph plotted, when the flow rate is between 0 – 0.024 dm^3/s, the efficiency of the pump is increase from 0 – 7.3%. Thus, the efficiency starts to increase when the flow rate is increase.

Table 4.8: Data tabulated on centrifugal pump at different speeds for Penara crude oil

No	Speed (rpm)	Flow rate (dm^3/s)	Head (m)	Power Input (W)	Efficiency (%)
1	0	0.000	0.929	0	0.0
2	60	0.000	0.929	0	0.0
3	1200	0.000	1.073	0	0.0
4	1800	0.029	0.984	0	0.3
5	2400	0.029	1.073	0	0.5
6	3000	0.108	1.195	1	1.0
7	3600	0.163	1.338	2	1.4

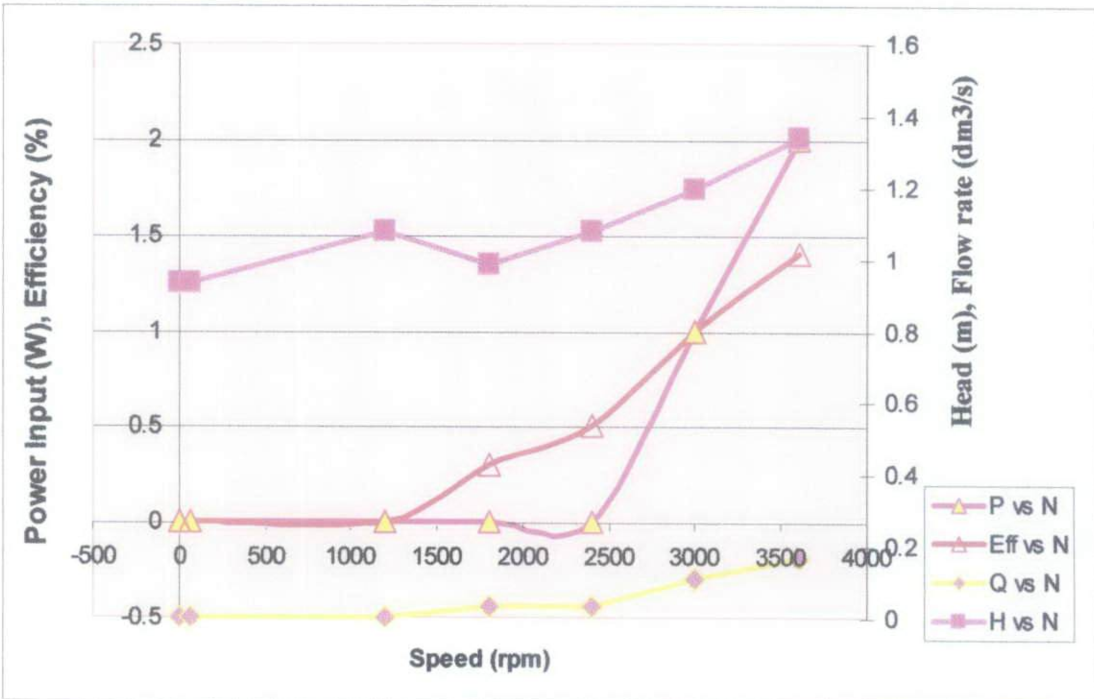


Figure 4.8: Performance curves of centrifugal pump at different speeds for Penara crude oil

Figure 4.8 shows the performance curves of centrifugal pump at different speeds for Penara crude oil. The graph plotted shows that the highest efficiency is 1.4% when the motor speed reaches 3600 rpm. As the speeds of the motor increase, the flow rates and power inputs also increase.

4.1.2 Experiment on Gear Pump Demonstration Unit

Experiments are conducted on gear pump demonstration unit (FM 22) to investigate the relationship between pressure head, power consumption and efficiency of a positive displacement gear pump at low flow rates. The experiment conducted based on two conditions which are conditions at different speeds and constant speed. In these experiments, four different types of liquids are used. The liquids used are as same as the liquid used for the centrifugal pump. The liquids used are water, light (TCOT) crude oil, medium (Angsi) crude oil and heavy (Penara) crude oil. Refer to Appendix E for the procedures of the experiment.

Table 4.9: Data tabulated on gear pump at constant speed for water

No	Head (m)	Power Input (W)	Overall Efficiency (%)	Volumetric Efficiency (%)	Volumetric Flowrate (dm^3/s)	Outlet Pressure (kPa)
1	26.212	5.0	0.00	0.4	0.001	289.160
2	24.745	4.5	4.30	0.3	0.001	273.096
3	21.436	4.0	34.90	2.0	0.005	236.865
4	18.657	3.7	48.30	5.4	0.014	206.445
5	10.477	3.3	89.50	14.7	0.038	116.895
6	7.355	3.2	74.41	17.4	0.045	82.715
7	5.170	3.2	63.00	20.1	0.052	58.789
8	4.108	2.5	67.20	21.1	0.055	47.168
9	3.047	2.0	57.60	22.8	0.059	35.547
10	2.766	1.0	27.50	23.1	0.060	32.471

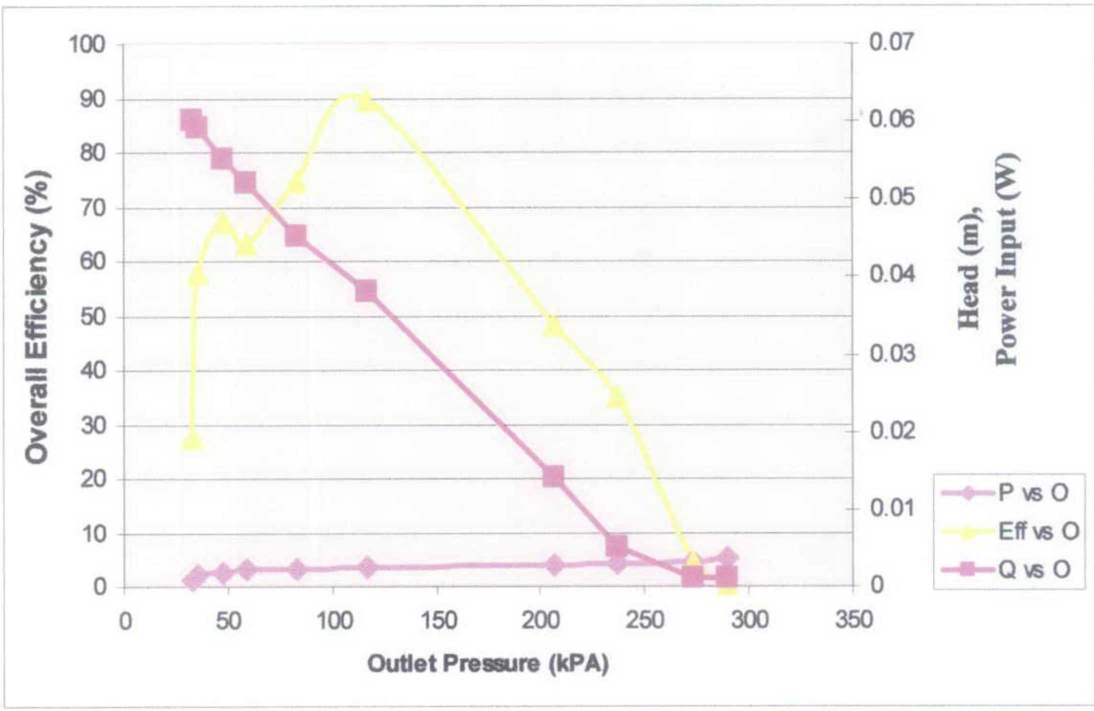


Figure 4.9: Performance curves of gear pump at constant speed for water

Based on the graph plotted in Figure 4.9, the highest efficiency can be obtained by the gear pump at constant speed, 3600 rpm for water as liquid used is 89.5% at 0.038 dm^3/s of flow rate. When the flow rate is as low as 0.001dm^3/s, the overall efficiency is 0%. As the volumetric flow rate increases from 0.001dm^3/s, the overall efficiency of the pump also increase. After reaching the best efficiency point at 89.5%, the efficiency starts to decrease as the volumetric flow rates decrease. As the flow rates increase, the total heads decrease. When the flow rates increase, the power inputs also increase.

Table 4.10: Data tabulated on gear pump at different speeds for water

No	Speed (rpm)	Head (m)	Power Input (W)	Overall Efficiency (%)	Volumetric Efficiency (%)	Volumetric Flowrate (dm^3/s)	Outlet Pressure (kPa)
1	0	0.200	0	0.0	0.0	0.000	0.000
2	60	1.704	0	0.1	0.0	0.002	20.850
3	1200	4.608	0	0.1	0.0	0.001	52.637
4	1800	4.702	0	0.1	0.0	0.001	53.662
5	2400	5.482	2	1.5	13.2	0.034	62.207
6	3000	6.200	4	4.4	22.4	0.058	70.068
7	3600	6.419	4	2.9	23.1	0.060	72.461

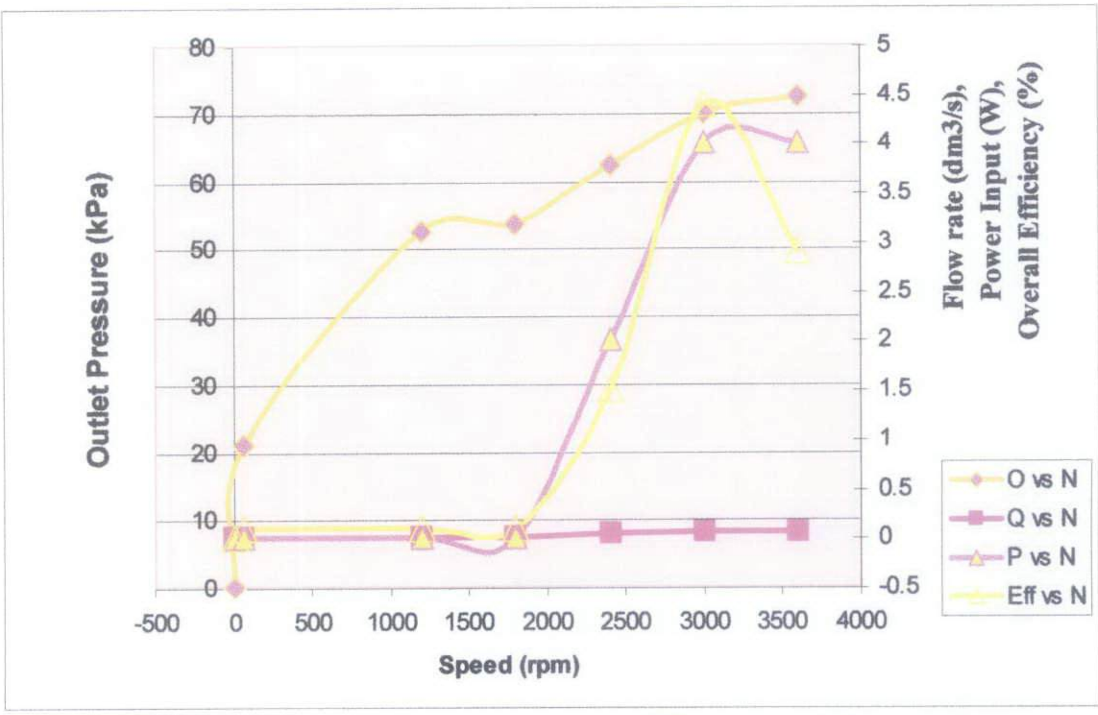


Figure 4.10: Performance curves of gear pump at different speeds for water

From Figure 4.10, when the speed of the motor is 0 rpm, the flow rate is 0dm3/s. The total head when the flow rate 0 dm^3/s is 0.2 m. The highest efficiency if the gear pump can be obtained is 4.4% at 3000 rpm. As the speeds of the pump increase, the power inputs also increase. Since the gear pump creates flow, the outlet pressure values are considered. If the speeds of the motor increase, the outlet pressure of the pump also increase.

Table 4.11: Data tabulated on gear pump at constant speed for TCOT crude oil

No	Head (m)	Power Input (W)	Overall Efficiency (%)	Volumetric Efficiency (%)	Volumetric Flowrate (dm^3/s)	Outlet Pressure (kPa)
1	27.399	3.5	8.0	0.3	0.001	302.148
2	24.027	3.4	9.6	0.4	0.001	265.234
3	22.091	3.2	9.7	0.4	0.001	244.043
4	18.001	3.1	39.4	0.4	0.002	199.268
5	16.003	2.8	35.0	0.4	0.002	177.393
6	13.006	2.4	28.5	0.4	0.002	144.580
7	12.038	1.9	13.2	0.4	0.002	133.984
8	9.072	1.9	3.5	0.3	0.003	101.514
9	6.075	0.6	4.3	0.3	0.003	68.701
10	3.016	0.0	1.2	0.4	0.003	35.205

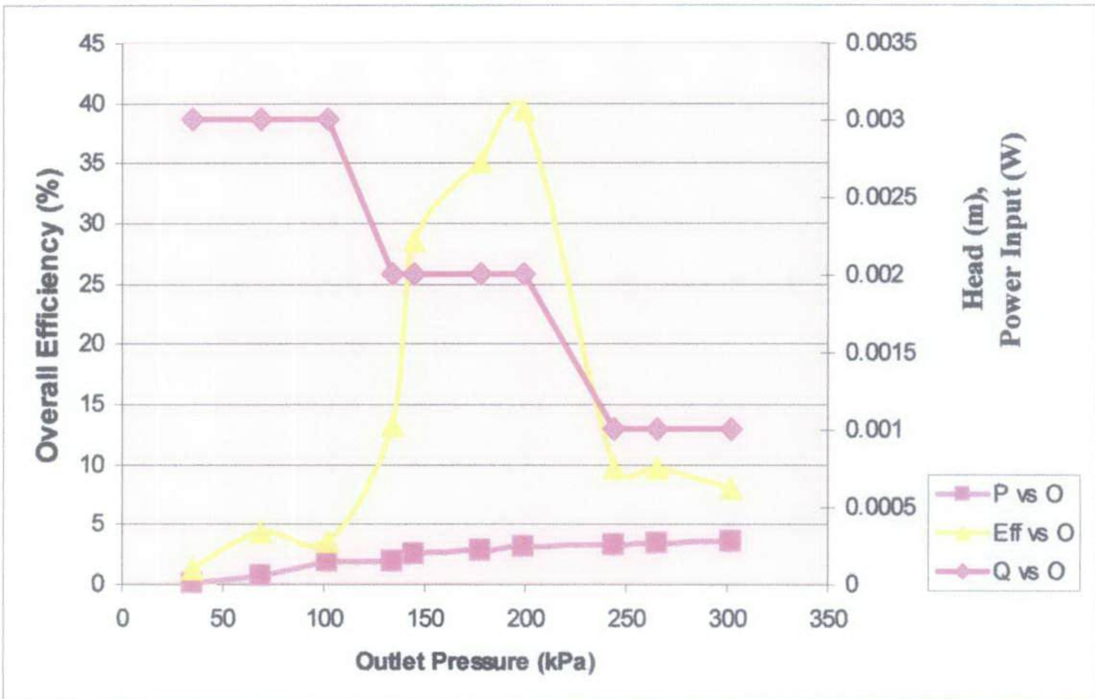


Figure 4.11: Performance curves of gear pump at constant speed for TCOT crude oil

The graph plotted in Figure 4.11 shows that the highest efficiency of the pump is 39.4% when the flow rate is $0.002dm^3/s$. The efficiency of gear pump is higher compared to the efficiency of the centrifugal pump in Figure 4.3 when the flow rate is $0.002dm^3/s$. Based on Figure 4.3, when the flow rate is 0.002 dm^3/s, the efficiency of the centrifugal pump is 1%.

Table 4.12: Data tabulated on gear pump at different speeds for TCOT crude oil

No	Speed (rpm)	Head (m)	Power Input (W)	Overall Efficiency (%)	Volumetric Efficiency (%)	Volumetric Flowrate (dm^3/s)	Outlet Pressure (kPa)
1	0	0.143	0	0.0	0.0	0.001	3.760
2	60	3.765	0	0.0	2.5	0.001	43.408
3	1200	4.858	0	0.0	1.1	0.001	55.371
4	1800	4.577	0	0.1	0.7	0.001	52.295
5	2400	4.589	0	0.1	0.6	0.001	52.400
6	3000	4.608	1	0.1	0.5	0.001	52.637
7	3600	6.231	2	0.1	0.5	0.001	70.410

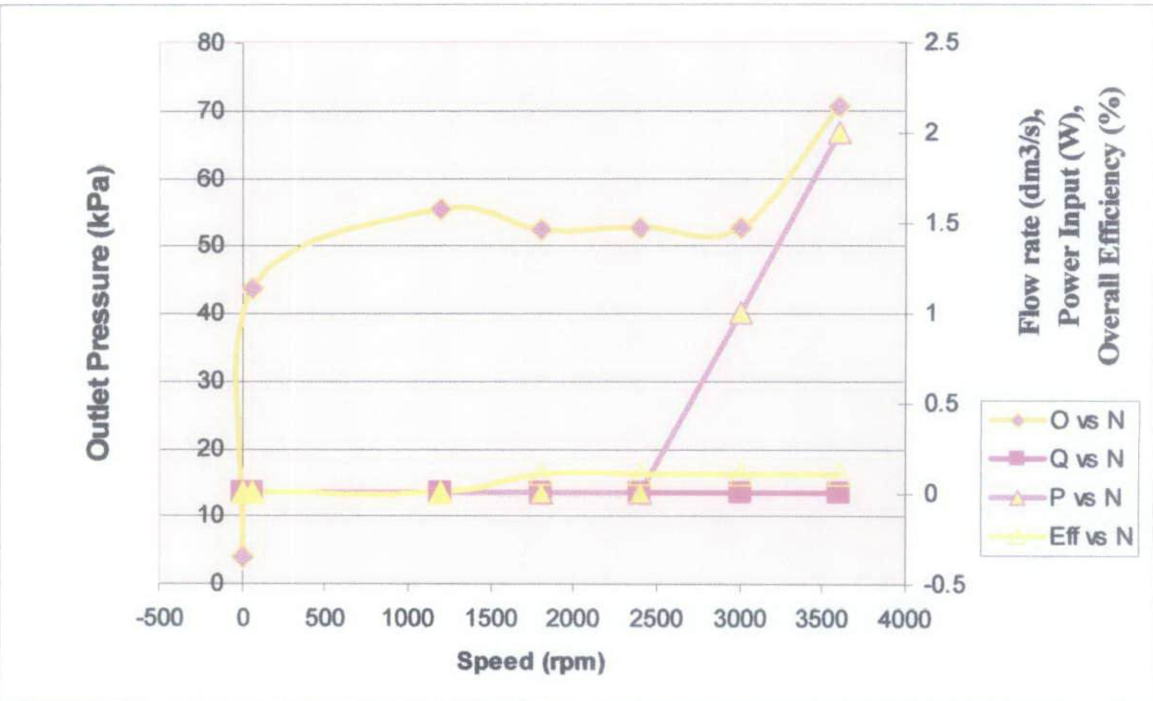


Figure 4.12: Performance curves of gear pump at different speeds for TCOT crude oil

The above graph shows that when the speeds of the motor increase, flow rates and power inputs increase. The best efficiency that can be obtained by the pump when TCOT crude oil is used as liquid is 0.1%.

Table 4.13: Data tabulated on gear pump at constant speed for Angsi crude oil

No	Head (m)	Power Input (W)	Overall Efficiency (%)	Volumetric Efficiency (%)	Volumetric Flowrate (dm^3/s)	Outlet Pressure (kPa)
1	30.052	3.7	43.9	0.4	0.001	331.201
2	27.086	3.4	9.5	0.3	0.001	298.730
3	24.120	3.3	17.6	0.4	0.001	266.266
4	21.123	2.9	6.2	0.4	0.001	233.447
5	18.095	2.1	7.9	0.3	0.001	200.293
6	15.067	1.9	3.8	0.3	0.001	167.139
7	12.257	1.4	3.1	0.3	0.001	136.377
8	9.010	1.3	7.9	0.4	0.001	100.830
9	6.075	0.6	1.5	0.3	0.001	68.701
10	3.390	0	0.8	0.3	0.001	39.307

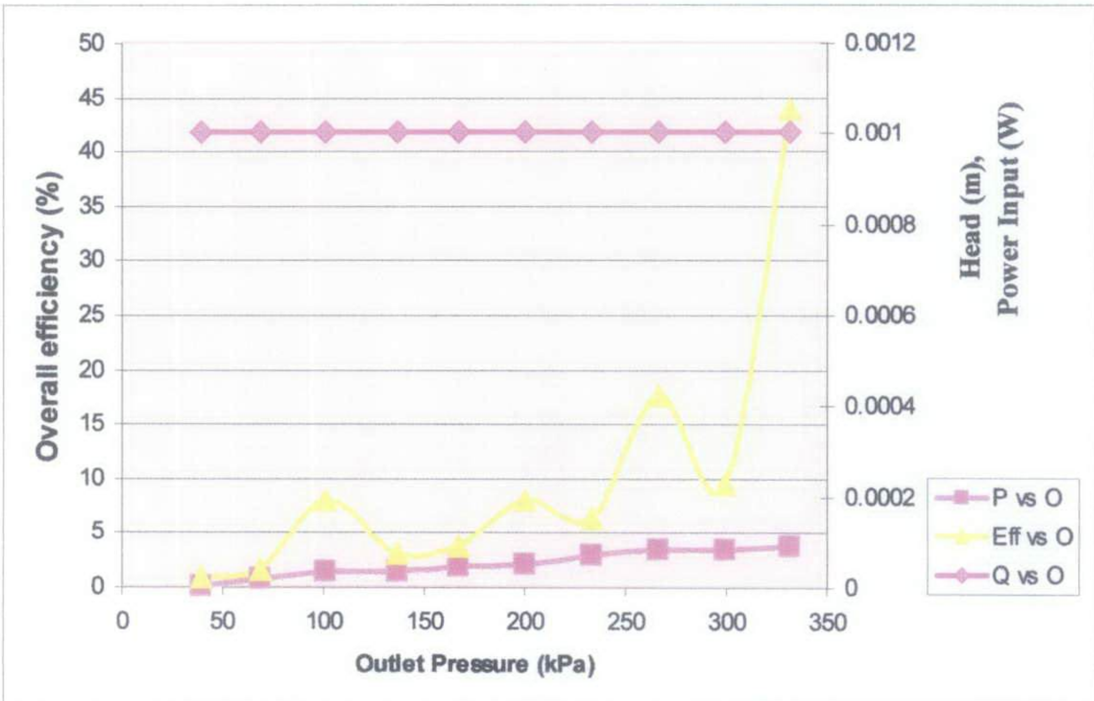


Figure 4.13: Performance curves of gear pump at constant speed for Angsi crude oil

The performance curves of gear pump at constant speed for Angsi crude oil shows that the highest efficiency can be obtained is 43.9% when the flow rate is $0.001dm^3/s$. The total head for Angsi crude oil is higher compared to the value of the total head when water and TCOT crude oil are used as liquid.

Table 4.14: Data tabulated on gear pump at different speeds for Angsi crude oil

No	Speed (rpm)	Head (m)	Power Input (W)	Overall Efficiency (%)	Volumetric Efficiency (%)	Volumetric Flowrate (dm^3/s)	Outlet Pressure (kPa)
1	0	0.0081	0	0.0	0.0	0.001	3.076
2	60	3.453	0	0.0	0.4	0.001	39.990
3	1200	3.703	0	0.0	0.9	0.001	42.725
4	1800	4.077	0	0.0	1.8	0.001	46.826
5	2400	4.702	0	0.1	0.8	0.001	53.662
6	3000	4.795	1	0.1	0.9	0.001	54.688
7	3600	4.858	2	0.1	0.5	0.001	55.371

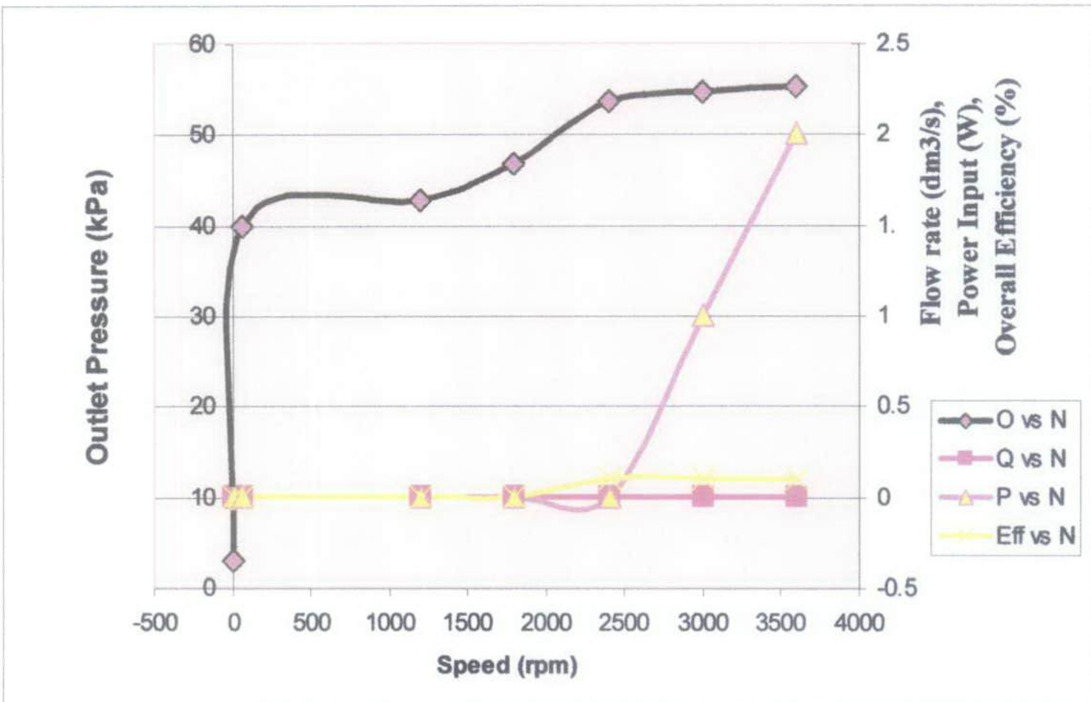


Figure 4.14: Performance curves of gear pump at different speed for Angsi crude oil

Based on the Figure 4.14 above, the highest efficiency, 0.1% can be obtained with the highest speed of the motor, 3600 rpm. The efficiency of the pump at different speeds condition for Angsi crude oil is lower than the efficiency of the pump when the water is used. As the speed of the motor increase, the power input and outlet pressure also increase.

Table 4.15: Data tabulated on gear pump at constant speed for Penara crude oil

No	Head (m)	Power Input (W)	Overall Efficiency (%)	Volumetric Efficiency (%)	Volumetric Flowrate (dm^3/s)	Outlet Pressure (kPa)
1	55.466	2.1	0.0	0.3	0.001	609.424
2	50.377	1.9	22.1	0.4	0.001	553.711
3	45.725	1.7	50.1	0.4	0.001	502.783
4	40.417	1.4	12.5	0.5	0.001	444.678
5	35.016	1.1	13.7	0.3	0.001	385.547
6	30.115	0.9	15.6	0.3	0.001	331.885
7	25.026	0.4	21.9	0.4	0.001	276.172
8	20.031	0.2	17.5	0.4	0.001	221.484
9	15.067	0.1	6.0	0.4	0.001	167.139
10	10.134	0	3.0	0.4	0.001	113.135

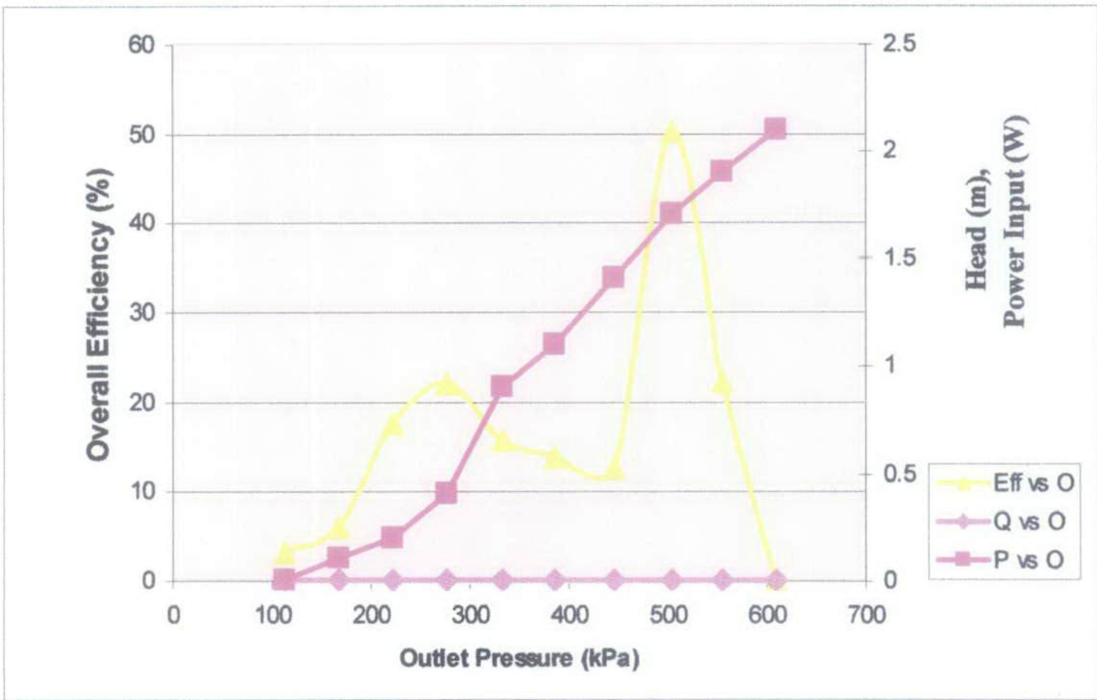


Figure 4.15: Performance curves of gear pump at constant speed for Penara crude oil

The above graph shows that the highest efficiency can be obtained is 50.1% when Penara crude oil is used as liquid. The efficiency of the gear pump is higher compared to the value efficiency of centrifugal pump at low flow rate when Penara crude oil is used. If the outlets pressure increase and the power inputs increase.

Table 4.16: Data tabulated on gear pump at different speeds for Penara crude oil

No	Speed (rpm)	Head (m)	Power Input (W)	Overall Efficiency (%)	Volumetric Efficiency (%)	Volumetric Flowrate (dm^3/s)	Outlet Pressure (kPa)
1	0	4.577	0	0.0	0.0	0.001	52.295
2	60	4.951	0	0.0	2.8	0.001	56.396
3	1200	5.300	0	0.0	1.1	0.001	55.469
4	1800	5.200	0	0.0	0.7	0.001	60.001
5	2400	5.357	0	0.1	0.6	0.001	60.840
6	3000	6.174	1	0.1	0.5	0.001	65.039
7	3600	9.728	2	0.1	0.4	0.001	108.691

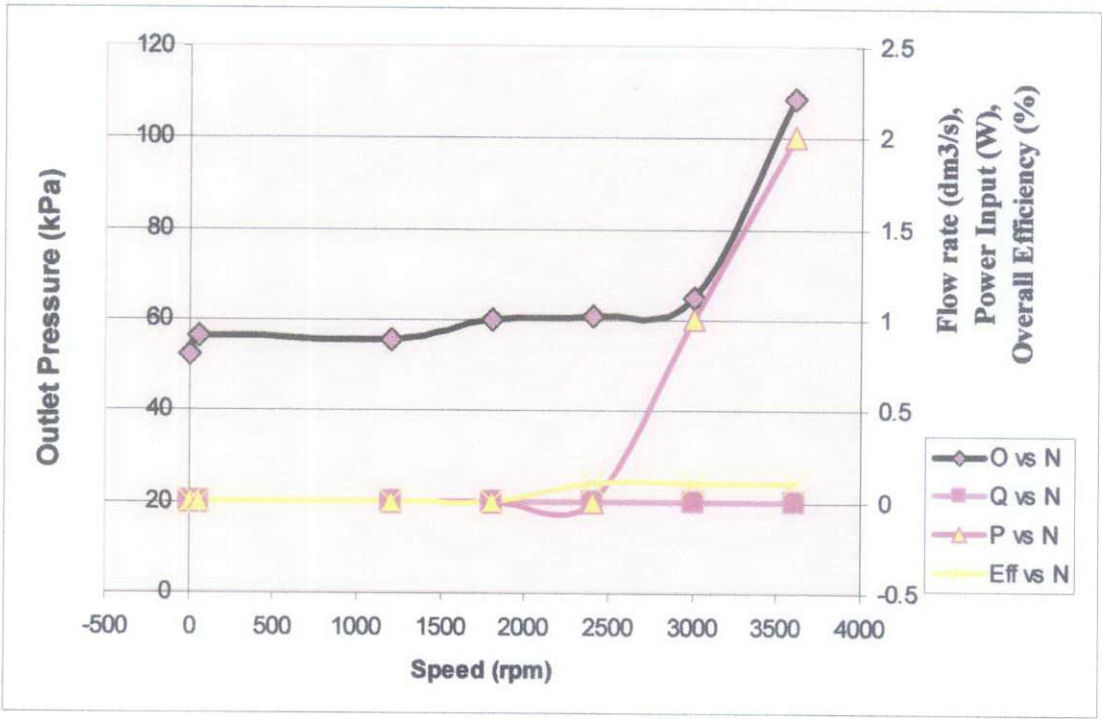


Figure 4.16: Performance curves of gear pump at different speeds for Penara crude oil

Figure 4.16 shows the performance curves of gear pump of at different speeds for Penara crude oil. The graph plotted shows that the highest efficiency is 0.1% when the motor speed is 3600 rpm. As the speed of the motor increase, the power input and outlet pressure also increase.

4.2 Calculation

4.2.1 Centrifugal Pump

Since the results obtained above are computer generated, the values are calculated by using the related equation from the literature review. Below are the equations involved:

Parameter:

- Diameter of the orifice, d = 0.018m
- Discharge coefficient, $C_d = 0.61$
- $\pi = 3.141592654$

Flow rate

$$Q = \frac{Cd x \Pi x\, d^2 \sqrt{2 X \rho X \Delta P}}{4\rho}$$

where density of the water, $\rho = 997\ kg/m^3$

$$Q = \frac{0.61 x \Pi x\ 0.018^2 \sqrt{2x997x837}}{4\,(997)}$$

$= 0.000201138\ m^3/s$

Pump Power

$P = \rho \times g \times Q \times H$

where gravity acceleration, $g = 9.81\ m/s^2$

$P = 997\ kg/m^3 \times 9.81\ m/s^2 \times 0.000201138 m^3/s \times 9.499\ m$

$= 17.91966\ W$

Overall efficiency

$\eta = P_{brake} / P_{motor}$

$\eta = 17.91966 / 1.95 = 9.189569$

4.2.2 Gear Pump

The values obtained from the results are calculated by using the related equation below:

Pump Power Output

$P = \rho \times g \times Q \times H$

where gravity acceleration, g = 9.81 m/s^2

$P = 997\ kg/m^3 \times 9.81\ m/s^2 \times 0.000005\ m^3/s \times 21.436m$

$= 1.048281493\ W$

Overall Efficiency

$\eta = P_{brake} / P_{motor}$

$= 1.048281493 / 3.42$

$= 30.65$

4.3 Discussion

4.3.1 Interpretation on Centrifugal Pump Demonstration Unit

1. Based on the experiment conducted on centrifugal pump for water as liquid at constant speed and different flow rate, as the flow rates increase, the power inputs also increase. The values of the power input indicate the power consumption of the pump at to obtain particular flow rates and heads. Power input (BHP) is a function of specific gravity. If the pumped liquid is other than 1.0 (water), in this project crude oil with different viscosities (TCOT, Angsi and Penara crude oil), then the BHP curve should be adjusted accordingly either by the manufacturer or by the engineer making the motor selection. In calculating the power input, there are four factors that cause a centrifugal

pump to be less efficient such as hydraulic losses, volumetric losses, mechanical losses and disk friction losses.

2. Based on Figure 4.1, if the flow rates increase the total heads decrease. By definition, the pump is a machine designed to add energy to water with the purpose of elevating or moving it through pipe. The centrifugal pump can elevate water in a vertical tube as the experiment set up to a point where the weight of the water and gravity will not permit any more elevation. The energy contained in water's weight is the same with the energy produced by the pump. This point called "shut-off head" where the point of the maximum elevation when the flow is zero.

3. For different types of crude oil (from Angsi platform, Penara platform and TCOT), the parameter value tabulated from the experiments are lower than data tabulated for water due to the viscosity of crude oil for both condition; at constant and different speeds. Refer to Table 2.1 for the viscosity values of the liquids used. Two of the major losses in a centrifugal pump are through fluid friction and disk friction. These losses vary with the viscosity of the liquid so that the head – capacity outputs as well as mechanical input differ from the values produced when handling water.

4. Newtonian fluid is defined as fluid for which the shear stress is linearly proportional to the shear strain rate means the fluid is continuously changes shape (deformation). If the fluid is Newtonian, the rate of deformation is proportional to the applied shear stress and the constant of proportionality is called viscosity. Since water and crude oil are Newtonian fluid, as viscosity increases the operational characteristics of a centrifugal pump will change per the following general rules; flow, head and efficiency are reduced and the brake horsepower required is increased. These changes are largely due to an increase in the fluid friction and the "disk" losses that occur due to viscous drag on impeller. The increased fluid friction reduces head and flow while viscous drag increases the horsepower required.

4.3.2 Interpretation on Gear Pump Demonstration Unit

1. Since gear pump is a positive displacement that creates flow, the manipulative variable is the outlet pressure. Based on the experiment conducted on gear pump for water as liquid at constant speed and different flow rate, as the outlet pressures increase, the power outputs also increase. The values of the power output indicate the power consumption of the pump at to obtain particular outlet pressure and volumetric efficiencies.

2. As the outlet pressures increase, the volumetric flow rates are decrease when the graph of the volumetric flow rates versus outlet pressure of the experiment on the water at constant speed. At low flow rates, gear pump requires more outlet pressure to move liquid from one place to another.

3. The viscosity of the liquid used must be always taken into consideration for the design and selection of the pump type. Liquid with higher viscosities require more time to enter the displacement chamber. The pump speed must be adjusted accordingly to avoid cavitations which reduce the volumetric efficiency and increase the wear. In this project, as the viscosity of the liquids increase, the overall efficiencies are decrease. Usually, efficiency often increases in positive displacement pump with increasing viscosity.

CHAPTER 5

CONCLUSION

Generally, centrifugal pump is more preferable to industrial application since it is more reliable and has lower maintenance expenses compared to the other pump. There are also certain application criteria that demand the use of positive displacement pump such as high viscosity of the fluid used, high pressure, low flow and high efficiency.

For centrifugal pump, when the flow rates increase, the power outputs increase and total heads decrease. The efficiency curve of the pump is a sinusoidal curve which pump reaches its maximum efficiency at best efficiency point at the respective flow rate, power output and total heads required. When the pump is operating out of the best efficiency point's range, the pump is losing its efficiency due to temperature rise of the liquid used. Based on Figure 4.1, when the centrifugal pump operates at a constant speed of 3600 rpm, the highest efficiency obtained is 89.53% at 0.507dm^3/s. From Figure 4.9, the overall efficiency obtained by gear pump is 89.50% at only 0.038dm^3/s when the pump runs at constant speed of 3600 rpm. By comparing these efficiency values, gear pump is more preferable for low flow rate use.

Based on Table 2.1, viscosity of the crude oil is higher than the viscosity of the water. By referring to Figure 4.3, the best efficiency of the centrifugal pump when TCOT crude oil used is 84% at 0.108dm^3/s. From Figure 4.11, the best efficiency obtained by gear pump when TCOT crude oil used is 39.4% at 0.0002dm^3/s. From the data obtained by centrifugal pump when TCOT crude oil is used, if the value of efficiency is interpolated, when the flow rate is 0.002dm^3/s, the efficiency of the pump is less than 13%. By comparing both efficiency values, gear pump is more preferable compared to centrifugal pump when the viscosity of the liquid used increases.

When the liquid flows at low capacity and high pressure, positive displacement pump such as gear pump is more applicable compared to the centrifugal pump. Gear pump is capable of moving a wide range of liquids such as entrained gasses, solids, low viscosity to high viscosity, low capacity and high pressure. Positive displacement creates flow and centrifugal pump creates pressure. Thus, positive displacement pump such as gear pump is more preferable when low capacity and high pressure head are considered.

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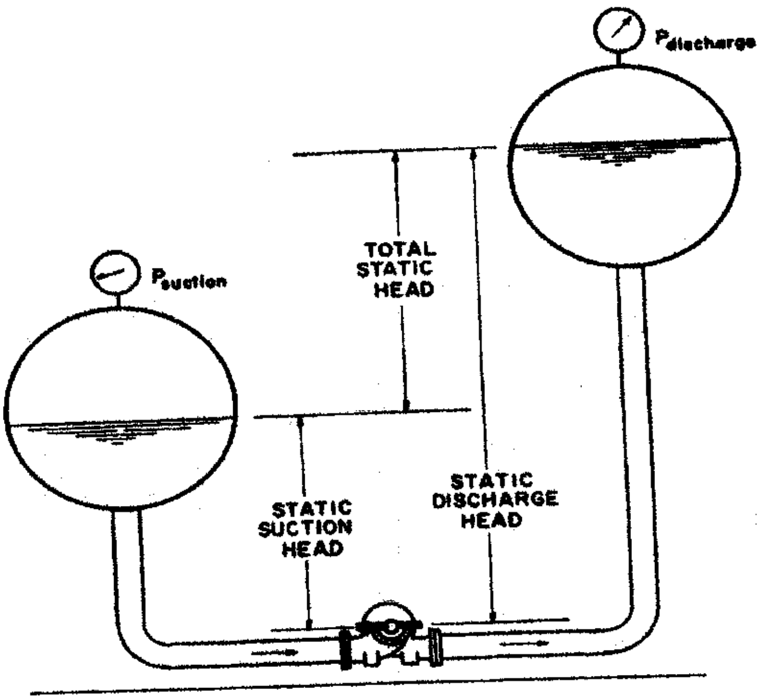


Figure A-1: System with pump suction and discharge vessel at pressures other than atmospheric (From *Centrifugal Pumps*, I.J Karassik, 2000)

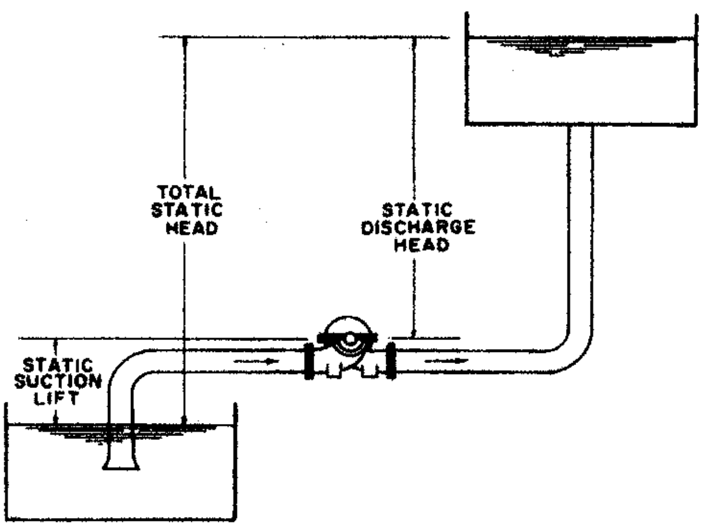


Figure A-2: Suction and discharge vessel at atmospheric pressure and suction liquid level below pump centerline (From *Centrifugal Pumps*, I.J Karassik, 2000)

Appendix B

Boundary Material	k_s, mm	k_s, inches
Glass, plastic	Smooth	Smooth
Copper or brass tubing	0.0015	6×10^{-5}
Wrought iron, steel	0.046	0.002
Asphalted cast iron	0.12	0.005
Galvanized iron	0.15	0.006
Cast iron	0.26	0.010
Concrete	0.3-3.0	0.012-0.12
Riveted steel	0.0-9	0.035-0.35
Rubber pipe (straight)	0.025	0.001

Table B-1: Equivalent sand grain roughness, k_s for various pipe materials.)](From *Engineering Fluid Mechanics*, Crowe, C.T, Elger, D.F, Roberson, J.A, , 8th Edition)

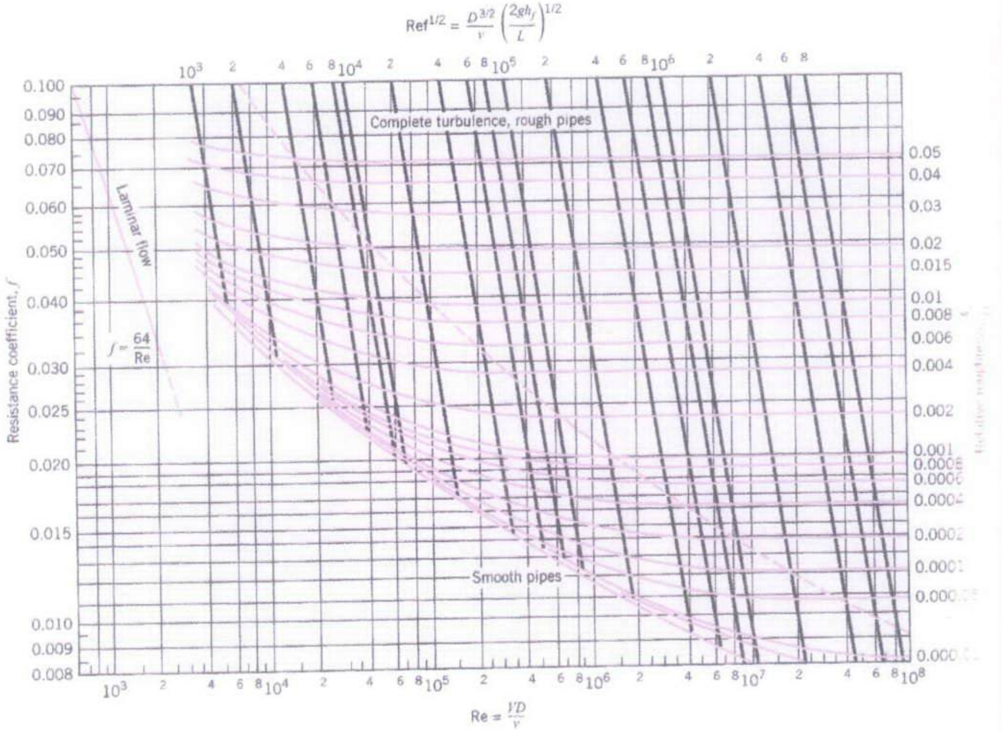


Figure C-1: *Resistance Coefficient, f versus Reynolds number. Reprinted minor variations. [After Moody (5)]*(From *Engineering Fluid Mechanics,* Crowe, C.T, Elger, D.F, Roberson, J.A, 8th Edition)

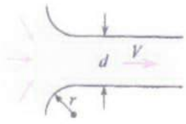
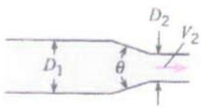
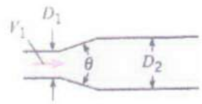
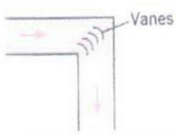
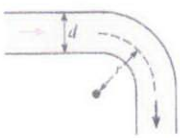
Description	Sketch	Additional Data	K	K	Source
Pipe entrance		r/d	K_e		(18)†
		0.0	0.50		
		0.1	0.12		
$h_L = K_e V^2/2g$		>0.2	0.03		
Contraction		D_2/D_1	K_C $u = 60°$	K_C $u = 180°$	(18)
		0.0	0.08	0.50	
		0.20	0.08	0.49	
		0.40	0.07	0.42	
		0.60	0.06	0.27	
		0.80	0.06	0.20	
$h_L = K_C V_2^2/2g$		0.90	0.06	0.10	
Expansion		D_1/D_2	K_E $u = 20°$	K_E $u = 180°$	(17)
		0.0		1.00	
		0.20	0.30	0.87	
		0.40	0.25	0.70	
		0.60	0.15	0.41	
$h_L = K_E V_1^2/2g$		0.80	0.10	0.15	
90° miter bend		Without vanes	$K_b = 1.1$		(23)
		With vanes	$K_b = 0.2$		(23)
90° smooth bend		r/d			(24) and (17)
		1	$K_b = 0.35$		
		2	0.19		
		4	0.16		
		6	0.21		
		8	0.28		
		10	0.32		
Threaded pipe fittings	Globe valve—wide open	$K_v = 10.0$			(23)
	Angle valve—wide open	$K_v = 5.0$			
	Gate valve—wide open	$K_v = 0.2$			
	Gate valve—half open	$K_v = 5.6$			
	Return bend	$K_b = 2.2$			
	Tee				
	straight-through flow	$K_t = 0.4$			
	side-outlet flow	$K_t = 1.8$			
	90° elbow	$K_b = 0.9$			
	45° elbow	$K_b = 0.4$			

Table D-1: Lost Coefficient for Various Transitions and Fittings (From *Engineering Fluid Mechanics,* Crowe, C.T, Elger, D.F, Roberson, J.A, 8th Edition)

Appendix E

The experiments

1) Experiment 1

Objective: To determine the efficiency of the centrifugal pump at low flow rate

Apparatus:

FM 20 – Capture Centrifugal Pump Demonstration Unit

Procedures:

1. The acrylic tank is filled with water.
2. Inlet valve is fully opened.
3. Discharge valve is fully closed and then pump is started (pump motor under minimum load)
4. Discharge valve is fully open and water is allowed to circulate until all air bubble has dispersed.
5. The diagram is viewed and the value of the flow indicated at the bottom of the screen is taken.
6. Discharge valve is gradually opened from the minimum flow rate to maximum flow rate.
7. All the necessary reading captured by the data logging software (differential pressure across orifice, pump pressure, power output, water temperature, total head and efficiency) are taken.
8. Experiment is repeated with crude oil from Angsi platform, Penara platform and TCOT as liquid.

2) Experiment 2

Objective: To determine the efficiency of a positive displacement gear pump at low flow rate

Apparatus:

FM 22 – Capture Gear Pump Demonstration Unit

Procedures:

1. The acrylic tank is filled with water.
2. If the gear pump is connected to an Integrating Wattmeter SWA1, power control is set on the SWA1 to 100% (The motor must not be operated at reduced speed)
3. Discharge valve is opened and then pump is started. (Pump motor is started under the minimum load) and the water is allowed to circulate until air bubbles has dispersed. The diagram is viewed and the value of the outlet pressure indicated in relevant box on the screen is noted.
4. The suitable increment is decided in pressure to give adequate sample points (typically 15 points between zero and maximum flow).
5. Discharge valve is fully closed to correspond to the condition if the highest pressure. When the measured readings as indicated in the boxes on the schematic diagram are sufficiently steady, take the readings of the parameters (flow rates, power output, pressure differences and efficiencies)
6. Discharge pump is open slightly to give the first decrement in outlet pressure on the screen.
7. Step 6 is repeated for a gradually increasing set of discharge valve openings. The final sample will be the point will correspond to discharge valve being fully opened.
8. Readings as indicated in the boxes on the schematic diagram are sufficiently steady, take the readings of the parameters (flow rates, power output, pressure differences and efficiencies) are taken.

Gantt chart **Appendix F**

No	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Study on the working principle of centrifugal pump and positive displacement pump														
2	Conduct experiment on centrifugal pump														
3	Conduct experiment on positive displacement pump														
4	Develop pumps' performance curves based on data														
5	Develop mathematical equation to calculate pumps' efficiencies														
6	Comparison analysis for both pumps														
6	Progress Report 1														
7	Progress Report 2														
8	Seminar														
9	Poster exhibition														
10	Dissertation final draft														
11	Oral presentation														
12	Dissertation final (hard bound)								Study week 7 days after oral presentation						

Table F-1: Gantt chart for Final Year Project II