AN ALTERNATIVE ARRANGEMENT OF METERED DOSING FLUID USING CENTRIFUGAL PUMP

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BY
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RECOMMENDATION OF THE BOARD OF EXAMINERS

The project titled, "**AN ALTERNATIVE ARRANGEMENT OF METERED DOSING FLUID USING CENTRIFUGAL PUMP**", submitted by **Md. Arafat Islam**, Roll No: **0411102097P**, Session: **April 2011**, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Engineering in Mechanical Engineering on March 21, 2016.

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It is hereby declared that, this project report or any part of it has not been submitted elsewhere for the award of any degree or qualification.

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ABSTRACT

Positive displacement dosing pumps are extensively used in various types of process industries in Bangladesh. They are widely used for metering small flow rates of a dosing fluid into a main flow. High head and low controllable flow rates make these pumps suitable for industrial flow metering applications. However their pulsating flow is not very suitable for proper mixing of fluids and they are much more expensive to buy and maintain. Considering such problems some alternative techniques may be suggested to control the fluid flow of a typical centrifugal pumps including - throttling, variable speed drive, impeller geometry control and bypass control. Variable speed drive and impeller geometry control are comparatively costly and the flow control by throttling is not an energy efficient process. Bypass flow control can be an alternative means to control the dosing flow range. An arrangement of creating dosing flow was developed using a typical low cost centrifugal pump with bypass flow technique. A wide range of dosing flow control was attained using fixed pump geometry and drive speed. The returning bulk flow from the pump into the main tank ensured better mixing due to churning effect which may eliminate the need of separate agitators.

In this project, performance of a dosing pump was evaluated and compared to an alternative arrangement of similar fluid flow from a centrifugal pump flow arrangement using bypass technique. Water was used as a working fluid of the pump. Experiments were performed in total four phases. The first phase consists of only performance evaluation of the dosing pump and it is found that, the range of the metered flow of the dosing pump is 22.4 -1.5 L/h at corresponding head of 0.7725-71.36 m. The power consumption is almost constant 72 watt. The maximum and minimum efficiency is around 4% and 0.01% respectively. In the second phase, performance study of the centrifugal pump was evaluated. The range of fluid flow rate is almost 2650-11.4 L/h at corresponding head of 0.973-28 m. The power consumption varies from maximum 677.92 watt to minimum 624.4 watt depending on the flow rate changes. The maximum overall efficiency is found around 13.5%. In order to reduce the discharge of the centrifugal pump, bypass flow arrangement has been established and the third phase of experiment was carried out. Similar types of flow rates could be possible to be attained by the arrangement and the new established flow range was found 2.66-23.01 L/h at corresponding head of 13.19-28.5 meter. The power consumption varies from maximum 677.92 to minimum 624.4 watt at this phase. Impeller diameter has been reduced to decrease the power consumption and new operating range has been established due to impeller modification, which varies form 2.83 -22.05 L/h at corresponding head of 6.01 -14.0 meter. With the modification, the power consumption reduces by 40 % compared to the centrifugal bypass arrangement without impeller diameter reduction. But it slightly decreases the overall efficiency. Operability of the modified system was tested at low voltage, which also showed improvement of overall efficiency and reduction of further power consumption by 32 % compared to bypass arrangement with impeller modification only. The capital cost can be saved by this centrifugal bypass flow system is approximately 87.5% of the capital cost of the dosing pump. This alternate system is more cost effective in terms of capital investment.

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Nomenclature

P_i	Pump Input Power
P_0	Hydraulic Power of Fluid
η_p	Pump Efficiency
η_o	Overall Efficiency
Υ	Specific Gravity
H	Head
Z	Datum Head
H_d	Delivery Head
H_s	Suction head
H_t	Total Head
NPSH	Net Positive Suction Head
ρ	Density
P	Pressure
Q	Flow Rate
N_s	Specific Speed
H_f	Friction Head
V_s	Suction Velocity Head
V_d	Discharge Velocity Head
H_{gs}	Suction pressure Gauge Reading
H_{gd}	Discharge Pressure Gauge reading
Whp	Water Horse Power
C.P	Centrifugal Pump
D.P	Diapharm Pump

Chapter 1

Introduction

1.1 Metering Pump

A metering pump moves a precise volume of liquid in a specified time period providing an accurate flow rate. Delivery of fluids in precise adjustable flow rates is sometimes called metering. The term "metering pump" is based on the application or use rather than the exact kind of pump used, although a couple of types of pumps are far more suitable than most other types of pumps for metering purpose.

Dosing pumps are low-volume pumps with controllable discharge rates that are used to inject additives or difficult-to-mix fluids into mixing, pumping, or batch/tank systems. Dosing pumps are usually made from plastic, thermoplastic, or stainless steel and feature mounting holes or accessories. Dosing pumps often have a controller which enables the fluid flow to be monitored and adjusted easily.

They are typically made to meter at flow rates which are practically constant (when averaged over time) within a wide range of discharge (outlet) pressure. Manufacturers provide each of their models of metering pumps with a maximum discharge pressure rating against which each model is guaranteed to be able to pump against. An engineer, designer, or user should ensure that the pressure and temperature ratings and wetted pump materials are compatible for the application and the type of liquid being pumped.

Most metering pumps have a pump head and a motor. The liquid being pumped goes through the pump head, entering through an inlet line and leaving through an outlet line. The motor is commonly an electric motor which drives the pump head.

1.2 Classification

Positive displacement pumps such as piston and diapharm pumps are commonly used for dosing. Centrifugal pumps can also be used when a large amount of discharge is required. Short discussions of such pumps are discussed below.

1.2.1 Piston Pump

Many metering pumps are piston-driven. Piston pumps are positive displacement pumps which can be designed to pump at practically constant flow rates (averaged over time) against a wide range of discharge pressure, including high discharge pressures of thousands of psi.

Piston-driven metering pumps commonly work as follows: There is a piston (sometimes called plunger), typically cylindrical, which can go in and out of a correspondingly shaped chamber in the pump head. The inlet and outlet lines are joined to the piston chamber. There are two check valves, often ball check valves, attached to the pump head, one at the inlet line and the other at the outlet line. The inlet valve allows flow from the inlet line to the piston chamber, but not in the reverse direction. The outlet valve allows flow from the chamber to the outlet line, but not in reverse. The motor repeatedly moves the piston into and out of the piston chamber, causing the volume of the chamber to repeatedly become smaller and larger. When the piston moves out, a vacuum is created. Low pressure in the chamber causes liquid to enter and fill the chamber through the inlet check valve, but higher pressure at the outlet causes the outlet valve to shut. Then when the piston moves in, it pressurizes the liquid in the chamber. High pressure in the chamber causes the inlet valve to shut and forces the outlet valve to open, forcing liquid out at the outlet. These alternating suction and discharge strokes are repeated over and over to meter the liquid. In back of the chamber, there is packing around the piston or a doughnut-shaped seal with a toroid-shaped sphincter-like spring inside compressing the seal around the piston. This holds the fluid pressure when the piston slides in and out and makes the pump leak-tight. The packing or seals can wear out after prolonged use and can be replaced. The metering rate can be adjusted by varying the stroke length by which the piston moves back and forth or varying the speed of the piston motion.

A single-piston pump delivers liquid to the outlet only during the discharge stroke. If the piston's suction and discharge strokes occur at the same speed and liquid is metered out half the time the pump is working, then the overall metering rate averaged over time equals half the average flow rate during the discharge stroke. Some single-piston pumps may have a constant slow piston motion for discharge and a quick retract motion for refilling the pump head. In such cases, the overall metering rate is practically equal to the pumping rate during the discharge stroke.

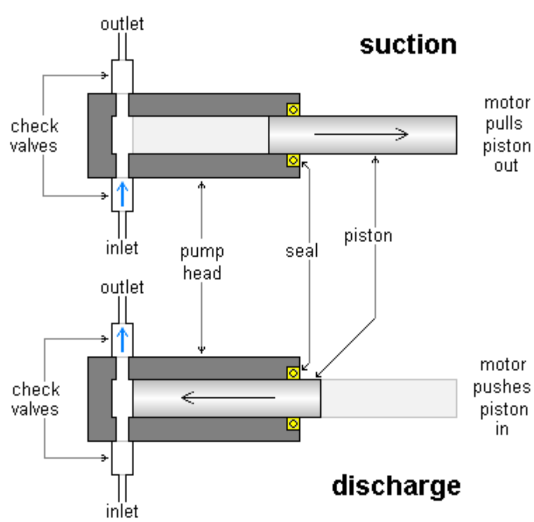

Figure 1.1: Schematic Diagram of typical Piston Pump [1]

1.2.2 Diapharm Pump

In order to avoid leakage at the packing or seal particularly when a liquid is dangerous, toxic, or noxious, diaphragm pumps are used for metering. Diaphragm pumps have a diaphragm through which repeated compression/decompression motion is transmitted. The liquid does not penetrate through the diaphragm, so the liquid inside the pump is sealed off from the outside. Such motion changes the volume of a chamber in the pump head so that liquid enters through an inlet check valve during decompression and exits through an outlet check valve during compression, in a manner similar to piston pumps. Diaphragm pumps can also be made which discharge at fairly high pressure. Diaphragm metering pumps are commonly hydraulically driven.

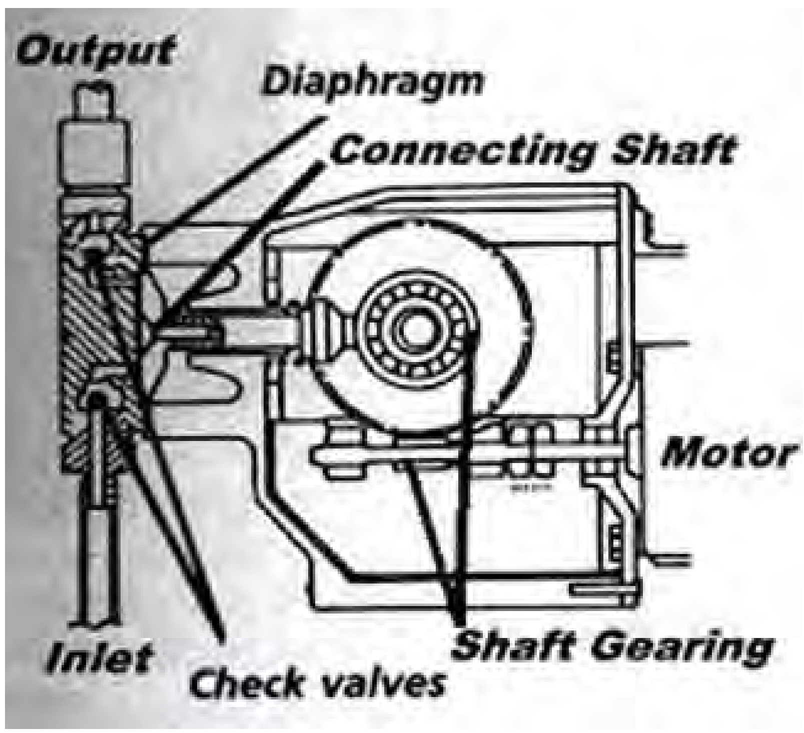

Figure 1.2: Schematic Diagram of a Typical Diapharm Pump [2]

1.2.3 Centrifugal Pump

Centrifugal pumps are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits.

Common uses include water, sewage, petroleum and petrochemical pumping.

The following figure represents the basic construction of centrifugal pumps. Flow metering of a centrifugal pump can be done by following ways-

- Speed Governing (Mechanical Speed Governing by Centrifugal Element and Electrical Speed governing by inverter)
- Voltage Variation
- Throttling
- Bypass Control
- Impeller Diameter changing
- Impeller pitch Changing

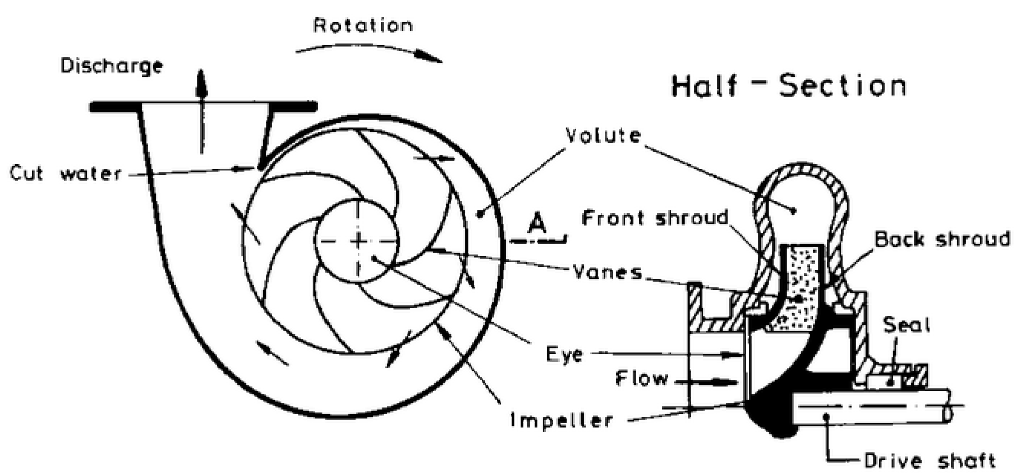

Figure 1.3: Schematic Diagram of a Typical Centrifugal Pump [3]

1.3 Background and Present State of the Problem

Positive displacement dosing pumps are extensively used in various types of processing industries in Bangladesh. They are widely used for metering small flow rates of a dosing fluid into a main flow. High head and low controllable flow rates make these pumps suitable for industrial flow metering applications [6]. However their pulsating flow is not very suitable for proper mixing of fluids and they are much more expensive to buy and maintain. Considering such problems some alternative techniques have been suggested to control the flow of fluid by typical centrifugal pumps [7] including - throttling, variable speed drive, impeller geometry modification and bypass flow control. Variable speed drive and impeller geometry control are comparatively costly and the flow control by throttling is not an energy efficient process [8]. Bypass flow control can be an alternative means to control the dosing flow ranges. An arrangement of creating a dosing fluid flow was developed using a typical low cost centrifugal pump using bypass technique [9]. A wide range of dosing flow control was attained using fixed pump geometry and drive speed. The returning bulk flow from the pump into the main tank ensured better mixing due to churning effect which may eliminate the need of separate agitators [10]. In this research work performance of a dosing pump system was evaluated and compared to an alternative arrangement of similar fluid flow from a centrifugal pump flow arrangement using bypass technique.

1.4 Objectives

1. To study the performance (head, discharge, power consumption and efficiency) of a variable displacement diaphragm type dosing pump system.
2. To select a centrifugal pump compatible with the fluid flow attained by the dosing pump.
3. Develop a bypass flow control system using the selected centrifugal pump for generating similar dosing fluid flow.
4. To study the performance (head, discharge, power consumption and efficiency) of the bypass flow arrangement using centrifugal pump.
5. Comparison of performances of two systems.
6. Make suggestions to improve system performance if required.

Chapter 2

Literature Review

2.1 Flow Metering Techniques of Fluid Pumps

Multiple techniques are available at present to control the pump flow rate. Depending on the types of the pump use flow control technique may varied. In most cases positive displacement pumps are used for flow metering and the metering of such pumps are easier and less costly. The basic advantage of using positive displacement pump is high head and low discharge rate. But centrifugal pumps are also uses for flow metering but a very low head and high discharge rate. Metering technique are expensive than positive displace pump. For both pumps flow can be metered in active and passive ways. Active method is the integrated flow controlled method and the passive method is modified or alternative method of flow metering. Moreover many researches are trying to find efficient ways to control the flow of fluid pumps [9]. In the chapter the flow metering technique practiced by positive displacement and centrifugal are discussed below.

2.1.1 Positive Displacement Pump Metering Techniques

- Variable Plunger Stroke/ Diapharm Movement
- Variable Speed
- Variable Flow Control Valve Used in the Down Stream (Throttling)

2.1.2 Centrifugal Pump Metering Techniques

It is often necessary to adapt pump capacities to temporary or permanent changes in the process demand. The capacity of a centrifugal pump can be regulated either at

- constant speed
- varying speed

2.1.2.1 Capacity Regulation on Varying Speed

Speed modulation is energy efficient since the energy to the pump is reduced with by decreasing the impeller speed.

The speed of the pump can be varied with

- hydraulic/hydrostatic drives - hydraulic coupling between input and output shaft - speed ratio 5 to 1 is controlled by adjusting the volume of oil in the coupling
- mechanical drives - belt and sheave drive
- eddy current drive/clutch - magnetic coupling transfer load torque between input and output shaft
- variable speed drives - inverters - AC drives - adjustable frequency drives - operates by varying the frequency and voltage to the electric motor

The c hange i n pow er consumption, he ad a nd v olume r ate c an be e stimated w ith t he he lp of the affinity laws.

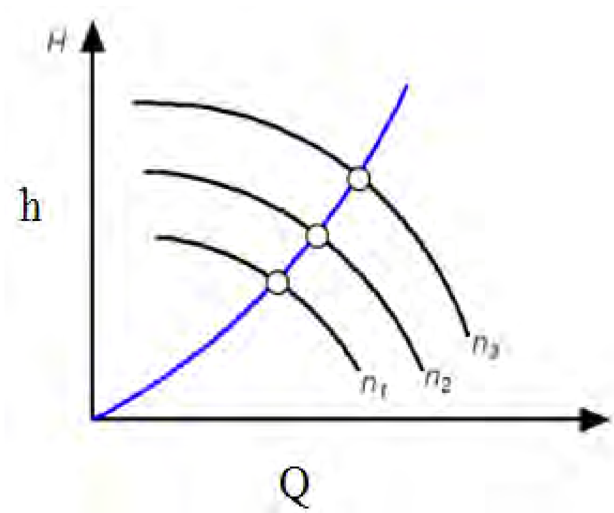

Figure 2.1: Capacity Regulation on Varying Speed [4]

2.1.2.2 Modulating Capacity at Constant Speed

Capacity can be regulated at constant speed by

- Throttling
- Bypassing Flow
- Changing Impeller Diameter
- Modifying the Impeller

Throttling- Throttling can be carried out by opening and closing a discharge valve.

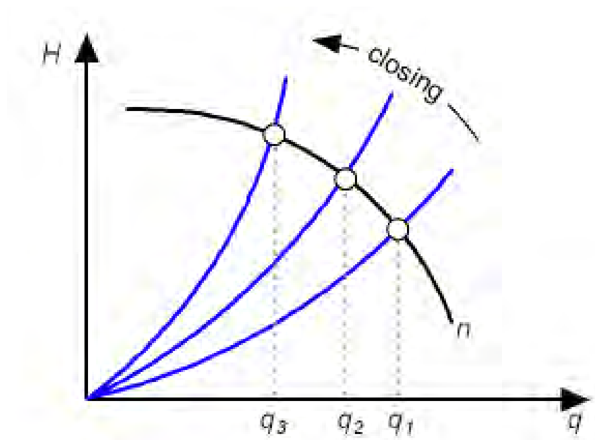

Figure 2.2: Flow Control by Throttling [4]

Throttling is energy inefficient since the energy to the pump is not reduced. Energy is wasted by increasing the dynamic loss.

Bypassing Flow- The discharge capacity can be regulated by leading a part of the discharge flow back to the suction side of the pump. Bypassing the flow is energy inefficient since the energy input to the pump is not reduced.

Changing the Impeller Diameter- Reducing the impellers diameter is a permanent change and the method can be used where the change in process demand is not temporary. The method may be energy efficient if the motor is changed and the energy consumption reduced

Modifying the Impeller-The flow rate and the head can be modulated by changing the pitch of the blades. Complicated and seldom used.

2.2 Effect of Flow Metering Process on Pump Power Consumptions of Centrifugal Pump

The following graph shows the (%) power consumption of pump by various flows metering process at various (%) flow rates.

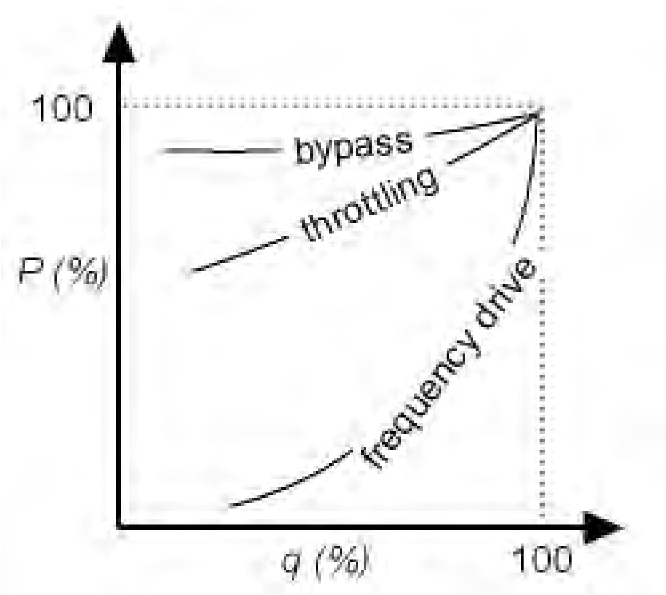

Figure 2.3: Power Consumption by Different Flow Metering Technique [4]

The following summery can be drawn from the above graph.

Table 2.1: Efficiency Comparison of Various Flow Controlling Methods

Bypass	Throttling	Variable Frequency Drive
Bypassing the flow is energy inefficient since the energy input to the pump is not reduced. This is a cheaper process.	Throttling is energy inefficient compared to bypass flow control, since the energy input to the pump is not reduced. Energy is wasted by increasing the dynamic loss. This is a cheaper process.	This is the most efficient process for flow metering of centrifugal pump. But the price of the frequency drive is very high and the flow metering process is costly.

2.3 Pump Selection

The following figure shows the typical flow character of a centrifugal pump.

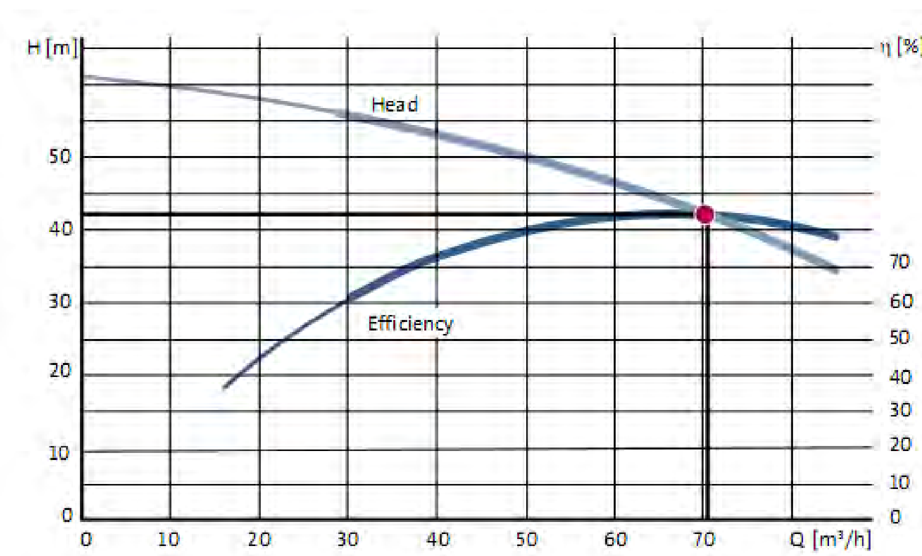

Figure 2.4: A Typical Pump Flow Character [5]

From the figure it is clear that the head of the pump decreases with the increase of the discharge and the efficiency of the pump increases with the increasing of the discharge up to a certain level. After that it Is decreases. So the intersecting point of the maximum efficiency and the head with corresponding discharge is the optimum operating point of that particular pump. While designing of selecting the pump it is the necessary issue to be considered.

2.4 Alternating Approach of Metering at a Low Discharge

As positive displacement pumps are widely used to control flow of fluid but these types of pumps including its flow metering process is costly and complex. Centrifugal pumps can be used for flow metering but it cannot be used at very low discharge and high head [8]. But there are some cheap flow metering techniques available by which flow control can be done [9]. The main problem is the relatively high power consumption by the centrifugal pump. This can be minimized by the geometrical modification of the pump considering the selection criteria [10]. In this project, bypass flow metering technique was used to control the fluid flow and to make the pump energy efficient impeller dimension was optimized additionally as per necessity. Performance study of both pumps has been performed at similar operating range to draw conclusion.

Chapter 3

Performance Tests of Pumps

3.1 Performance Test of Centrifugal Pump

A pump is a mechanical device for lifting of a liquid by creating pressure head. A centrifugal pump consists of an impeller rotating in a casing with suitable seals to preventing leakage.

Centrifugal pumps need priming before starting i.e. the suction line, casing and the portion of the delivery pipe up to the delivery valve are filled with the liquid to be pumped. Centrifugal pump are not positive displacement pump and it can be run with the discharge valve closed, in which case the energy supplied is dissipated within the turbulence and friction.

For testing the pump may be driven either in a calibrated a-c or d-c motor or an un-calibrated motor with a torsion meter or dynamometer.

The following parameters are to be measures for performance testing of the pump and the related equations are discussed below.

3.1.1 Capacity

The volumetric capacity is the volume of liquid delivered by the pump into the delivery pipe in unit time. The capacity may be measured by one of the following methods.

- By means of flow meter direct indication of the instantaneous flow.
- By means of calibrated tank and stop-watch. Dividing the total volume of collected water by time taken gives the flow rate. That is Q = Volume of Collected Water/ Time
- By means of orifice meter placed in the delivery line. Here, Q[L/s]= $K\sqrt{h}$

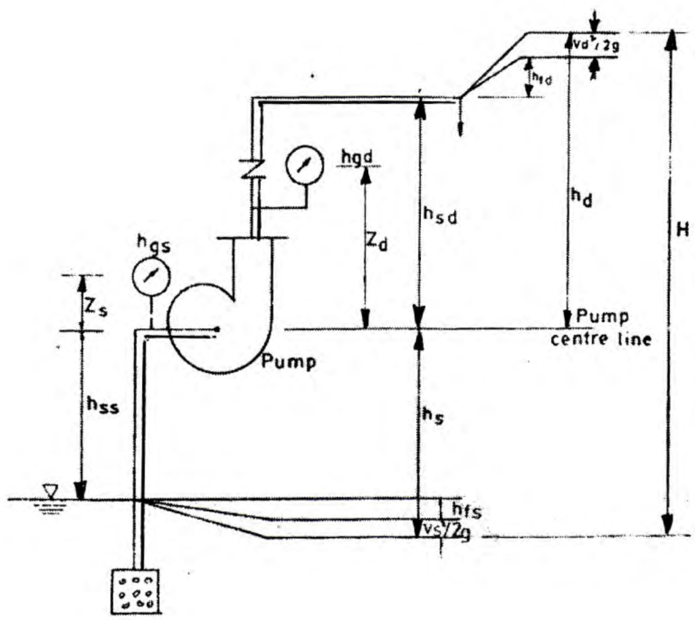

Figure 3.1: Centrifugal Pump Test Rig

3.1.2 Measurement of Head

The following symbols of Figure 3.1 are to be used to measure the head.

h_{fd}= Friction and exit loses in the delivery pipe [m].

h_{fs} = Friction and entry loses in the suction pipe[m].

h_{sd}= Suction head delivery [m].

h_{ss}= Static suction head [m].

h_d= Total delivery head [m].

h_s= Total dynamic suction head [m].

$= h_{sg} + Z_s + Vs^2/2g$

h_{gd}= Pressure gauge reading at the delivery side [m].

h_{gs}= Pressure gauge reading at the suction side [m].

H= Total dynamic head [m].

Z= Vertical distance of the pressure gauge in the suction line from the pump horizontal center line [m].

[m]= Meters of liquid column

Then the total dynamic head will be

$H = h_d + h_s$

$= (h_{gd} + Z_d + Vd^2/2g) + (h_{sd} + Z_s + Vs^2/2g)$

3.1.3 Measurement of Power and Efficiency

The extreme power given to the main shaft is called the shaft horsepower (Shp). And the effective power given by the pump to a liquid to be pumped is called water horse power (Whp). The Shp can be measured directly if the pump is coupled with a motor with a torsion meter or dynamometer and can be calculated from the input to a calibrated motor.

The the water horse power (Whp) is measures as

Whp= $\rho g QH$ (kW)

Where,

ρ = Density of water ($m^{3/}$ kg)

g = Gravitational acceleration (m/s^2)

Q= Capacity [m^3/S]

H= Total Head [m]

The ratio of the Whp to the Shp is called the pump efficiency and is expressed as

Pump Efficiency, $\eta_p = \frac{Whp\ [W]}{Shp\ [w]}$ X 100

Overall Efficiency $\eta = \frac{Whp}{Input\ \ Electrical\ \ Power}$ X 100

3.2 Performance Test of Dosing Pump

Reciprocating or dosing pump is a positive displacement pump. It consists of a piston and a cylinder in case of reciprocating pump and dosing and cylinder in case of dosing pump. It is driven by external source that is by electric motor. Thin the cylinder piston or dosing moves backwards and forwards and these movements create a vacuum pressure and a positive pressure in the cylinder by means of which water is pumped. These types of pumps are use for producing very high head.

Air Vessel is fitted to the suction and delivery pipes to reduce the acceleration head. The schematic diagram of a typical positive displacement pump performance test setup rig is shown below.

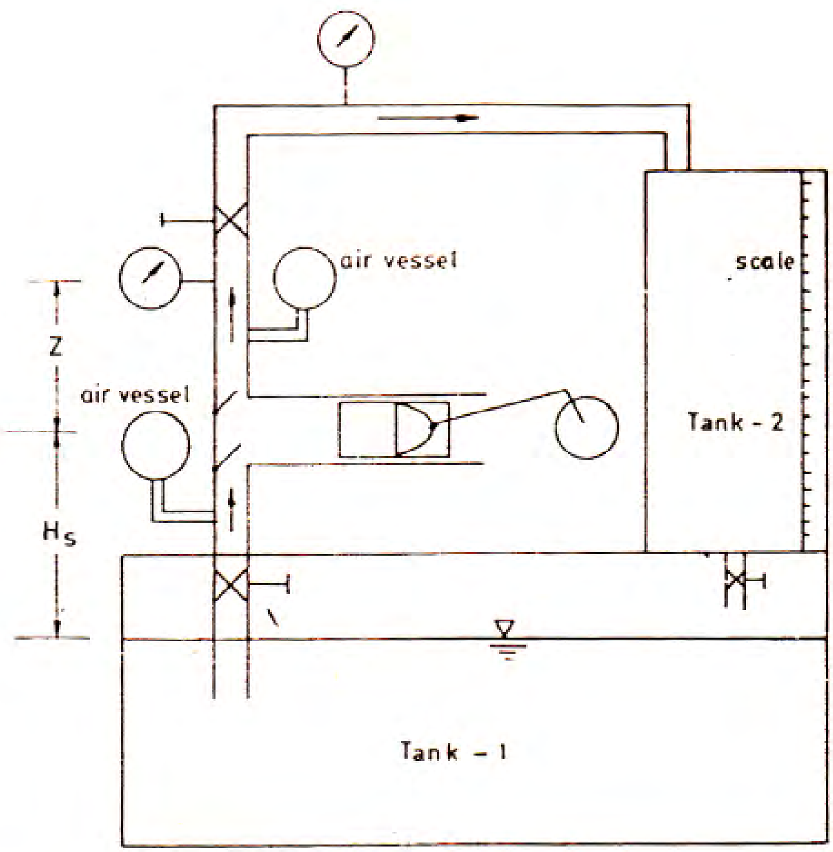

Figure 3.2: Positive Displacement Pump Test Rig

To identify the pump performance, the following parameters are to me measured. Generally a typical test rig consists of pressure gauge, flow meter, ammeter, volt meter and throttle valve.

3.2.1 Discharge

The discharge Q of the pump can be found by collecting water in a tank for a specific time. Thus,

$Q[m^3/S]=Q/T$

Where Q [m^3] is the volume of water collected during the time of T seconds.

3.2.2 Input Power

The power input to the electric motor Pm can be calculated as

$P_m[Watt]= VI \, Cos\phi$

Where, V is the voltage in volts. I is the current in ampere and Cosϕ is the power factor. Is the watt meter is connected to the motor, then, Pm can be reduced directly from the wattmeter. The power input Pi to the pump can be calculated if the efficiency of the motor is known. i.e

$P_i[Watt]= Pm[Watt] \times \eta_{motor}$

Where, η_{motor} is the motor efficiency

3.2.3 Total Head

$H[m] = H_s + H_d$

Where H_s is the suction head and H_d is the delivery head.

According to the setup of figure 3.3

$H[m] = H_s + Z + 10^5 p/\rho g$

Where,

Z[m]= distance between the centers of the delivery pressure gauge and the pump

P[bar] = pressure gauge reading

ρ [Kg/m^3]= density of water (1000 Kg/m^3)

3.2.4 Output Power

The water horse power (Whp) can be calculated as

Whp= $\rho g Q H$ (kW)

Where,

ρ = Density of water ($m^{3/}$ kg)

g = Gravitational acceleration (m/s^2)

Q= Capacity [m^3/s]

H= Total Head [m]

3.2.5 Efficiency

Pump Efficiency, $\eta_p = \frac{Whp\ [W]}{Shp\ [w]}$ X 100

Overall Efficiency $\eta = \frac{Whp}{Input\ \ Electrical\ \ Power}$ X 100

Chapter 4

Experimental Setup

4.1 Experimental Setup

Two experimental arrangements were used to carry out the experiments. One is for the performance study of Dosing pump and other is for the performance study of the centrifugal pump. Centrifugal arrangement is also subdivided into bypass arrangement and conventional centrifugal pump arrangement. In this chapter, experimental set up and the method of testing is discussed in brief.

4.1.1 Experimental Set Up of Dosing Pump

The following figure 4.1 and 4.2 present the schematic and the real diagram of the diapharm experimental setup. Dimensions, which are shown in the schematic diagram, were exactly used to do all necessary calculation for analyzing the pump performance.

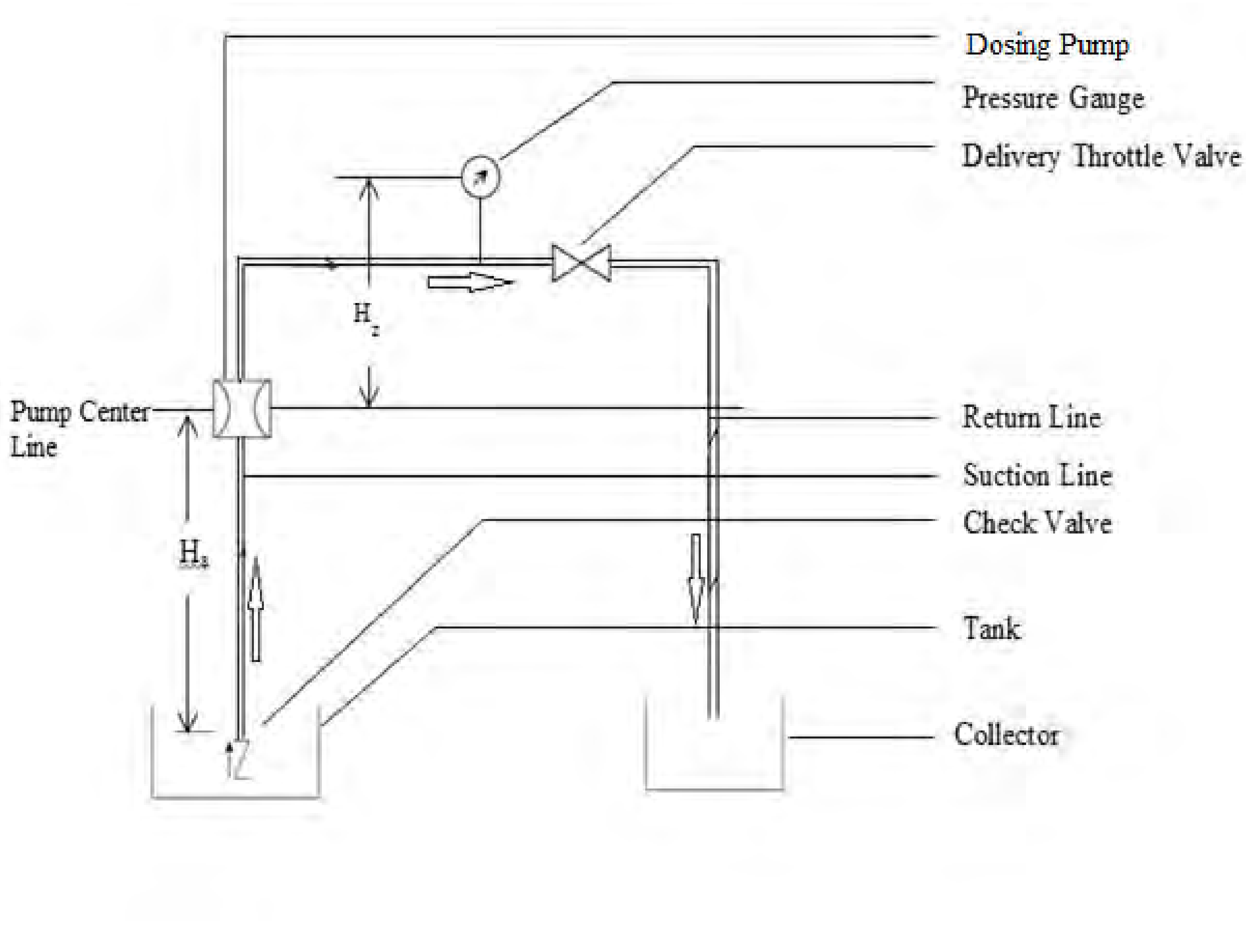

Figure 4.1: Schematic Diagram of Dosing Pump Arrangement

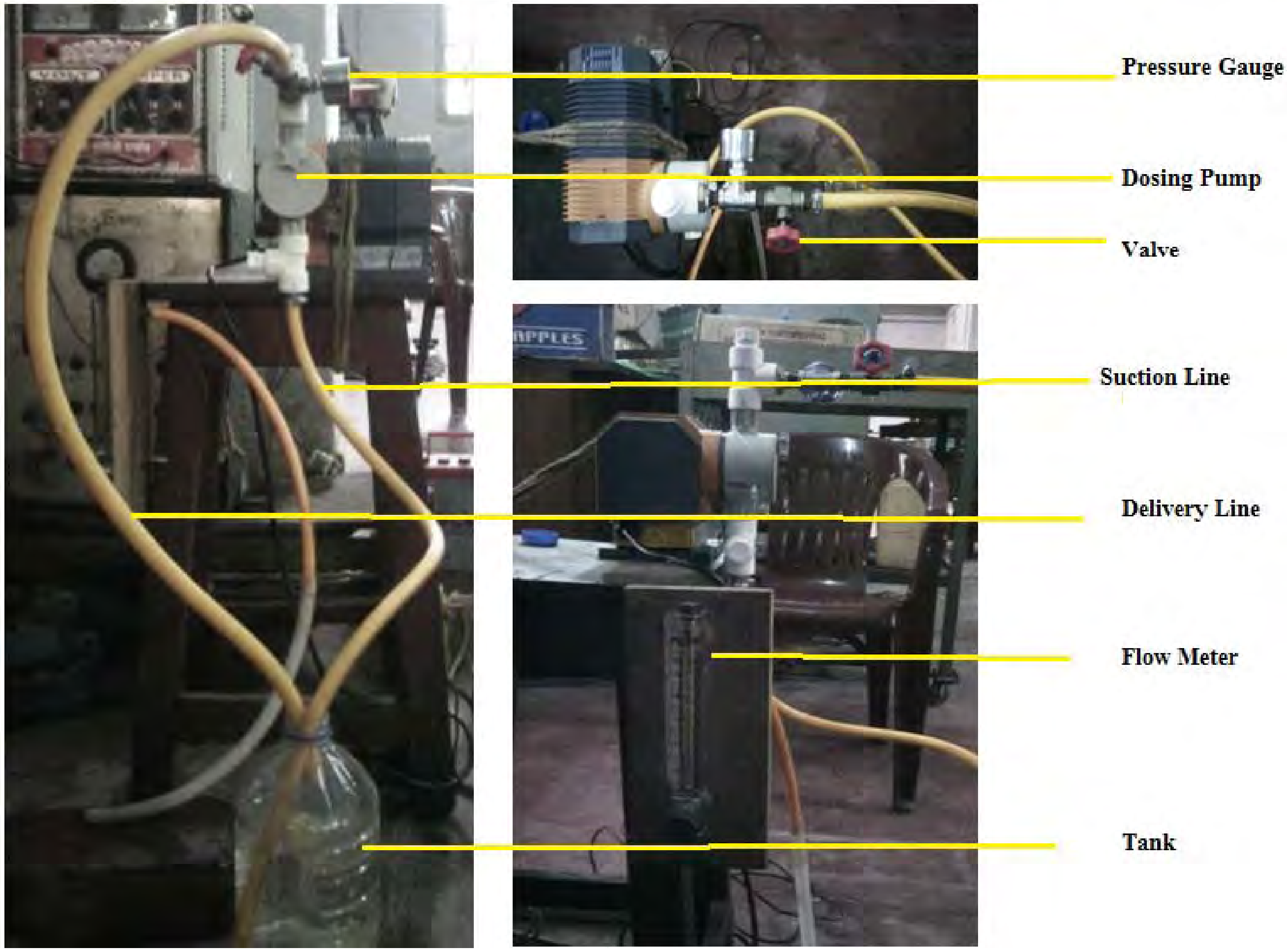

Figure 4.2: Front View, Top View and Left Hand Side View of the Experimental Setup

Dosing Pump Specification

Model: ALPb
Country of Origin: Germany
Power Supply: 220V
Frequency: 50 Hz
Maximum Discharge: 22.5 L/h at 0 bar and 1.2 L/h at 7 bar
Maximum Head: 72 m at 100% stroke length
Maximum Suction Head: 1m
Power Consumption 72 watt
Stroke Variation: 20-100% of its total stroke length
The set up consists of the following

a. **Dosing Pump**: Alpha ALPb motor driven diapharm type pump (manufactured by ProMinent, Germany) is used to carry out the experiment. The maximum head of the pump is around 72 meter at a minimum discharge rate at 1.5 L/h and the maximum discharge rate is around 22.4 L/h at a minimum head of zero meter. The stroke length of the pump is adjustable from minimum 10% up to maximum 100% of its total stroke length. It is the primary way of changing the pump flow rate without using external throttling valve. The maximum power consumption of the pump is around 72 watt. Figure 4.3 presents the internal dimension of the dosing pump.

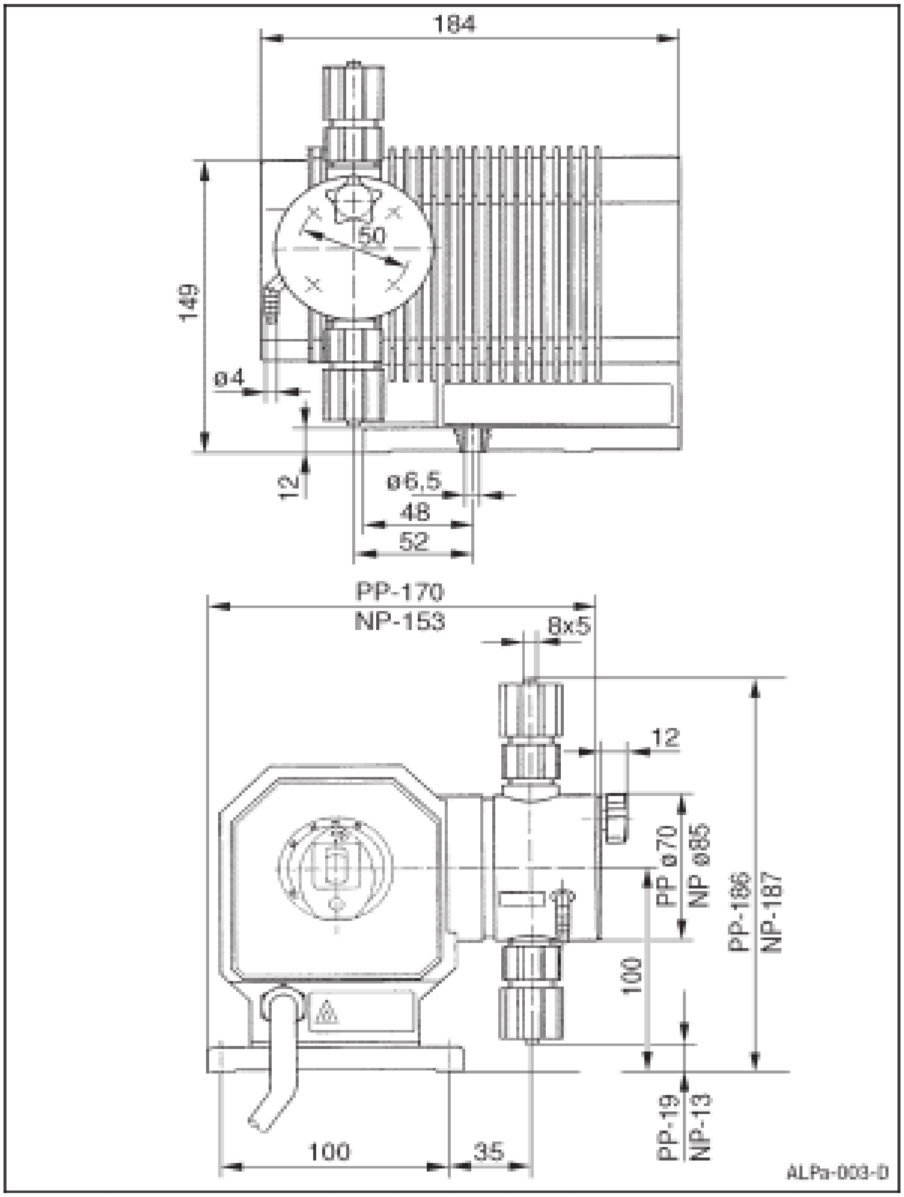

Figure 4.3: Dimension of the Dosing Pump

b. **Water Tank**: Water tank is used as a water reservoir. The water pumping circuit is a close loop circuit. That means water that is pumped from the tank ultimately return into the tank.

c. **Hose Pipe**: Flexible hose pipe of ½ inch diameter is used.

d. **Throttle Valve**: Gate valve is use for flow metering.

e. **Pressure Gauge**: A pressure gauge is used to check the delivery side pressure of the pump to calculate the delivery head. As the pumping circuit is a close circuit arrangement, so the water level is considered as constant and the height from the tank water level to the dosing of the pump is considered as suction head.

f. **Voltmeter and Watt Meter**: Voltmeter is used to measure the voltage and the watt meter is used to measure the current of the pump.

4.1.2 Experimental Set Up of Centrifugal Pump

Following figure 4.4 and 4.5 present the schematic and the real diagram of the centrifugal pump experimental setup. Dimensions, which are shown in the schematic diagram, were exactly used to do all necessary calculation for analyzing the pump performance. A 30 m head, 60 L/m discharge and 1 hp centrifugal pump has been selected for the experiment. Lower hp centrifugal pumps are available in the market but the maximum head of such pumps are found not more than 14 meter. Moreover the maximum head of the dosing pump is around 72 meter. So very low head centrifugal pumps are not suitable for comparative study. On the other hand very high head, high discharge centrifugal pumps are also not suitable as because of high horse power motor. That is why this centrifugal pump has been selected for the experiment.

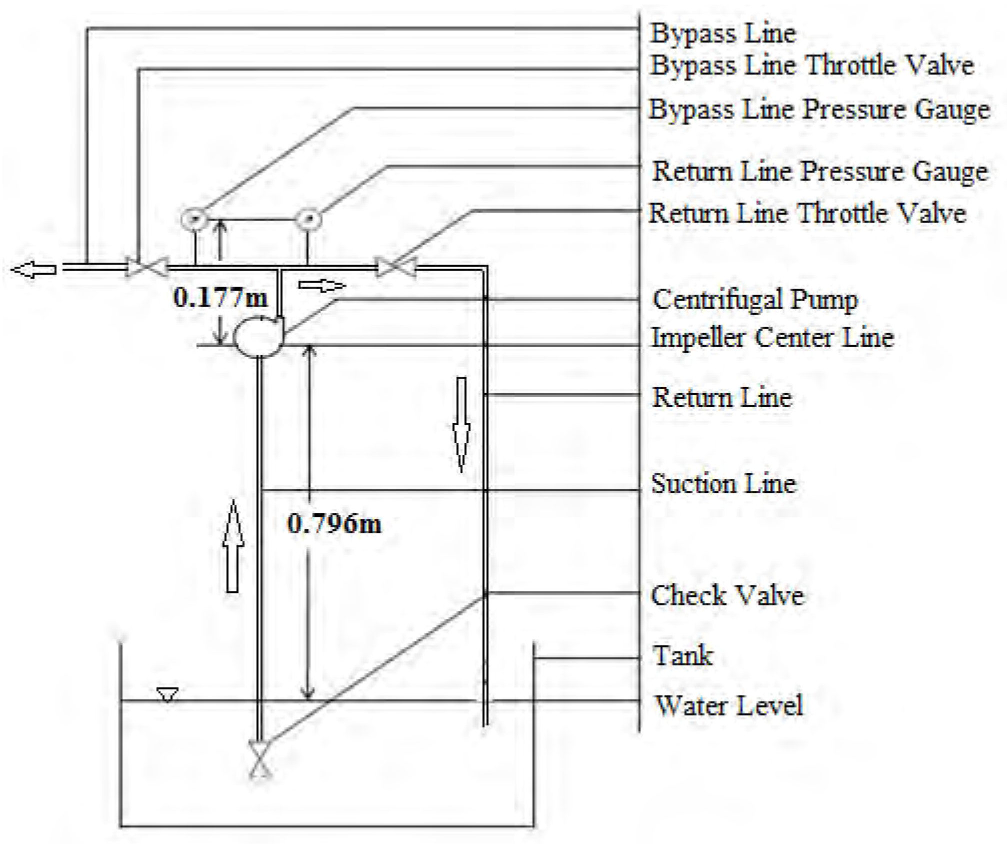

Figure 4.4: Schematic Diagram of Centrifugal Bypass Arrangement

Specification of Centrifugal Pump

Model: JSW-10M
Maximum Head 30 m
Maximum Discharge 60 L/m
Maximum Suction Head: 9 m

Voltage: 220 Volt
Frequency: 50 Hz
Power: 1HP
rpm: 2800
Suction and Delivery Dia: 1 inch / 1 inch

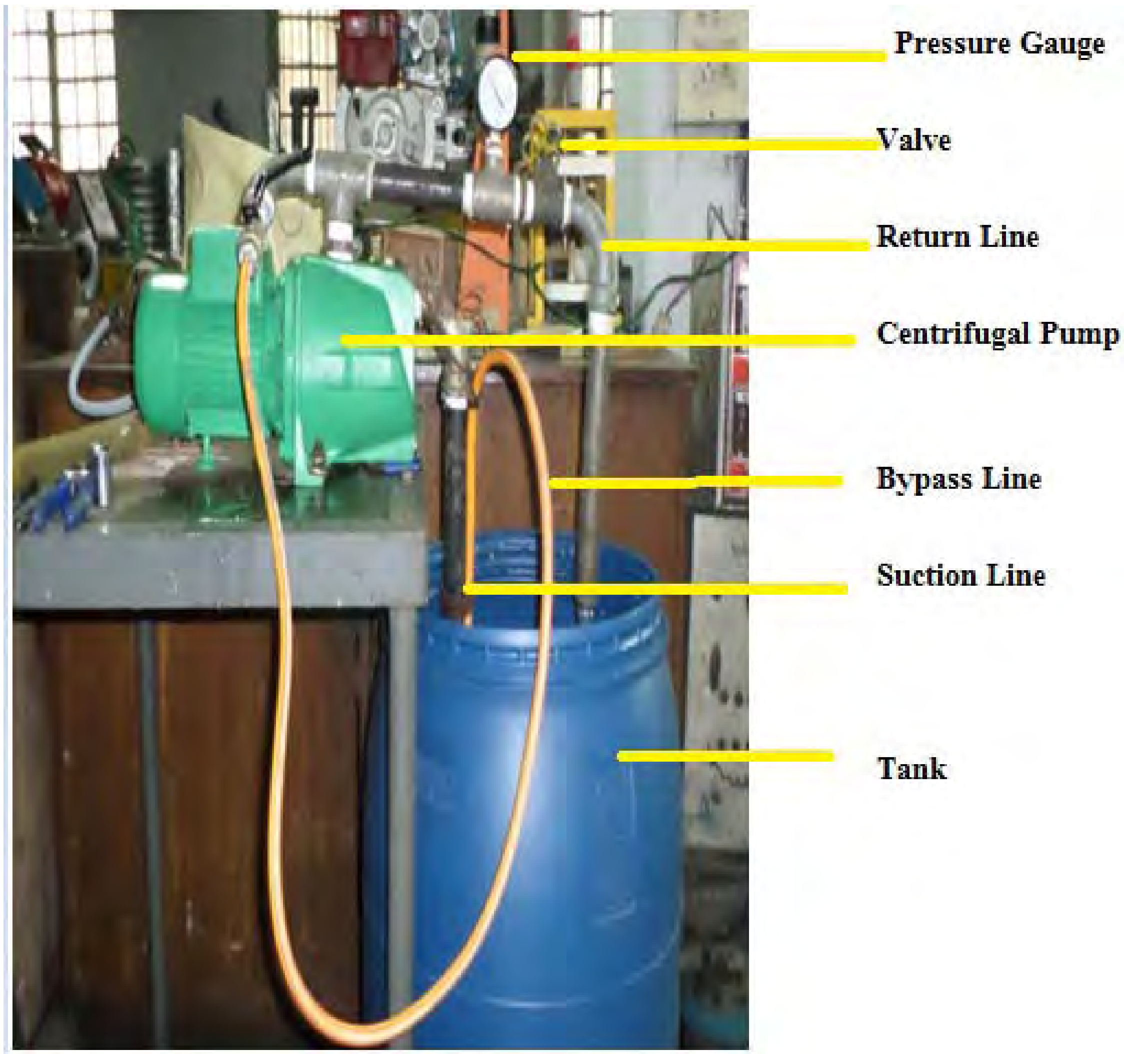

Figure 4.5: Centrifugal Bypass Arrangement

The set up consists of the following

a. **Centrifugal Pump**: A local Centrifugal Pump is used to carry out the experiment. The maximum head of the pump is around 28 meter at a minimum discharge rate at 11.88 L/h and the maximum discharge rate is around 2650 L/h at a minimum head of zero meter. The pump is coupled with a 1 horse power motor. The accuracy of the flow rate, head and input power are ± 0.1%, ± 0.1% and ± 0.1% respectively.

b. **Water Tank**: A 180 liter water tank is used as a water reservoir. The water pumping circuit is a close loop circuit. That means water which is pumped from the tank, ultimately return into the tank.

c. **Flexible Hose Pipe**: Flexible hose pipe of ½ inch diameter is used for bypass flow control.

d. **Solid Pipe and Fittings**: Solid pipe of 1 inch diameter and 1 inch fittings is used to make the pump circuit.

e. **Throttle Valve**: Gate valves are used for flow metering. There are two gate valves in the arrangement. One valve controls the pump flow that directly returns into the tank and the other one finely tuned the bypass flow.

f. **Pressure Gauge**: Pressure gauge is used to measure the delivery side pressure of the dosing pump for calculating total head.

g. **Voltmeter and Watt Meter:** Voltmeter is used to measure the voltage and the watt meter is used to measure the current of the pump.

h. **Potentiometer**: Potentiometer is used to control the voltage.

4.2 Experimental Methodology

Performance measurements were taken in four phases.

4.2.1 First Phase:

Phase one of the experiment was done with the dosing pump arrangement. Dimension, that are shown the in the figure 4.1, were used to make all the necessary calculation. The flow rate of water was measured manually. Mass of the collected water was divided time to measure the flow rate. Suction and delivery velocity heads were calculated for the equation Q=AV. Flow rates were controlled by adjusting the stroke length as well as using throttling valve in downstream of the dosing pump. For analyzing the pump performance, heads at various discharge rates were measured. Corresponding pump input powers requirement were also measured to calculate the overall pump efficiencies. The main aim of this phase was to establish the diaphragm pump performance only.

4.2.2 Second Phase:

Second Phase of the experiment was done with the bypass flow arrangement with a centrifugal pump. Dimension, that are shown the in the figure 4.4, were used to make all the necessary calculation. The flow rate of water was measured manually. Mass of the collected water was divided by time taken to calculate flow rate. Suction and delivery velocity head was calculated for the equation Q=AV. Flow rate was controlled by throttling valve both for bypass line and return line. For analyzing the bypass arrangement performance, heads at various discharge rates were measured. Corresponding pump input power requirement was also measured to calculate the pump efficiencies. There were two objectives of tests in this phase. First one was only establish the centrifugal pump performance keeping the bypass flow closed and the second one was only measure the bypass arrangement performance. After that, flow rates similar to the dosing metered pump were attained by the bypass arrangement and comparative study has been made between bypass arrangement and dosing pump.

4.2.3 Third Phase:

After analyzing the experimental data of phase two it was found that, the bypass centrifugal arrangement was not very energy efficient. In order to make the system energy efficient, the diameter of the centrifugal pump impeller has been reduced from 5 inch to 3.10 inch as shown in figure 4.6. After that, the same experimental procedure like phase two has been repeated. Main objectives of this phase were, to analyze geometrically modified pump performance, attain flow rates similar to the dosing pump and make performance comparison between two arrangements.

Figure 4.6: Impeller Diameter (a) Original and (b) after Reduction

4.2.3 Phase Four:

In this phase, voltage regulator/potentiometer was used to make study whether the geometrically modified pump is able to run with a low voltage or not. After incorporating voltage regulator, experimental procedure similar to the phase three was repeated. Bypass arrangement was able to run successfully with a low voltage of 160 volts without compensating the pump performance of the phase three. Figure 4.7 shows the potentiometer used for voltage regulation.

Figure 4.7: Voltage Variac

Chapter 5

Results and Discussions

5.1 Performance Curves of Dosing Pump

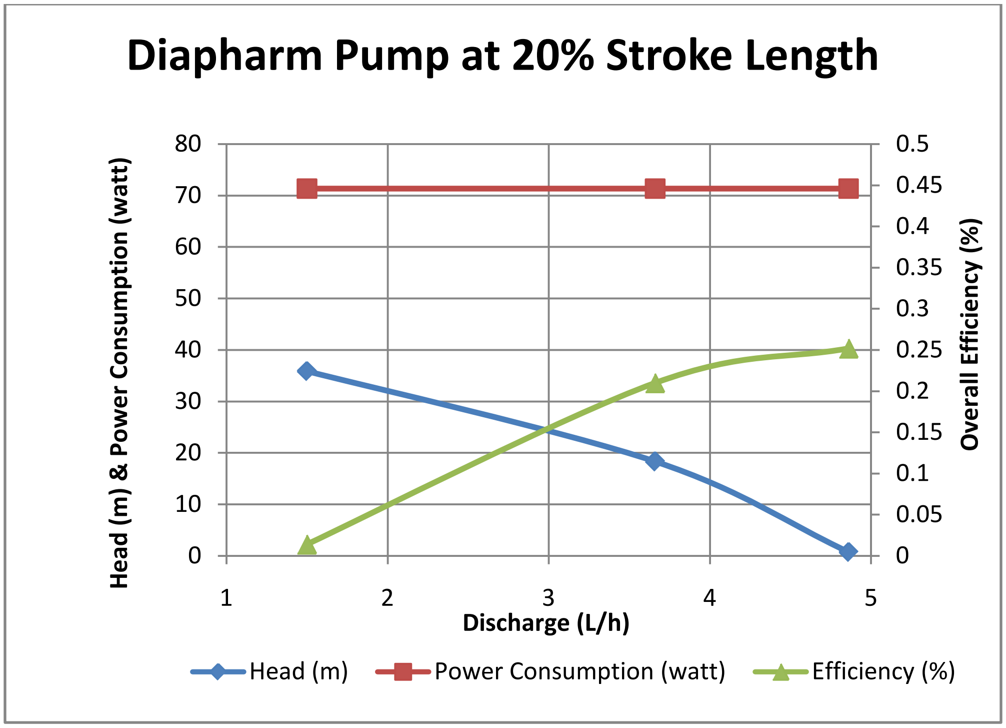

Figure 5.1: Performance Curves of Dosing Pump at 20% Stroke

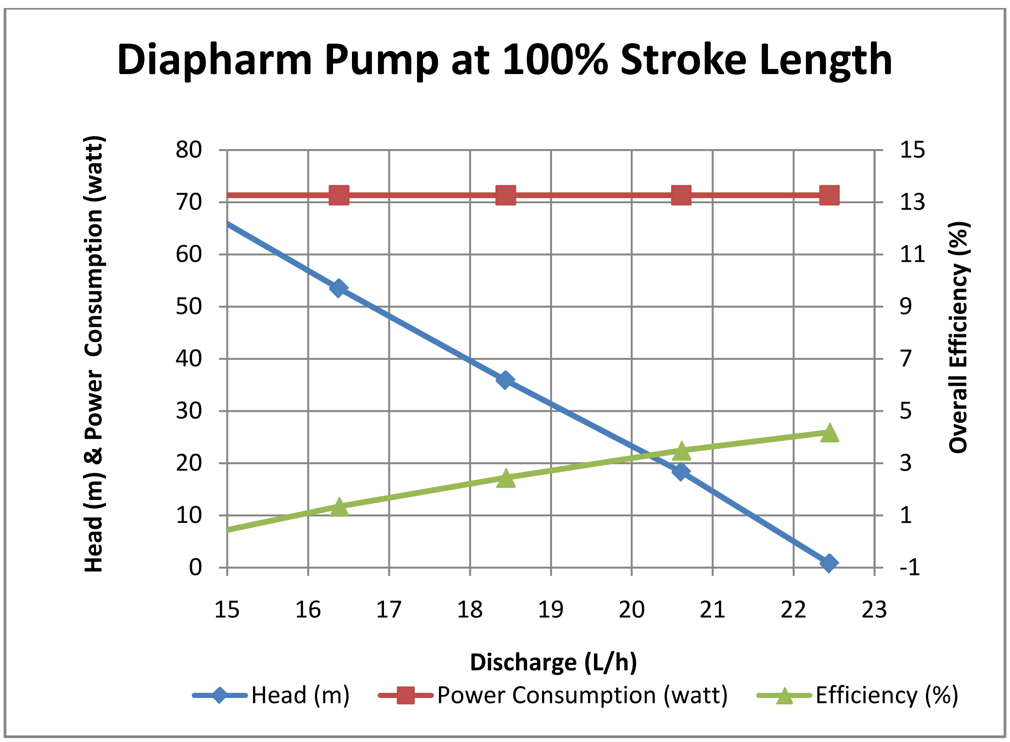

Figure 5.2: Performance Curves of Dosing Pump at 100% Stroke

Figures 5.1 and 5.2 present the performance curves of the dosing pump at 20 and 100 percent stroke lengths. From the graph it is clear that, head decreases with the increases of discharges. Overall efficiency increases with the increasing of the discharges as the energy imparted on the fluid is related to the discharge as well as the head. But at a very high discharge head become very low and for this reason after a certain discharge, further increment of discharges decrease the overall efficiency.

The power consumption of the dosing pump was almost found to be constant (71.36 watt) for all discharges, through the metering range of the pump was found 1.5-22.4 L/h. So there is very low impact on the power consumption by the pump when flow rate changes.

Flow range attained by the dosing pump is around 1.5-22.4 L/h at corresponding head of 0 meter and 71 meter respectively. The maximum overall efficiency of the pump is found 4.19% at the maximum head of its 100 percent stroke length. On the other hand the minimum overall efficiency of the dosing pump is found around 0.014% at minimum head of its 20% stroke length.

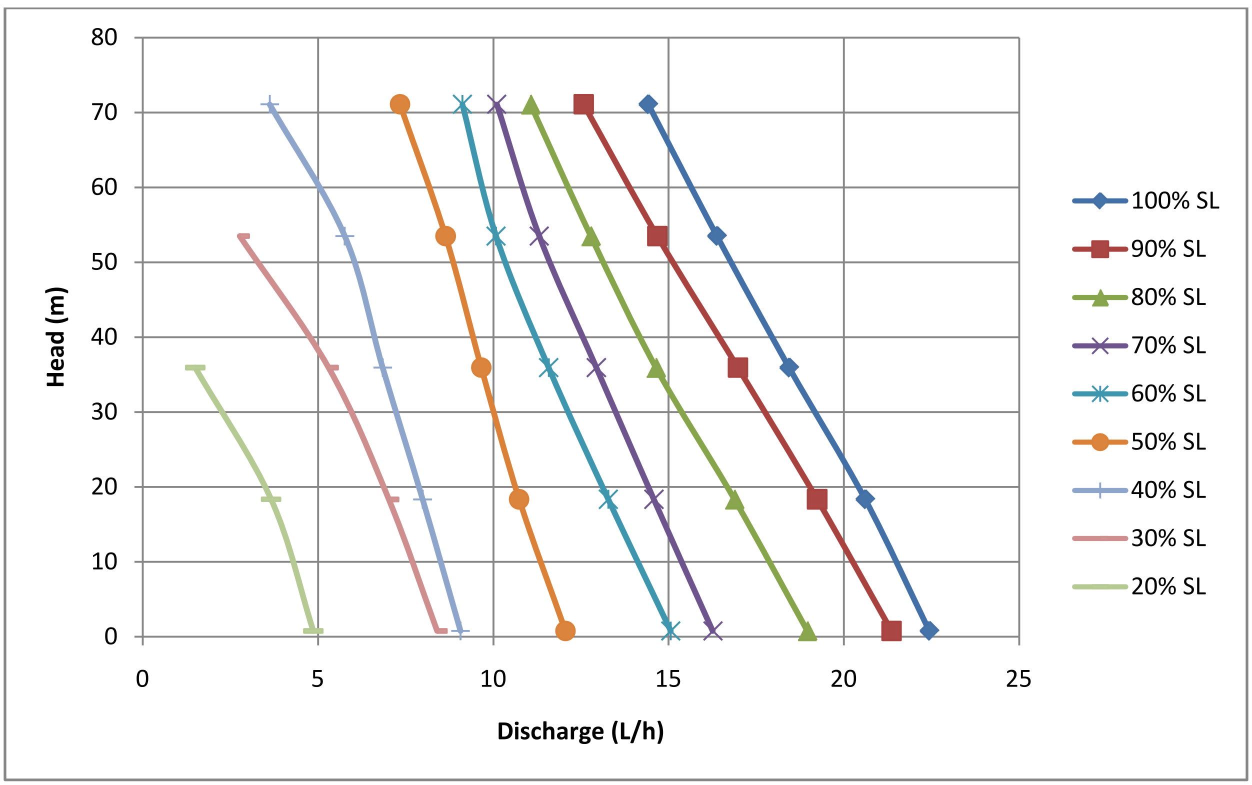

Figure 5.3: Head Vs Discharge of the Dosing Pump at Various Stroke Lengths

Figure 5.3 presents the head Vs discharge of the dosing pump at its various stroke lengths. Stroke length was adjusted at the beginning of the experiment and flow control was performed by valve throttling. For all adjustable stroke lengths, flow rates were measured at same different heads to get the curves. These curves were further used to attain similar of small flow rates by the centrifugal bypass arrangement. These curves show that, the maximum discharge is 22.44 L/h at 0.7725 m head for its 100 % stroke length and the minimum discharge is 1.5L/h at 35.29 m head for its 20% stroke length.

5.2 Performance Curves of Centrifugal Pump

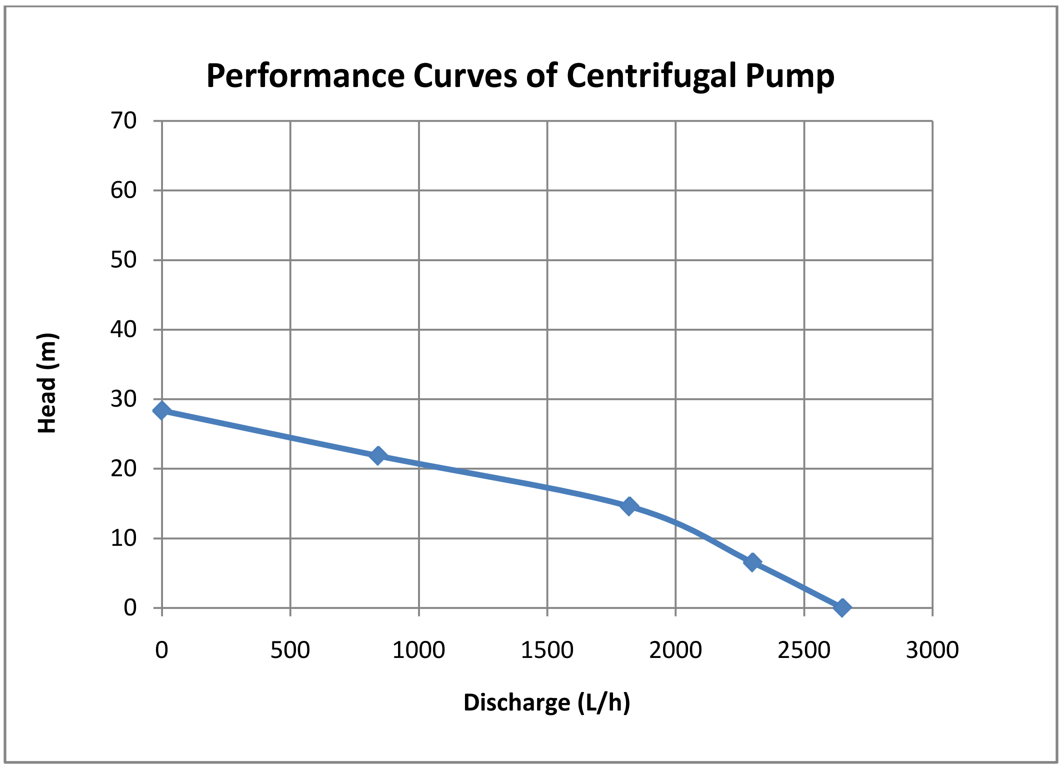

Figure 5.4: Discharge Vs Head of Centrifugal Pump

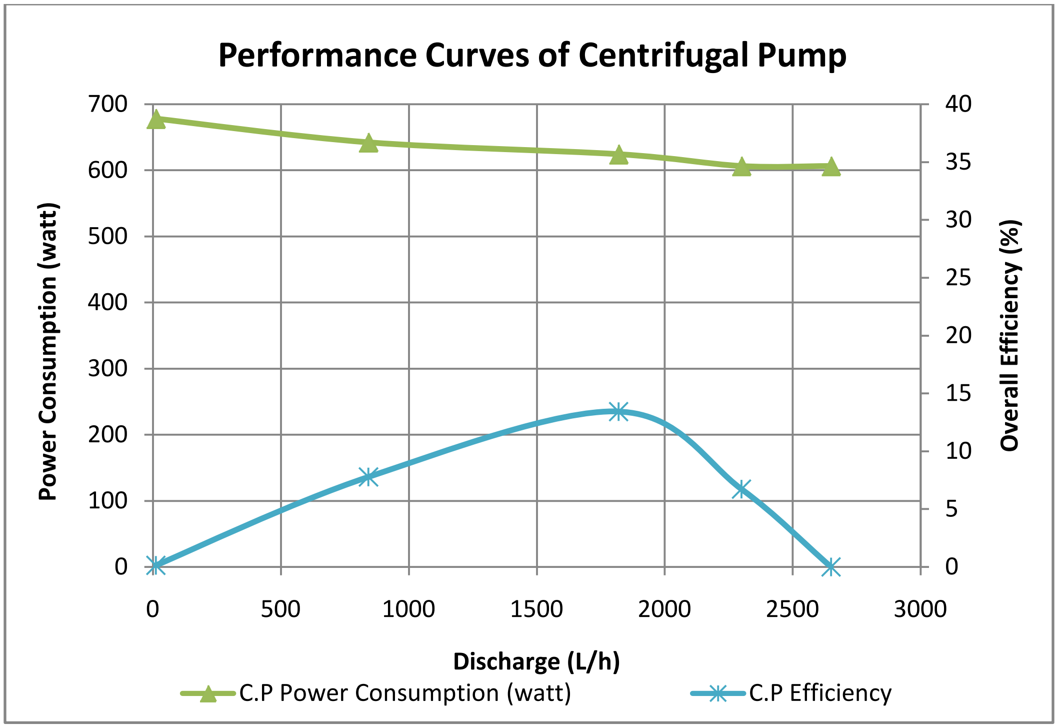

Figure 5.5: Performance Curves of Centrifugal Pump

Figure 5.4 presents the head Vs discharge curves of centrifugal pump. The graph shows that, the maximum discharge of the centrifugal pump is 44.18 L/m or 2650L/h at corresponding head of 0.973 meter and the minimum discharge of the centrifugal pump is 11.4 L/h at corresponding head of 28.35 meter. As the dosing pump flow metering range has been found 1.5-22.44L/h, so it was difficult to attain similar types of low flow rate by the centrifugal pump. The minimum flow rate attained by the centrifugal pump was almost half of the maximum flow rate to dosing pump. Considering this phenomenon bypass flow metering has been done to attain similar range of flow.

Figure 5.5 presents the performance curve of centrifugal pump. Similar to the conventional performance curve pattern, for this case, efficiency first increases and after that is decreases. The maximum overall efficiency 13.43 % was possible to attain at 14.56 m head and the corresponding discharge of 35.33 L/m. This is the best operating point of this centrifugal pump. The efficiency of this jet centrifugal pump was compared with a market renowned Pedrollo (CPm 158 model) centrifugal pump. The 1 hp Pedrlollo (CPm 150 model) centrifugal pump can operate at the maximum overall efficiency of 40%. The maximum discharge of the Pedrollo (CPm 150 model) centrifugal pump is double compared to the jet centrifugal pump. Moreover, the Pedrollo pump having lower head compared to the jet centrifugal pump used in this experiment. That's why, the jet centrifugal pump can able operate at high head and lower discharge compared to the market available Pedrollo pump, but at lower overall efficiency. The performance data of Pedrollo (CPm 150 model) centrifugal pump is attached in annex D.

5.3 Performance Curves of Centrifugal Pump with the Bypass Flow Arrangement

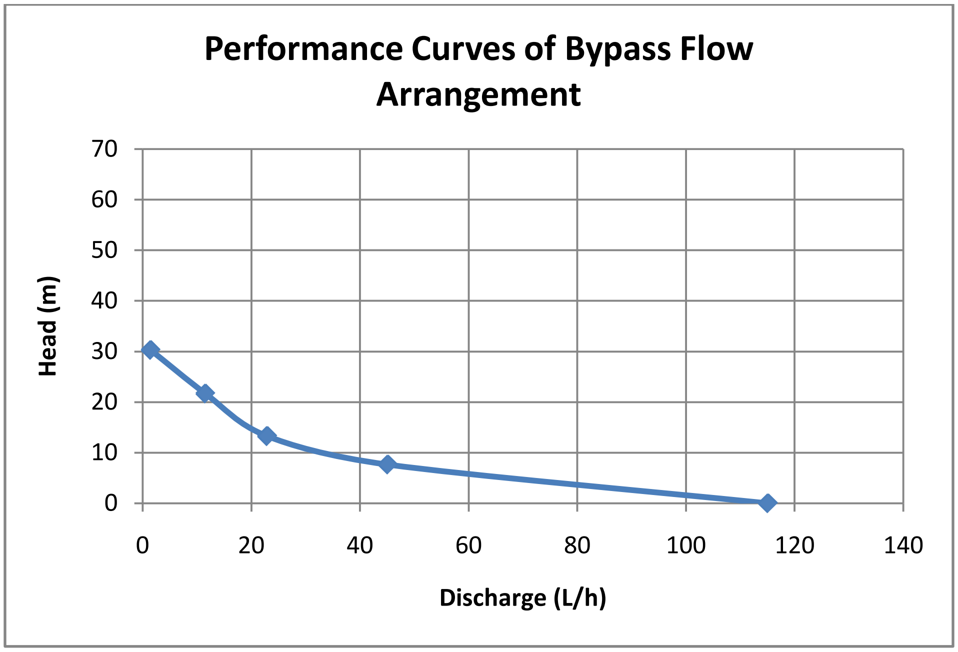

Figure 5.6: Discharge Vs Head Curve of Centrifugal Bypass Flow Arrangement

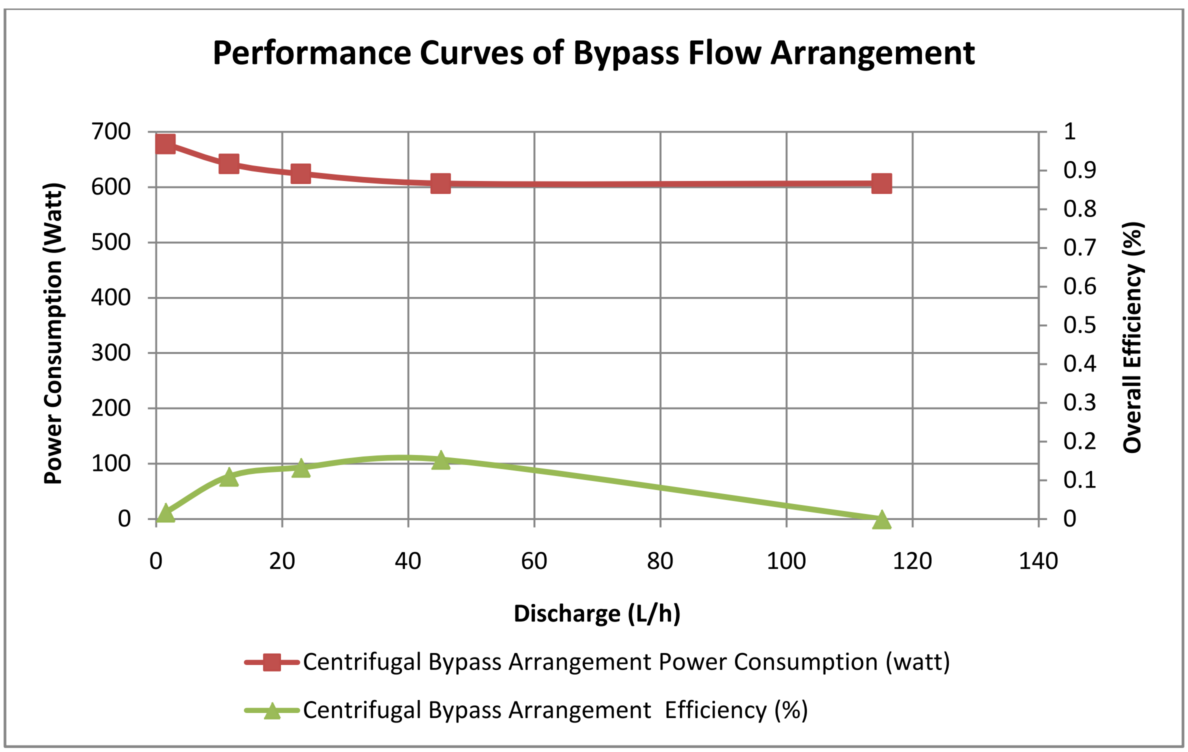

Figure 5.7: Performance Curves of Centrifugal Bypass Flow Arrangement

Figure 5.6 presents the performance curves of the Bypass Centrifugal arrangement. From the graph it is seen that, the maximum flow rate attained by the bypass arrangement is around 115.08 L/h at 0.973 meter head and the minimum flow rate is attained around 1.44 L/h at 30 meter head. The maximum overall efficiency 0.154% is found at the discharge of 44.12 L/h at corresponding head of 7.64 meter. It is clear that, with the bypass centrifugal arrangement minimum flow rate 1.44L/h can be possible to attain which is similar to the lower flow rate of dosing pump. Even though the maximum flow rate of bypass arrangement is still comparatively higher than the dosing pump, but now, there is a new option in hand to compare the bypass centrifugal arrangement with dosing pump up to the maximum discharge of rate of 22.44 L/h at its corresponding heads.

5.4 Comparative Discharge Vs Head Curves

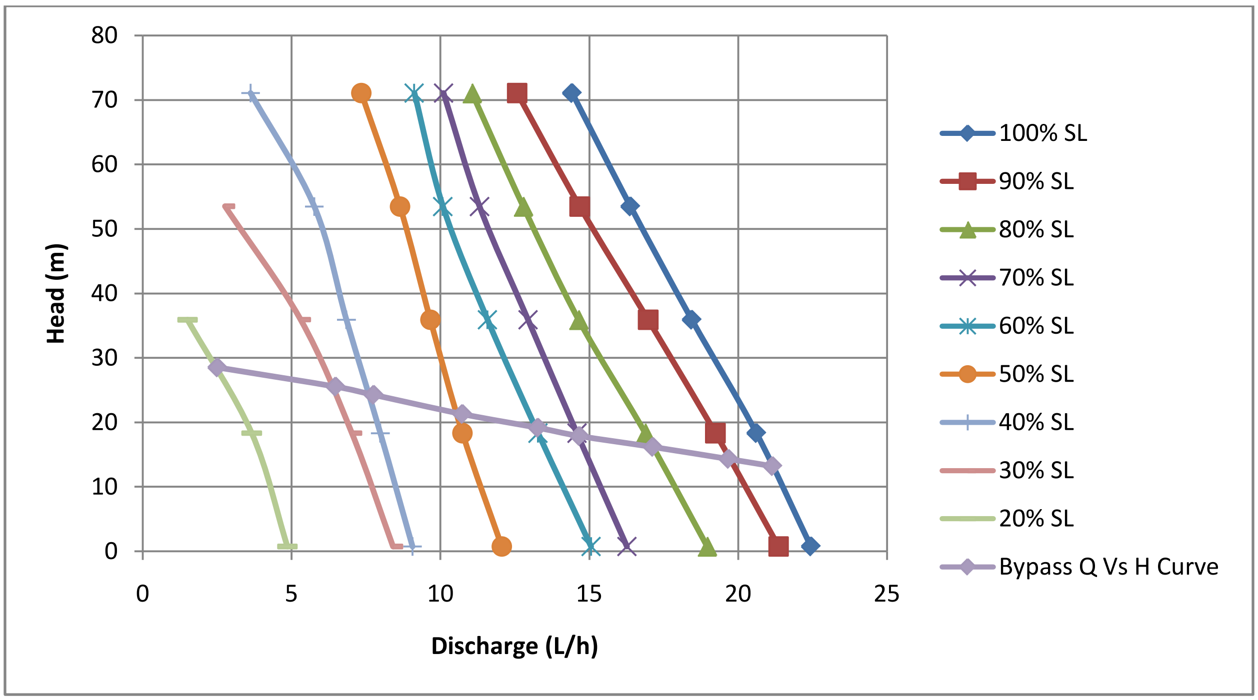

Figure 5.8: Superimposed Discharge Vs Head Curves of Dosing Pump and Centrifugal Bypass Flow Arrangement

Figure 5.8 presents the superimposed head Vs discharge curves of dosing pump and centrifugal bypass arrangement. To compare both pumps it is necessary to attain the same flow rates at same heads. The purple line shows the discharge Vs head curve of bypass flow. The maximum flow rate is attained around 21.83 L/h at 13.09 m head and the minimum flow rate is attained around 2.66L/h at 28.52 m head. The head Vs discharge curve of bypass arrangement intersects all the head Vs discharge curves of dosing pump at specific points. So similar flows are possible to attain by the bypass arrangement and it was physically done to make comparative performance study of both pumps at these intersecting points.

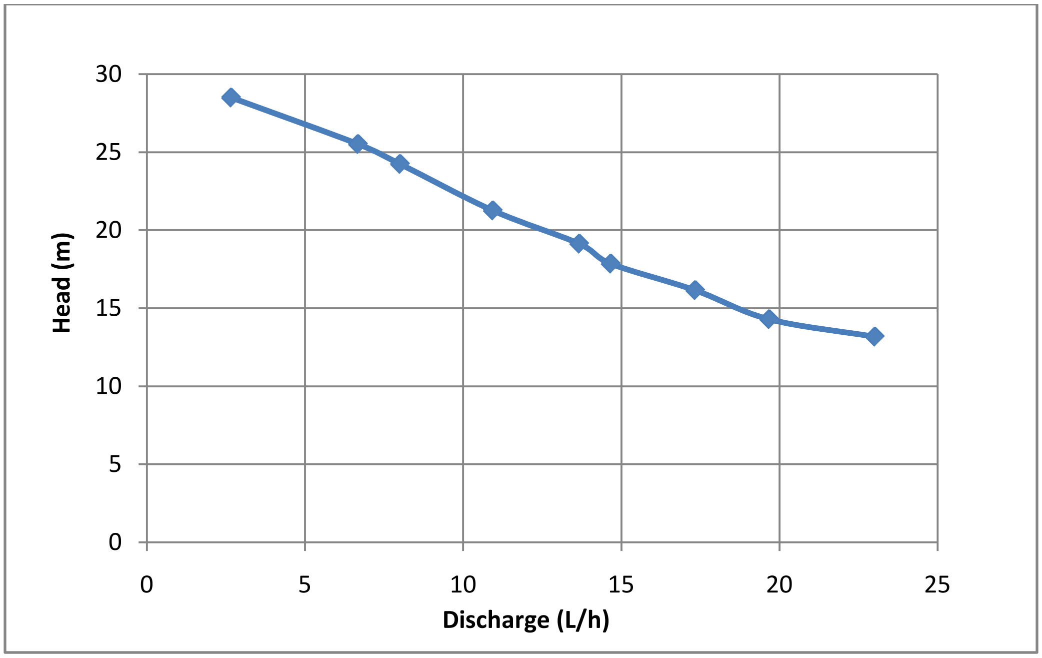

Figure 5.9: Head Vs Discharge Curve of Both Pumps at Points of Comparison

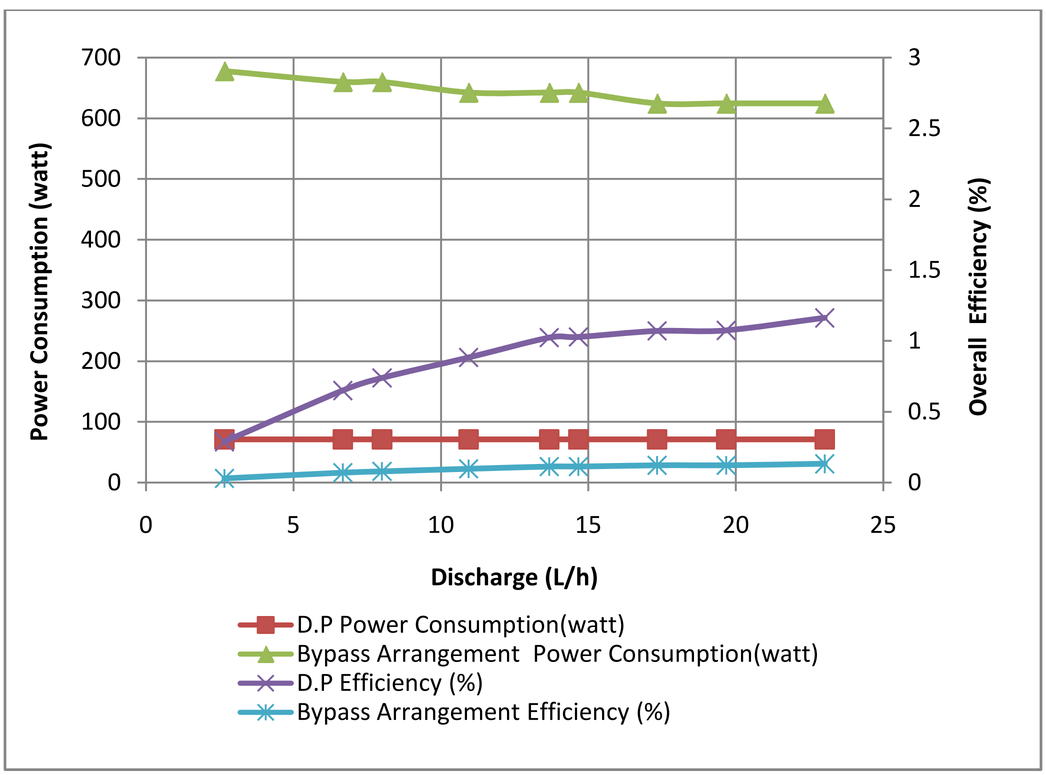

Figure 5.10: Comparative Performance Curves of Both Pumps

From figure 5.9 and 5.10, it is clear that, for same flow rates and heads, the power consumption of the bypass centrifugal arrangement is higher than the power consumption of the dosing pump.

The power consumption of dosing pump is 71.36 watt and it is constant. But with the increase of the discharge the power consumption of the bypass centrifugal arrangements is decreases. Power consumption is maximum (677.92 watt) at corresponding 28.51 meter head and 2.66 L/h discharge. The minimum power consumption is found at 13.19 meter head at a corresponding discharge of 21.85 L/h. The overall efficiency of the dosing pump remains always higher than the bypass centrifugal arrangement, as the input power required for dosing pump is lower. The highest overall efficiency of the dosing pump is around 1.163% and the lowest overall efficiency is 0.289%. On the other hand the highest overall efficiency of the bypass centrifugal arrangement is 0.139% and the lowest overall efficiency is found 0.0304%. High input power required to operate bypass centrifugal arrangement makes the metering energy inefficient.

In summery it can be stated that, with the bypass centrifugal arrangement, flow metering can be possible to perform at a range similar to the dosing pump. But considering power consumption, the system is not that much energy efficient for commercial using as an alternative replacement of dosing pump. Impeller modification was investigated to improve its performance.

5.5 Performance Curves of Centrifugal Pump with the Bypass Flow Arrangement after Impeller Modification

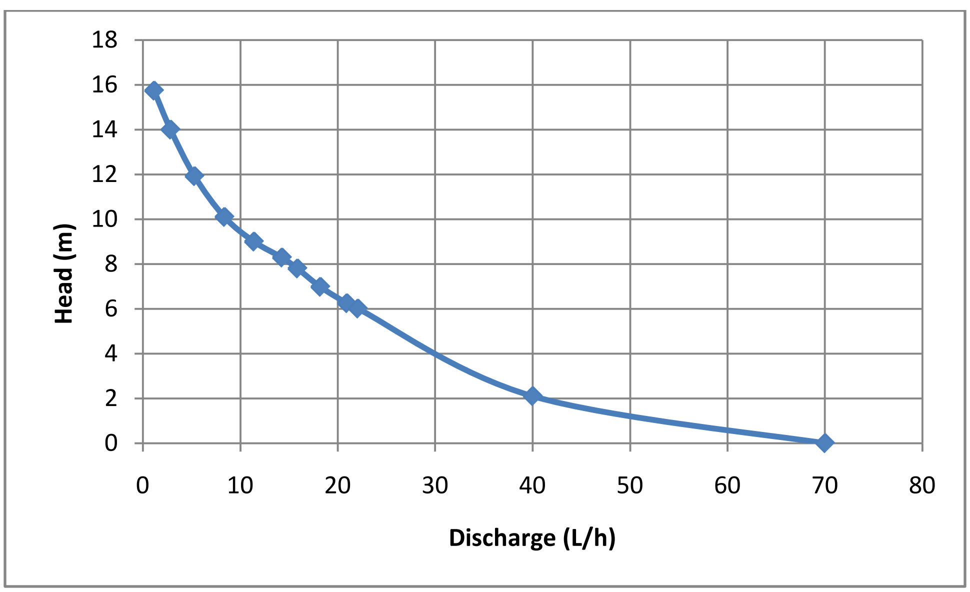

Figure 5. 11: Discharge Vs Head Curve of Centrifugal Bypass Arrangement after Impeller Modification

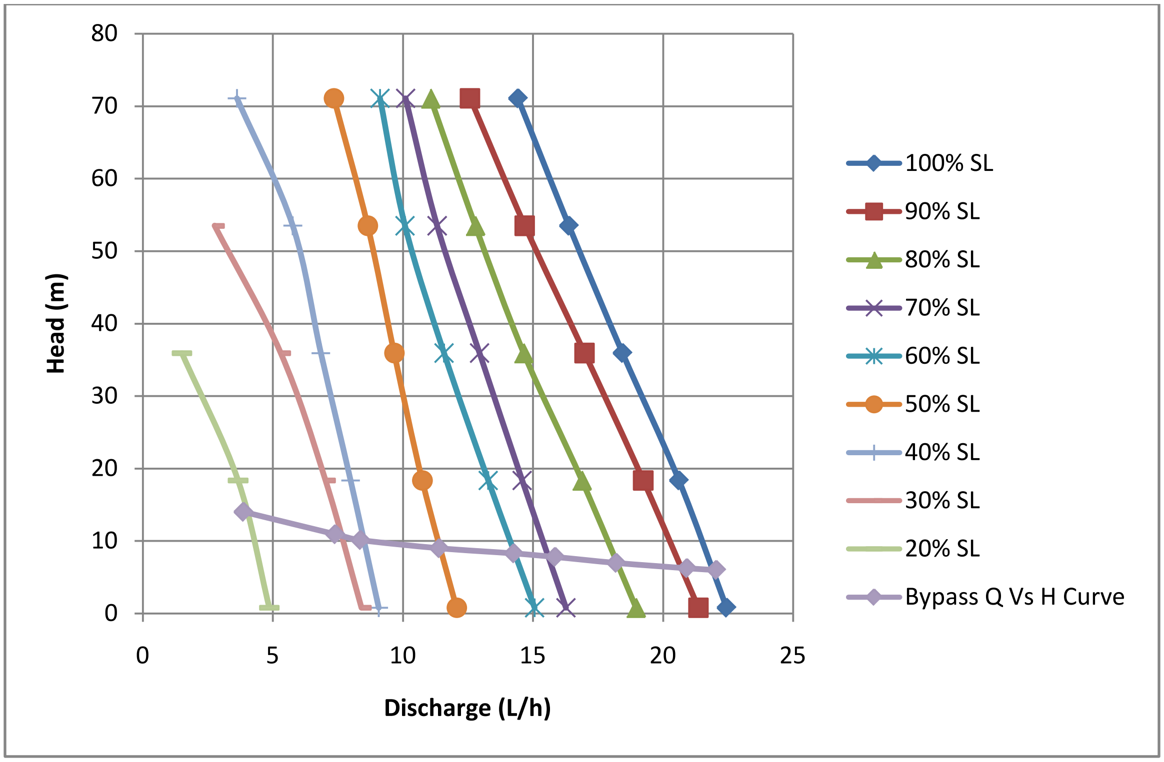

Figure 5.12: Superimposed Discharge Vs Head Curves of Dosing Pump and Centrifugal Bypass Arrangement after Impeller Modification

Figure 5.11 presents the head Vs discharge curve of bypass centrifugal arrangement after impeller modification. The maximum discharge found 70 L/h is still comparably higher than the maximum discharge of dosing pump. That's why, from the discharge Vs head curve of figure 5.11, the discharge upto maximum 22.05 l/h and its corresponding head has been taken for making comparative study. A new operating range has been established after impeller modification as shown in the figure 5.13. The maximum discharge, 22.05 L/h is found at 6.01 meter head and the minimum discharge 2.83 L/h is found at 14 meter head for new operating range. Comparative performance study has been made at all intersecting points of the superimposed curve as shown in the figure 5.13.

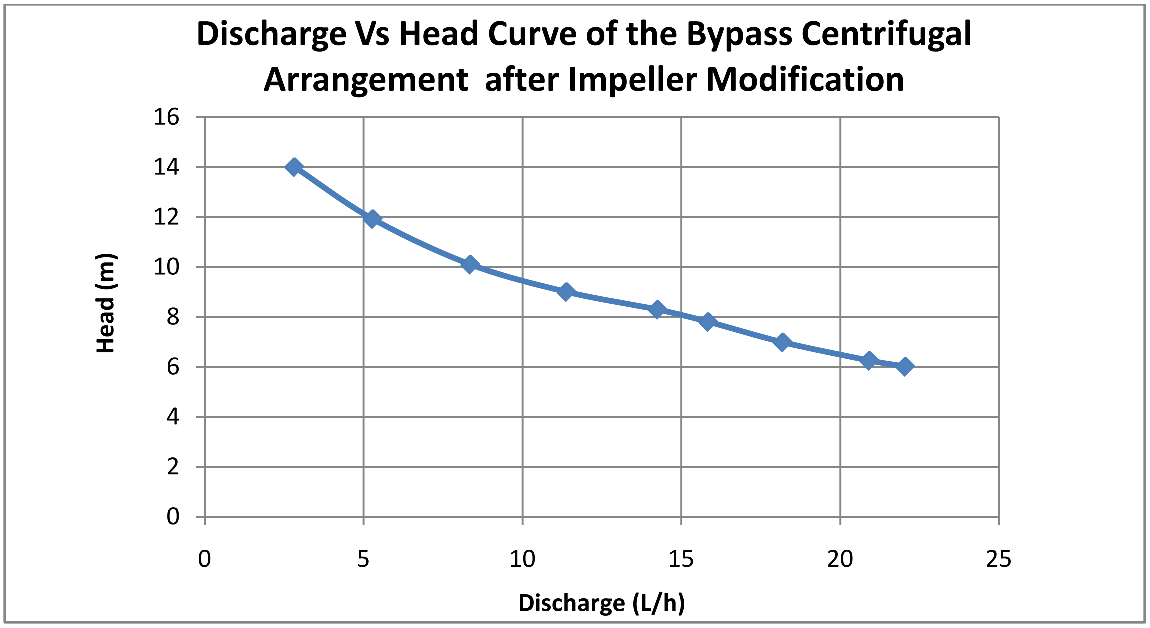

Figure 5.13 : Discharge Vs Head Curve of both Pumps at Points of Comparison after Impeller Modification

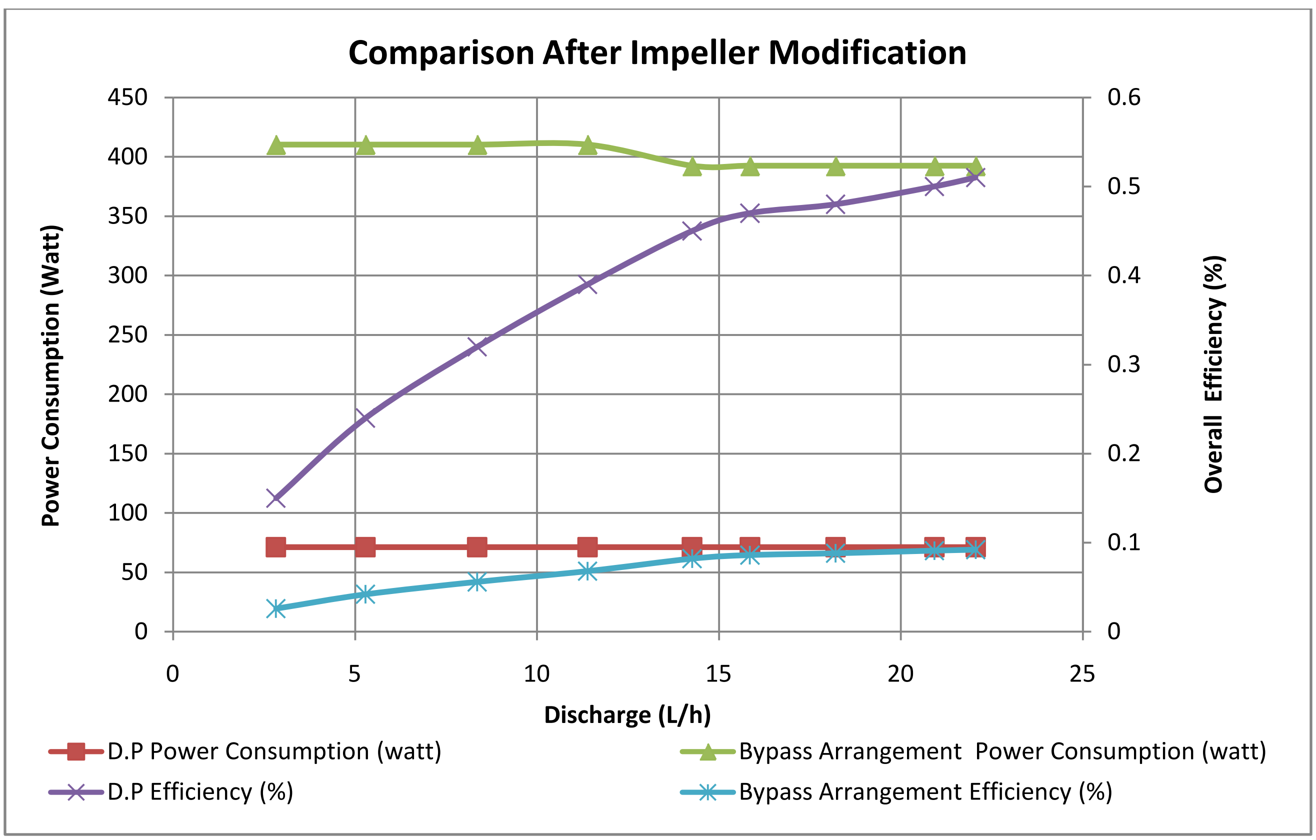

Figure 5.14 : Comparative Performance Curves of Both Pumps after Impeller Diameter Modification

From the figure 5.13 and 5.14, it is clear that, for same flow rates and heads, the power consumption of the bypass centrifugal arrangement is higher the power consumption of the dosing pumps. But in case of impeller modification the power consumption of the bypass centrifugal arrangement drops down rapidly. Because, by reducing the diameter of the impeller, it imparts low energy to the fluid and hence less amount of power is required to operate the pump by compensating head and discharge. The power consumption of dosing pump is 71.36 watt and it is constant. But with the increase of the discharge the power consumption of the bypass centrifugal arrangements is decreases. For new arrangement the power consumption is maximum (410.3 watt) at corresponding head and discharge of 14 m and 2.83 L/h respectively. This is almost 40% lower than the previous maximum power consumption. The minimum power consumption is found 392.48 watt at corresponding 6.01 meter head and 22.05 L/h discharge. This is almost 43% lower than the previous minimum power consumption. With the modification, flow metering range of the bypass arrangement is found (2.83-22.05L/h) at corresponding heads of (14-22.05 m) respectively. The range of maximum to minimum power consumption is (410-392.48 watt). Whereas, the previous bypass centrifugal arrangement (without impeller modification) exhibits flow metering range of (2.66-21.83 L/h) at corresponding heads of (13.19-28.51m). Where, the maximum to minimum power consumption range is around (677.92-624.4 watt) respectively. The maximum overall efficiency of the dosing pump is found 0.51% at corresponding head of 6.01 m and minimum overall efficiency is found 0.15% at corresponding head of 14m. On the other hand, the maximum and minimum overall efficiency of the centrifugal bypass arrangement is found 0.092% and 0.026% respectively at corresponding head of 6.01 and 14 m. After impeller modification, the maximum overall efficiency of the bypass centrifugal pump reduces form 0.13% to 0.092 %. The reasons behind lowering the overall efficiency are- reduction of head and discharge after impeller attenuation. Ultimately it reduces the hydraulic power. But impeller modification is an energy efficient approach as it reduces the input power consumption. So after modification, the operation will be more cost effective.

Even after modification, the centrifugal bypass flow arrangement's power consumption remains much higher than the dosing pump. Moreover, the overall efficiency of the system has been decreased after modification. That's why the setup has been further tested at low voltage to investigate better performance.

5.6 Comparative Performance Curves at Low Voltage Operation after Impeller Modification

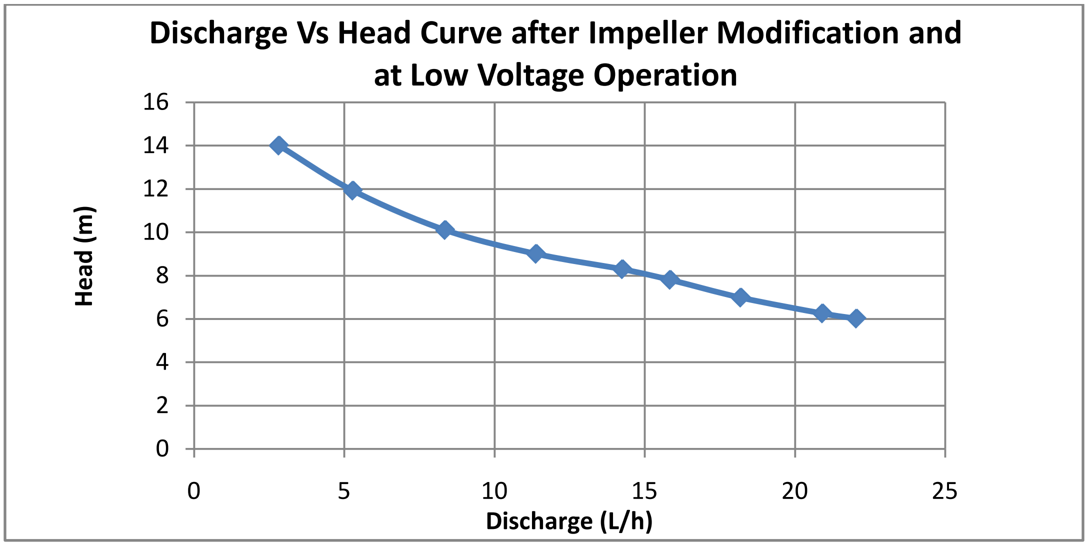

Figure 5.15: Discharge Vs Head Curve of both Pumps at Points of Comparison after Impeller Modification and at Low Voltage Operation

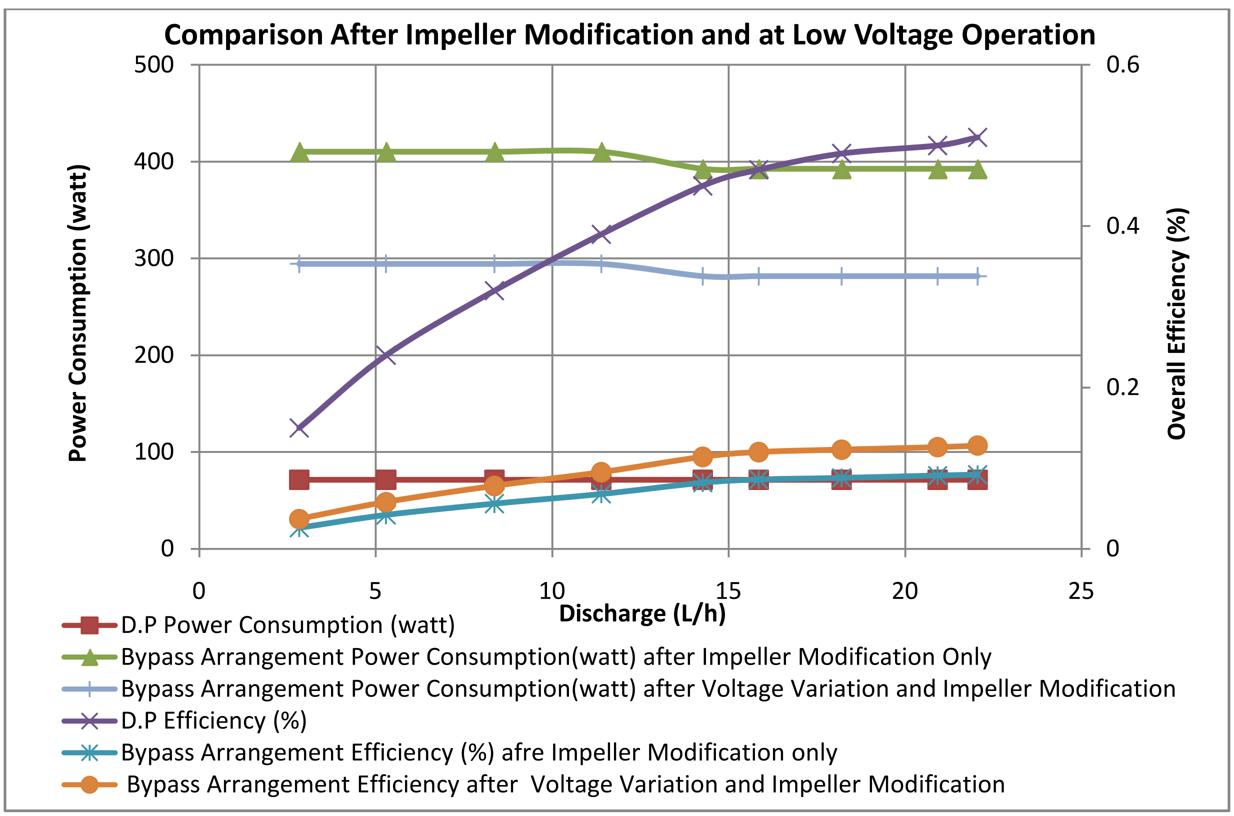

Figure 5.16 : Comparative Performance Curves after Impeller Modified and at Low Voltage Operation

From the experiment, it is found that, after reducing the impeller diameter the setup was able to run at a lower voltage of 160 volt without altering the previous discharge Vs head curve (is shown in Figure 5.15). As pump speed remained constant at this operating voltage. That is why the maximum power consumption is found 281.6 watt at same corresponding head and discharge rate of 14 meter and 2.83 L/h respectively. The maximum power consumption reduces form 410.3 watt to 281.6 watt which is approximately 32% lower than the previous modification (i.e. only with impeller dia reduction). This is an energy efficient technique to operate the bypass centrifugal arrangement up to a corresponding discharge and head of 2.83-22.05 L/h and 6.01-14 m respectively. The maximum overall efficiency of the centrifugal bypass flow arrangement increases form 0.092% to 0.128 percent which is around 28 % higher than the previous modification.

In summery is can be stated that, the range of heads and discharge rates of centrifugal pump can be altered by bypass flow arrangement. In this project, starting from the primary stage of experiment, the flow metering has been successfully carried out by the new approach but the energy efficiency was not up to the mark initially because of its high power consumption. Moreover the discharge rate of the centrifugal pump was high. In order to overcome this problem the impeller diameter has been modified. Reduced impeller diameter decreases power consumption by compensating heads and discharge. It also slightly reduces the pump overall efficiency but does not affect that much on pump operation. As the arrangement itself running at a very low efficiency and impeller modification reduces the power consumption by 40% compared to bypass centrifugal arrangement without modification. Operability of the modified system was tested at low voltage, which also showed improvement of overall efficiency and reduction of further power consumption compared to the modification of phase three. It decreases the cost of operation. Moreover, the capital cost can be saved by this bypass flow arrangement is approximately 87.5% of the capital cost of the dosing pump. So this system is more cost effective in terms of capital investment.

5.7 Performance, Energy Consumption and Cost Analysis

Table 5.1: Summery of Performance, Energy Consumption and Cost Analysis

Dosing Pump (Alpha ALPb Model)	**Modified Centrifugal Bypass Arrangement**	**Cost Difference From Dosing Pump**
Performance and Energy Consumption Maximum Head: 72 meter Maximum Discharge: 22.4 L/h Minimum Head: 0 meter Minimum Discharge: 1.2 L/h Maximum Power Consumption: 72 watt Minimum Power Consumption: 72 watt	**Performance and Energy Consumption** Maximum Head: 14 meter Maximum Discharge: 22.05 L/h Minimum Head: 6.01 meter Minimum Discharge: 2.83 L/h Maximum Power Consumption: 294.4 watt Minimum Power Consumption: 281.6 watt	
Cost Analysis Capital Cost Pump Cost: Tk. 25000/= BDT Variable Costs Piping Cost: Tk. 1000/= BDT Instrumentation Cost: Tk. 1000/= BDT Tank Cost: Tk. 500/= BDT Total Cost of the System: Tk. 27,000/= BDT	**Cost Analysis** Capital Cost Pump Cost: Tk. 3200/= BDT Variable Costs Piping Cost: Tk. 1500/= BDT Instrumentation Cost: Tk. 1500/= BDT Tank Cost: Tk. 1000/= BDT Total Cost of the System: Tk. 7,200/= BDT	**Capital Cost** = 21,800/= BDT
Operating Cost : 0.432 Tk. / h	Operating Cost: 1.764 Tk./ h	Operating Cost =1.332 Tk./ h

NOTE: Cost of Electricity = 6 Tk. / kWh.

5.8 Implementation of Bypass Centrifugal Arrangement in Salt Industries of Bangladesh

Already, total two salt industries (Molla Salt and Super Salt Industriy) of Narayanganj zone has successfully installed bypass centrifugal arrangement for dosing of water and KIO_3 mixture. This project was run by BUET for upgradation of salt iodations plant in Narayanganj zone. In Molla Salt Industries, the solution of 450g KIO3 in 13 liter water could be successfully dosed by the bypass arrangement to mix up with 5 tons of salt per hour.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

i. Performance test of a variable stroke diapharm type dosing pump and a fixed speed centrifugal pump was carried out. The results show that, both operate at low efficiencies (4% for dosing and 13% for centrifugal pump) at their optimum operation. Dosing pumps are less available and more expensive compared to the centrifugal pumps.

ii. Low discharge rate of dosing pump of 1.4-22.4 L/h could not be directly attained by the smallest available centrifugal pump which range from 11 -2650 L/h for similar heads. Alternately bypass flow technique could be successfully applied for attaining similar flow from the centrifugal pump.

iii. Using bypass flow control technology the centrifugal pump was able to discharge very similar flow compare to the dosing pump output under same pressure. The bypass flow had the added advantage of being continuous instead of being pulsating. The major part of the return flow in this arrangement churns the dosing fluid in the supply tank eliminating the need of stirrer. However, the efficiency of the bypass flows was much less. Only about 0.14% compared to 4% efficiency attained by the dosing pump.

iv. Reducing the impeller diameter (form 127mm –78mm) by 38.5 % reduced the power consumption by 40% compared to bypass flow arrangement without modification. But the maximum overall efficiency slightly decreased. The setup was also tested successfully at low voltage operation upto 160 volt input. It further reduced the power consumption by 32% compared to the modification of third phase and hence increased the maximum overall efficiency by 28%.

v. Capital cost can be saved by this bypass centrifugal arrangement is Tk. 21,800, which is around 87.5% of the capital cost of the dosing pump, while the electricity cost would be four times higher compared to the dosing pump. The operating cost of this bypass centrifugal arrangement would be around Tk.1.764/h. So it can be a cost effective solution.

6.2 Recommendations

i. Pump flow, specially dosing pump flow is pulsating. Using air chamber may improve flow continuity which may improve pump performance.

ii. In addition to the impeller diameter reduction, other dimensional parameters like- blade angle, blade pitch etc. can be modified to attain small flow rate and lower power consumption.

iii. Employing smaller horse power motor, speed controlling of motor using inverter could be tried out to improve the efficiency.

iv. More accurate measurement instrumentation may be used for more detailed performance study.

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Appendix A

Performance Curves of Dosing Pump

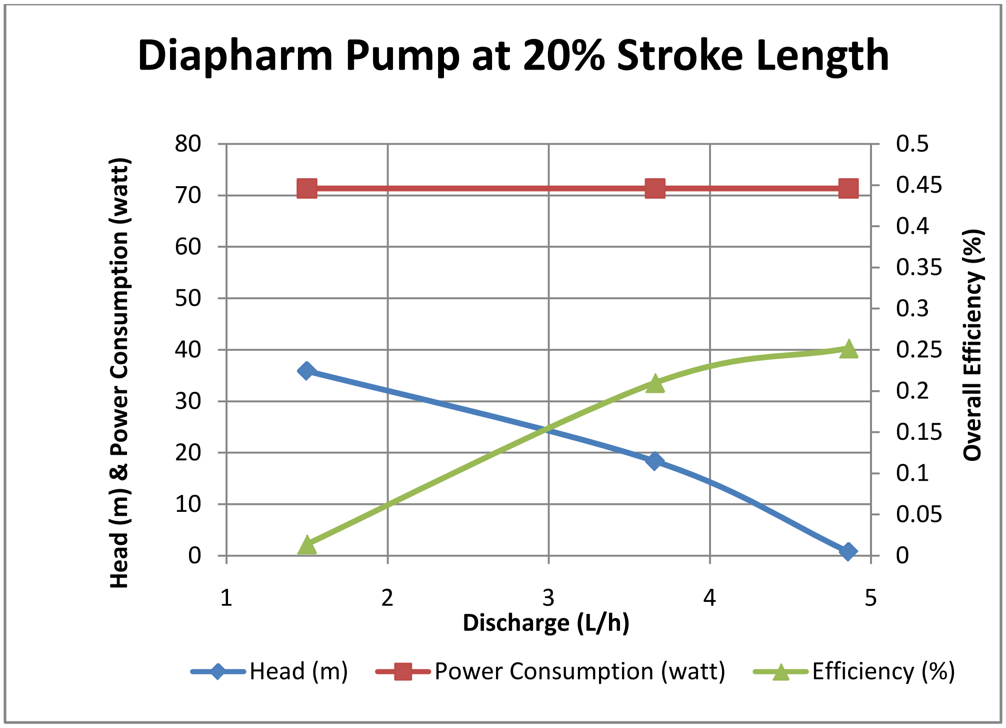


Figure A.1: Performance Curves of Dosing Pump at 20% Stroke

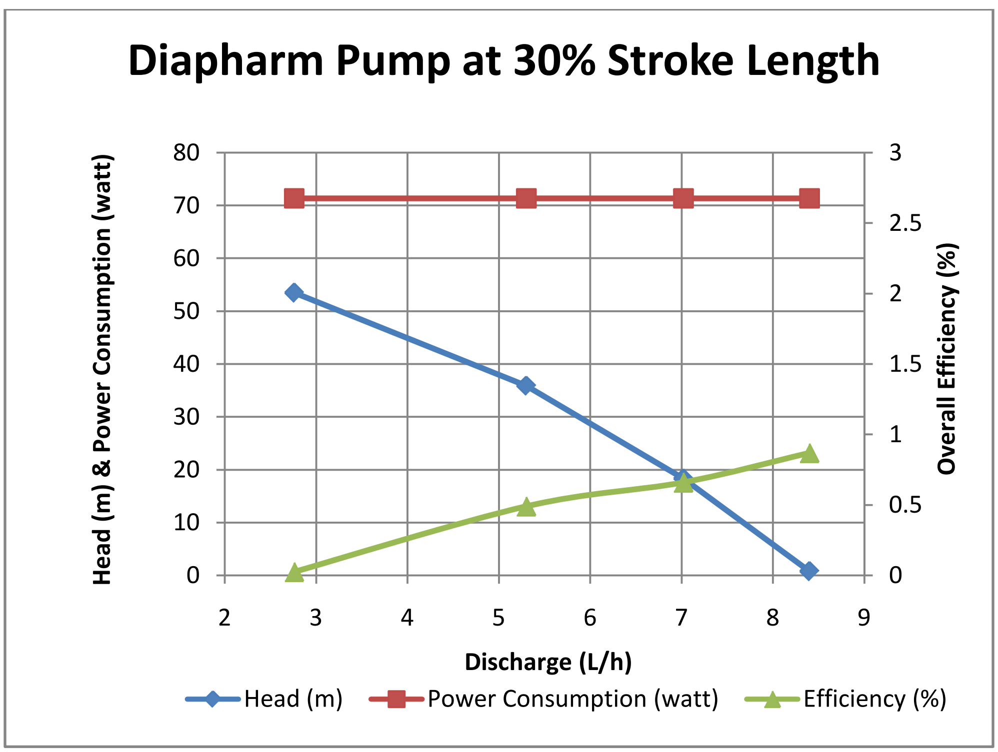


Figure A.2: Performance Curves of Dosing Pump at 30% Stroke

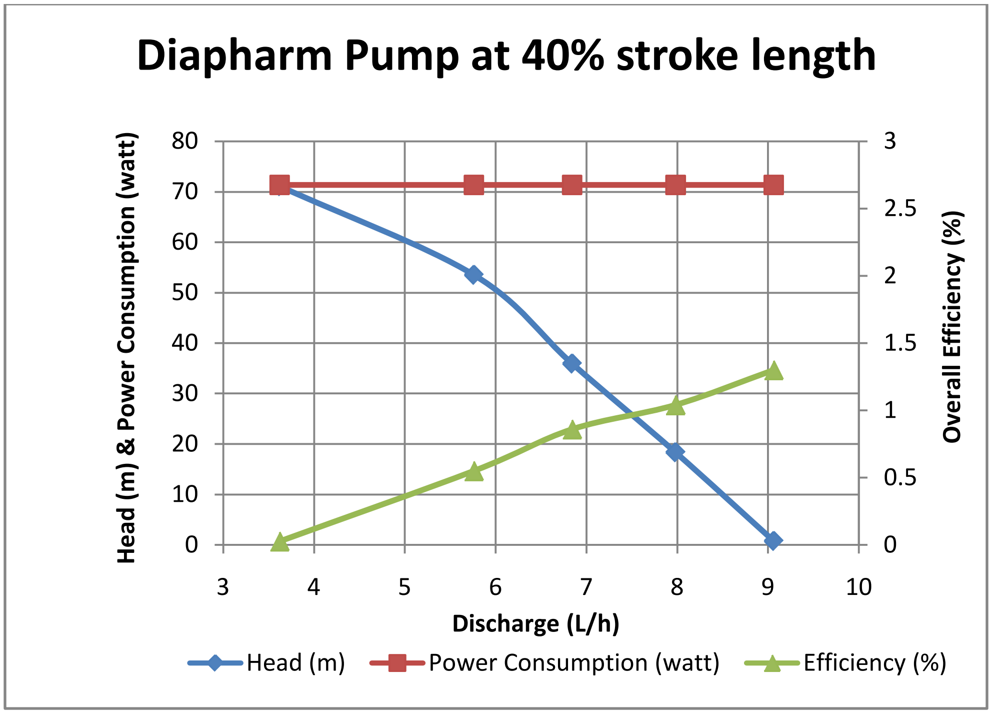


Figure A.3: Performance Curves of Dosing Pump at 40% Stroke

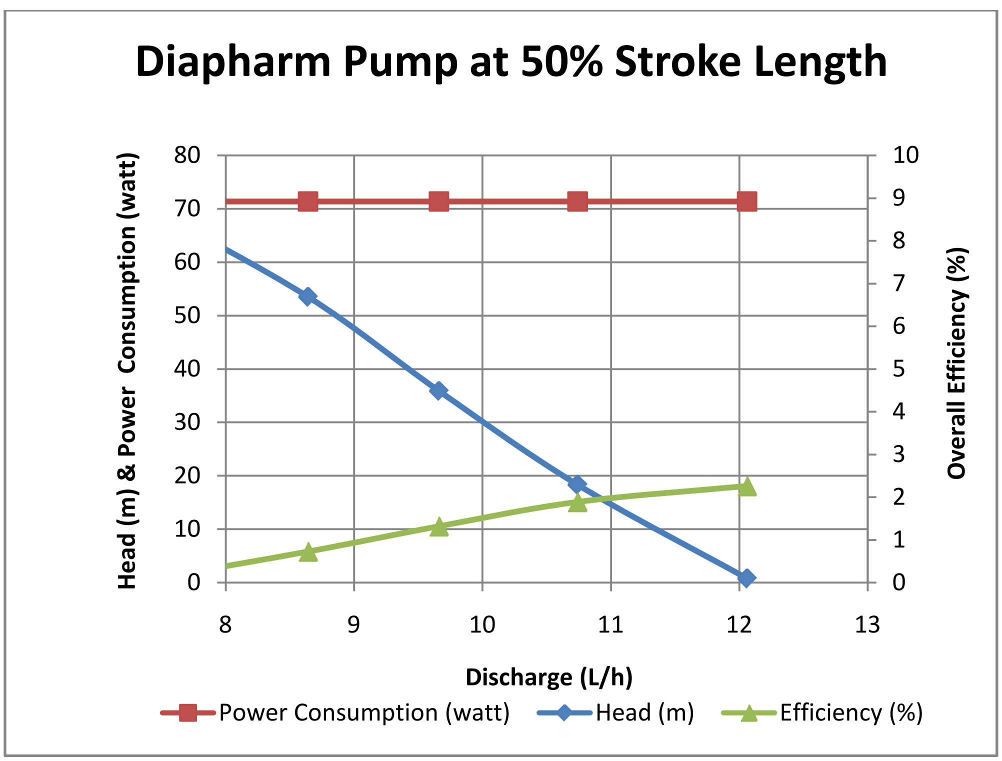


Figure A.4: Performance Curves of Dosing Pump at 50% Stroke.

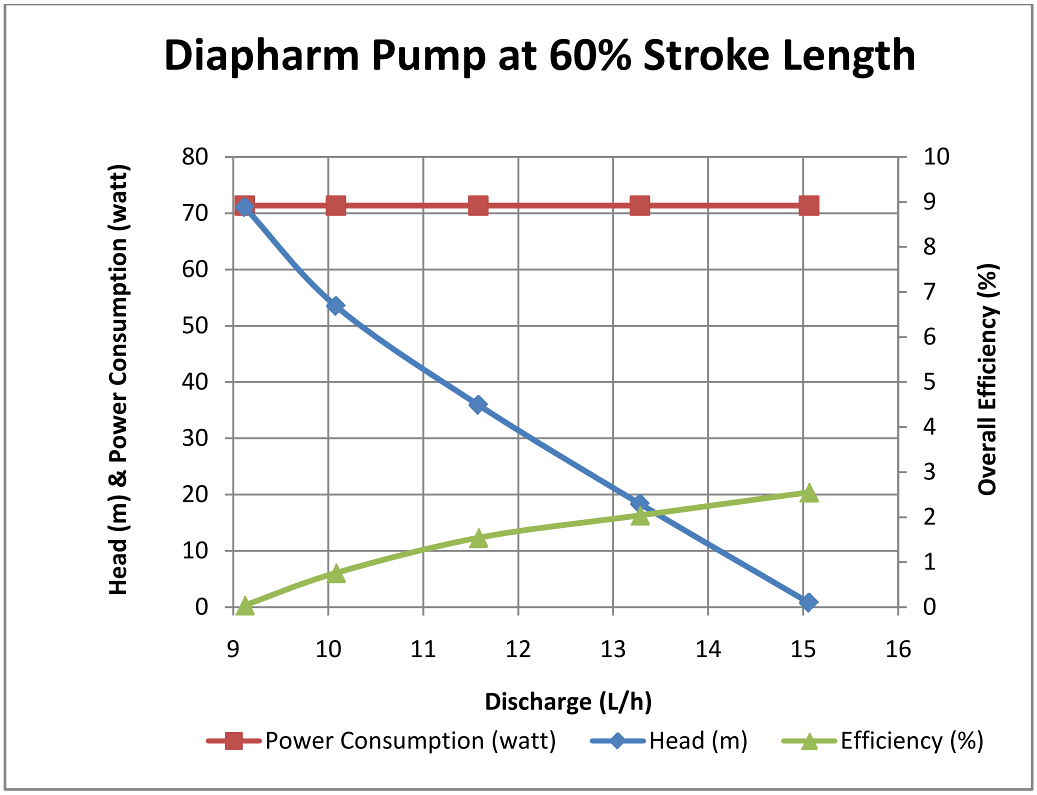


Figure A.5: Performance Curves of Dosing Pump at 60% Stroke

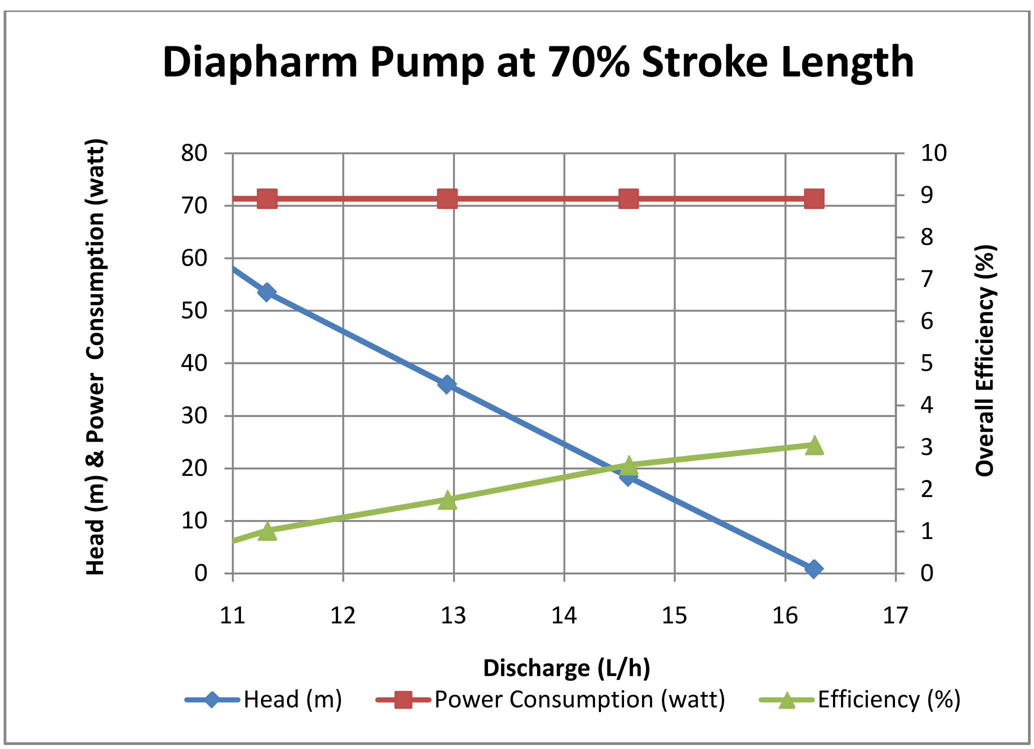


Figure A.6: Performance Curves of Dosing Pump at 70% Stroke

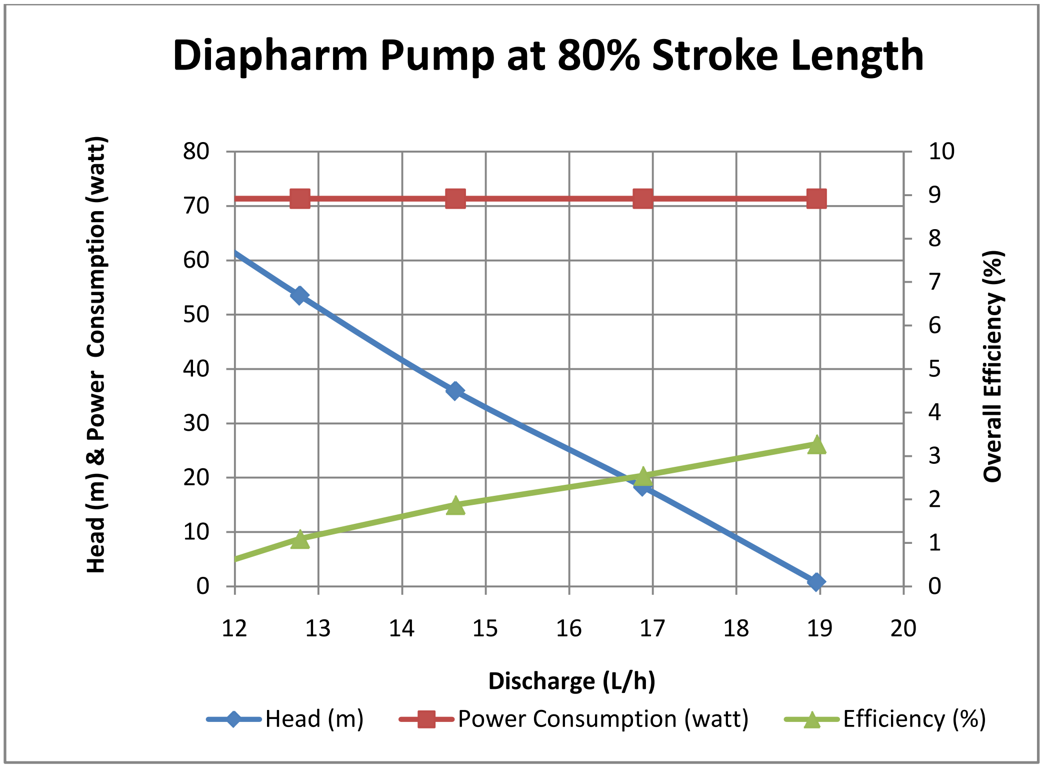


Figure A.7: Performance Curves of Dosing Pump at 80% Stroke

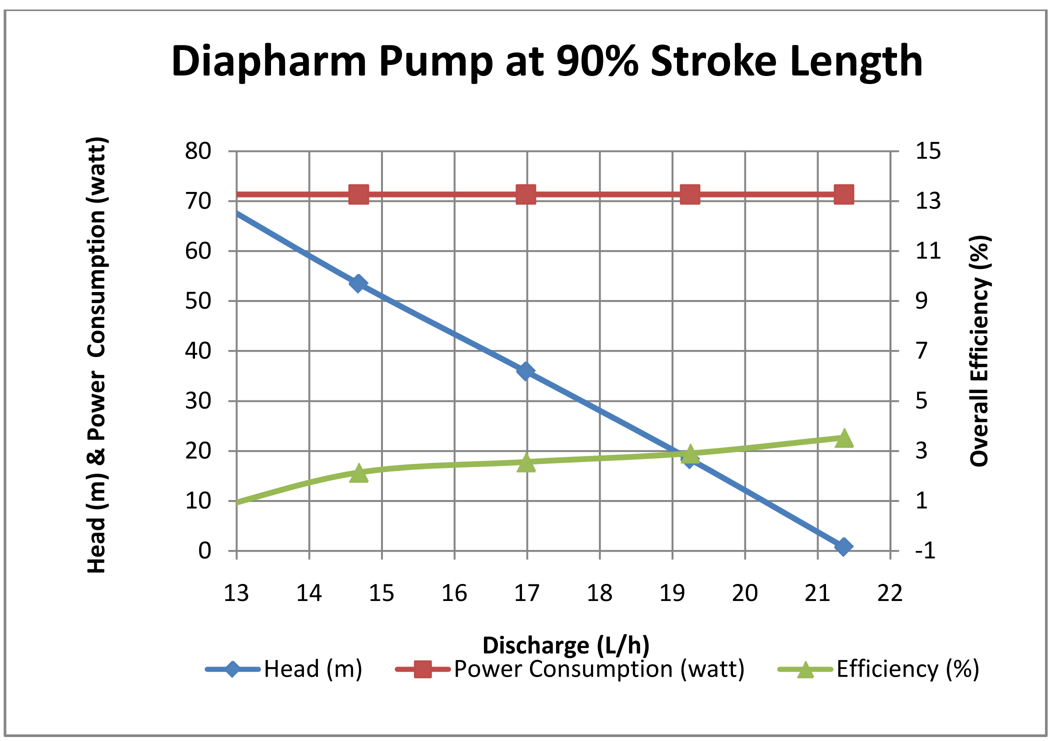


Figure A.8: Performance Curves of Dosing Pump at 90% Stroke

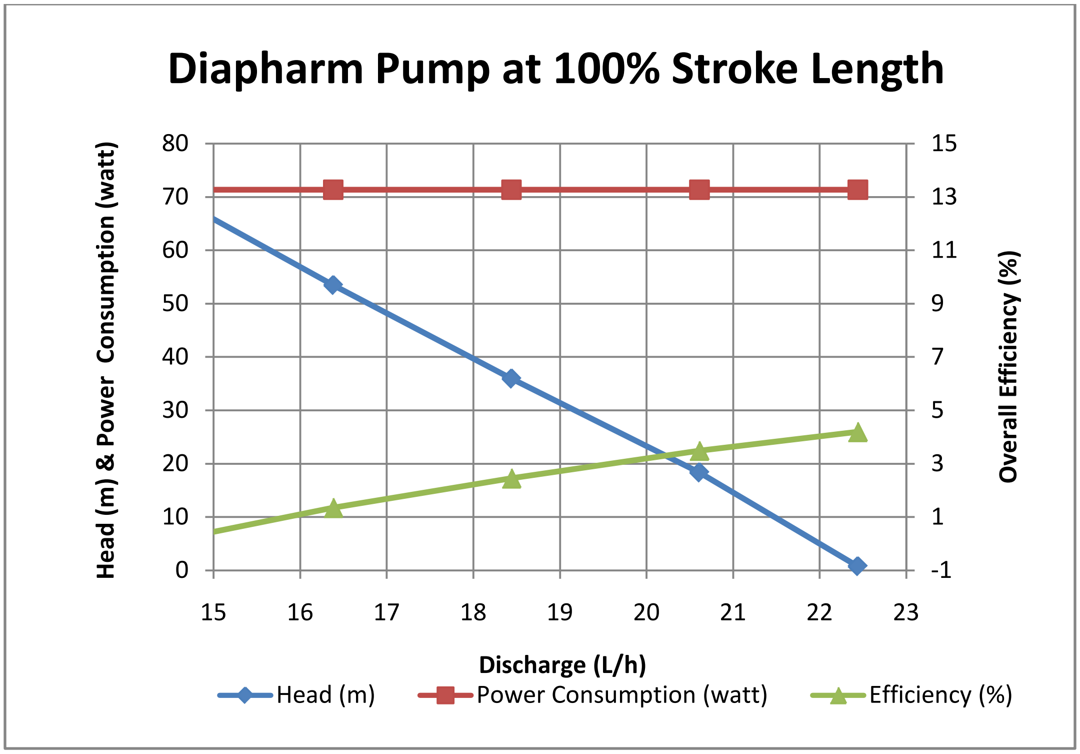


Figure A.9: Performance Curves of Dosing Pump at 100% Stroke

Appendix B

Sample Calculations

B.1 Sample Calculation of Dosing Pump for 71.3 m Head (at 100% Stroke Length)

Input volt=223

Current= 0.4 amp

Input Power (Pi) = VICosǾ= 223X0.4X0.8 =71.34 watt

Total Head= Hs + Z + H_d = 0.69+0.0825+70.3=71.07

Flow Rate Q= 4.28E-6 m^3/s

Hydraulic Power P_o= YQH = 9.81X 1000X4.28E-6X71.3=2.99 watt

Overall Efficiency = P_o / Pi = 4.19

B.2 Sample Calculation of Centrifugal Pump (at 28.39 m Head)

Input volt=223

Current= 3.8 amp

Input Power (Pi) = VICosǾ= 223X3.8X0.8 =677.92watt

Total Head= Hs + Z + H_d = 0.796+0.177+27.417=28.39m

Flow Rate Q= 3.167E-6 m^3/s

Hydraulic Power P_o= YQH = 9.81X1000X3.167E-6X28.39 =0.88069 watt

Overall Efficiency = P_o / Pi = 0.13%

B.3 Sample Calculation of Bypass Centrifugal Arrangement (at 30.4m Head)

Input volt=223

Current= 3.8 amp

Input Power (Pi) = VICosǾ= 223X3.8X0.8 =677.92watt

Total Head= Hs + Z + H_d = 0.796+0.177+29.256=30.4m

Flow Rate Q= 4.0E-7 m^3/s

Hydraulic Power P_o= YQH = 9.81X 1000X4.0E-7X30.4 =0.1192 watt

Overall Efficiency = P_o / Pi = 0.0175%

B.4 Sample Calculation of Comparison of Bypass Centrifugal Arrangement with Dosing Pump (at 28.35m Head)

Input volt=223

Current= 3.8 amp

Input Power (Pi) = VICosǾ= 223X3.8X0.8 =677.92watt

Total Head= Hs + Z + H_d = 0.796+0.177+27.412=28.35.4m

Flow Rate Q= 7.38E-7 m^3/s

Hydraulic Power P_o= YQH = 9.81X 1000X7.38E-7X30.4 =0.2055 watt

Bypass Centrifugal Arrangement Efficiency = P_o / Pi = 0.034%

Dosing Pump Overall Efficiency = P_o / Pi = 0.289%

B.5 Sample Calculation of Comparison of Bypass Centrifugal Arrangement with Dosing Pump after Impeller Modification (at 28.35m Head)

Input volt=223

Current= 2.2 amp

Dosing Pump Input Power (Pi) = VICosǾ= 223X0.4X0.8 =71.34 watt

Centrifugal Arrangement Input Power (Pi) = VICosǾ= 223X2.2X0.8 =392.48watt

Total Head= Hs + Z + H_d = 0.796+0.177+5.624=6.594m

Flow Rate Q= 5.583E-6 m^3/s

Hydraulic Power P_o= YQH = 9.81X 1000X5.583E-6X30.4 =0.361 watt

Overall Efficiency of Bypass Centrifugal Arrangement= P_o / Pi = 0.091%

Overall Efficiency of Dosing Pump= P_o / Pi = 0.50%

B.6 Sample Calculation of Comparison of Bypass Centrifugal Arrangement with Dosing Pump after Impeller Modification and Voltage Variation (at 28.35m Head)

Input volt=223

Current= 2.2 amp

Dosing Pump Input Power (Pi) = VICosǾ= 223X0.4X0.8 =71.34 watt

Centrifugal Arrangement Input Power (Pi) = VICosǾ= 160X2.2X0.8 =281.6watt

Total Head= Hs + Z + H_d = 0.796+0.177+5.624=6.594m

Flow Rate Q= 5.583E-6 m^3/s

Hydraulic Power P_o= YQH = 9.81X 1000X5.583E-6X30.4 =0.361 watt

Overall Efficiency of Bypass Centrifugal Arrangement= P_o / Pi = 0.128%

Overall Efficiency of Dosing Pump= P_o / Pi = 0.50%

Appendix C

Experimental Data

Centrifugal Pump Performance Data

Table C.1: Centrifugal Bypass Arrangement Performance Data

Observations	Discharge (L/h)	Head (m)	Input Power (Watt)	Overall Efficiency (%)
1.	115.08	0.973	606.56	0.16
2.	45.12	7.64	606.56	0.154
3.	22.92	13.264	624.24	0.133
4.	11.52	21.7	642.24	0.11
5.	1.44	29.256	677.92	0.0175

Table C.2: Data Set of Performance Comparison without Impeller Modification

Obs.	Discharge (L/h)	Head (m)	Dosing Pump Power Input (watt)	Centrifugal Pump Power Input (watt)	Hydraulic Power of both Pumps (watt)	Dosing Pump Overall Efficiency (%)	Bypass Centrifugal Pump Overall Efficiency (%)
1.	2.66	28.39	71.36	677.92	0.20665	0.289	0.0304
2.	6.67	25.53	71.36	660.08	0.464	0.65	0.0703
3.	8.0	24.25	71.36	660.08	0.5287	0.74	0.0801
4.	10.93	21.27	71.36	642.24	0.634	0.884	0.0987
5.	13.67	19.14	71.36	642.24	0.731	1.024	0.1138
6.	14.66	17.87	71.36	642.24	0.734	1.028	0.1143
7.	17.33	16.17	71.36	6.24.40	0.764	1.071	0.1224
8.	19.67	14.31	71.36	6.24.40	0.767	1.075	0.1229
9.	23.01	13.19	71.36	6.24.40	0.83	1.163	0.1329

Table C.3: Corresponding Current and Voltage without Impeller Modification of the Centrifugal Pump

Obs.	Centrifugal Pump Current (amps)	Dosing Pump Current (amps)	Voltage (volt)
1.	3.8	0.4	223
2.	3.7	0.4	223
3.	3.7	0.4	223
4.	3.6	0.4	223
5.	3.6	0.4	223
6.	3.6	0.4	223
7.	3.5	0.4	223
8.	3.5	0.4	223
9.	3.5	0.4	223

Table C.4: Data Set of Performance Comparison after Impeller Modification and at Low Voltage Operation

Obs.	Head (m)	Discharge (L/h)	Centrifugal Pump Input Power (watt)	Dosing Pump Input Power (watt)	Fluid Power (watt)	Overall Eff. (%) Centrifugal Pump	Overall Eff. (%) Dosing Pump	Input Power after Voltage Variation (watt)	Overall Eff. (%) after Low Voltage Operation
1.	14.0	2.83	410.0	71.36	0.108	0.026	0.15	294.4	0.037
2.	11.92	5.29	410.0	71.36	0.172	0.042	0.24	294.4	0.058
3.	10.10	8.36	410.0	71.36	0.230	0.056	0.32	294.4	0.078
4.	9.0	11.39	410.0	71.36	0.279	0.068	0.39	294.4	0.095
5.	8.29	14.26	392.48	71.36	0.322	0.082	0.45	281.6	0.114
6.	7.80	15.85	392.48	71.36	0.337	0.086	0.47	281.6	0.12
7.	6.98	18.20	392.48	71.36	0.346	0.088	0.48	281.6	0.123
8.	6.59	20.10	392.48	71.36	0.356	0.091	0.5	281.6	0.126
9.	6.01	22.05	392.48	71.36	0.361	0.092	0.51	281.6	0.128

Table C.5: Corresponding Current Requirement at Low voltage Operation after Impeller Modification

Obs.	Centrifugal Pump Current (amps)	Discharge (L/h)
1.	2.3	2.83
2.	2.3	5.29
3.	2.3	8.36
4.	2.3	11.39
5.	2.2	14.26
6.	2.2	15.85
7.	2.2	18.20
8.	2.2	20.10
9.	2.2	22.05

Note: Low Operating Voltage- 160 V

Dosing Pump Performance Data

Table C.6: Dosing Pump Head Vs Discharge Data Set

Obs.	Head (m)	Discharge (L/h) at Various Stroke Length								
		100%	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**
1.	0.7725	22.44	21.36	18.96	16.26	15.06	12.06	9.06	8.4	4.86
2.	18.34	20.61	19.24	16.88	14.58	13.28	10.74	7.98	7.02	3.66
3.	35.92	18.44	16.98	14.64	12.94	11.58	9.66	6.84	5.3	1.5
5.	53.49	16.38	14.68	12.78	11.31	10.08	8.64	5.76	2.76	4.86
5	71.07	14.42	12.58	11.06	10.1	9.12	7.34	3.62		

Note:

Constant Voltage 223 Volt

Input Current is 0.4 amps

Constant Power Consumption of 71.36 watt

Table C.7: Dosing Pump Performance Data

For 20 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	4.86	0.7725	71.36	0.252
2.	3.66	18.34	71.36	0.21
3.	1.5	35.92	71.36	0.0141

For 30 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	8.4	0.7725	71.36	0.87
2.	7.02	18.34	71.36	0.66
3.	5.3	35.92	71.36	0.49
4.	2.76	53.49	71.36	0.025

For 40 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	9.06	0.7725	71.36	1.3
2.	7.98	18.34	71.36	1.04
3.	6.84	35.92	71.36	0.86
4.	5.76	53.49	71.36	0.55
5.	3.62	71.07	71.36	0.027

For 50 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	12.06	0.7725	71.36	2.26
2.	10.74	18.34	71.36	1.89
3.	9.66	35.92	71.36	1.32
4.	8.64	53.49	71.36	0.73
5.	7.34	71.07	71.36	0.035

For 60 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	15.06	0.7725	71.36	2.55
2.	13.28	18.34	71.36	2.04
3.	11.58	35.92	71.36	1.54
4.	10.08	53.49	71.36	0.76
5.	9.12	71.07	71.36	0.043

For 70 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	16.26	0.7725	71.36	3.06
2.	14.58	18.34	71.36	2.58
3.	12.94	35.92	71.36	1.76
4.	11.31	53.49	71.36	1.02
5.	10.1	71.07	71.36	0.048

For 80 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	18.96	0.7725	71.36	3.28
2.	16.88	18.34	71.36	2.55
3.	14.64	35.92	71.36	1.88
4.	12.78	53.49	71.36	1.1
5.	11.06	71.07	71.36	0.054

For 90 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	21.36	0.7725	71.36	3.54
2.	19.24	18.34	71.36	2.91
3.	16.98	35.92	71.36	2.56
4.	14.68	53.49	71.36	2.14

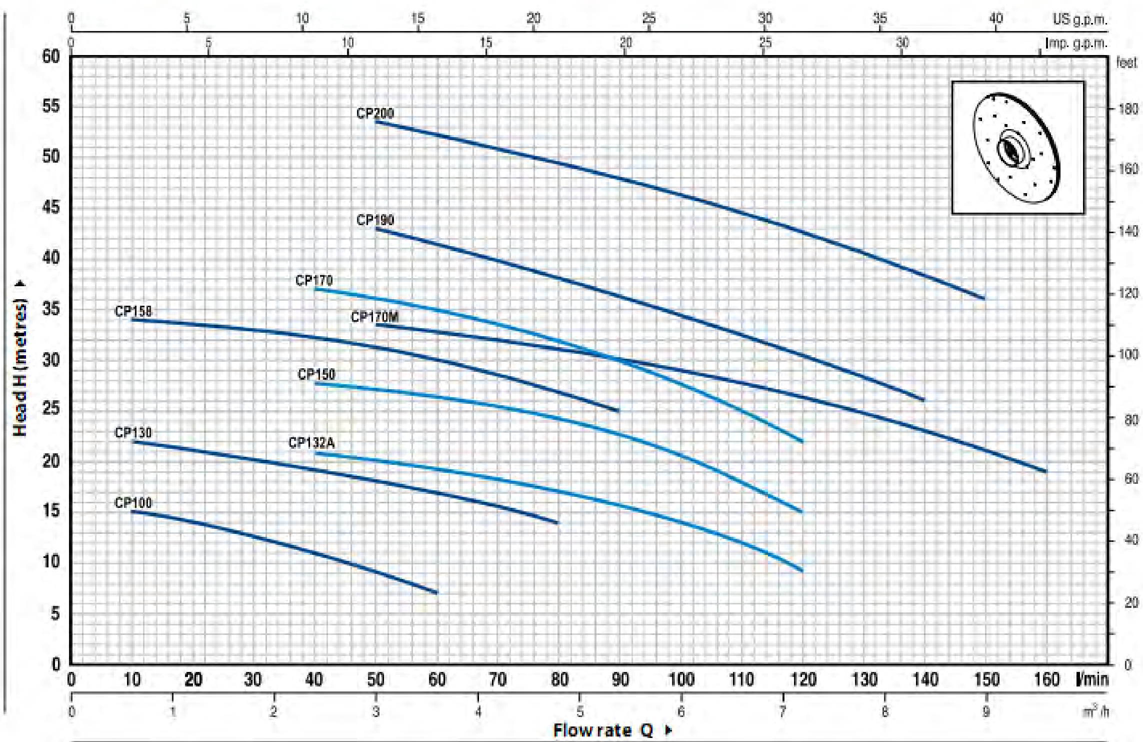
For 100 % Stroke Length of Dosing Pump				
Obs.	**Discharge (L/h)**	**Head (m)**	**Power Consumption (watt)**	**Overall Efficiency (%)**
1.	22.44	0.7725	71.36	4.19
2.	20.61	18.34	71.36	3.49
3.	18.44	35.92	71.36	2.45
4.	16.38	53.49	71.36	1.345
5.	14.42	71.07	71.36	0.065

Appendix D

Performance Data of Pedrollo Centrifugal Pump

Performance Data of Pedrollo (Cpm150 Model) Centrifugal Pump

CHARACTERISTIC CURVES AND PERFORMANCE DATA 50 Hz n= 2900 1/min HS= 0 m



MODEL		POWER		Q	m³/h	0	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	7.8	8.4	9.0	9.6
Single-phase	Three-phase	kW	HP		l/min	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
CPm 100	–	0.25	0.33			16	15	14	12.5	11	9	7										
CPm 130	CP 130	0.37	0.50			23	22	21	20	19	18	17	15.5	14								
CPm 132A	CP 132A	0.60	0.85			23	–	22	21.5	21	20	19	18	17	16	14	12	9				
CPm 150	CP 150	0.75	1			29.5	–	29	28.5	28	27.5	26.5	26	24.5	23	21	18	15				
CPm 158	CP 158	0.75	1	H	metres	36	34	33.5	33	32.5	31.5	30	28.5	27	25							
CPm 170	CP 170	1.1	1.5			41	–	–	38	37	36	35	33.5	32	30	27.5	25	22				
CPm 170M	CP 170M	1.1	1.5			36	–	–	35	34.5	33.5	33	32	31	30	29	28	26.5	25	23	21	19
CPm 190	CP 190	1.5	2			48	–	–	46	44.5	43	41.5	40	38	36	34.5	32.5	30.5	28	26		
–	CP 200	2.2	3			56	–	–	55	54.5	53.5	52	51	49.5	48	46	44.5	42.5	40.5	38.5	36	

Q = Flow rate **H** = Total manometric head **HS** = Suction height

Tolerance of characteristic curves in compliance with EN ISO 9906 App. A.