

CENTRIFUGAL PUMP: Parallel and Series Operation

11/11/02

CENTRIFUGAL PUMP

Location

Sub-basement SB-92. (Manual is available)

Introduction

This experiment illustrates the basic operation and characteristics of centrifugal pumps. The experiment will explore flow rates, pressure head, and efficiency of a single pump and of two identical pumps that are run in series or in parallel.

In this experiment, there are two pumps connected through a pipe work that allows for them to be operated individually, in series or in parallel.

When identical pumps are in series the pressure head is doubled but the flow rate remains the same. This is useful when a high pressure is needed but the same flow rate as of a single pump is sufficient. In this case however the second pump in the series must have the ability to operate at a higher suction pressure, which is produced by the first pump. When pumps are run in parallel the flow is increased and the pressure head produced is around the same as a single pump (these are for *identical* pumps run in parallel like the ones used in this experiment).³

Another concept illustrated in this lab is the efficiency of a pump. Energy can take different forms and a part of engineering is transferring the most of one type of energy to another and quantifying the efficiency. The energy in this experiment is actually put through two transformations. First electrical energy, which is the energy put into the system, is transferred to mechanical energy, which is the energy required to spin the shaft and impeller. Second, the mechanical energy is transferred into energy of the fluid. This is accomplished through the pumps rotation, which transfers the velocity energy of the water to pressure energy. The overall efficiency is the product of the mechanical (shaft) efficiency and the thermodynamic efficiency, as shown below:

Overall efficiency is calculated by:

$$\eta_{overall} = \frac{Power_{fluid}}{Power_{electrical}} \times 100\% = \eta_{shaft} \times \eta_{thermodynamic}$$

Where shaft efficiency is calculated by:

$$\eta_{shaft} = \frac{Power_{mechanical}}{Power_{electrical}} \times 100\%$$

and thermodynamic efficiency is calculated by:

$$\eta_{thermodynamic} = \frac{Power_{fluid}}{Power_{mechical}} \times 100\%$$

The centrifugal pump is one of the most widely used pumps for transferring liquids. This is for a number of reasons. Centrifugal pumps are very quiet in comparison to other pumps. They have a relatively low operating and maintenance costs. Centrifugal pumps take up little floor space and create a uniform, nonpulsating flow.

Pumps are used in almost all aspects of industry and engineering from feeds to reactors or distillation columns in chemical engineering to pumping storm water in civil and environmental. They are an integral part of engineering and an understanding of how they work is important for any type of engineer.

Theory

The principle operation of a centripetal pump is to convert fluid velocity into pressure energy. The pump consists of three components, an inlet duct, an impeller, and a volute.²

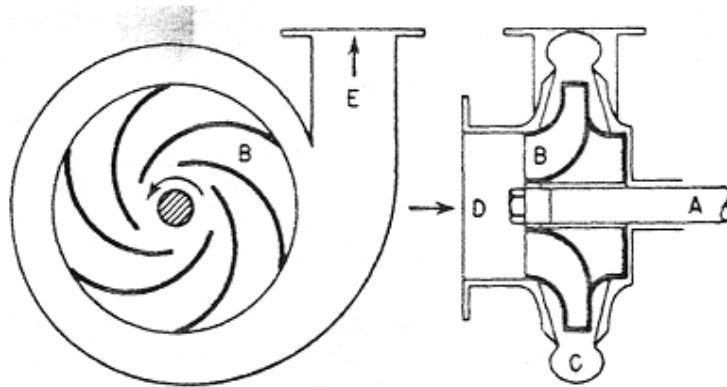


Figure 1¹

Fluid enters the inlet duct (D). As the shaft (A) rotates, the impeller (B), which is connected to the shaft, also rotates. The impeller consists of a number of blades that project the fluid outward when rotating. This centrifugal force gives the fluid a high velocity. Next, the moving fluid passes through the pump case (C) and then into the volute (E). The volute chamber has a uniformly increasing area. This increasing area decreases the fluids velocity, which converts the velocity energy into pressure energy.¹ Two characteristics a pump produces are pressure head and volumetric flow. The pressure head created from the pump is:

$$H = H_d - H_s$$

Unit cancellation: $L = L + L,$

where H_d is the discharge pressure head and H_s is the suction head. Head is measured in units of length. Due to the fact that head is a way of denoting pressure, it can be easily determined using a pressure gauge, as long as the pressure taps are located at the pump suction and discharge ports.

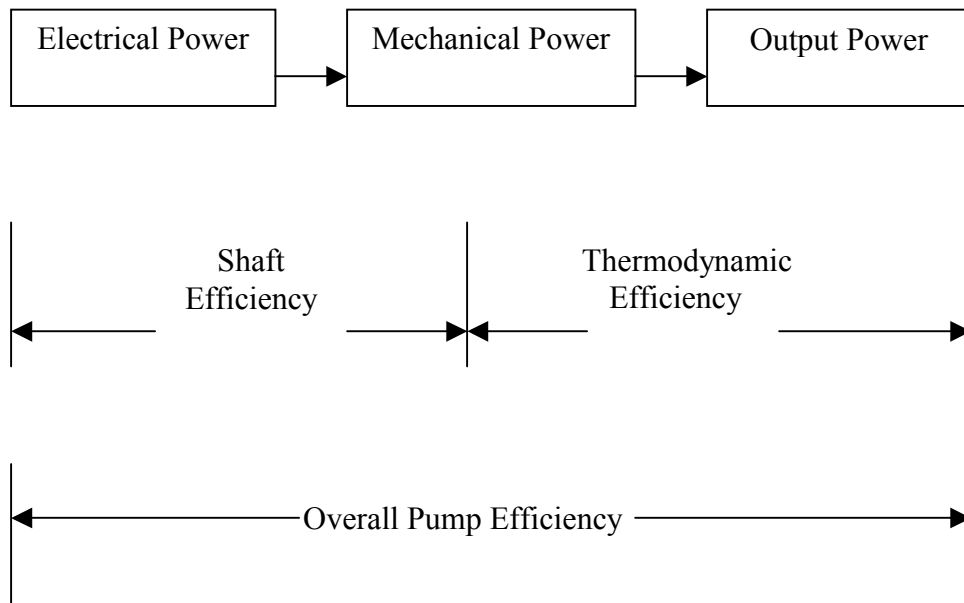
Pumps also deliver a certain capacity (Q) that is also known as a volumetric flow rate. There are various instruments and ways to measure flow rates. This experiment offers two devices to calculate the flow rate of the pump, a V-notch weir and a venturimeter.

An empirical expression provided for the venturimeter is available, and another one is available in the literature¹. It is also possible to measure Q by collecting the water overflowing the V-notch over a specific time.

Efficiency

The power to drive the pump is always greater than the output power of the fluid being pumped. The power is usually lost due to hydraulic losses, volumetric losses, and mechanical losses². Efficiency is a comparison (ratio) between the power coming out of the system and that put into the system. When the efficiency is high, the system is minimizing those losses.

There are two types of power transformations that occur in this experiment: 1.) electrical power, which is transferred into mechanical power via the pump motor, and 2.) mechanical power, that rotates the shaft, turns the impeller, and transfers power to the fluid. For each transition of power there is efficiency, including an overall efficiency. The following diagram shows the power distribution and the related efficiency.



The electrical power is the power needed to run the pump. This is calculated by multiplying the input current times the input voltage.

$$\text{Power}_{\text{electrical}} = V \times I$$

Where: $\text{Power}_{\text{electrical}} = [\text{W}]$, $V = \text{voltage} [\text{V}]$, $I = \text{Current} [\text{A}]$

Unit cancellation: $W \equiv V \times A$

The mechanical power is the power the rotating shaft exerts on the impeller and on the motor housing in the form of torque. Mechanical power is:

$$\text{Power}_{\text{mechanical}} = \frac{2\pi \cdot N \cdot T}{60}$$

Where: $T = 0.165 \cdot F$

Unit cancellation:

Where: $\text{Power}_{\text{mechanical}} = \text{W}$, $N = \text{Speed} [\text{rpm's}]$, $T = \text{Torque} [\text{N*m}]$,

$F = \text{Torque gauge reading} [\text{N}]$

Unit cancellation: $F \cdot L / T = (1/T) \cdot (F \cdot L)$

The fluid output power of the pump is combination of the flow rate and the pressure head created by the pump. This is the primary function of the pump. The equation for the fluid output power is:

$$\text{Power}_{\text{fluid}} = g \cdot Q \cdot H \cdot \rho_{\text{water}}$$

Where: $Power_{fluid} = [W]$, $g = 9.81 \text{ m/s}^2$, $Q = \text{Flow quantity } [m^3/s]$,
 $H = \text{Pressure head } [m]$, $\rho_{water} = \text{density of water}$

$$\text{Unit cancellation: } ML^2/T^3 = (L/T^2) * (L^3/T) * (L) * (M/L^3)$$

Therefore the maximum power required to drive the pump will occur as the flow quantity approached Q_{max} .

The efficiency of the pump is the ratio of the output power to the input power of the pump. The three types of efficiencies for each power transition for the overall centrifugal pump system are as follows.

Shaft efficiency is calculated by:

$$\eta_{shaft} = \frac{Power_{mechanical}}{Power_{electrical}} \times 100\%$$

Unit cancellation

Thermodynamic efficiency is calculated by:

$$\eta_{ther\ mod\ ynamic} = \frac{Power_{fluid}}{Power_{mechical}} \times 100\%$$

Unit cancellation

Overall efficiency is calculated by:

$$\eta_{overall} = \frac{Power_{fluid}}{Power_{electrical}} \times 100\%$$

Unit cancellation

Objective

The objective of this experiment is to understand the basic operation and characteristics of a centrifugal pump. There are several major topics that will be looked at in order to better understand centrifugal pumps:

- A comparison of various flow rate measuring devices
- The efficiency of the pump
- Creating various pump curves consisting of flow rate, pressure head, and efficiency
- Comparing operation of both pumps in series or parallel configurations
- Verifying the “pump relations” for a constant impeller diameter pump at several rpm values

Tasks

Flow Rate Determination

The first task that must be completed for any of the experiments is to fill and prime the pumps. The water in the basin underneath the pumps must be filled up to, but no higher than the bottom of the V-notch weir. The pumps must then be primed. Priming the pumps is filling them up with water. This must be done in order to begin running them.

There are three different flow rate measurements for this pump. One is using the pressure drop along the venturimeter. The second is using the height difference between the two compartments in the pump and measuring it using the V-notch weir. The third is to accumulate the water in a bucket as it flows over the V-notch weir and monitor the time required to fill the bucket.

Single Pump Task

Operate a single pump and determine its overall, mechanical and thermodynamic efficiencies over a range of conditions. You have the ability to change two parameters, power to the pump, via the variac, and resistance to flow on the discharge side of the pump, by varying the valve position. It is your responsibility to determine the most appropriate way to represent your results. It is also your responsibility to collect the appropriate data for determining all of the efficiencies.

Dual Pump Task

There are two pumps in this experiment that can be operated in series or in parallel. A comparison should be done comparing the flow rate and the pressure produced by using the pumps in series and parallel. You should be able to demonstrate the difference between pumps operating in series and in parallel.

Equipment Schematic

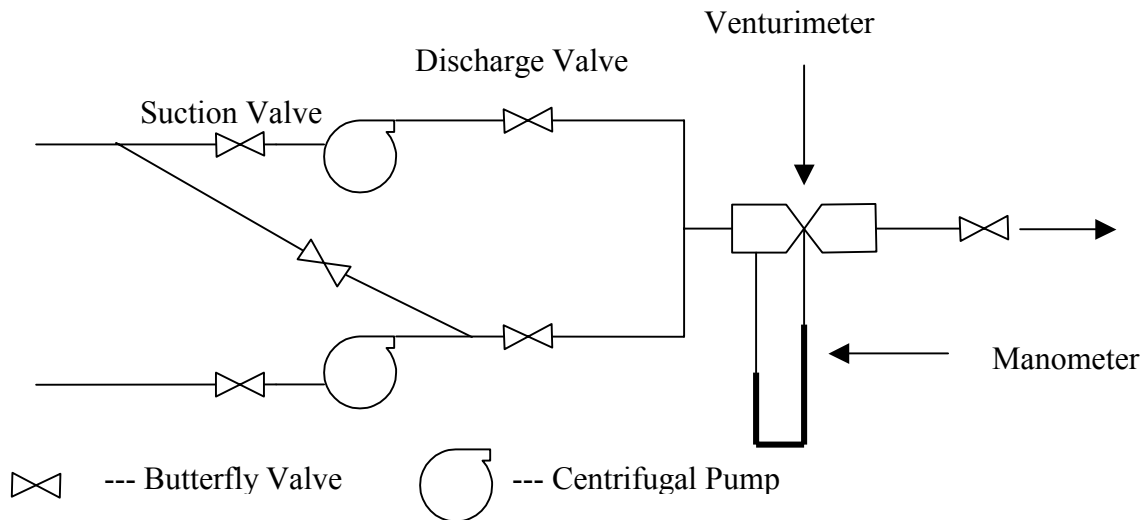


Figure 2

Description of Equipment

V-notch weir

A weir is a dam across two open channels, which has an opening of fixed dimensions and shape. Fluid is able to build up on one side of the weir and flow across². The V shape has specific and dependable characteristics, which can be determined from tables and actual flow calibrations. The flow calibration curve for the V-notch weir for this experiment is in Appendix A. As the fluid is pumped into the discharge channel, the flowing fluid backs up. A head is increased and the height of the head can be recorded from the gauge on the side of the tank. The flow rate can then be extrapolated for the V-notch calibration curve using the head measurement.

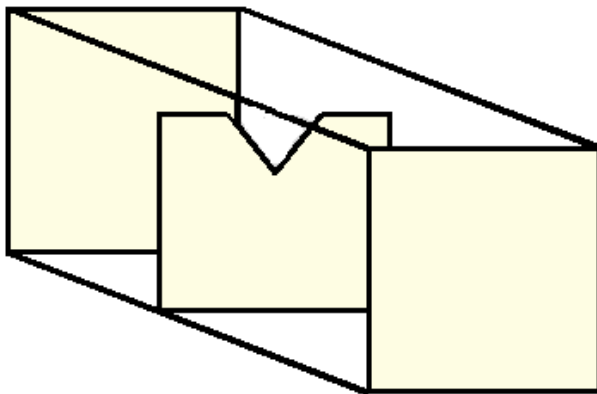
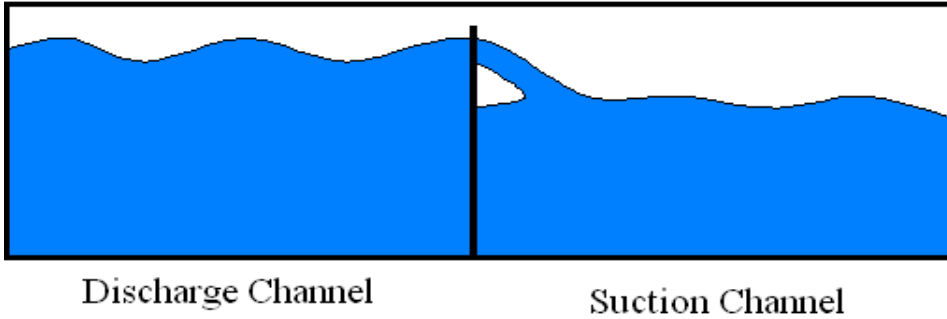


Diagram of V-notch Weir in water tank



Venturimeter

A venturimeter is the other device used in this experiment to calculate volumetric flow. The shape of the meter creates a pressure drop between the inlet section and the narrower throat section. This pressure drop is measured with the manometer.

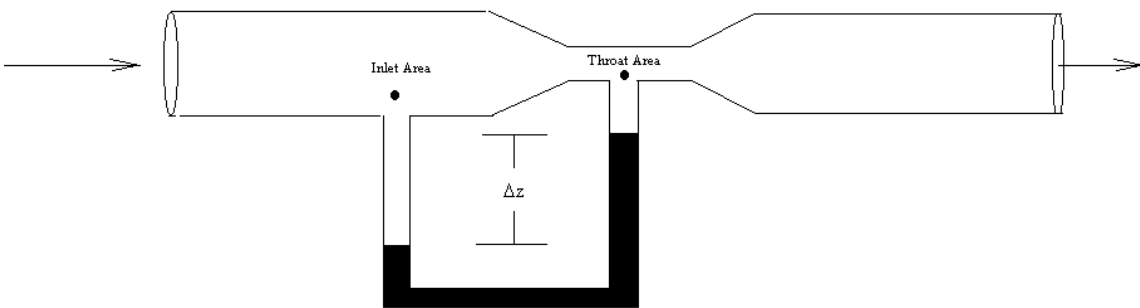


Figure 3

Fluid flows through the inlet area and in to the throat area. A pressure drop is created due to the change in pipe area. The manometer records the differential pressure.

A volumetric flow rate can be calculated in conjunction with the measured pressure drop, inlet and throat areas, and the densities of the mercury and the interested fluid. The equation for the volumetric flow rate is:

$$Q = A \sqrt{\frac{2(\rho_{HG} - \rho)g\Delta z}{\rho[A/a]^2 - 1}}$$

Table 1: Relevant Pump Characteristics

A calibration curve for flow is also in Appendix A. The flow rate can easily be interpolated from the curve using the corresponding manometer height. It is your responsibility to verify this curve or to generate your own curve.

Torque Arm

As the motor shaft turns, a torque is transferred to the motor housing. The torque gauge exerts a force on the motor which counter balances the torque of the motor. To zero the torque arm ensure that the motor is off. Then turn the torque gauge until the horizontal pin, which is connected to the motor just barely, touches the lower pin on the torque gauge. Turn the top piece of the gauge until it reads zero. Now the torque gauge is zeroed. To measure the torque of the motor, balance the torque of the motor by increasing the torque of the gauge until the horizontal pin just barely touches the lower gauge pin.

Symbol	Name	Units
Q	Volumetric Flow Rate	m ³ /s
A	Inlet Area	m
a	Throat Area	m
ρ_m	Density of mercury	kg/m ³
ρ	Density of interested Fluid	kg/m ³
g	Acceleration of gravity	m/s ²
Δz	Manometer Height	m

Equipment Procedure

1. Insure that both pumps are primed
2. If pumps are not primed, See “Commissioning the Pump” in the Lab Manual, or consult your instructor.
3. Zero the V-notch, barometer, and torque gauges.
4. The entire system is now ready to operate.
5. The discharge valve can be set to give different pressures. If the discharge pressure is not registering, slightly close the valve.
6. Compare the different flow rate determination methods to see if they are in agreement.
7. Compile the data for the corresponding pump curve, which you have chosen.
8. For series and parallel operations be sure to run the pumps at the same conditions for both methods.

Series Operation

9. With both pumps running, open the crossover valve and close the outlet valve to pump A. Also the Inlet valve to pump A should be open, while the Inlet valve to pump B should be closed.

Parallel Operation

10. While both pumps are running, ensure the crossover valve is closed. Open the outlet and inlet valves for both pumps.
10. Compare the head and flow characteristics for the parallel and series setups.

Data Analysis

The diameters of the inlet and throat areas for the venturimeter are:

$D=55.6\text{mm}$ (inlet)

$d= 30.9\text{mm}$ (throat)

The following data can be collected for the various experiments:

Variac Setting	Voltage	Amperage	Suction Pressure [Bar]	Discharge pressure [Bar]	Delta Z [cm]	V-notch reading [mm]	Force [N]	RPM's
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Collect the selected data and use it along with the corresponding formulas and calibration curves to create pump curves and comparisons.

Pump relations

The following relations can be found in most references and books on centrifugal pumps. They are valid for the same pump at various rpm values.

Flow rate

$$\left(\frac{rpm_1}{rpm_2} \right) = \left(\frac{capacity_1}{capacity_2} \right)$$

Head/Pressure Drop across Pump

$$\left(\frac{rpm_1}{rpm_2} \right)^2 = \left(\frac{head_1}{head_2} \right)$$

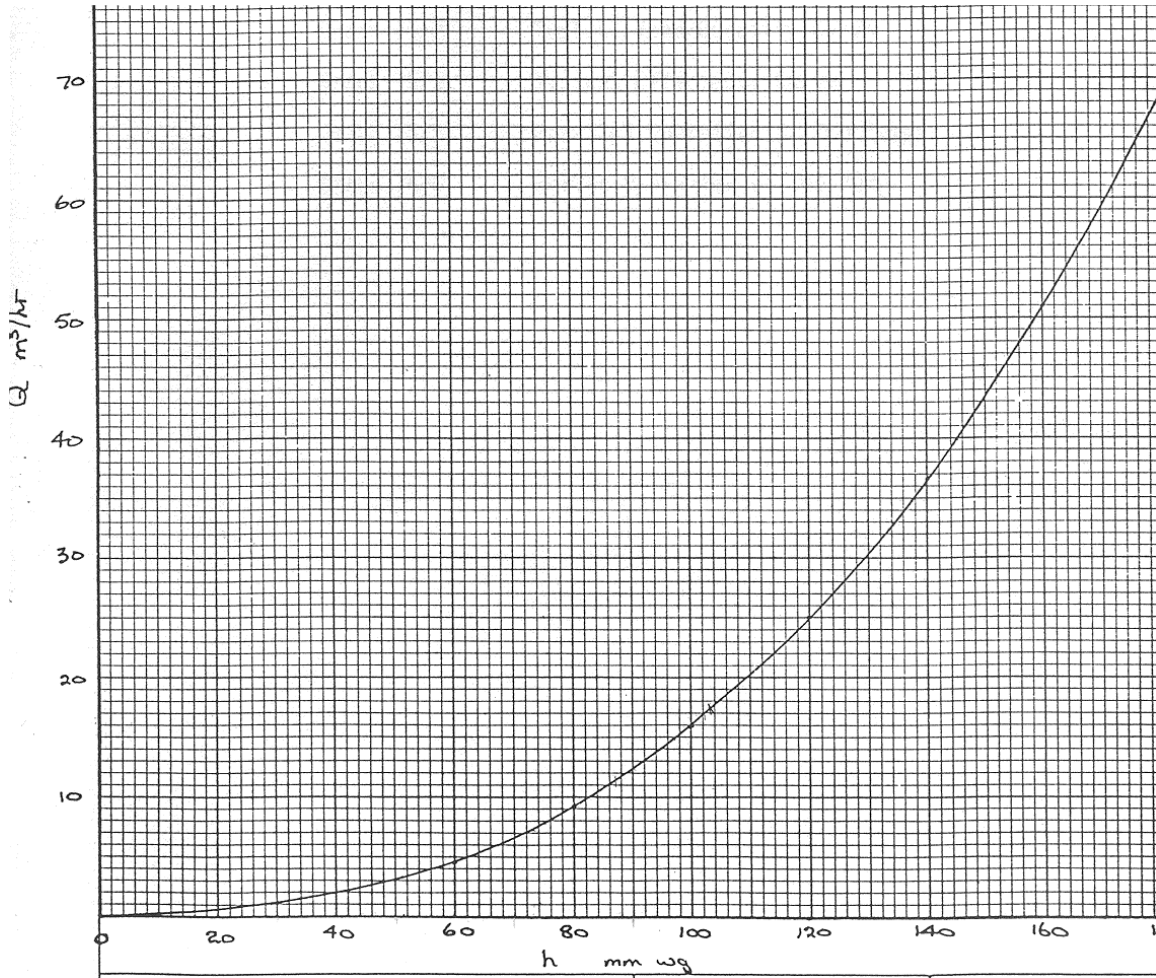
Power

$$\left(\frac{rpm_1}{rpm_2} \right)^3 = \left(\frac{power_1}{power_2} \right)$$

Can you verify these relations and substantiate their basis in theory?

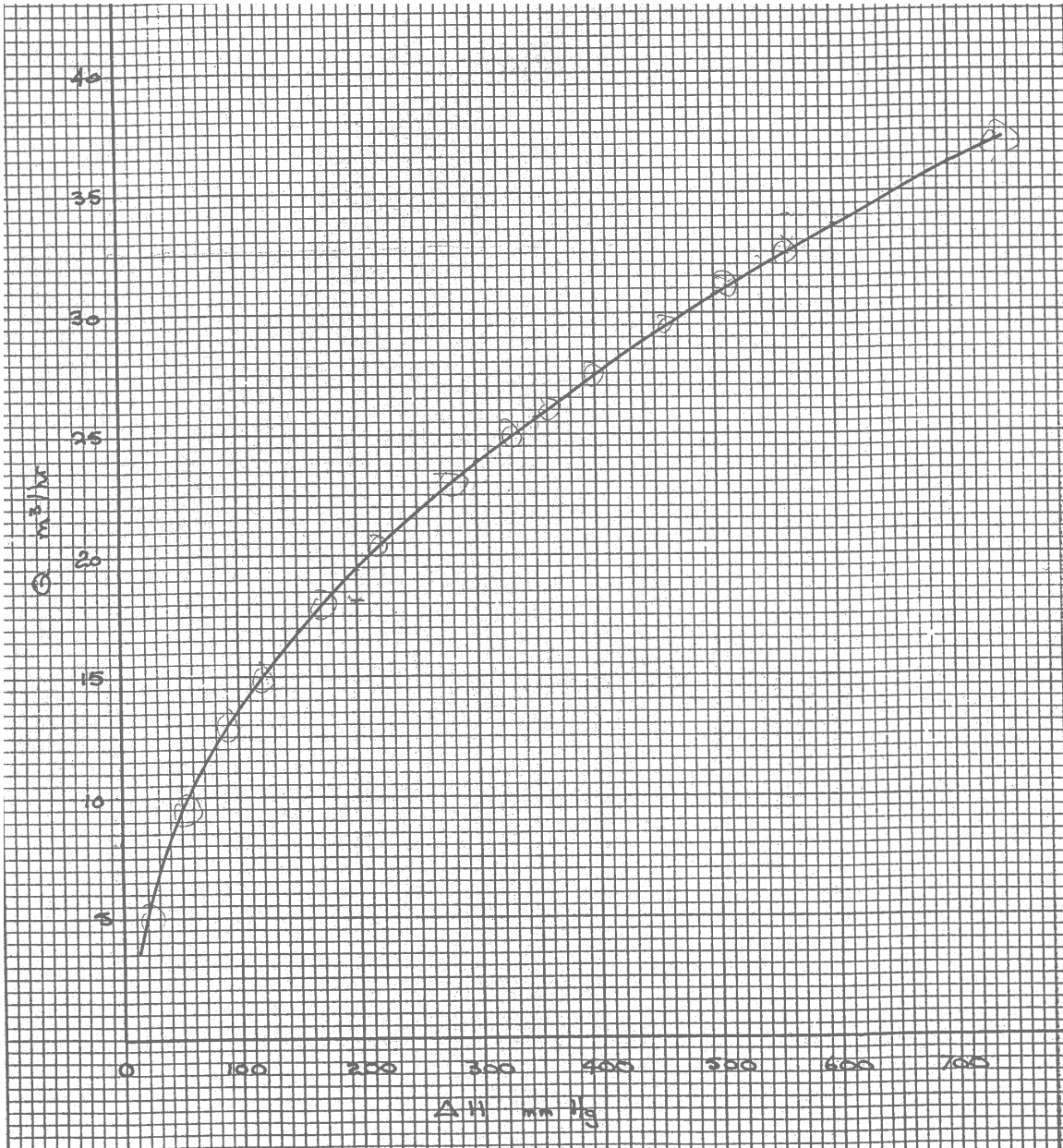
Appendix A

V- Notch Calibration Plot



*Taken from page 23 of the Gilkes equipment manual.

Venturimeter Calibration Plot



*Taken from page 22 of the Gilkes equipment manual.

References

1. Perry, Robert, H., Green, Don, W., 1997. Perry's Chemical Engineers' Handbook 7th, New York, McGraw-Hill, 6-9.
2. Kroschwitz, Jacqueline, I. Eds. Howe-Grant, Mary, Eds. 1996. Kirk-Othmer Encyclopedia of Chemical Technology 4th, New York, John Wiley & Sons, 11, 124.
3. Pump World. Parallel Pump Operation Using Identical Pumps. April 23, 2000
[Http://www.PumpWorld.com/parallel_pumping_identical.htm](http://www.PumpWorld.com/parallel_pumping_identical.htm) [Accessed June 8, 2000].
4. Gilkes, Gilbert. Gilkes GH 75 Technical Handbook Parallel-Series Centrifugal Pump Set. Kendal, Gilbert Gilkes & Gordon LTD.

EXTRA INFORMATION NOT PLACED YET

Basic explanation and operation of experimental equipment

Venturimeter

A Venturimeter is a device used to calculate volumetric flow. The shape of the meter creates a pressure drop between the inlet section and the narrower throat section. This pressure drop is measured with the manometer. A volumetric flow rate can be calculated in conjunction with the measured pressure drop, inlet and throat areas, and the densities of the mercury and the interested fluid.

V-Notch Weir

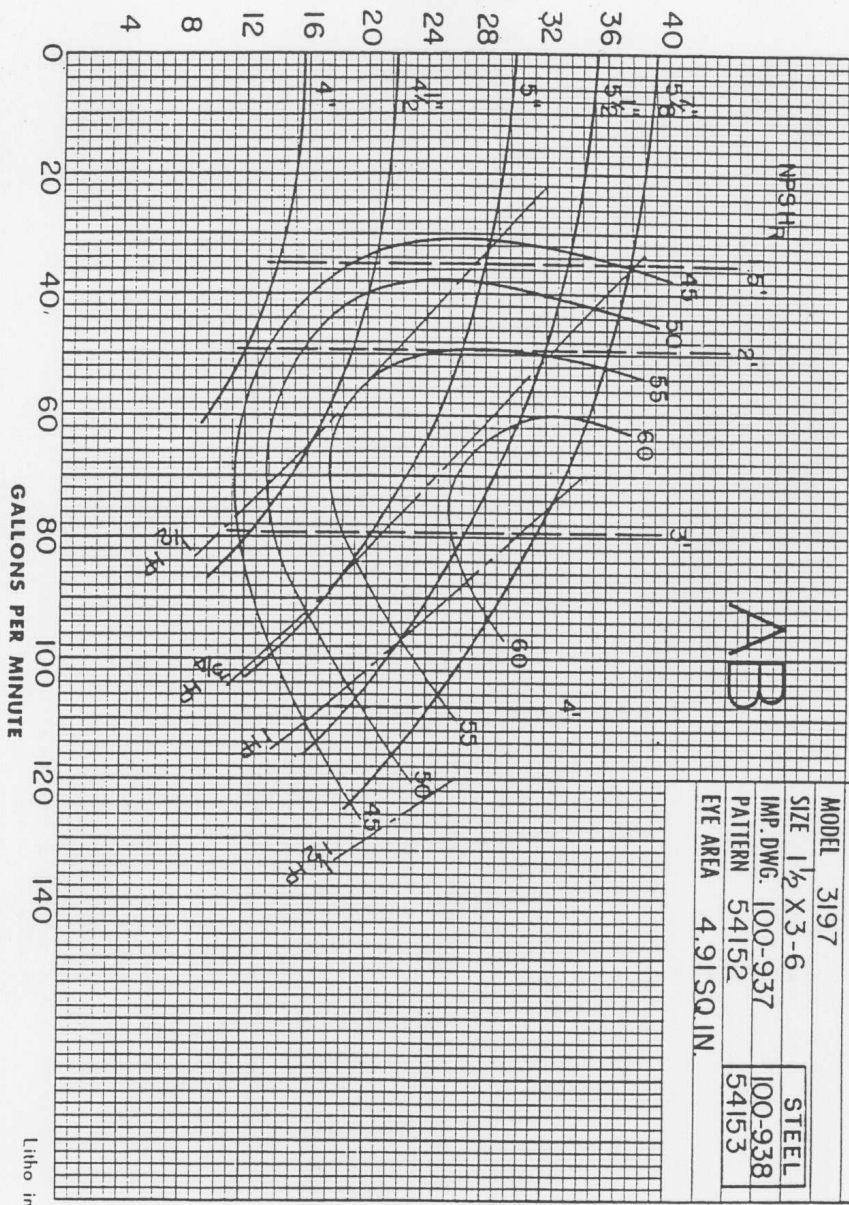
The V-notch weir is another means for calculation the flow rate. A height gauge is attached to the outlet tub, which measures the added height of the water displaced to the outlet tub. At zero flow the gauge will read zero. The flow rate can be derived from the reading of the V-notch head and the characteristic curve supplied by the manufacturer.

GOULDS PUMPS, INC.
 BENECA FALLS, N. Y.

CENTRIFUGAL PUMP CHARACTERISTICS

RPM 1750 CDS 1676

MODEL 3197	STEEL
SIZE 1 1/2 X 3-6	100-938
IMP. DWG. 100-937	54153
PATTERN 54152	
EYE AREA 4.91 SQ. IN.	



Litho in U. S. A. FLP

**1750
 R. P. M.**

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