Centrifugal Pump Characteristics for Crude Oil Transfer

by

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Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2010

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 not been undertaken or done by unspecified sources or persons.

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NOOR SYAFFYNAS BT YUSOFF

ABSTRACT

The objectives of the project are to determine the range viscosity and specific gravity of crude oil to be transferred using centrifugal pump, to evaluate the important characteristic of centrifugal pump to be used for crude oil transfer suitable for a range of crude oil properties and to evaluate temperature effect on crude oil properties, hence centrifugal pump characteristics curve. The problem faces in this project is effective and efficient crude oil transfer using centrifugal pump requires a proper design for different types of crude oil properties and the characteristics of centrifugal pump. There are two characteristics of crude oil that always affected efficiency and the performance of centrifugal pump which are viscosity and specific gravity. Crude oil consists of three types which are light crude oil, medium crude oil and heavy crude oil. Heavy crude oil is very viscous in properties followed by medium crude oil and light crude oil. Flow rate of pump decreases as viscosity (heavy crude oil) increase and decrease as specific gravity of crude oil increase. Characteristics of centrifugal pump which are total head, efficiency, net positive suction head required and brake horsepower will be affected if flow rate of the pump low. A few experiments have been set-up to study the characteristic curves when centrifugal pump pumping different properties of fluids. First experiments were density test and viscosity test. Second experiment was pump test rig experiment to see the effect of fluid properties towards pump performance and lastly, temperature effect test on fluids during centrifugal pump pumping the fluid. The highest viscosity of crude oil was heavy crude oil with 4.034 cp and the highest specific gravity was sea water with 1.027. Head of pump when pumping water was higher compared to pumping heavy crude oil with shut off head 8.434 m. Centrifugal pump was very efficient when pumping water with 17.858. Power output required to pump sea water was the higher with 19W compared to other fluids. Net positive suction head required of diesel and light crude oil showed the high differential value between vapor head and suction head which was 83% from 0 flow rate to 0.0002 m^3/s flow rate. Fluids will be heated up in order to decrease the viscosity effect of fluids, hence increase the pump performances. The results had shown that the theory has been approved when the same pattern performance graph were executed.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Oil and Gas Industries imposed an ever increasing demand for moving liquids from one location to another. Energy has to be imparted to the liquids in order to move the liquids through pipes and channels. The energy, usually mechanical, provided by a prime mover is transferred to liquid by a device called a pump [1]. This project is basically a study about centrifugal pump characteristics for crude oil transfer. It is a known fact that crude oils vary in viscosity and density because crude oils were found in various sources. Viscosity and specific gravity of the crude oils will affect the performance curves of a centrifugal pump. There are four main characteristics of centrifugal pump which vary with increasing flow rates. They are head of pump, efficiency of pump, brake horse power, (BHP), and Net Positive Suction Head Required, ($NPSH_r$). Different properties of crude oils will give different effects on centrifugal pump. The flow rates of the centrifugal pump depend on types of crude oils which are light crude oil, medium crude oil and heavy crude oil. Since the types of crude oil may vary from source, temperature effect towards crude oil will be put into consideration in order to increase the centrifugal pump performance. The higher the temperature of crude oil, the lower the viscosity of the crude will experience, hence improve the centrifugal pump performance.

1.2 Problem Statement

As known in Malaysia, there are a few crude oil terminals, for instance Terengganu Crude Oil Terminal (TCOT), Bintulu Crude Oil Terminal (BCOT), and Miri Crude Oil Terminal (MCOT). All the terminals use centrifugal pump which is known as crude oil transfer pump to transfer crude oil from storage tank to load into ship tank for export purpose. Efficiency of crude oil transfer pump varies during moving different types of crude oils. Less viscous crude oil present good performance curve especially pump head curve whereby high pump head results high performance pump compare to the high viscous crude oil present awful performance curve. So, when the crude oil transfers pump face with very high viscous crude oil, it will bring difficulty to the pump to transfer the crude. Therefore, a study has done to see how big the affect of viscosity and specific gravity towards the characteristics of centrifugal pumps.

1.3 Objectives

The objectives of the project are:

a. To provide a general guideline on acceptable range of crude oil properties such as viscosity and specific gravity to be transferred by using centrifugal pump.
b. To evaluate the important characteristics of centrifugal pump use for crude oil transfer suitable for acceptable range of crude oil properties.
c. To evaluate temperature effect on crude oil properties, hence centrifugal pump characteristics curve.

1.4 Scope of Study

The project would start with the data gathering and critical study on centrifugal pump characteristics. A specific case study will be discussed on centrifugal pump used for crude oil transfer. Then, two experiments will be carried out by using a few types of fluids such as water, sea water, diesel, light crude oil, medium crude oil and heavy crude oil which are pump test rig and temperature effect on fluids experiment to correlate the theoretical knowledge with practices. The experiments include quantitative and qualitative approached in developing the performance curves of centrifugal pump for various types of fluids. Temperature effects on fluids will be further analyzed to observe the effect of increasing fluid temperature towards centrifugal pump performance.

1.5 Significance of Work

The relevancy of this project is viscous fluids results low performance pump especially on pump head, efficiency and break horsepower required. So, by increasing the temperature of fluids especially crude oil will help in improvement of pump performance curve. By general rules, heat-up the crude oil results viscosity of crude oil to decrease hence improve the pump performance curve. The result of the study will provide a relevant consequence to the research and development of oil and gas industry.

CHAPTER 2

LITERATURE REVIEW

2.1 Viscosity and Specific Gravity Effect to Centrifugal Pump Performance

2.1.1 Viscosity

In the article title Specific Gravity and Viscosity, viscosity is a liquid property that is independent of specific gravity unlike specific gravity; it can be very complex [2]. Viscosity can affect all of the operational characteristics of a pump. Viscosity is defined as the "internal" friction of a liquid and is due to the cohesive forces of the molecules that make up the liquid. Viscosity normally measure in centipoises (cP) and centistokes (cSt).

Centrifugal pumps are often used to pump liquids with viscosities up to 2000 SSU and sometimes higher. 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 [2]. These changes are largely due to an increase in the fluid friction and the "disk" friction losses that occur due to viscous drag on impeller. The increased fluid friction reduces head and flow while viscous drag increases the horsepower required.

In the early sixties, the Hydraulic Institute (HI) developed a graphical system that used a collection of viscous test data to predict centrifugal pump performance when pumping liquids of varying viscosity. The graph 2.1 provided correction factors that adjusted the liquid based values for head, flow, and hydraulic efficiency. Although the results were reasonably reliable, the system was limited to true Newtonian liquids pumped by radial flow impellers. Another limitation of the system was that the test data used to provide the correction factors was based on petroleum oils and often understated pump performance when pumping other types of viscous liquids [2].

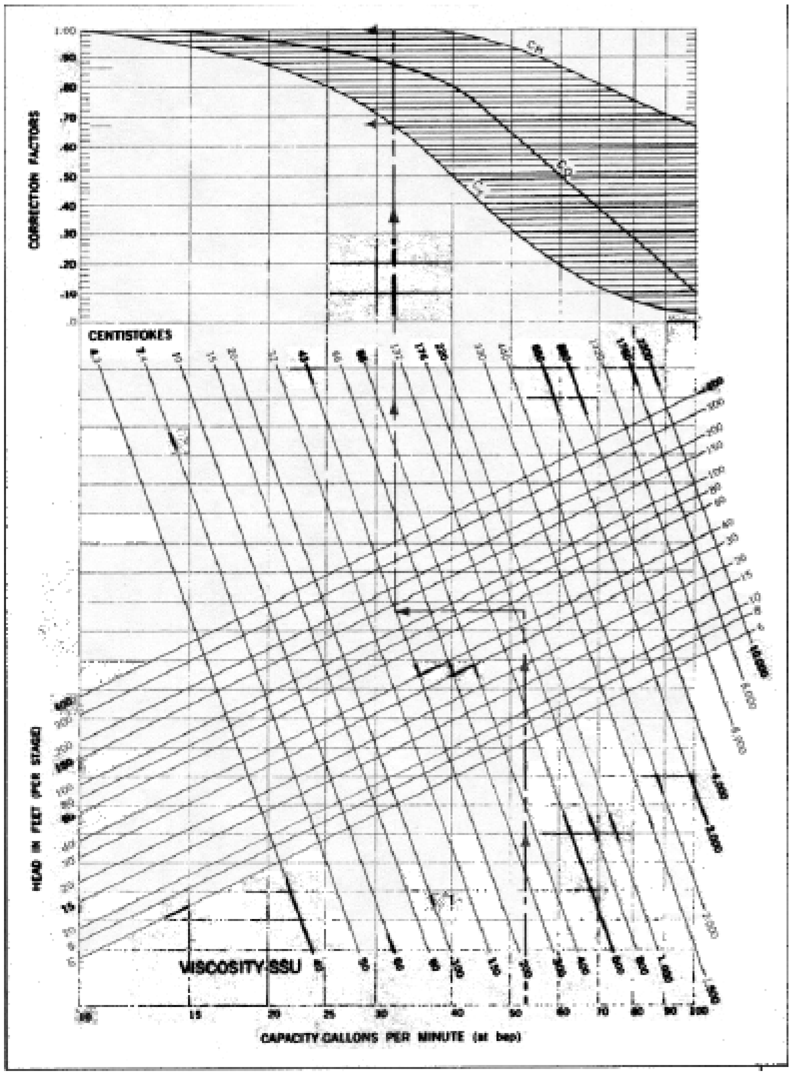

Figure 2.1 Correction factor chart for viscosity [3]

2.1.1 Specific Gravity

In the article title Specific Gravity and Viscosity by Joe Evans, normally water is the only liquid that flows through the centrifugal pumps [2]. So, specific gravity and viscosity is not factors when sizing them. But if work with other liquids, the effect of these properties on those, water based, head/ capacity curves need to consider.

Specific gravity is the ratio of density substances to the density of water. Specific gravity is important when sizing a centrifugal pump because it is indicative of the weight of the fluid and its weight will have a direct effect on amount of work performed by the pump.

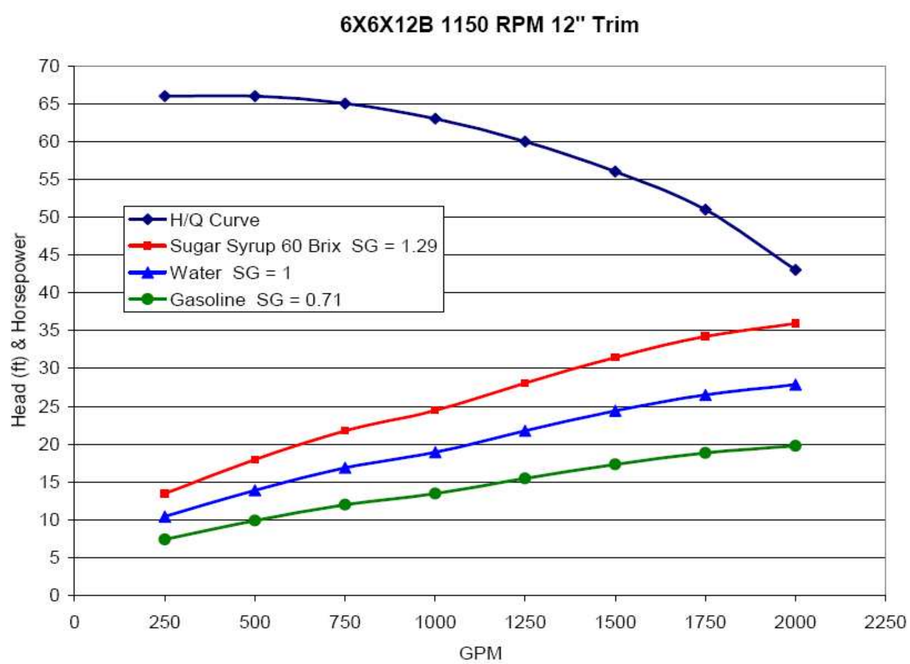

Figure 2.2 The graph head (ft) and horsepower versus capacity discharge (Q) [2]

The downward sloping curve in the upper portion of the graph is the H/Q curve and the red, blue and green curves are the horsepower curves for three different liquids. The blue curve shows the horsepower required for water (SG =1). The red and green curves show the horsepower required to pump sugar syrup (SG =1.29) and gasoline (SG = 0.71) [2]. In analyzing the three horsepower curves at each flow point, the increasing and decreasing is directly proportional to the specific gravity of that particular liquid. As long as the viscosity of a liquid is similar to water, its specific gravity will have no effect upon pump performance. It will; however, directly affect the input power required to pump that particular liquid.

Specific gravity can also have effect upon the onset of cavitations in a particular pump. Heavier liquids cause a proportional increase in a pump's suction energy and those with a high suction energy level are more likely to experience cavitations damage [2].

$$\gamma = \frac{\rho\ oil}{\rho\ water} \tag{2.1}$$

γ = Specific gravity

ρ_{Oil} = density of oil

ρ_{Water} = density of water, (1000kg/m^3)

2.2 Effect of Fluids on Centrifugal Pump Performance and Flow Pattern in the Impeller

In the journal Effects of Viscosity of Fluids on Centrifugal Pump Performance and Flow Pattern in the Impeller, Wen-Guang Li stated that high viscosity fluids results in rapid increases in the disc friction losses over outsides of the impeller shroud and hub as well as the hydraulic losses in flow channels of the pump, thus affect the pump performance [4]. In this paper, centrifugal pump performances are tested by using water and viscous oil as working fluids whose kinematic viscosity is 1 and 48 mm^2/s, respectively.

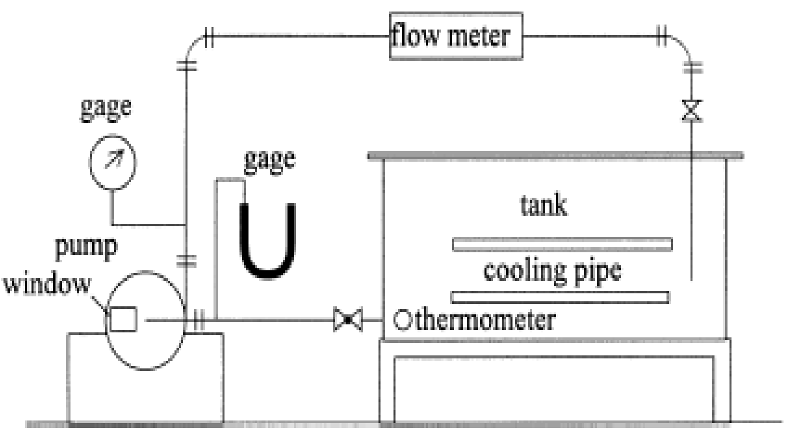

Figure 2.3 Centrifugal Pump Test Rigs [4]

A special centrifugal pump test rig, shown in Figure 2.3 was used to test the pump performance when the pump was pumping viscous oil or water. Working fluids are the special transparent viscous oil refined from crude oils and tap water, respectively. When the viscous oil was pumping, the temperature of oil would be rising due to high friction losses between oil and flow channel walls. Refer to Figure 2.4. Thus, cooling water would be flowing in the cooling pipe installed in the oil tank to maintain the temperature at constant level.

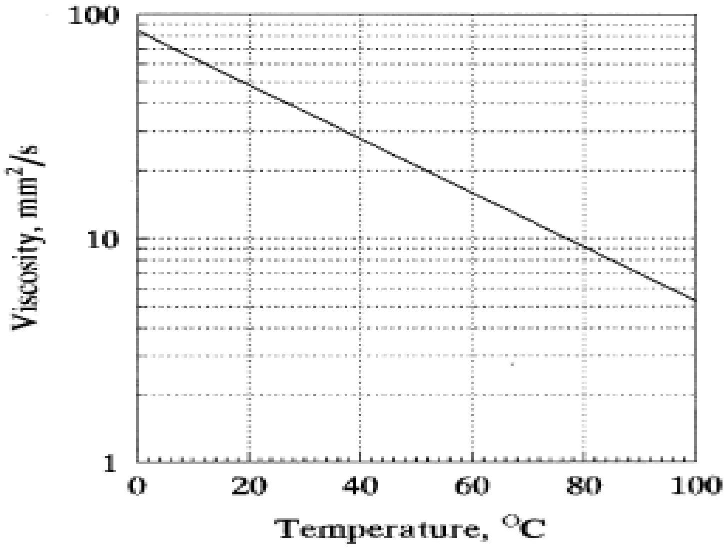

Figure 2.4 Viscosity-Temperature Curve of Oil [4]

Figure 2.5 shows the centrifugal pump performances while the pump handles water and viscous oil at rotating speed n=1485 rpm at 20°C. The best efficiency points (BEP) located at Q_{BEP} = 5.93 and 5.86 l/s, corresponding to the best efficiencies are 56.65% and 47.2%, respectively [4].

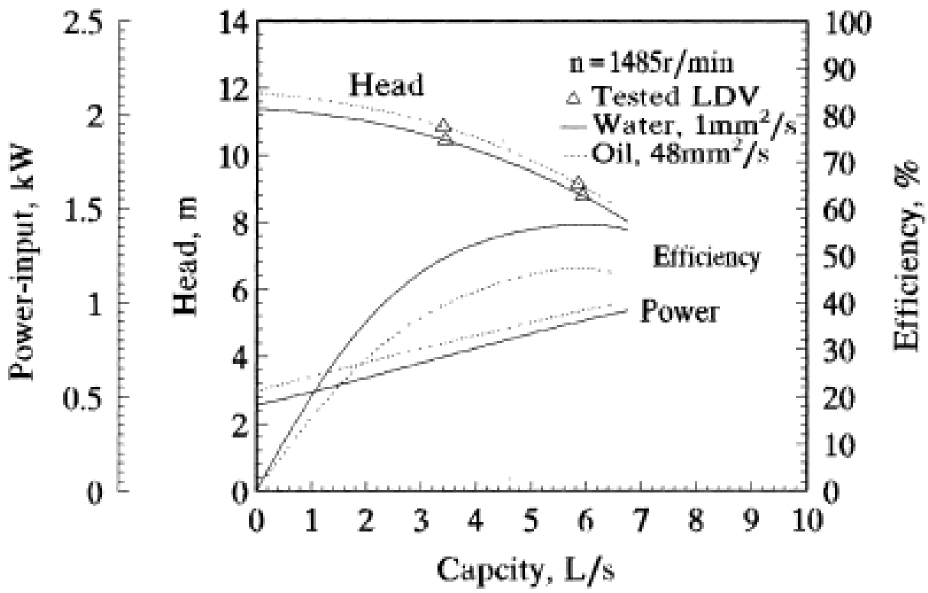

Figure 2.5 Pump Performances for Different Viscosities [4]

The pump head and power-input for the pump handling oil are higher than those for handling water, but efficiency for handling oil is lower than those handling water, but the efficiency for handling oil is lower than that for handling water as shown in Figure 2.5. The pump efficiency is dropping while pumping the oil results from the fact that the disc friction losses over the outsides of the impeller shroud and hub as well as the hydraulic losses in flow channel of pump are increasing rapidly [4].

2.3 Considering the Effect of Crude Oil Viscosity on Pumping Requirements

The paper Considering the Effect of Crude Oil Viscosity on Pumping Requirement stated the objectives of the paper were to study the effect °API and the line average temperature has on the pumping power requirement [5]. The purpose of this study were to show that pumping power requirement varies as the crude oil °API changes and increasing °API or line average temperature reduces the crude oil viscosity [4].

In this review, the Hydraulic Institute (HI), procedure was applied for correcting pump curves for viscosity effect. HI uses a performance factor, called Parameter B which includes terms for viscosity, speed, flow rate and total head. The basic equation for parameter B is given as equation 2.2;

$$B = K\left[\frac{(\nu_{vis})^{0.50}(H_{BEP-W})^{0.0625}}{(Q_{BEP-W})^{0.375}(N)^{0.25}}\right] \tag{2.2}$$

Where:

B = Performance factor

K = 16.5 for SI units

= 26.5 for USCS (FPS)

η_{vies} = Viscous fluid Kinematic viscosity – cSt

H_{BEP-W} = Water head per stage at BEP – m (ft)

Q_{BEP-W} = Water flow rate at BEP – m^3/h (gpm)

N = Pump shaft speed – rpm

2.3.1 Effect of Line Average Temperature (Seasonal Variation)

Study the effect of the line average temperature on the pumping power requirement, an in house computer program called OP & P (Oil Production and Processing) was used to perform the calculations outlined. For a 35°API crude oil in the pipeline described the required pumping power was calculated for line average temperature ranging 21.1 to 37.8°C (70 to 100°F). The required pumping power was compared with an arbitrary base case (85°F or 29.4°C and constant η = 0.75) [4].

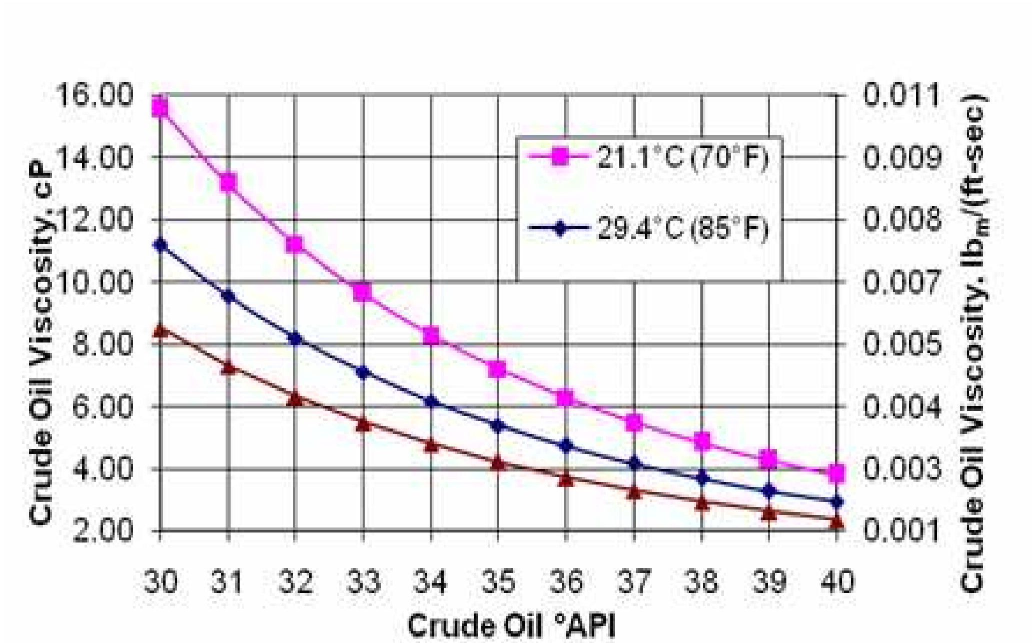

Figure 2.5 Variations of Crude Oil Viscosity with °API and Temperature [4]

Note that as the line average temperature increases the power requirement decreases. This can be explained by referring to Figure 2.5 in which the oil viscosity decreases as temperature increases. Lower viscosity results in higher Reynolds number, therefore the friction factor decreases.

Refer to equation below:

$$Re = \frac{(V)(D)(\rho)}{\mu} \tag{2.3}$$

Where:

Re = Reynolds number

V = Velocity (m/s)

D = Diameter (m)

ρ = Density (kg/m^3)

μ = Viscosity (kg/ms^{-1})

2.3.2 Effect of Variation of Crude Oil °API

In this case, the effect of crude oil °API on the total pump power requirement for three different line average temperatures was studied. For each line average temperature, the crude oil °API was varied from 30 to 40 and the total pumping power requirement was calculated and compared to the base case (35 °API and average line temperature of 29.4°C = 85°F) [4].

For each case the percent change in total power requirement was calculated and is presented in Figure 2.6.

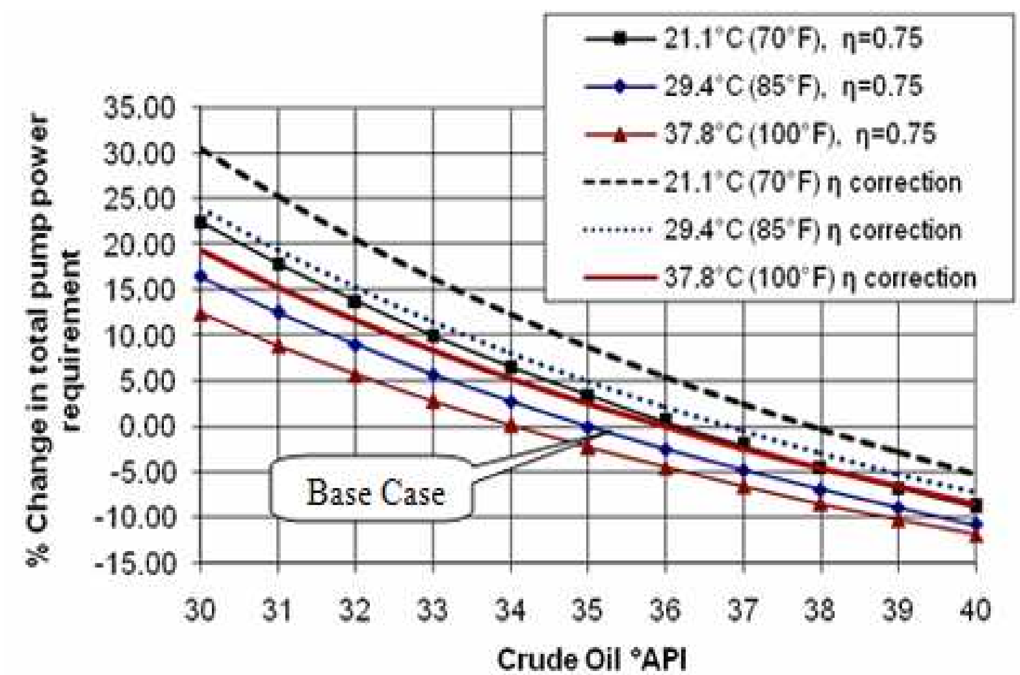

Figure 2.6 Effect of crude oil °API on Pump Power Requirement [4]

As shown, when °API increases the total power requirement decreases. This also can be explained by referring to Figure 2.6 in which the crude oil viscosity decreases as °API increases. The effect of viscosity is more pronounced at lower line average temperature (i.e. 21.1 °C or 70 °F). Figure 2.6 also indicates that there is about 30% change in total power requirement as °API varies from 30 to 40 °API [4].

CHAPTER 3

METHODOLOGY

3.1 Introduction of Project's Methodology

The methodology and procedure to conduct the project is divided into Literature Review, Information Gathering, Laboratory Works, Data Analysis and Report Preparations. The summary of the activities are as illustrated in Figure 3.6. Methodology and procedure is important to ensure that the project done correctly and obtained good result at the end of the project. The Gantt chart of this project illustrated in **APPENDIX 1**.

3.2 Literature Review

The literature review done on the centrifugal pump characteristics such as total head of centrifugal pump, efficiency of centrifugal pump, brake horsepower of centrifugal pump and net positive suction head of centrifugal pump. The literature review also including the properties of crude oil which are viscosity and specific gravity that give effect to performance curve of centrifugal pump. Temperature effect on crude oil will be studied in order to add more value into the research study. All the information was referring to respective books, journals and websites.

3.3 Field Data

The design specification of crude oil transfer pump which is centrifugal pump had been taken at the Terengganu Crude Oil Terminal (TCOT). The performance curve of crude oil transfer pump at TCOT will be compared to the performance curve of centrifugal pump FM20 that flowing different types of crude oils. Light crude oil had been collected during the visit. Then, early January, heavy crude oil and medium crude oil had been taken at PETRONAS Research Sdn. Bhd. in order to precede with centrifugal pump test rig experiments.

3.4 Laboratory Work

Based on literature review, experiment and test method will be developed before conducting experimental work.

3.4.1 Experiment 1: Viscosity and Density Measurement on Different Types of Fluid

The next phase of the project is to set experiments in order to determine viscosity and density of water, salt water, diesel, light crude oil, medium crude oil and heavy crude oil. All parameters used are followed exactly with the right procedure. The procedure of both experiments is illustrated in **APPENDIX 3.**

Figure 3.1 Experiment set-ups for viscosity and density measurement

3.4.2 Experiment 2: Test Using the Pump Test Rig and Fluid Sample of Different Properties

The next step of the project is to set pump test rig experiments by using six different properties of fluids which are water, sea water, diesel, light crude oil, medium crude oil and heavy crude oil. The data were taken to execute performance graph of the centrifugal pump. There are four characteristics of centrifugal pump that had been evaluated which are:

1. Head versus Pump Capacity
2. Efficiency versus Pump Capacity
3. Brake Horsepower versus Pump Capacity
4. Net Positive Suction Head versus Pump Capacity

The procedure of the experiment can be referred to **APPENDIX 4**.

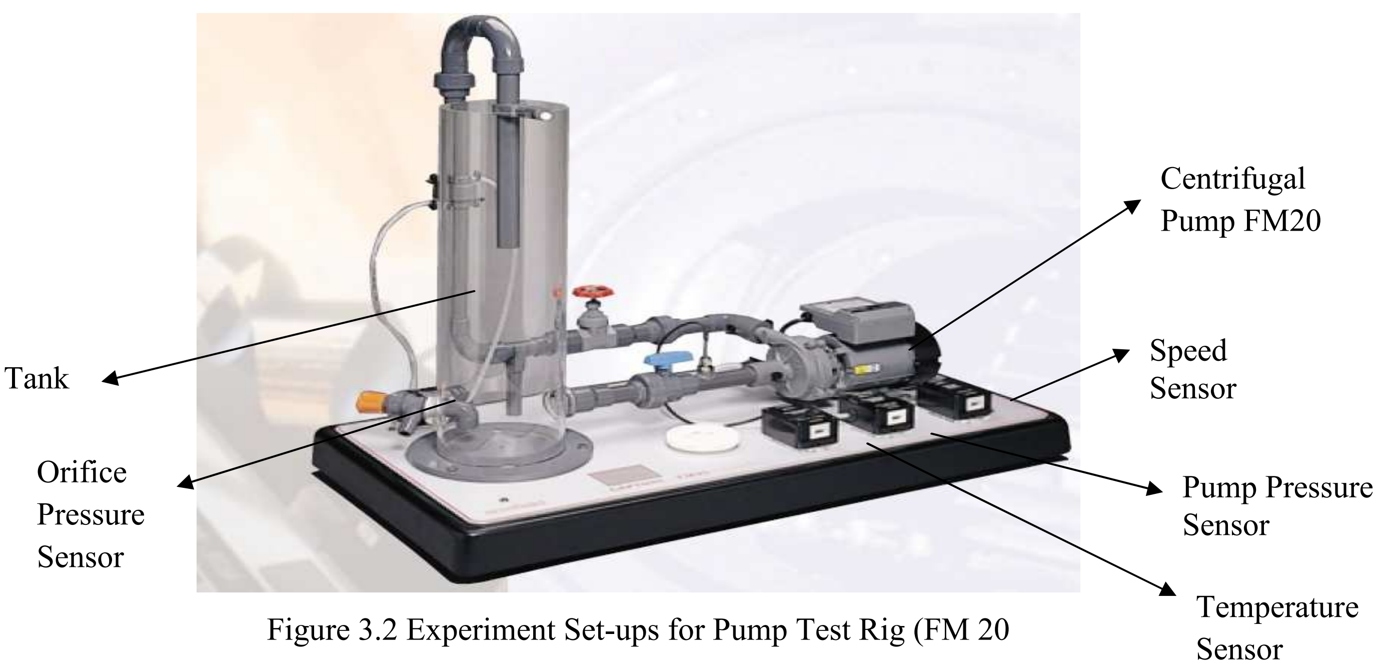

Figure 3.2 Experiment Set-ups for Pump Test Rig (FM 20

3.4.3 Temperature Effect Experiment

The last experiment set up which is putting heating element in the tank in order to heat up the fluids. Raise up temperature of the fluid will cause the decrease of viscosity of fluids. So the set up for temperature effect experiment can be referred to Figure 3.3.

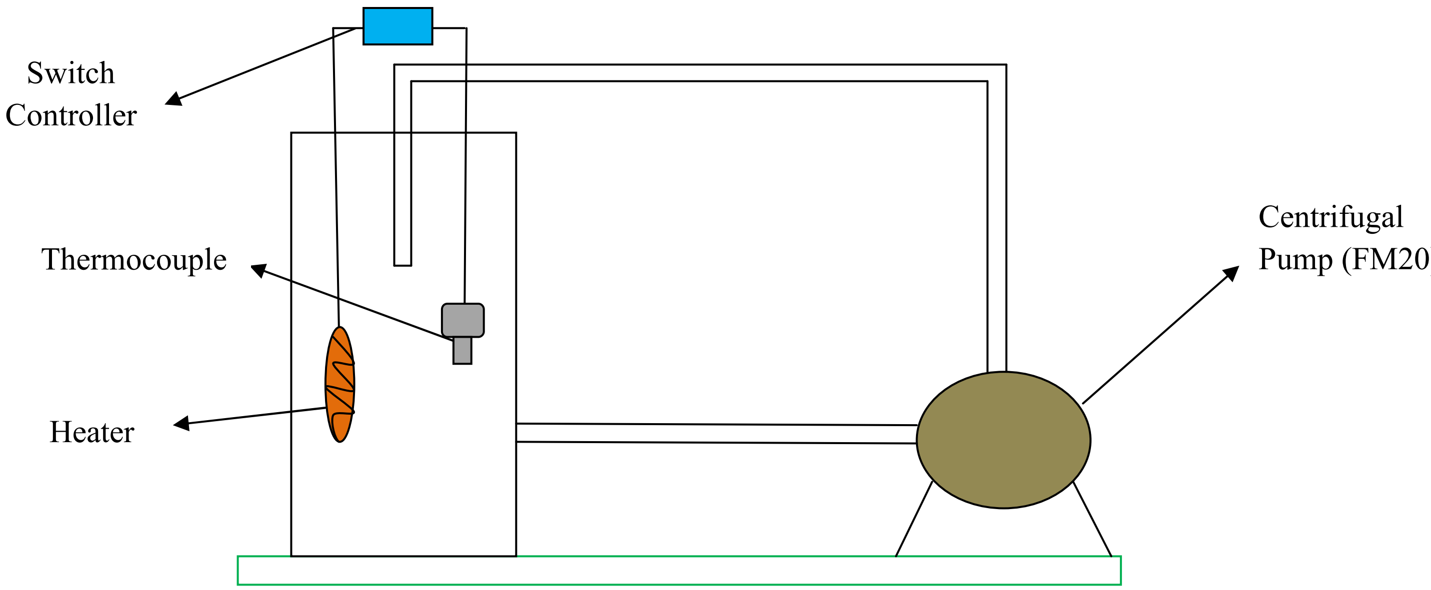

Figure 3.3 Set Up for Temperature Effect Experiment (FM 20)

Figure 3.4 Experiment Set-ups at Lab Fluid Mechanic Block 20

Procedure of the experiment can be referred to **APPENDIX 5.**

3.5 Tools Required

Tools that need to be complete the experimental work are viscometer, scale, and beaker, centrifugal pump set up (FM20), heater, thermocouple, switch controller, water, sea water, diesel, light crude oil, medium crude oil and heavy crude oil.

Figure 3.5 Pictures of equipment required for experiments

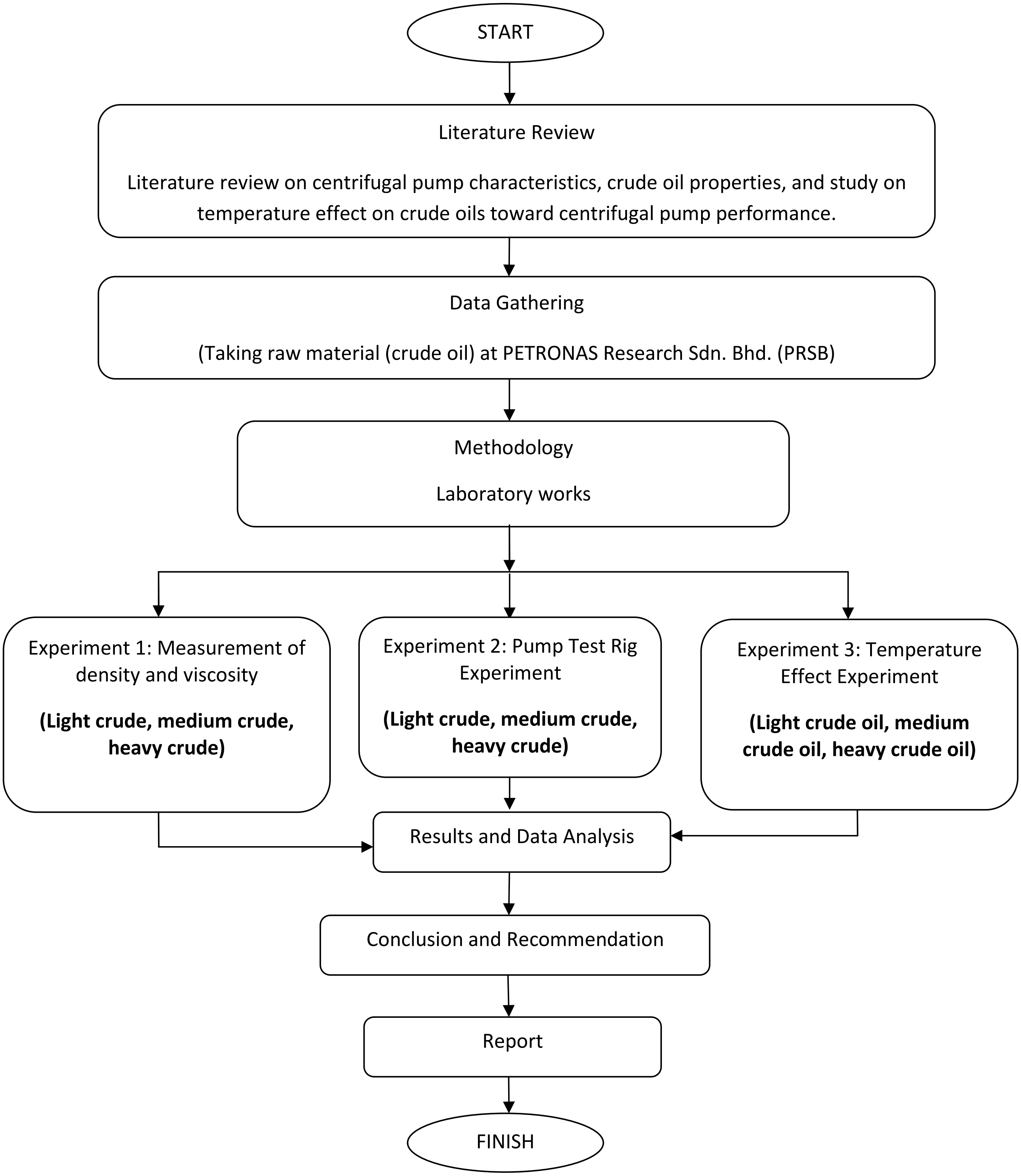

Figure 3.6 Project Flow Schematic Diagrams

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data Gathering and Analysis

From the first visit to Terengganu Crude Oil Terminal (TCOT), there are several information had been collected. The crude oil export pumps, tag number P-380A/B are horizontally split case, variable speed, united centrifugal pump, model k30 x 29 DVS driven by Ruston TB5000 gas turbine engines. The centrifugal pump uses for the experiments also horizontal and variable in speed.

a. Information Gathering

Design Capacity	:	7162 m^3/hr
Discharge Head	:	157.9 m
Velocity	:	1780 rpm
Fluid Pump	:	Crude Oil
Pumping Temperature	:	37.8°C
Crude Oil Viscosity	:	< 7 at 40°C

b. TCOT Export Pump Performance

The main objective of the test is to determine the pump performance in the system. The pump performance will be verified against the manufacturer's guarantee so as to ensure that the pumps can meet the production demand capacity.

The export Pump Head-Capacity test curve is given in two graphs:

i. The first graph shows the pump test performance curve.

ii. The second graph gives the same information after speed correction (using Fan Laws) and the vendor's shop test curve for comparison.

The Head-Capacity test curve was about as expected. However, there was a deviation of about 7% at the test flow rate of 4287 m^3/hr with a speed of 1380 rpm. This deviation can be attributed to inaccuracy in instrumentation measuring pressures, speed and flow rate. Also, the use of the Fan Laws to correct the Head-Capacity curve losses some accuracy for speed changes of more than about 10%.

The BHP of the turbine driver and, therefore, the pump efficiency could not be determined due to insufficient engine performance documents and installed field instrumentation. The graph can be seen in Figure 4.1 and Figure 4.2.

The test on the export pump was carried out at low speed and low flow rates due to process constraints. Further tests at higher speed and at various flow rates are needed to conclusively establish that the pump performance is acceptable. Thus far, the pump is performing as expected.

Pump performance graphs at the field will be used as the references for the centrifugal pump (FM20) performance graphs in the experiments.

Figure 4.1 Performance Curve Graph from Manufacturer for Export Pump

Figure 4.2 Performance Curve Graph during Testing in TCOT for Export Pump

4.2 Error Measurement

Every data collected from the experiments have undergone error analysis. Uncertainty error, basis error and root sum square error had been applied to each data used for graph executing in the results.

Uncertainty error is a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measure end [5]. Uncertainty errors are normally taken from the manufacturer specification given. For temperature sensor and differential pressure sensors, uncertainty given was 1%.

Basis error is the error obtained from the data collected due to fluctuation or unstable. Standard deviation was calculated in order to find the basis error [6]. Root sum square error is a frequently-used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated. RMSD is a good measure of precision [7].

The largest uncertainty for pump head of water was 9.395 ∓ 4.67 m and it occurs at 0 m^3/s flow rate. The largest uncertainty pump head for sea water was 9.672 ∓ 3.82 m, followed by pump head diesel which was 7.684 ∓ 3.45 m, pump head light crude oil 7.321 ∓ 3.21 m, pump head medium crude oil 1.462 ∓ 0.42 m and pump head heavy crude oil was 1.227 ∓ 0.38 m at 0 m^3/s.

The largest uncertainty for efficiency of water was 17.723 ∓ 5.87 m, followed by efficiency of sea water which was 5.692 ∓ 2.04, efficiency for diesel was 1.02 ∓ 0.32, efficiency for light crude oil was 0.93 ∓ 0.18, efficiency for medium crude oil 0.71 ∓ 0.09 and efficiency for heavy crude oil was 0.92 ∓ 0.15.

The largest uncertainty for power output of water was 12.44 ∓ 6.72 m, followed by power output of sea water which was 19 ∓ 4.32 m, power output for diesel was 2.62 ∓

1.56 m, power output for light crude oil was 3.80 ∓ 1.87 m, power output for medium crude oil was 0.71 ∓ 0.21 m, and power output for heavy crude oil was 0.92 ∓ 0.31 m.

The largest uncertainty for net positive suction head of water was 91.361 ∓ 6.32 m, followed by net positive suction head of sea water which was 94.145 ∓ 5.85 m, net positive suction head of diesel was 73.123 ∓ 4.78 m, net positive suction head of light crude oil was 71.882 ∓ 4.628 m, net positive suction head of medium crude oil was 13.024 ∓ 1.402 m and net positive suction head of heavy crude oil was 11.458 ∓ 1.203 m.

4.3 Experiment Measurement Density and Viscosity

An experiment measurement of density and viscosity of different fluids such as water, salt water, diesel, light crude oil, medium crude oil and heavy crude oil will give overview for the next experiment of centrifugal pump performance curves. There are some effects to the performance curve when centrifugal pump deal with different viscosity and density of fluids. As the test will carried out as in the *Table 4.1*:

Table 4.1 Data Collecting Table for Density Test

Components	Volume (l)	Fluid mass (kg)	Density, ρ (kg/m^3)	Specific Gravity, γ	Publish Value	Calibration Value (%)
Water	0.50	0.513	1026	1.000	1.000	0
Sea Water	0.50	0.527	1054	1.027	1.02-1.03	0.3-0.68
Diesel (Cetane)	0.50	0.430	860	0.840	0.82-0.95	2.38-13.1
Light Crude Oil (TCOT)	0.38	0.306	805.26	0.780	0.76-0.79	1.28-2.56
Medium Crude Oil (Penara)	0.15	0.112	746.67	0.723	0.805-0.825	11.34-14.11
Heavy Crude Oil (Angsi)	0.17	0.133	782.35	0.763	0.825-0.847	7.4-11.01

The equation that will be used to calculate density is:

$$\rho = \frac{m}{v} \qquad (4.1)$$

Where:

ρ = Density of fluids (kg/m^3)

m = Mass of fluids (kg)

v = Volume of fluids (m^3)

The equation that will be used to calculate specific gravity is:

$$\gamma = \rho_{oil} / \rho_{water} \quad (4.2)$$

Where:

ρ_{Oil} = Density of Oil

ρ_{Water} = Density of Water

γ = Specific Gravity

From the result above, sea water has been recorded as the highest density which is 1054 kg/m^3, follow by water with 1026 kg/m^3, diesel with 860 kg/m^3, then light crude oil with 805.26 kg/m^3, heavy crude oil with 782.35 kg/m^3 and the lowest density is medium crude oil with 746.67 kg/m^3. The data above also had shown the specific gravity of each fluid. The highest specific gravity is sea water with 1.027. The lowest is medium crude oil which is 0.723. As for theoretical, specific gravity of light crude oil lies in the range of 0.76 to 0.79, specific gravity of medium crude oil lies in the range of 0.805 to 0.825 and specific gravity of heavy crude oil lies on the range 0.825 to 0.847. In this experiment show that sea water will require a lot of horsepower to pump it because of the highest specific gravity and medium crude oil will require the lowest horsepower to pump it but the density of fluids or specific gravity of fluids will not give much impact to the performance curve compare to the viscosity effect of the fluids.

Table 4.2 Data Collecting Table for Viscosity Test

Fluids Component	Publish Value (cp)	Experimental Viscosity (cp)	Calibration Value (%)
Water	1.00	0.890	11
Sea water	1.18	1.080	8.5
Diesel (Cetane)	1.68-5.04	1.970	17.26-60.91
Light Crude Oil (TCOT)	1.60-3.80	1.520	8-60
Medium Crude Oil (Penara)	3.50-9.70	2.966	15.26-69.42
Heavy Crude Oil (Angsi)	4.90-17.80	4.034	17.67-77.34

The equation that will be used to calculate viscosity is:

$$\mu = \rho v \tag{4.3}$$

Where:

μ = Dynamic viscosity

ρ = Density of fluids (kg/m^3)

v = Kinematic viscosity (m/s^{-2})

This experiment has been repeated five times for each fluids component. From the experiments conducted, heavy crude oil recorded as the highest viscosity which is 4.304 cp, followed by medium crude oil with viscosity 2.966 cp, diesel with viscosity 1.970 cp, light crude oil with viscosity 1.520 cp, sea water with viscosity 1.080 cp and lastly water with viscosity 0.890 cp. In the literature review stated that viscosity will give more impact to the performance curve of centrifugal pump during pumping compare to specific gravity. Even though the specific gravity of sea water is greater compare to other fluids, but viscosity of sea water is just 1.08 lower than other fluids. So, it will not give more effect to the performance curves. The flow of the liquids will be clarified by doing pump test rig experiments in order to obtain the performance curves of centrifugal pump.

4.4 Data Gathering, Analysis and Experiment using the Pump Test Rig and Fluid Sample of Different Properties

Each experiment will be doing with variation of fluids such as water, salt water, diesel, light crude oil, medium crude oil and heavy crude oil. Water will be used as the less viscous fluid, follow by sea water, light crude oil, diesel, medium crude oil and heavy crude oil as the highest viscosity fluid.

Below are the data collecting for pump performance curves:

Table 4.3 Data Collecting Table for Performance Curve Test (Water)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.000000	9.395	0.00	0.00	28.62	91.373
2	6.24E-05	8.941	5.074	5.47	27.40	85.907
3	0.000101	8.779	9.544	8.68	69.98	82.019
4	0.00015	8.434	17.858	12.44	28.70	74.234
5	0.000203	5.285	16.696	10.52	29.56	37.691

Table 4.4 Data Collecting Table for Performance Curve Test (Sea Water)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.000000	9.681	0.000	0.00	27.96	94.145
2	5.28E-05	9.620	1.700	5.00	26.50	93.528
3	0.000103	9.541	3.640	9.40	27.24	93.173
4	0.000149	9.525	4.860	14.20	28.06	92.151
5	0.000203	9.447	5.784	19.00	29.30	90.970

Table 4.5 Data Collecting Table for Performance Curve Test (Diesel)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.000000	7.624	0.00	0.00	29.12	74.014
2	4.96E-05	7.692	0.72	3.22	33.72	74.522
3	0.000104	3.804	1.04	3.33	33.18	36.429
4	0.000149	1.894	0.75	2.38	33.74	17.546
5	0.000201	1.548	0.75	2.62	33.86	11.997

Table 4.6 Data Collecting Table for Performance Curve Test (Light Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.000000	7.443	0.00	0.00	31.84	72.188
2	5.32E-05	7.163	0.59	2.20	32.68	69.379
3	0.000105	3.307	0.63	2.60	33.7	31.575
4	0.000150	1.715	0.93	3.20	34.14	15.795
5	0.000188	1.393	0.57	3.80	33.92	12.354

Table 4.7 Data Collecting Table for Performance Curve Test (Medium Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.000000	1.471	0.00	0.00	27.08	12.633
2	5.64E-05	1.341	0.13	1.00	31.74	12.048
3	0.000102	1.299	0.23	1.00	33.22	11.841
4	0.000148	1.280	0.58	2.00	36.50	11.534
5	0.000201	1.265	0.71	3.00	38.04	13.024

Table 4.8 Data Collecting Table for Performance Curve Test (Heavy Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.000000	1.244	0.00	0.00	25.26	10.635
2	0.000053	1.141	0.25	1.00	27.56	10.237
3	0.000098	1.109	0.48	1.00	29.26	10.032
4	0.000149	1.156	0.92	2.00	30.42	10.267
5	0.000201	1.143	0.74	2.60	31.40	11.559

The equation used is:

$$Po = \rho g Q H \tag{4.4}$$

Po = Power Output (W)

H = Head (m)

Q = Flow rate (m^3/s)

$$Pin = \frac{2\Pi N}{60} T \tag{4.5}$$

Pin = Power Input (W)

N = revolution per minutes

T = Torque (N.m)

$$\eta = \frac{Po}{Pin} \tag{4.6}$$

η = Efficiency (decimal)

Po = Power Output (W)

Pin = Power Input (W)

4.4.1 Experimental Centrifugal Pump Performance Curve

a. Head versus Pump Capacity

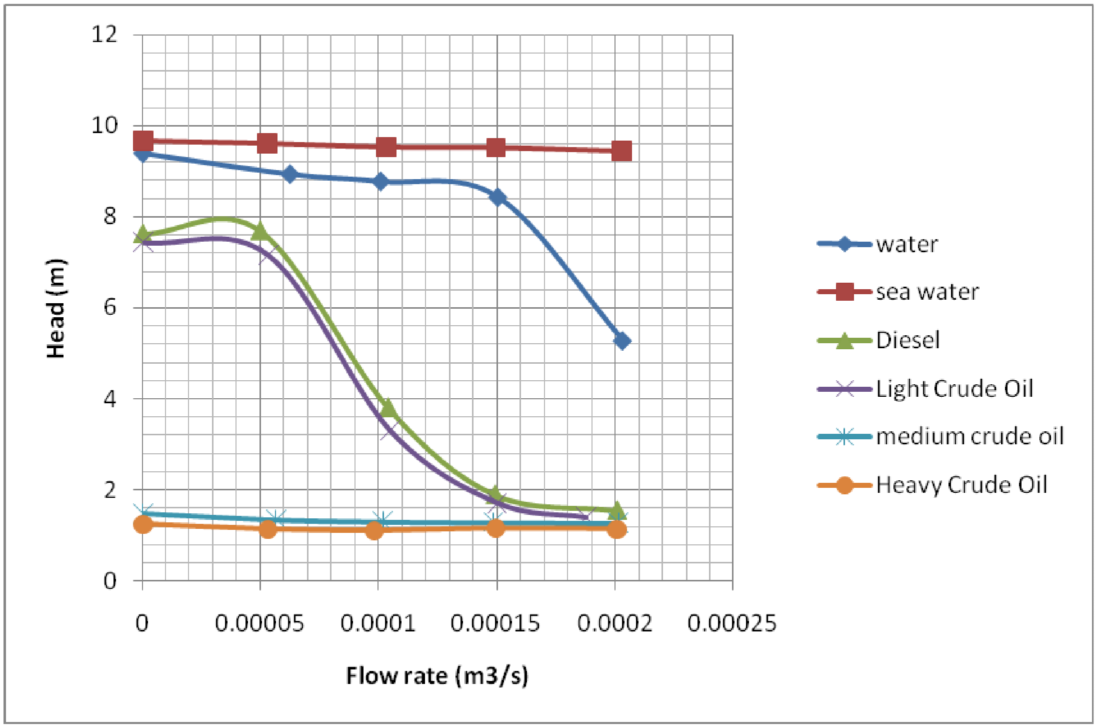

Figure 4.3 Experimental graphs for head of pump versus pump capacity

The graph above had shown the result of head of centrifugal pump versus pump capacity for different types of fluid. At 0 flow rate, sea water showed the highest shut off head which is 9.681 m followed by water with 9.350 m, diesel with 7.624 m, light crude oil with 7.443 m, medium crude oil with 1.471 m and lastly heavy crude oil with 1.244 m. As can see in the graph, sea water achieved the highest head value in every flow rate. These graphs prove the theoretical where the higher the specific gravity, the higher pump head value during pumping. At flow rate 0.00015 m^3/s, pump head value during pumping water which is 8.434m sharply decreased to 5.285m when pumping 0.0002 m^3/s of water. During pumping diesel and light crude oil at 0.00005 m^3/s, the head value of both fluids decreased sharply about 75% until 0.00015 m^3/s flow rate. Heavy crude oil and medium crude oil showed the lowest pump head value during pumping in every flow rate.

b. Efficiency versus Pump Capacity

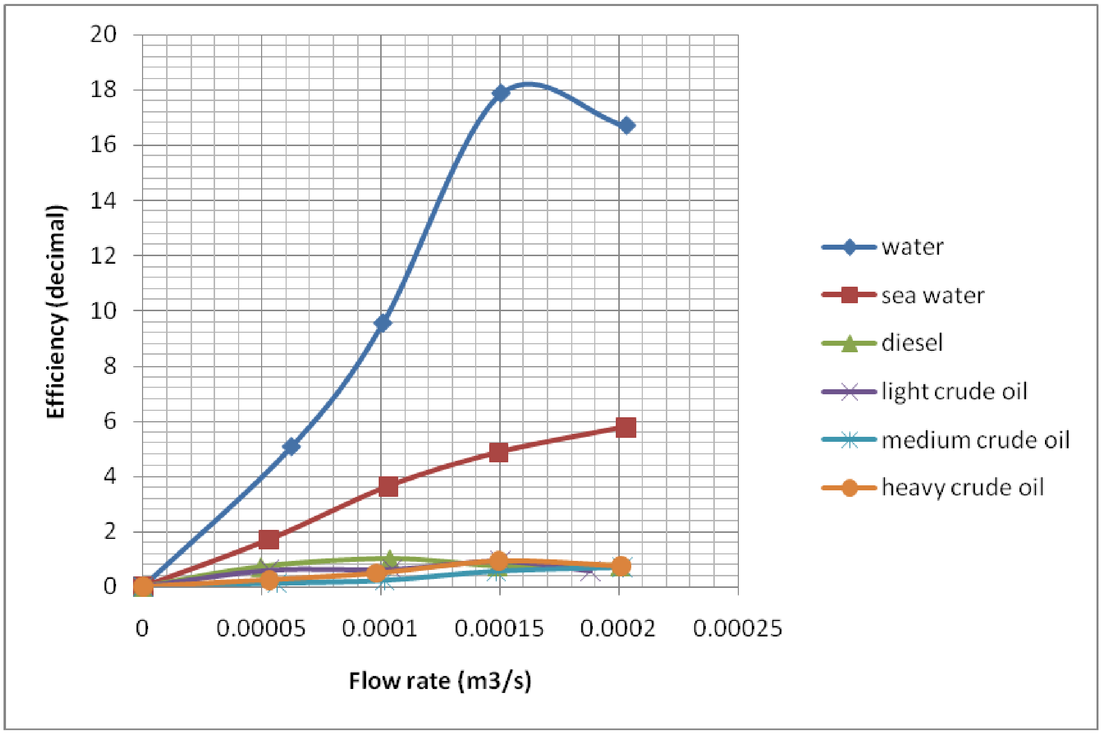

Figure 4.4 Experimental graphs for efficiency of pump versus pump capacity

The graph above had shown the experimental graphs of efficiency of six different fluids which are water, sea water, light crude oil, diesel, medium crude oil and heavy crude oil. At 0.00015 m^3/s, best efficiency point during pumping water is 17.858 followed by best efficiency point of sea water which is 5.784 at flow rate 0.0002 m^3/s. At flow rate 0.0001, best efficiency point of diesel is 1.04. Then, best efficiency point of light crude oil lies on 0.93 at flow rate 0.00015 m^3/s. Heavy crude oil recorded its best efficiency point which is 0.92 at 0.00015 m^3/s. Lastly, medium crude oil recorded its best efficiency point with 0.71 at flow rate 0.0002 m^3/s. As expected, centrifugal pump is very efficient when pumping the less viscous fluids such as water and salt water. Even though centrifugal pump very efficient to pump less viscous fluids but centrifugal pump still can pump different types of crude oils but with some modification design to achieve the best efficiency point maximally.

c. **Brake Horsepower versus Pump Capacity**

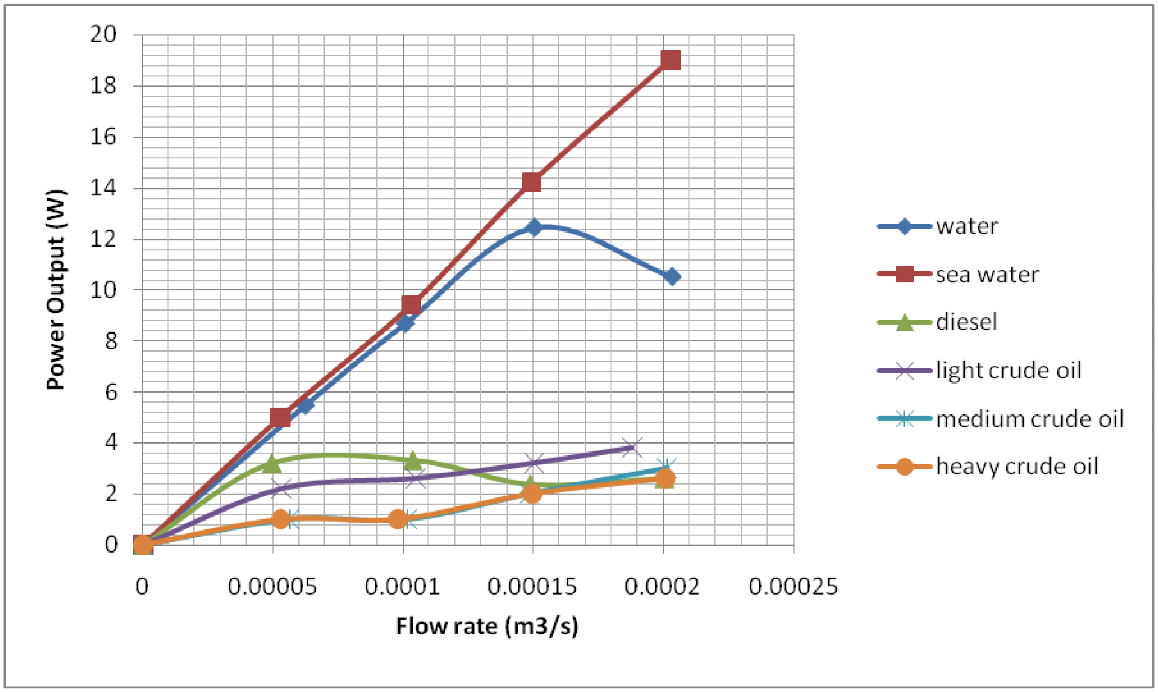

Figure 4.5 Experimental graphs for brake horsepower versus pump capacity

The graph above had shown brake horsepower of pump versus pump capacity of different types of fluids which were water, sea water, diesel, light crude oil, medium crude oil and heavy crude oil. Power output required to pump sea water was much higher compare to other fluids with sharply increase in every flow rate. At 0.0002 m^3/s flow rate, the brake horsepower required to pump sea water was 19 W. Maximum brake horsepower required to pump water was 12.44 W at 0.00015 m^3/s flow rate. Next, light crude oil recorded its maximum brake horsepower required to pump it was 3.8 W at 0.0002 m^3/s. Last but not least, brake horsepower required to pump diesel was 3.33 W at 0.00005 m^3/s. Lastly, heavy crude oil and medium crude oil required 3 W of brake horsepower maximally to pump them. So, this experiment had proved that the higher the specific gravity, the greater number of brake horsepower required pumping it.

d. Net Positive Suction Head Required versus Pump Capacity

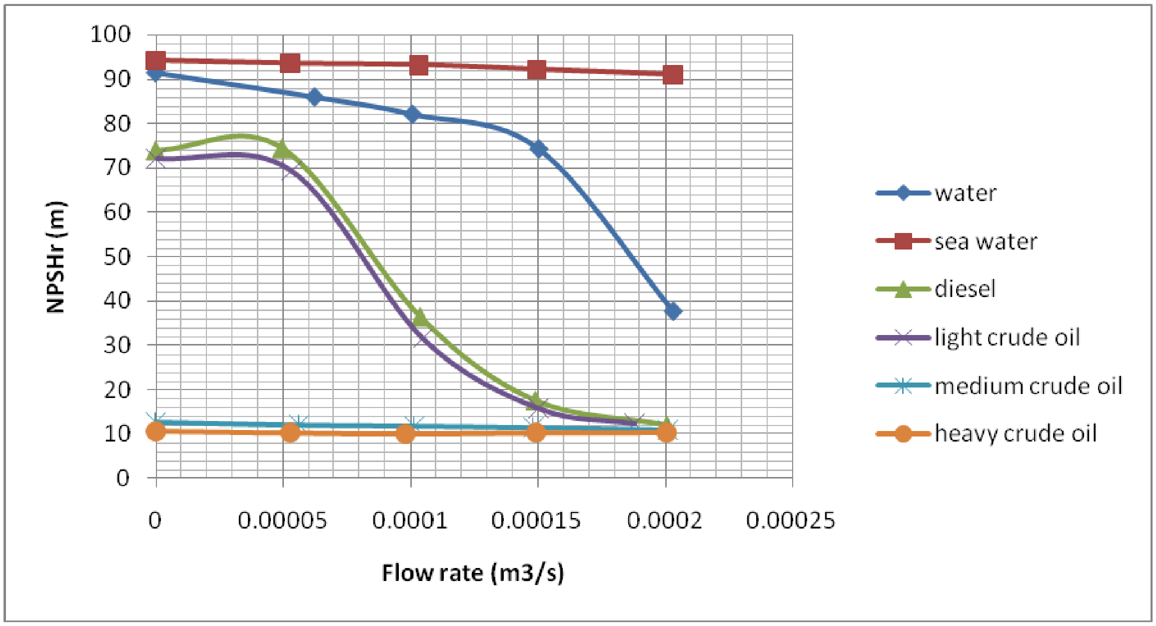

Figure 4.6 Experimental graphs for net positive suction head required versus pump capacity

In the study of centrifugal pump characteristics, net positive suction head required versus pump capacity is the one characteristic that most likely affect the performance curve of pump. Heavy crude oil recorded the smallest differential pressure value which was 0.9246 m from 0 m^3/s flow rate to 0.0002 m^3/s flow rate but diesel recorded as the highest differential pressure value which was 62.0164 m from 0 m^3/s flow rate to 0.0002 m^3/s flow rate. At 0.00005 m^3/s flow rate, diesel, water and light crude oil showed decrement until 0.0002 m^3/s flow rate. Diesel and light crude showed decrement about 83% from 0 m^3/s flow rate until 0.0002 m^3/s flow rate. Water showed decrement about 59% from 0 m^3/s flow rate until 0.0002 m^3/s flow rate. From the study in literature review, when pumping viscous fluid such as heavy crude oil, there was small differential pressure between suction head and vapor head occurred but in order to avoid cavitations from occur, net positive suction head available must higher than net positive suction head required. Normally, it was rarely cavitations occurred when pumping low viscous fluid.

4.5 Data Gathering, Analysis and Experiment Temperature Effect for Different Properties of Crude Oil

Each experiment will be doing with variation of fluids properties such as light crude oil, medium crude oil and heavy crude oil. Normally, flash point of crude oil is in the range of 52°C to 90°C. So, the experiments need to be conducted below the flash point of the crude oil since to avoid phase changing. The reason why crude oil had been heated up because crude oil viscosity will be decreased, hence improve the performance curve of centrifugal pump.

Below are the data collecting at 30°C for pump performance curves:

Table 4.9 Data Collecting Table for Performance Curve Test (Light Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.00000	8.452	0.00	0.00	30.00	74.1462
2	0.00005	8.021	0.69	2.20	30.00	70.5438
3	0.00010	6.317	0.79	2.40	30.00	41.0832
4	0.00015	4.684	0.98	3.00	30.00	25.9374
5	0.00020	2.386	0.62	3.20	30.00	14.9021

Table 4.10 Data Collecting Table for Performance Curve Test (Medium Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.00000	2.402	0.00	0.00	30.00	14.7530
2	0.00005	2.321	0.15	0.84	30.00	12.2338
3	0.00010	1.935	0.29	0.93	30.00	13.9708
4	0.00015	1.860	0.67	1.20	30.00	13.6028
5	0.00020	1.821	0.82	1.30	30.00	12.0214

Table 4.11 Data Collecting Table for Performance Curve Test (Heavy Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.00000	2.312	0.00	0.00	30.00	11.9842
2	0.00005	2.077	0.28	0.82	30.00	11.9594
3	0.00010	1.921	0.52	1.20	30.00	11.4872
4	0.00015	1.856	0.93	1.60	30.00	10.9087
5	0.00020	1.818	0.87	2.00	30.00	10.5297

Below are the data collecting at 35°C for pump performance curves:

Table 4.12 Data Collecting Table for Performance Curve Test (Light Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.00000	8.892	0.00	0.00	35.00	78.0925
2	0.00005	8.438	0.70	2.70	35.00	72.7341
3	0.00010	7.409	0.85	2.20	35.00	52.6432
4	0.00015	5.695	0.99	2.60	35.00	27.3871
5	0.00020	3.401	0.74	3.00	35.00	17.7629

Table 4.13 Data Collecting Table for Performance Curve Test (Medium Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.00000	2.804	0.00	0.00	35.00	16.0952
2	0.00005	1.745	0.36	0.82	35.00	15.9845
3	0.00010	2.380	0.54	0.91	35.00	15.3904
4	0.00015	2.169	0.95	1.00	35.00	14.9128
5	0.00020	1.980	0.89	1.10	35.00	13.8471

Table 4.14 Data Collecting Table for Performance Curve Test (Heavy Crude Oil)

Reading	Flow rate (m3/s)	Head (m)	Efficiency (decimal)	Power output (W)	Temperature (°C)	NPSH (m)
1	0.00000	2.591	0.00	0.00	35.00	12.3027
2	0.00005	2.321	0.173	0.71	35.00	12.1045
3	0.00010	1.962	0.350	1.00	35.00	11.9650
4	0.00015	1.875	0.691	1.36	35.00	11.3085
5	0.00020	1.836	0.838	1.80	35.00	10.9432

The equation used is:

$$Po = \rho g Q H \tag{4.7}$$

Po = Power Output (W)

H = Head (m)

Q = Flow rate (m^3/s)

$$Pin = \frac{2\Pi N}{60} T \tag{4.8}$$

Pin = Power Input (W)

N = revolution per minutes

T = Torque (N.m)

$$\eta = \frac{Po}{Pin} \tag{4.9}$$

η = Efficiency (decimal)

Po = Power Output (W)

Pin = Power Input (W)

4.5.1 Experimental Temperature Effect on Centrifugal Pump Performance Curve

a. Light Crude Oil

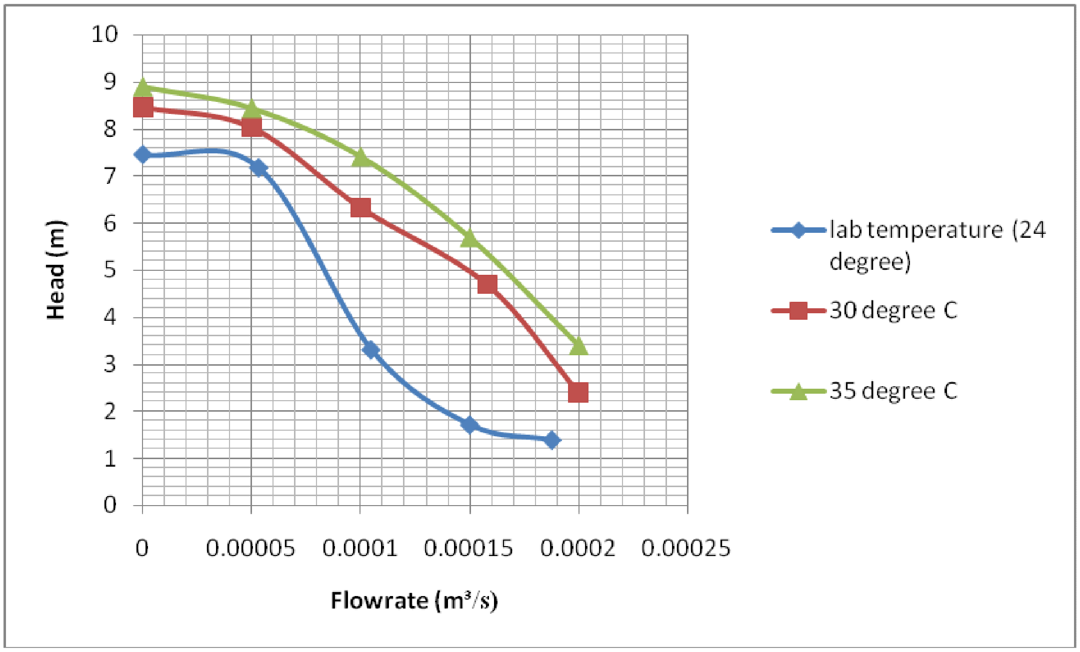

Figure 4.7 Experimental graphs for head of pump versus pump capacity

The graph above showed the result of head of centrifugal pump versus pump capacity for light crude oil at different temperature. At lab temperature which is 24°C, head of the centrifugal pump was the lowest compare to head of pump at 30°C and 35°C temperature. At 0 m^3/s flow rate, head of pump at 35°C during pumping light crude oil was 8.892 m, followed by head of pump at 30°C which was 8.452 m and lastly head of pump at 24°C which was 7.443 m. It showed that there was about 19% increasing in pump head when light crude oil had been heated up from 24°C to 35°C. Those graphs proved that when heated up crude oil will decrease the viscosity effect of crude oil hence increase the centrifugal pump performance curve.

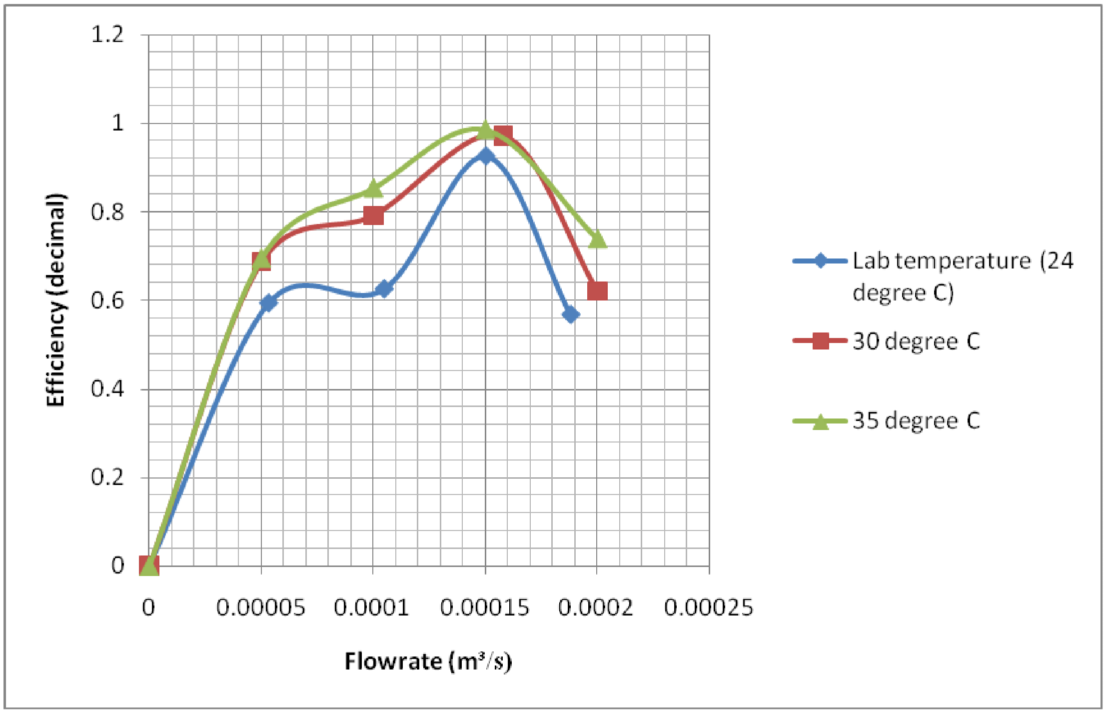

Figure 4.8 Experimental graphs for efficiency of pump versus pump capacity

Figure 4.8 above showed the experimental graphs of efficiency of light crude oil at different temperatures which were at lab temperature, 24°C, 30°C and 35°C. At 0.00015 m^3/s, best efficiency point during pumping light crude oil at 24°C was 0.926. Best efficiency point during pumping light crude oil at temperature 30°C was 0.973 at 0.000158 m^3/s and the highest best efficiency point during pumping light crude oil at temperature 35°C was 0.986 at 0.00015 m^3/s. Best efficiency point of light crude oil was increased about 6% when pumping light crude oil from lab temperature 24°C to 35°C temperature. At 0.0002 m^3/s flow rate, efficiency of the pump decreased for every temperature because the pump was achieved its best efficiency at 0.00015 m^3/s flow rate. As expected, centrifugal pump is very efficient when pumping light crude oil that had been heated up to 35°C since viscosity of the light crude oil had been decreased.

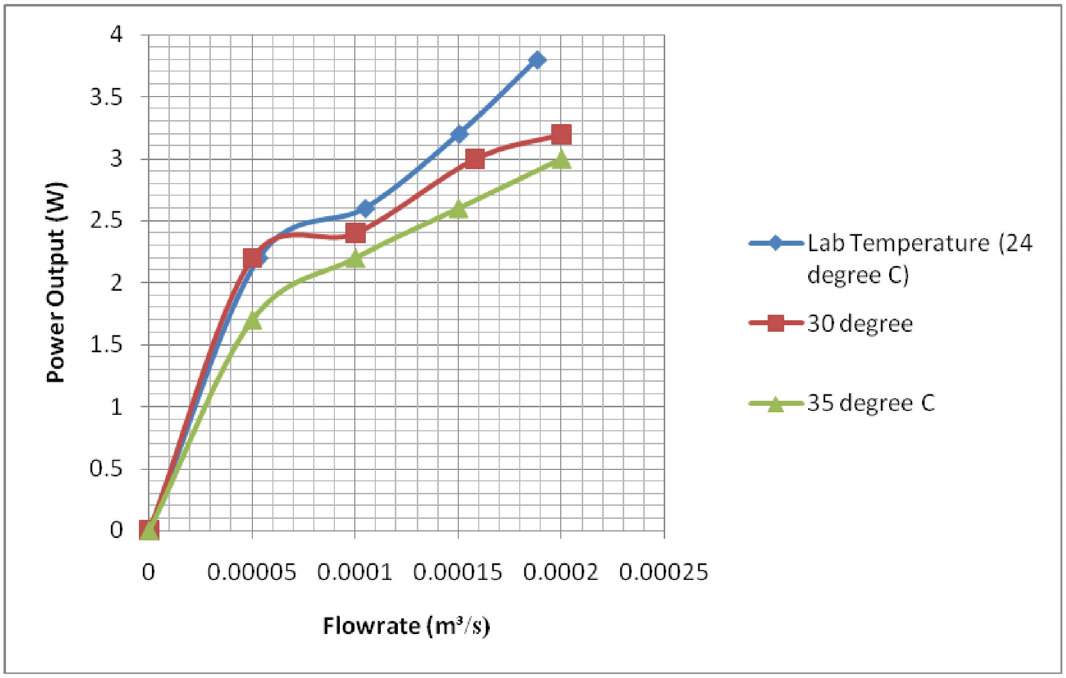

Figure 4.9 Experimental graphs for power output of pump versus pump capacity

The graphs above in figure 4.9 illustrated that experimental graph for power output of pump versus pump capacity for different temperature of light crude oil. At 35°C temperature, the power output required to pump light crude oil was the lowest compare to 30°C temperature and 24°C temperature of light crude oil. At 0.0002 m^3/s flow rate, the highest power output required to pump light crude oil at 24°C was 3.8W followed by 30°C was 3.2W and lastly at 35°C was 3.0W. The power requirement to pump light crude oil at 35°C temperature had been decreased about 21% from power requirement to pump light crude oil at lab temperature. As expected, light crude oil was decreasing its viscosity during heated up, hence increased the centrifugal pump performance.

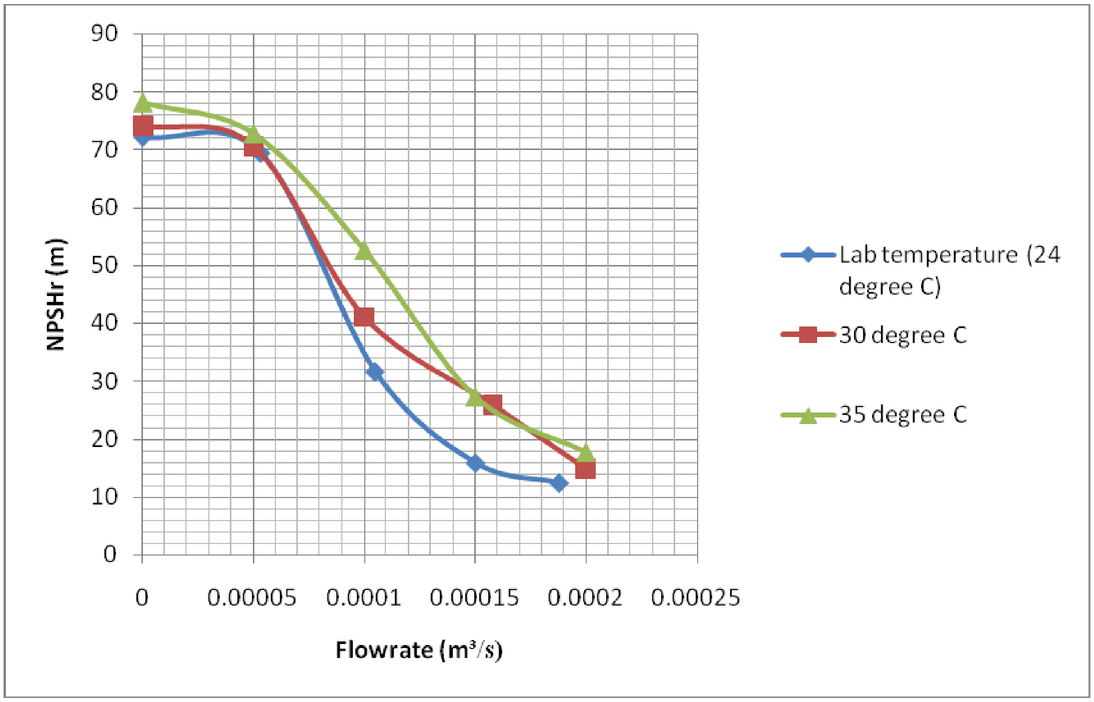

Figure 4.10 Experimental graphs for net positive suction head required of pump versus pump capacity

In the study of centrifugal pump characteristics, net positive suction head required versus pump capacity is the one characteristic that most likely affect the performance curve of pump. Net positive suction head required of pump at lab temperature, 24°C showed the smallest differential value which was 59.2441 m from 0 m^3/s flow rate to 0.0002 m^3/s flow rate but net positive suction head required at 35°C temperature recorded as the highest differential value which was 60.3296 m from m^3/s flow rate to 0.0002 m^3/s flow rate. At 30°C temperature, net positive suction head required recorded differential value which was 59.8336 m. From the study in literature review, when pumping viscous fluid such as light crude oil at lab temperature, 24°C, there was small differential pressure between suction head and vapor head occurred but in order to avoid cavitations from occur, net positive suction head available must higher than net positive suction head required. Normally, it was rarely cavitations occurred when pumping low viscous fluid.

b. Medium Crude Oil

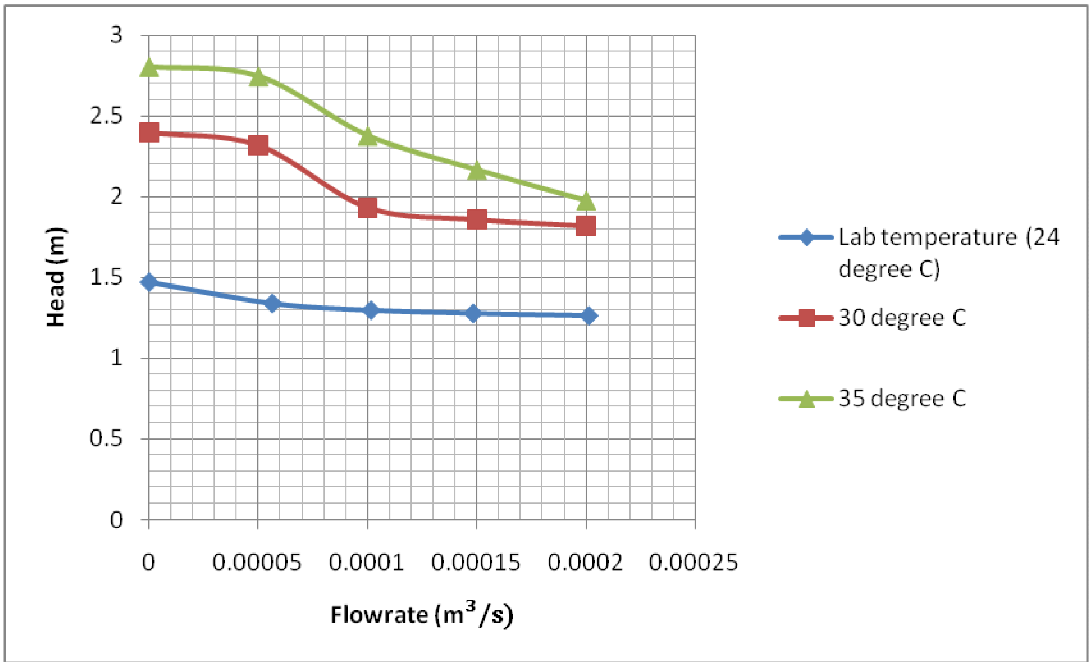

Figure 4.11 Experimental graphs for head of pump versus pump capacity

The graph above in figure 4.11 explained the result of head of centrifugal pump versus pump capacity for medium crude oil at different temperatures which were at 24°C, 30°C and 35°C. At lab temperature which is 24°C, head of the centrifugal pump was the lowest compare to head of pump at 30°C and 35°C temperature. At 0 m^3/s flow rate, head of pump at 35°C during pumping medium crude oil was 2.804 m, followed by head of pump at 30°C which was 2.402 m and lastly head of pump at 24°C which was 1.471 m. It showed that there was about 90% increasing in pump head when medium crude oil had been heated up from 24°C to 35°C. Those graphs proved that when heated up crude oil will decrease the viscosity effect of crude oil hence increased the centrifugal pump performance curves.

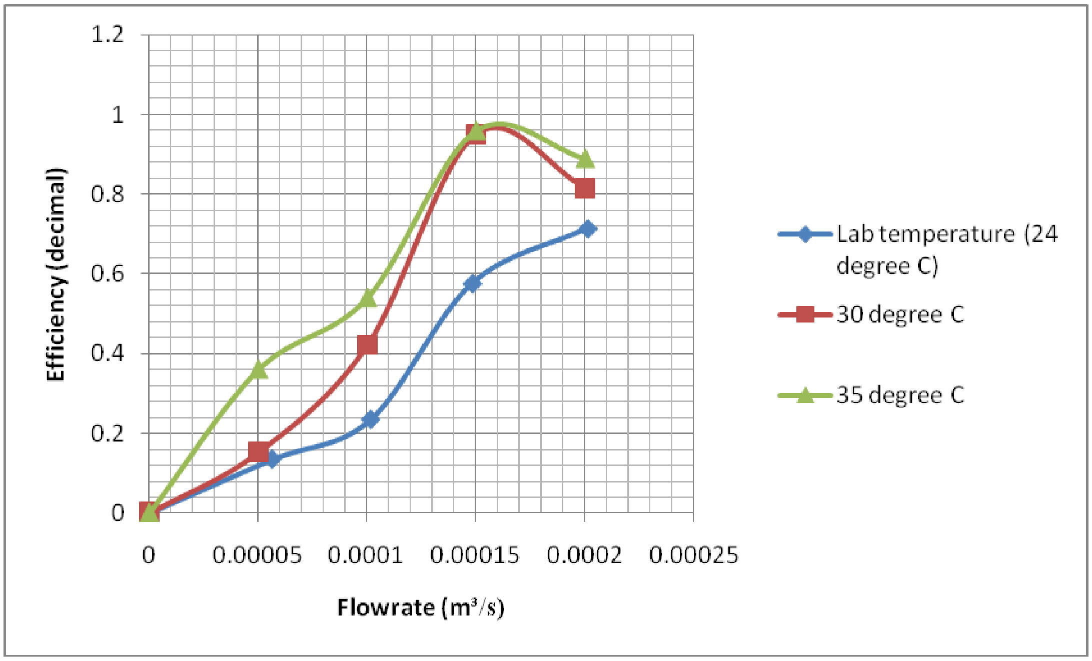

Figure 4.12 Experimental graphs for efficiency of pump versus pump capacity

Figure 4.12 above showed the experimental graphs of efficiency of medium crude oil at different temperatures which were at lab temperature, 24°C, 30°C and 35°C. At 0.000201 m^3/s, best efficiency point during pumping medium crude oil at 24°C was 0.714. Best efficiency point during pumping medium crude oil at temperature 30°C was 0.950 at 0.00015 m^3/s and the highest best efficiency point during pumping medium crude oil at temperature 35°C was 0.96 at 0.00015 m^3/s. Best efficiency point of light crude oil increased about 34% when pumping medium crude oil at from lab temperature 24°C to 35°C. At 0.0002 m^3/s flow rate, efficiency of the pump decreased for 30°C and 35°C temperature because the pump was achieved its best efficiency at 0.00015 m^3/s flow rate. As expected, centrifugal pump is very efficient when pumping medium crude oil that had been heated up to 35°C temperature since viscosity of the medium crude oil had been decreased.

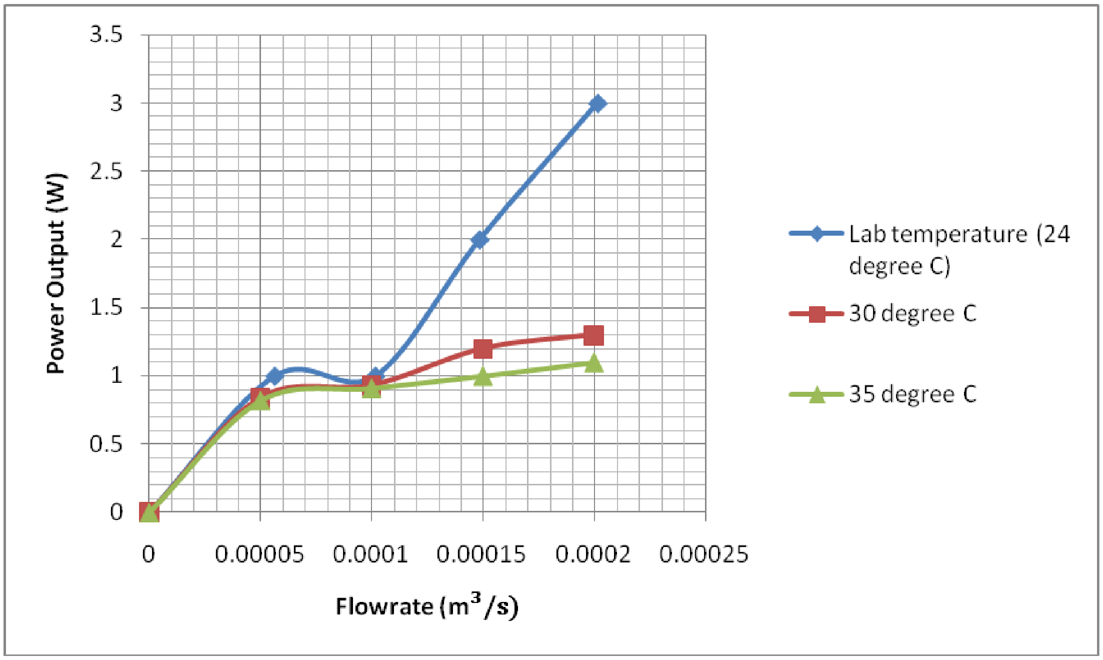

Figure 4.13 Experimental graphs for power output of pump versus pump capacity

The graphs above in figure 4.13 illustrate that experimental graph for power output of pump versus pump capacity for different temperatures of medium crude oil. At 35°C temperature, the power output required to pump medium crude oil was the lowest compare to 30°C temperature and 24°C temperature of medium crude oil. At 0.0002 m^3/s flow rate, the highest power output required to pump medium crude oil at 24°C was 3.0W followed by 30°C was 1.3W and lastly at 35°C was 1.1W. The power requirement to pump medium crude oil at 35°C temperature had been decreased about 63% from power requirement to pump medium crude oil at lab temperature. As expected, medium crude oil was decreasing its viscosity during heated up, hence increased the centrifugal pump performance.

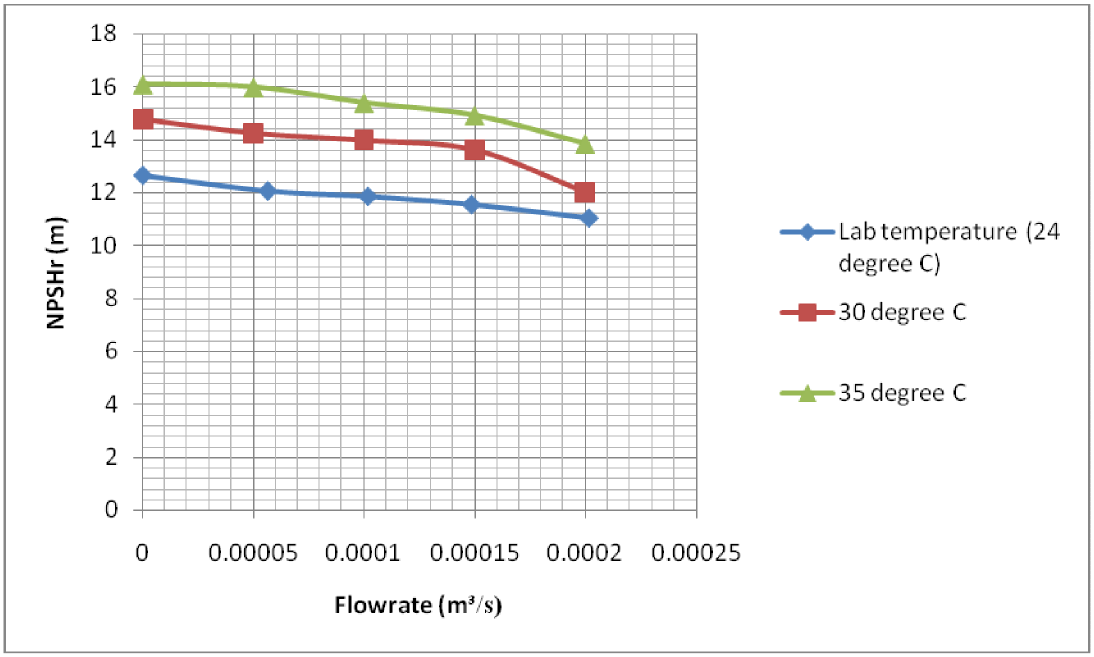

Figure 4.14 Experimental graphs for net positive suction head required of pump versus pump capacity

In the study of centrifugal pump characteristics, net positive suction head required versus pump capacity is the one characteristic that most likely affect the performance curve of pump. Net positive suction head required of pump at lab temperature, 24°C showed the smallest differential value which was 1.6094 m from 0 m^3/s flow rate to 0.0002 m^3/s flow rate but net positive suction head required at 35°C temperature recorded as the highest differential value which was 2.7316 m from m^3/s flow rate to 0.0002 m^3/s flow rate. At 30°C temperature, net positive suction head required recorded differential value which was 2.2481 m. From the study in literature review, when pumping viscous fluid such as medium crude oil at lab temperature, 24°C, there was small differential pressure between suction head and vapor head occurred

c. Heavy Crude Oil

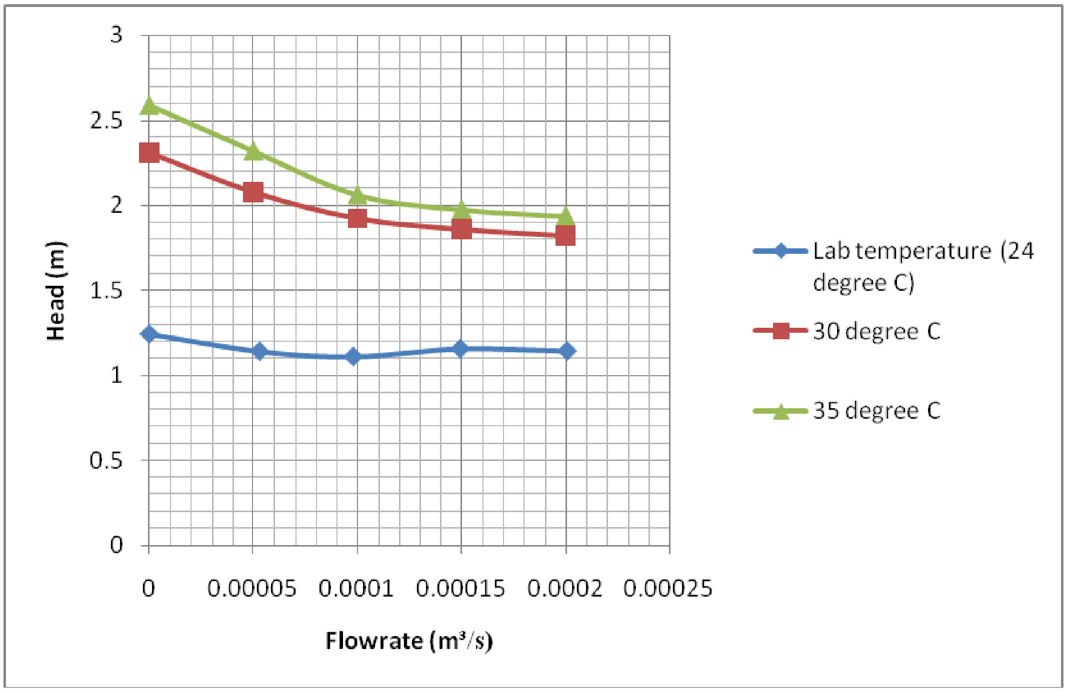

Figure 4.15 Experimental graphs for head of pump versus pump capacity

The graph above in figure 4.15 demonstrated the result of head of centrifugal pump versus pump capacity for heavy crude oil at different temperatures which were at 24°C, 30°C and 35°C. At lab temperature which is 24°C, head of the centrifugal pump was the lowest compare to head of pump at 30°C and 35°C temperature. At 0 m^3/s flow rate, head of pump at 35°C during pumping heavy crude oil was 2.591 m, followed by head of pump at 30°C which was 2.312 m and lastly head of pump at 24°C which was 1.244 m. It showed that there was about 52% increasing in pump head when heavy crude oil had been heated up from 24°C to 35°C. Those graphs proved that when heated up crude oil will decrease the viscosity effect of crude oil hence increased the centrifugal pump performance curves.

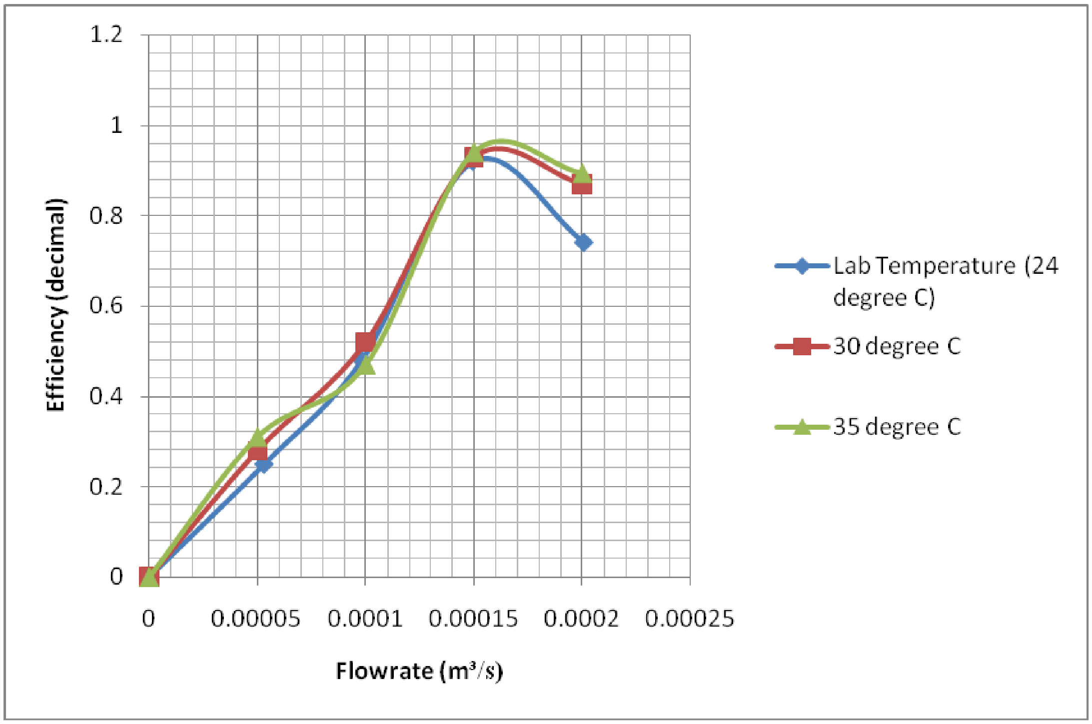

Figure 4.16 Experimental graphs for efficiency of pump versus pump capacity

Figure 4.16 above showed the experimental graphs of efficiency of heavy crude oil at different temperatures which were at lab temperature, 24°C, 30°C and 35°C. At 0.000149 m^3/s, best efficiency point during pumping heavy crude oil at 24°C was 0.920. Best efficiency point during pumping heavy crude oil at temperature 30°C was 0.930 at 0.00015 m^3/s and the highest best efficiency point during pumping light crude oil at temperature 35°C was 0.940 at 0.00015 m^3/s. Best efficiency point of heavy crude oil increased about 2% when pumping light crude oil from lab temperature 24°C to 35°C. At 0.0002 m^3/s flow rate, efficiency of the pump decreased for every temperature because the pump was achieved its best efficiency at 0.00015 m^3/s flow rate. As expected, centrifugal pump is very efficient when pumping light crude oil that had been heated up to 35°C temperature since viscosity of the light crude oil had been decreased.

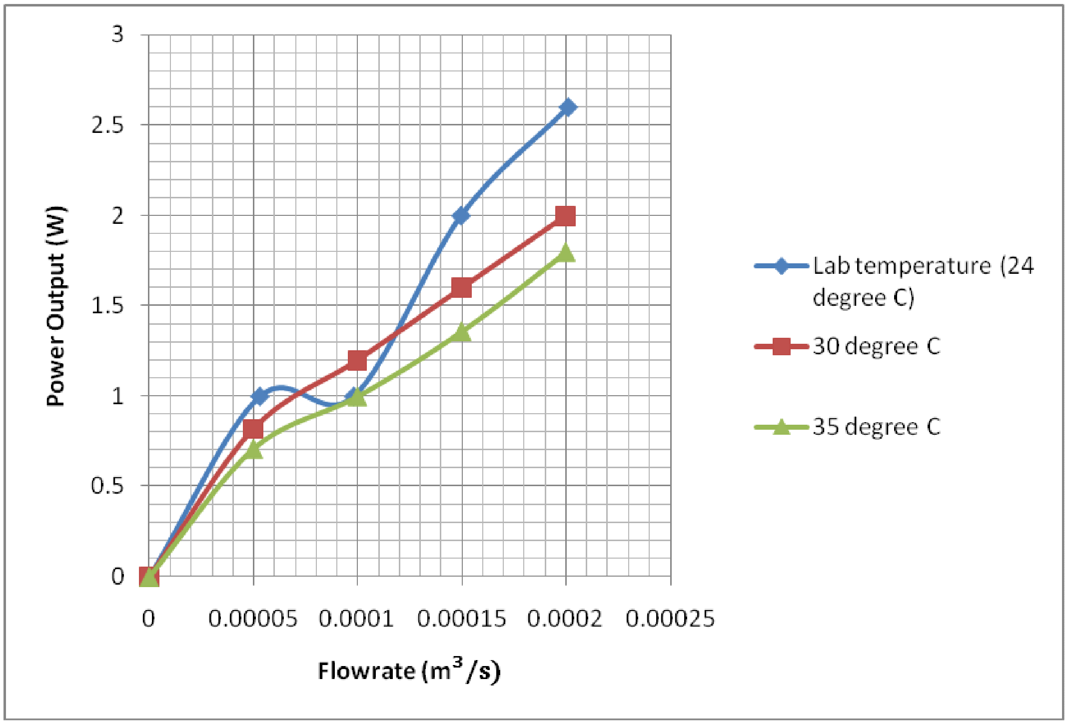

Figure 4.17 Experimental graphs for power output of pump versus pump capacity

The graphs above in figure 4.17 illustrate that experimental graph for power output of pump versus pump capacity for different temperatures of heavy crude oil. At 35°C temperature, the power output required to pump heavy crude oil was the lowest compare to 30°C temperature and 24°C temperature of medium crude oil. At 0.0002 m^3/s flow rate, the highest power output required to pump heavy crude oil at 24°C was 3.224W followed by 30°C which was 2.00W and lastly at 35°C power required was 1.80W. The power requirement to pump heavy crude oil at 35°C temperature had been decreased about 44% from power requirement to pump heavy crude oil at lab temperature. As expected, heavy crude oil was decreasing its viscosity during heated up, hence increased the centrifugal pump performance.

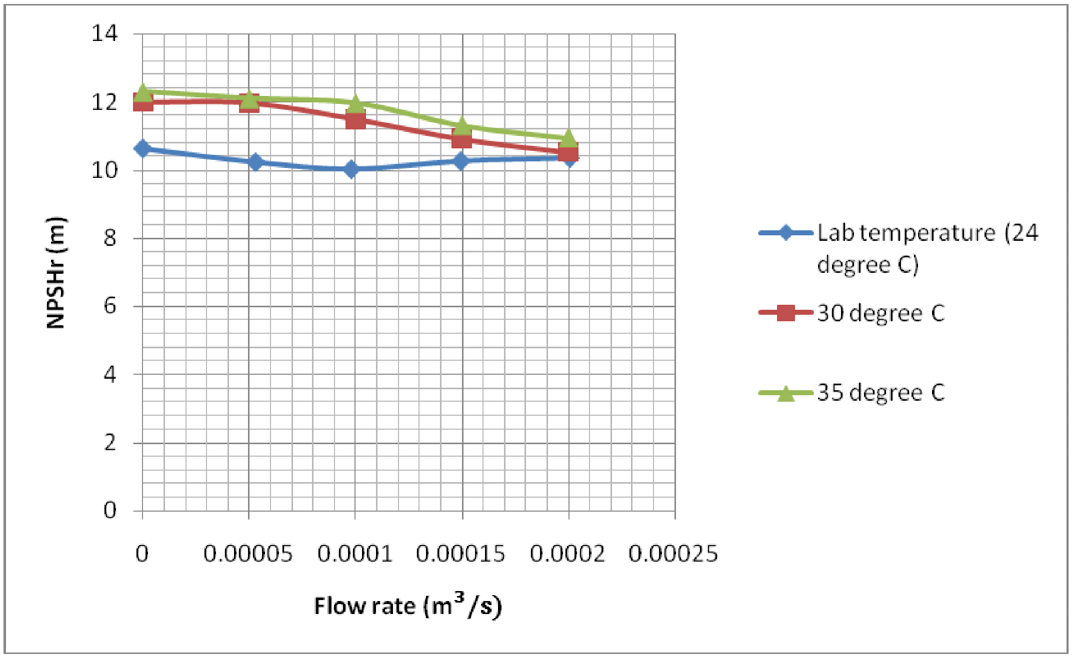

Figure 4.18 Experimental graphs for net positive suction head required of pump versus pump capacity

In the study of centrifugal pump characteristics, net positive suction head required versus pump capacity is the one characteristic that most likely affect the performance curve of pump. Net positive suction head required of pump at lab temperature, 24°C showed the smallest differential value which was 0.6030 m from 0 m^3/s flow rate to 0.0002 m^3/s flow rate but net positive suction head required at 35°C temperature recorded as the highest differential value which was 1.4545 m from m^3/s flow rate to 0.0002 m^3/s flow rate. At 30°C temperature, net positive suction head required recorded differential value which was 1.3595 m. From the study in literature review, when pumping viscous fluid such as heavy crude oil at lab temperature, 24°C, there was small differential pressure between suction head and vapor head occurred

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, the two experiments conducted had been finished base on the Gantt chart. The result of experiment measurement of density for 6 different fluids which are water, salt water, diesel, light crude oil, medium crude oil and heavy crude oil showed that sea water has the highest specific gravity follow by water, diesel, light crude oil, heavy crude oil and medium crude oil. So, the ranges of specific gravity for crude oil to be transferred by using centrifugal pump normally in between **0.723 to 1.027**.

Then, the result of experiment measurement of viscosity for seven different fluids also had been conducted. Heavy crude oil recorded as the viscous fluid followed by medium crude oil, diesel, light crude oil, salt water and water. In the data collecting from TCOT, normally crude oil viscosity pumped for export was less than 7 cp. Here, the author can conclude that the range viscosity crude oil that can be pumped by centrifugal pump is between **0.890 cp to 4.034 cp.** The first objective to provide a guideline on acceptable range of crude oil properties which are viscosity and specific gravity to be transferred by using centrifugal pump had been achieved.

The second experiment which is test using pump test rig and fluid samples of different properties had been conducted. The result had been achieved in the experiments were the same as expected performance graph. So, the author can conclude that there are four important characteristics of centrifugal pump that had been evaluated for crude oil transfer suitable for a range of crude oil properties which are **pump head, efficiency,**

brake horsepower and net positive suction head required. The second objective to evaluate the important characteristics of centrifugal pump used for crude oil transfer suitable for a range of crude oil properties had been achieved.

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The last experiment, temperature effect experiment by using modified pump test rig (FM20) had been conducted. The results that has achieved were the same as literature review study since **viscosity of crude oil decreased due to crude oil had been heated up**. So, the author can conclude that third objective which is to evaluate temperature effect on crude oil properties, hence centrifugal pump characteristics curve has been achieved.

5.2 Recommendation

There are some suggested recommendations for future improvement:

i. Install cooling elements to maintain the temperature during pumping different types of fluids.
ii. Install heat exchanger or heater in the storage tank of crude oil in order to decrease the viscosity effect of fluids, hence increase the pump performance.
iii. Test pump performance with the highest density and the highest viscosity of fluids in order to see the limit of viscosity and density of fluid that can be pumped by centrifugal pump.

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LIST OF APPENDICES

APPENDIX 1: FINAL YEAR SECOND SEMESTER GANTT CHART

No	Details of Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Literature Review															
	• Study the difference in properties of crude oils	X	X	X	X				M							
	• Study the viscosity effect of different properties of fluids			X	X	X	X		I							
	• Study the temperature effect on crude oil towards pump performance				X	X	X	X	D	X	X	X	X			
2.	Methodology								T							
	• Collecting three different properties of crude oils at PRSB	X	X						E							
	• Lab Experiment		X	X	X	X	X	X	R	X	X	X				
									M							
3.	Results and Discussion															
	• Execute graph from experiments			X	X	X	X	X		X	X	X				
	• Analyze the graph				X	X	X	X		X	X	X				
									B							
4.	Report								R							
	• Submission of Progress Report 1				X				E							
	• Submission of Progress Report 2								A	X						
	• Attend Seminar								K	X						
	• Poster Exhibition												X			
	• Submission of Dissertation Final Draft															X
	• Oral Presentation															X
	• Submission of Dissertation (Hardbound)															X

APPENDIX 2: FINAL YEAR SECOND SEMESTER MILESTONE

No	Detail of Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project work continues	X	X	X					M							
2	Submission of progress report 1				X				I							
3	Project work continues					X	X	X	D							
4	Submission of progress report 2									X						
5	Seminar (compulsory)								B	X						
6	Project work continues								R	X	X	X	X	X	X	X
7	Poster exhibition								E				X			
8	Submission of dissertation final draft								A							X
9	Oral presentation								K							X
10	Submission of dissertation (hard bound)															X

APPENDIX 3: PROCEDURE EXPERIMENT DENSITY AND VISCOSITY

Procedure Measuring Density

1. Measure the mass of empty beaker.
2. Pour water into the beaker with certain quantity.
3. Measure the mass of water.
4. Calculate the density of water.
5. Repeat the experiment with different liquids (salt water, light crude oil, medium crude oil and heavy crude oil)

Procedure Measuring Viscosity

1. Pour the water into empty beaker.
2. Select the right spindle for water based on the range of actual viscosity.
3. Install the spindle and switch on the viscometer.
4. Put ½ level of spindle into the water.
   Note: Do not let the spindle touch the bottom of the beaker. It will damage the spindle.
5. Set the velocity of the spindle.
6. Wait until the reading appears.
7. Repeat the experiment again by using salt water, diesel, light crude oil, medium crude oil and heavy crude oil.

APPENDIX 4: PROCEDURE EXPERIMENT PUMP TEST RIG

Procedure of Pump Test Rig Experiment

1. Pour the water into the tank.
2. Then switch on the motor of the centrifugal pump and let the pump running for a while.
3. After a few minutes, select the motor speed to 60 Hz and varying the flow rate of water from 0 m^3/s to 0.0002 m^3/s. Then, take the reading. Repeat 5 times.
   Note: All the readings can be read from the computer.
4. Repeat the experiment with salt water, diesel, light crude oil, medium crude oil and heavy crude oil. Repeat 5 times for each fluid.

APPENDIX 5: PROCEDURE EXPERIMENT TEMPERATURE EFFECT ON FLUID ON PUMP TEST RIG

Procedure Experiment of Temperature Effect on Fluid on Pump Test Rig

1. Pour the water into the tank.
2. Then switch on the motor of the centrifugal pump and let the pump running for a while.
3. After a few minutes, select the motor speed to 60 Hz and switch on temperature controller to 30 °C. Let until fluid temperature reach 30 °C.
4. Then, varying flow rate of the water and take the reading.
   Note: All the readings can be read from the computer.
5. Next, increase the temperature controller to 30 °C and 35 °C. For every temperature, take the readings.
6. Repeat the experiment with salt water, diesel, light crude oil, medium crude oil and heavy crude oil.

APPENDIX 6: CALCULATION DENSITY MEASUREMENT EXPERIMENT

Density of water, $\rho = \frac{m}{v}$

$= 0.513\ kg / 0.0005\ m^3$

$= 1026\ kg/m^3$

Specific gravity of water, $\gamma = \rho_{water} / \rho_{water}$

$= 1026\ kg/m^3 / 1026 kg/m^3$

$= 1.0$

Density of sea water, $\rho = \frac{m}{v}$

$= 0.527\ kg / 0.0005\ m^3$

$= 1054\ kg/m^3$

Specific gravity of water, $\gamma = \rho_{sea\ water} / \rho_{water}$

$= 1054\ kg/m^3 / 1026 kg/m^3$

$= 1.027$

Density of diesel, $\rho = \frac{m}{v}$

$= 0.43\ kg / 0.0005\ m^3$

$= 860\ kg/m^3$

Specific gravity of diesel, $\gamma = \rho_{diesel} / \rho_{water}$

$= 860\ kg/m^3 / 1026 kg/m^3$

$= 0.84$

Density of light crude oil, $\rho = \frac{m}{v}$

$= 0.306 \text{ kg} / 0.00038 \text{ m}^3$

$= 805.26 \text{ kg/m}^3$

Specific gravity of light crude oil, $\gamma = \rho_{crude\ oil} / \rho_{water}$

$= 805.26 \text{ kg/m}^3 / 1026\text{kg/m}^3$

$= 0.78$

Density of medium crude oil, $\rho = \frac{m}{v}$

$= 0.112 \text{ kg} / 0.00015 \text{ m}^3$

$= 746.67 \text{ kg/m}^3$

Specific gravity of medium crude oil, $\gamma = \rho_{crude\ oil} / \rho_{water}$

$= 746.67 \text{ kg/m}^3 / 1026\text{kg/m}^3$

$= 0.723$

Density of medium crude oil, $\rho = \frac{m}{v}$

$= 0.133 \text{ kg} / 0.00017 \text{ m}^3$

$= 782.35 \text{ kg/m}^3$

Specific gravity of medium crude oil, $\gamma = \rho_{crude\ oil} / \rho_{water}$

$= 782.35 \text{ kg/m}^3 / 1026\text{kg/m}^3$

$= 0.763$

APPENDIX 7: PICTURES OF CRUDE OIL EXPORT PUMP (P-380A/B)

APPENDIX 8: EXPERIMENTAL ACCURACY

The uncertainty analyses of the active vortex generator and flow control device heat transfer experiments were calculated using the methods of Kline and McClintock (1953), Wheeler and Ganji (2004) and Taylor (1997)

In order to identify the uncertainty in each of the final results presented, five steps are followed. An example is given below for the centrifugal pump head used in the calculation for pump performance curve.

1. The systematic uncertainty is calculated for the mean water pump head (given that the differential pressure sensor has 1% accuracy) in this case 1% x 9.395 m = 0.09395 m.

2. To find the random uncertainty, the standard deviation of the pump head readings is required, and found to be 0.005678 m. The random uncertainty is then calculated with a sample size of 5. The result is a random uncertainty of 0.0377m.

3. Both the random and systematic uncertainties are combined using a root square sum calculation to give a total uncertainty in the pump head of $\sqrt{0.09395^2 + 0.0377^2} = 0.1012\, m.$

4. The remainder of the variables which appear in the head pump equation, $H = (Psi\ x\ 2.31)/\gamma$, are subject to the same analysis as in step 1 to 3.

5. The result are propagated through the pump head equation using the following formula,

   $= \sqrt{((\delta H/\delta psi)^2) + (\delta H/\delta \gamma)^2)}$

Where,

$\delta H/\delta psi = 2.31/\boldsymbol{\gamma}$

$\delta H/\delta\boldsymbol{\gamma} = PSI \times 2.31$

to give final uncertainty confidence, of 9.395 ∓ 4.67 m. This represents the largest uncertainty for pump head of water and it occurs at 0 m^3/s flow rate.

The procedure was repeated for efficiency, brake horsepower and net positive suction head.