

Centrifugal Pump(Armfield)

OBJECTIVE

The objective of this experiment is to investigate the operating characteristics of a centrifugal pump used to transport water. Explore plots of varying head, power and efficiency by altering the volumetric flow rate. Calculate friction factors using the Colebrook and Blasius equations and compare the methods.

INTRODUCTION

In a centrifugal pump, the mechanical energy of the liquid is increased by centrifugal action. The liquid enters through a suction connection concentric with the axis of an impeller. The impeller is a high speed rotary element with radial vanes integrally cast in it. Liquid flows outward in the spaces between the vanes and leaves the impeller at a considerably greater velocity with respect to the ground than at the entrance to the impeller. The liquid leaving the outer periphery of the pump is collected in a spiral casing called a volute. It then leaves the pump through a tangential discharge connection. In the volute the velocity head of the liquid from the impeller is converted into pressure head. The power is applied to the fluid by the impeller. The impeller is direct connected through a drive shaft to an electric motor.

The use of characteristic curves to present the operating characteristics of a pump is commonly done in industry. Characteristic curves can be used to aid engineers in the selection of pumps needed for their process and determine the maximum efficiency of a pump over a range of operating conditions.

The volumetric flow rate, Q , for this pump is calculated from pressure drop readings obtained from an orifice meter

$$Q = \frac{C_d \pi \sqrt{2\rho \Delta p}}{4\rho}$$

Where C_d is the orifice discharge coefficient, ρ is the density of the fluid, and Δp is the pressure drop across the orifice meter.

The pump head, H , is found from a derivation of Bernoulli's Equation.

$$H = \left[\frac{p_2}{\rho} - \frac{p_1}{\rho} \right] + \left[\frac{(u_2^2 - u_1^2)}{2g} \right] + [z_2 - z_1]$$

In this equation, u is the velocity of the fluid, g is the gravitational constant, p is the pressure, and z is the height of the fluid from a reference point. The pump head is calculated from data obtained from the orifice meter and measurements of pipe lengths.

The efficiency of the pump, η , can be calculated from the following equation

$$\eta = \frac{P_f}{P_m} \times 100\%$$

The power supplied by the motor, P_m , is controlled by the dial located on the wattmeter. The power absorbed by the fluid, P_f , is found using the following equation where

$$P_f = \rho gQH$$

Values of Constants

Description of Constant	Value
Orifice Plate Diameter	0.017 m
Orifice discharge coefficient (C_d)	0.74
Change in elevation between pressure points	0.048 m
Radius of pipe	0.00975 m

REFERENCES

Wilkes, J.O., "Fluid Mechanics for Chemical Engineers", Prentice Hall Ptr, New Jersey, pp. 64-66, 174-179, 1999

de Nevers, N., "Fluid Mechanics for Chemical Engineers, 2nd ed., McGraw-Hill, New York, pp. 139-144, 334-339, 1991

EQUIPMENT

1. FM20 Centrifugal Pump Demonstration Unit
2. SWA1 integrating wattmeter
3. IFD4 Interface device
4. PC
5. Meter stick
6. 3.5" Floppy Disk

CHEMICALS/MATERIALS

1. Deionized water

EQUIPMENT SETUP

A diagram of the apparatus is shown in Figure 1.

The equipment is comprised of a centrifugal pump (6) driven by an electric motor (19) mounted on a base. Also attached to the base is a clear acrylic reservoir (11) and associated pipework for continuous circulation. Deionized water is used as the fluid and a drain valve (10) at the base of the reservoir allows the water to be drained after use.

Sensors are incorporated on the unit to facilitate analysis of the pump performance when connected to the parallel port of a suitable microcomputer via an Armfield "POD" interface. Additional pressure taps are included in the pipework to permit connection to appropriate calibration instruments.

The fluid flow through the centrifugal pump is regulated by a flow control valve (16) installed in the pump discharge pipework. The head/flow produced by the pump can be varied by adjustment of this valve. A valve (9) is installed in the inlet pipework to permit the effect of suction losses to be investigated.

A spare impeller is attached to the base in order to allow visual inspection of the impeller which is installed inside the volute of the water pump.

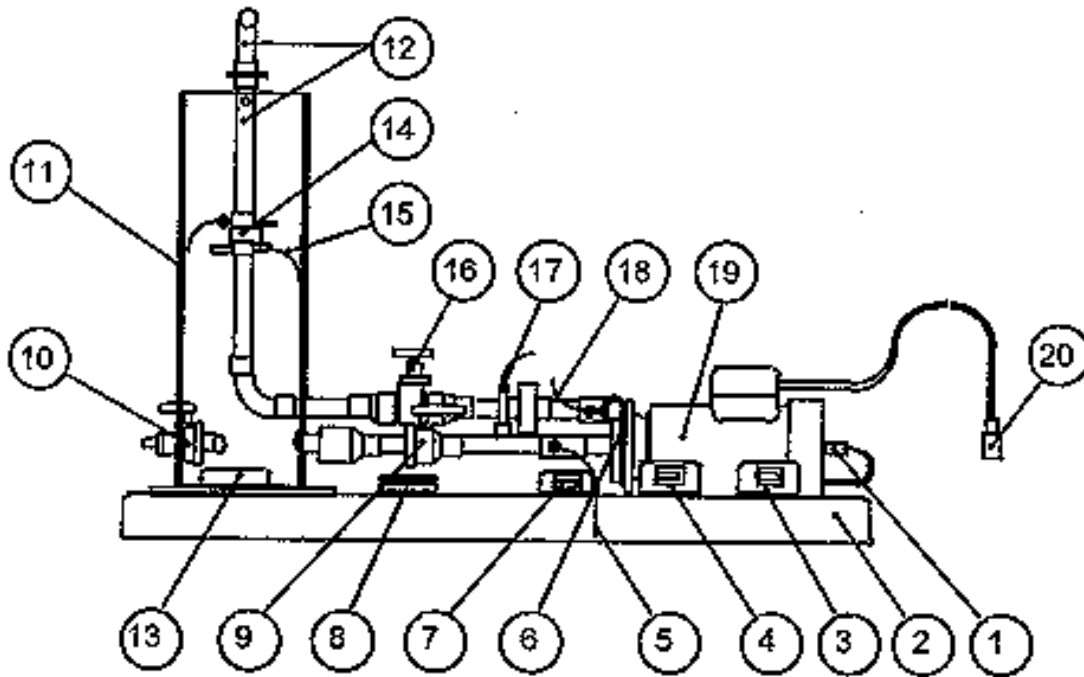


Figure 1. FM 20 Centrifugal Pump Unit

Diagram courtesy of Armfield Limited

A brief description of the sensors that monitor the performance of the pump is given below.

A differential pressure sensor, SPW1, is connected to channel 1 on the IFD4.

This sensor is a pressure sensitive piezoresistive device with appropriate signal conditioning contained in a protective case (13). It is connected to the appropriate pressure taps in the pipework using flexible tubing. This sensor is used to measure the pressure developed across the orifice plate (14) installed in pump discharge pipework. The volume flow rate of water through the pump is calculated using this measurement. Additional taps are provided for connection to appropriate instrumentation to facilitate calibration of the sensor.

A differential pressure sensor, SPW3, is connected to channel 2 on the IFD4.

This sensor is a pressure sensitive piezoresistive device with appropriate signal conditioning contained in a protective case (4). It is connected to the appropriate pressure taps in the pipework using flexible tubing. This sensor is used to measure the difference in pressure between the inlet and outlet of the pump. The head developed

by the pump is calculated using this measurement. Additional taps are provided for connection to appropriate instrumentation to facilitate calibration of the sensor.

A rotational speed sensor, SSO1, is connected to channel 3 on the IFD4.

This sensor is comprised of a reflective infra-red opto switch (1) on a remote lead with appropriate signal conditioning contained in a protective case (3). It is used to measure the rotational speed of the motor/pump impeller. A non-contacting optical tachometer may be used to calibrate the rotational speed sensor.

A temperature sensor, STS1, is connected to channel 4 on the IFD4.

This sensor is a temperature sensitive semiconductor device (17) on a remote lead with appropriate signal conditioning contained in a protective case. It is used to measure the temperature of the water entering the pump. The sensor is inserted through the wall of the pump inlet pipe utilizing a waterproof gland. The sensor can be removed for calibration using appropriate instrumentation.

An integrating wattmeter, SWA1, is connected to channel 5 on the IFD4.

This is a separate unit and is connected between the pump power cord and one of the power outlets on the IFD4. This unit provides power to the pump and also provides a measurement of the electrical power supplied to the pump motor. The integrating wattmeter can be calibrated using a suitable twin trace oscilloscope.

Before starting the experiment, familiarize yourself with the centrifugal pump demonstration unit. Determine where the orifice meter is, where the pump is, and which direction the pump will transport the water.

Check to ensure that the water in the reservoir is within three (3) to five (5) inches from the top of the column. If the water is lower than five inches, air can become entrained in the pump when pumping at high speeds.

Supply power to the surge protector outlet strip below the computer monitor and to the IFD4 Interface Console located below the centrifugal pump unit. The IFD4 interface is a control panel that supplies power to the pump controller and to the sensors. It also serves as the interface to relay the data to the computer.

The pump controller (Integrating Wattmeter SWA1) is located to the left of the IFD4. The dial on the controller adjusts the speed of the pump.

Turn on the computer. Once Windows 95 is loaded, start the FM20 Centrifugal Pump Demonstration Unit program by double clicking on the FM20 Capture icon on the Desktop. See Attachment 1 for additional information on the FM20 software.

Turn on the three power switches located on the IFD4 Interface Console. Make sure the two valves at locations 9 and 16 on Figure 1. are fully open.

To familiarize yourself with how this apparatus works, click on the **Diagram** button located in the upper left corner of your monitor. Use the dial on the pump controller (SWA1) to vary the power to the pump. This changes the pump rpm and flow rate. Click on the **Tables** button to view the data supplied by this program. Data is written to this table when you click on the **Take Sample** button.

When you are familiar with the apparatus, click on **Labsheets** on the menu bar and select the first experiment you were asked to perform. Information about the experiment and the steps needed to perform it will appear in a window. This information can be printed on the printer. Follow the instructions to complete each experiment you were asked to perform.

PROCEDURE

This procedure corresponds to Exercise 3 in the **Labsheets**.

1. Make sure that the pump is turned off. Open the pump intake valve (9) fully. Close the pump discharge valve (16). Start the pump and adjust the power controller to 100% (maximum pump speed). Open the discharge valve (16) fully and allow all of the air bubbles to exit the system.
2. Close the discharge valve (16) to correspond to the condition of no flow. Adjust the power controller to give a motor speed of 20 Hz. When the readings as indicated in the boxes on the diagram at the bottom of the monitor are sufficiently steady, select **Take Sample**. This represents the first point on the characteristic curve. DO NOT leave the pump in this condition for very long or the water will heat up, change the viscosity and invalidate the results.
3. Open the discharge valve (16) a small amount so there is an increase in the flow rate as indicated in the boxes at the bottom of the monitor. Adjust the dial on the power controller to keep the motor speed at 20 Hz. When the readings are steady, again select **Take Sample**. Open the discharge valve in $\frac{1}{2}$ turn increments, adjust the power and select **Take Sample** so that 10 to 15 data points are taken. The final point will correspond to the discharge valve (16) being fully open.
4. When sample collection has been completed for a motor speed of 20 Hz, save the file to 3.5" floppy disk. This data file can be opened with Microsoft Excel.
5. Repeat the experiment for motor speeds of 30 and 50 Hz. Observe how the motor speed relates to efficiency.
6. Measure pipe lengths for use in the friction factor calculations.
7. When finished turn the power controller to 0%. Turn the power switch to the console and the power strip to off. Unplug the console and power strip from their power sources.

SAFETY NOTES

1. Wear safety glasses with side shields or goggles.
2. Water and electricity are not compatible and can cause serious injury if they come into contact. There is a potential for the water spills using this equipment. Be careful.

WASTE DISPOSAL PROCEDURES

1. There is no waste from this experiment.

01/07

Attachment 1

The FM20 software program running in Windows 95 on a PC will display the measurements from the measurement sensors and calculate appropriate variables. A maximum of 30 data samples can be collected in a table. The following variables are also calculated and placed into the table.

1. Volume flow rate, Q_v , (m^3/sec)
2. Pump total head, H_d , (m)
3. Pump power output, P , (Watt)
4. Overall efficiency, E_{gr} , (%)

The software can display the following performance curves and copy them to a printer.

1. Rotational Speed vs Volume Flow Rate
2. Motor Input Power vs Volume Flow Rate
3. Pump Total Head vs Volume Flow Rate
4. Pump Power Output vs Volume Flow Rate
5. Overall Efficiency vs Volume Flow Rate

The data can be saved to a text file which can be imported into a spreadsheet. The file that is created is a comma delimited file. At this point in time, the files will have to be saved to a 3.5" floppy disk. They can also be saved to the **student** directory on the hard drive and then copied to a floppy disk.

NOTE: A 3.5" floppy disk will be needed for this experiment.

To start the software double click on the **FM20 Capture** icon on the Desktop. The software will prompt you for USER DATA. Fill out the information asked for on the form and click on OK. The software will finish loading. Information about the unit, software and instructions for 6 exercises are included in the help files. A short summary of the items on the menu bar is given below. A more detailed explanation can be found in the software help file.

1. File - Includes commands to **save** and **retrieve** files, a **clear** command to erase the data file from the table.
2. Install - Instructions for installation of the unit.
3. Software - Help file that gives information about the software.
4. Nomenclature - Explanation of the variables used in the calculations.
5. LabSheets - Information about centrifugal pumps and instructions for performing 7 separate exercises.

6. Parameters - Lists the constants used in the calculation of the variables.
7. Help - Listing of the help files.

A short summary of each button on the button bar is given below.

1. Diagram - A window pops up with a graphic of the pump unit. The graphic shows the values of the measured variables. The calculated variables are shown along the bottom of the graphic.
2. Charts - A window pops up with a bar chart showing the values of the measured variables. The calculated variables are shown along the bottom of the graphic.
3. Graphs - A graph pops up showing a plot of a selected variable vs Total Flow Rate. Along the right side are buttons used to select the variable (s) for graphing; to change the scaling on the graph; to change the style of the graph; to print the graph; to copy the graph to wmf format.
4. Tables - A tabular display of the data collected when the **Take Sample** button is pressed. The first five columns show the data from the sensors on the FM20, while the remaining columns show the calculated results. A time stamp is included with each reading. This table can be scrolled up and down as necessary to observe a maximum of 30 samples.
5. Calibr - Two screens allowing zero and span adjustment of the sensors, and permitting tests to demonstrate the linearity of the sensors.
6. Student - Access to the student assignment for this equipment.
7. Take Sample - A sample from each of the five measurement sensors is taken, and added to any previous data.
8. Print Screen - A copy of the current screen is output to the current Windows printer.
9. Exit - Exits the program.

The software allows the display of two of the variables on the left vs volume flow rate with two different y-axis units. Each graph has a set of three buttons associated with it.

1. Choosing **Copy** will result in an image of the graph being copied onto the Windows clipboard. This image can then be pasted into another suitable application.
2. **Print** will result in an image of the graph being sent to the current Windows printer.
3. **Write** will result in an image of the graph being written to a file on the disk. You may choose a location and name for the file and you may select between Bitmap (.BMP) and Windows Metafile (.WMF) formats.

Department of Chemical Engineering
Stockroom Checkout slip

Centrifugal Pump

ChE 4211

Name: _____ Group No.: _____ Date: _____
(print name)

Lab No.: Lab 1 12:00 - 4:50 PM Lab 2 3:00 - 4:50 PM
(circle one)

Equipment	Out	In	Equipment	Out	In

Name: _____
(Signature)