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Design and Fabrication of an Automated Discharge Collection Unit for the Synthetic Hydro-experimental Machine.

FYP 18-03

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Declaration

We hereby declare that the work contained in this report is original; researched and documented by the undersigned students. It has not been used or presented elsewhere in any form for award of any academic qualification or otherwise. Any material obtained from other parties have been duly acknowledged. We have ensured that no violation of copyright or intellectual property rights have been committed.

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Abstract

The synthetic hydro-experimental machine used for fluid mechanics experiments in the fluids lab at Jomo Kenyatta University employs an older technology in the measurement of the dynamic pressure component in fluids. The machine is wholly mechanical as most of the parameter manipulations and measurements are done mechanically. During fluid flow experiments such as determining the coefficient of discharge for the Venturi and the orifice, one controls the flow rate by opening the gate valve in small steps by hand, reads the differential pressure from the alcohol manometers, measures the temperature, and time of the discharge simultaneously, and finally the weight of the discharge. The step size can be inconsistent since it is determined by human intuition. The initiation of time and temperature measurement is to be synchronized with discharge collection. This is of course not usually the case with this machine since it is mechanical and cannot be achieved by a human. These limitations result in a huge error margin in the calculation of the coefficient of discharge.

This project proposal seeks to reduce this error margin while maintaining the credibility of the experiment through the automation of the discharge collection unit. This will involve precisely controlling the gate valve in steps, and automating the discharge collection mechanism by techniques such as precisely collecting the discharge in steps, digitizing the temperature, time, and weight measurement of the discharge, and reducing environmental influence on these measurements. An ergonomic user interface would also be integrated to allow for parameter manipulations and monitoring.

This automation is expected to reduce the oftenly huge error margins in fluid flow experiments due to human errors.

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GPIO General Purpose Input Output

SKE Single Kernel Estimate

1 Introduction

1.1 Background

Fluid flow properties are measured using a variety of meters, including the turbine-type flow meter, the rotameter, the orifice meter, and the venturi meter [5]. Each meter works by altering a physical property of the flowing fluid and then measuring that change. The flow is then related to the measured change [6].

The Synthetic Hydro-Experimental machine, currently installed in JKUAT, is a configurable machine with these flow meters. This machine is used to conduct experiments to establish relationships between the fluid flow properties and the behavior of the flow. It has a lift pump, gate valves, alcohol manometers, pressure gauges, a Pelton turbine, a Venturi, an orifice, and water reservoirs. During experiments, the lift pump is turned on, and the discharge valve is fully opened to establish a steady flow. The discharge valve is then closed. The valve is opened in small steps depending on the number of steps required. For each step, the discharge is collected, and its temperature is measured within a specific time interval. Finally, the weight of the collected discharge is also measured.

1.2 Problem statement

In fluid flow experiments involving the Venturi, and the orifice, the discharge steps are to be precisely opened, and the time and temperature measurements are taken simultaneously with discharge collection in order to obtain values that are within a tolerable range. This is not the case with the Synthetic Hydro-Experimental machine currently used in JKUAT since it is wholly mechanical and some of the simultaneous measurements cannot be simply achieved by a human. The flow rate is controlled by a gate valve in small steps determined by human intuition which can be inconsistent. With these inconsistencies, the results can often be outside the tolerable range. Automating the discharge collection process can minimize the error in the results and still preserve the credibility of the experiment.

1.3 Objectives

1.3.1 Main objective

The main objective of this project is to automate the discharge collection process for the Synthetic Hydro-Experimental machine.

1.3.2 Specific objectives

1. To design an automated discharge flow control unit that can precisely discharge in steps.
2. To design and fabricate a discharge collection unit with automated weight, time and temperature measurements.
3. To design a user interface and the control algorithm.

1.4 Justification

This automation will simplify the discharge collection process and ensure consistency and precision of the results obtained in each step during fluid flow experiments done on the machine. With such automation, one person can also singly complete the experiment with not much strain as opposed to the current state. The automated system will also be modular that it can be easily mounted and dismounted from the main machine with no major adjustments.

2 Literature Review

2.1 Introduction

Fluid flow measurement involves the measurement of the properties of a smooth and uninterrupted stream of flowing particles that conform to a pipe. These flow properties include the coefficient of discharge, mass flow rate, fluid velocity, differential pressure, and conductivity coefficients. They are altered and measured by flow measuring devices such as the Venturi, the Orifice, turbine flow meters and rotameters [7]. These measurements are finally related to the flow using the Bernoulli's equation.

Fluid flow experiments involve collecting the discharge within specific time intervals. This is usually done simultaneously with the temperature measurement of the discharge in order to minimize the environmental effect on this reading. The weight of the discharge is finally measured for the computation of the mass flow rate property of the flow.

2.2 Existing Technologies

Some advanced and even rudimentary technologies have been used in place of the Synthetic Hydro-Experimental machine for the determination of fluid flow properties. The technologies include :

2.2.1 Computational Fluid Dynamics

Computational fluid dynamics (CFD) is a powerful modelling and analysis technique that utilizes finite difference techniques to solve highly non-linear differential equation of pressure, energy, relative humidity, air temperature and velocity [8]. It can be used to model fluid flow in flow measurement devices.

Tukimin et al [1] conducted a CFD analysis using an Single Kernel Estimate (SKE) turbulence model to determine the coefficient of discharge of a Venturi tube, and finally compared the results to those obtained from a physical experimental setup. The test loop shown in figure 2.1 was used both in a physical setup and a CFD model.

They designed a CFD model using the ANSYS Design Modeller software. The model

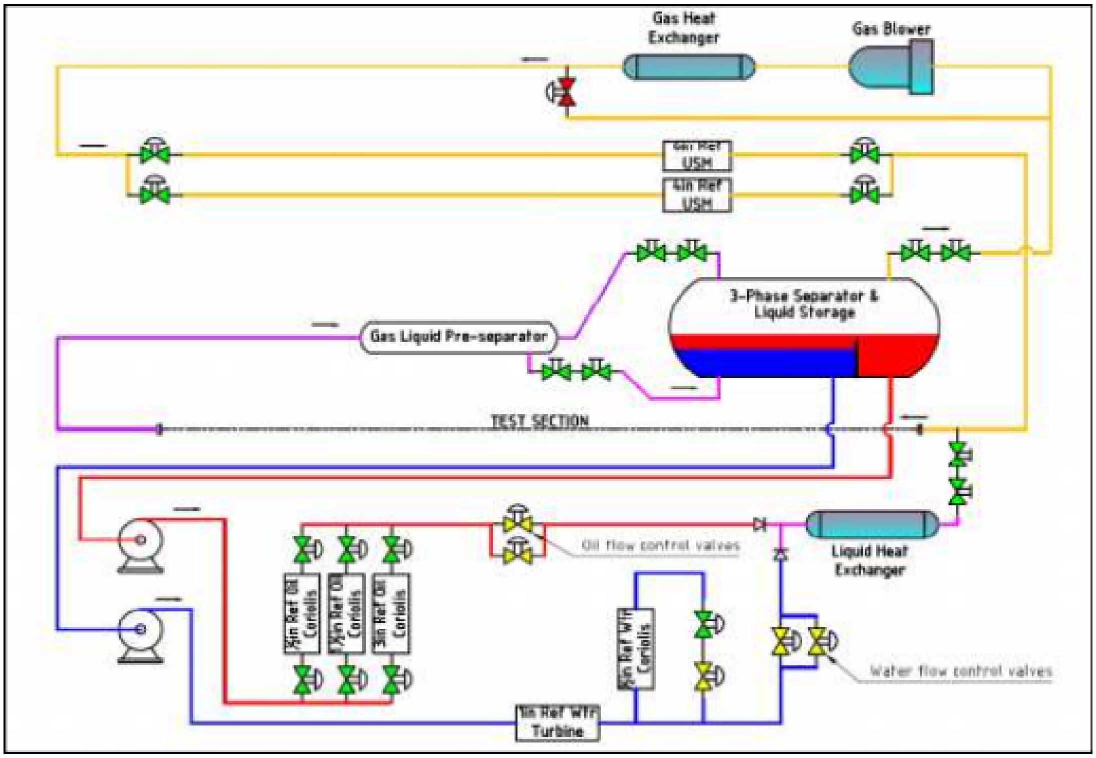

Figure 2.1: Test loop schematic [1]

Table 2.1: Calculated C_d

Venturi under Test	Average Discharge Coefficient	Average Discharge Coefficient
	From experiment	From CFD post
Venturi 1	0.99366	0.984347

consists of a Venturi tube, designed according to the standards ISO 5167:2003 [9], and a liquid and gas system. They did a physical experiment using the same test matrix used in the numerical simulation model. Finally, they computed the coefficient of discharge of the venturi using equationt 2.1.

$$Cd = \frac{4m\sqrt{1-\beta^4}}{\pi\varepsilon d^2\sqrt{200000Dp_1\rho_1}} \tag{2.1}$$

The results obtained in 2.1 showed a difference of less than 1% between the C_d obtained from the two setups.

Table 2.2: Results

Reading No.	Experiment	CFD analysis
1	0.9724	0.9619
2	0.9592	0.9689
3	0.9779	0.9692

Tamhankar et al [2] also did a similar experiment using a CFD model designed in ANSYS Fluent 13.0 utilizing a Realizable k-ϵ turbulence model which is superior to a Standard k-ϵ turbulence model and compared the results to those obtained from an experimental setup show in figure 2.2.

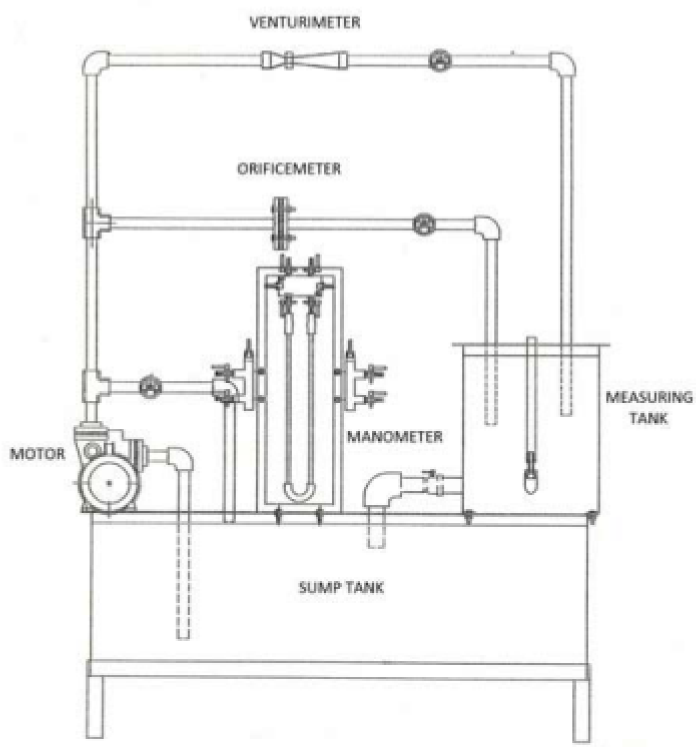

Figure 2.2: Experimental setup [2]

Table 2.2 shows the results obtained from the study

The study concluded that difference in values of the coefficient of discharge obtained from the model and those obtained from the experimental setup was less than 5% .

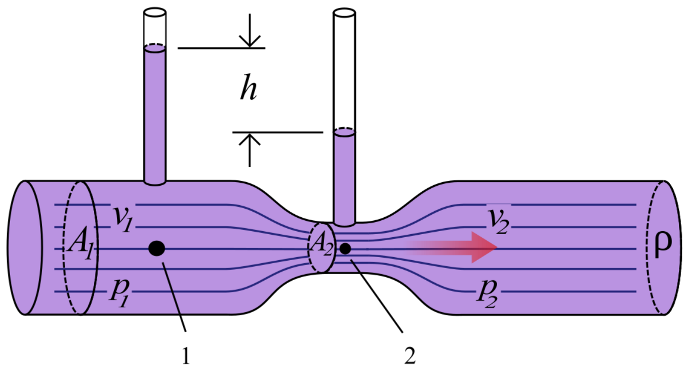

Figure 2.3: Venturi meter

2.2.2 Analytical Predictions

This technique utilizes the Bernoulli's equation to establish an analytical correlation between the fluid flow and the coefficient of discharge of the Venturi meter.

Figure 2.3 shows the Venturi meter. Assuming the flow is ideal and applying the Bernoulli's equation before and after the contraction,

$$\begin{aligned}
&\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 \\
&\text{But } Z_1 = Z_2, \\
&\frac{(p_1 - p_2)}{\rho} = \frac{(v_2^2 - v_1^2)}{2} \\
&\frac{(p_1 - p_2)}{\rho} = \frac{v_2^2}{2}\left(1 - \frac{A_2^2}{A_1^2}\right) \\
&\frac{\Delta p}{\rho} = \frac{v_2^2}{2}\left(1 - \beta^4\right) \\
&v_2 = \frac{1}{\sqrt{1-\beta^4}}\sqrt{\frac{2\Delta p}{\rho}}
\end{aligned} \tag{2.2}$$

Applying the continuity equation to the result of the derivation in 2.2,

$$\begin{aligned}
&Q_{th} = A_1 v_1 = A_2 v_2 \\
&Q_{th} = A_2 v_2 = \frac{1}{\sqrt{1-\beta^4}}\frac{\pi d^2}{4}\sqrt{\frac{2\Delta p}{\rho}}
\end{aligned} \tag{2.3}$$

Equation 2.3 of theoretical flow rate is based on the assumption that the flow is steady, incompressible, inviscid, irrotational, no losses and the velocities V_1 and V_2 are constant across the cross section [10].

$$\mathrm{Q_{act}} = \frac{\mathrm{C_{d_{st}d}}}{\sqrt{1-\beta^4}} \frac{\pi \mathrm{d}^2}{4} \sqrt{\frac{2\Delta \mathrm{p}}{\rho}} \tag{2.4}$$

The frictional and viscous losses in a laminar flow can be estimated by the Darcy's law

$$\mathrm{H_L} = \frac{(\Delta \mathrm{p})_{\mathrm{viscous}}}{\rho \mathrm{g}} = \mathrm{f} \frac{\mathrm{v}^2}{2\ \mathrm{g}} \frac{\mathrm{D}}{\mathrm{D}} \tag{2.5}$$

where 'f' is the friction factor.

Coefficient of discharge equation 2.7 where for laminar flow, 'f' is given by equation 2.6 . This equation is derived from both the Darcy's law equation and the theoretical flow rate equation 2.3.

$$f = \frac{64}{R_{ed}} \tag{2.6}$$

$$C_{\mathrm{d}} = 0.995 \sqrt{\frac{1}{(1+3f)}} \tag{2.7}$$

Arun et al [10] did a comparision of the C_d obtained by this method and that obtained from a CFD simulation. The study concluded that the results from the two methods had an uncertainty of 0.9%.

2.3 Related Works

Discharge collection techniques have been developed for various applications. Some of these applications can be adapted for the Synthetic Hydro-Experimental machine.

2.3.1 Electromagnetic activation

Angelo et al [3] implemented this technique in the design and testing of an Modular Automatic Water Sampler (MAWS). They designed MAWS and mount them on Unmanned

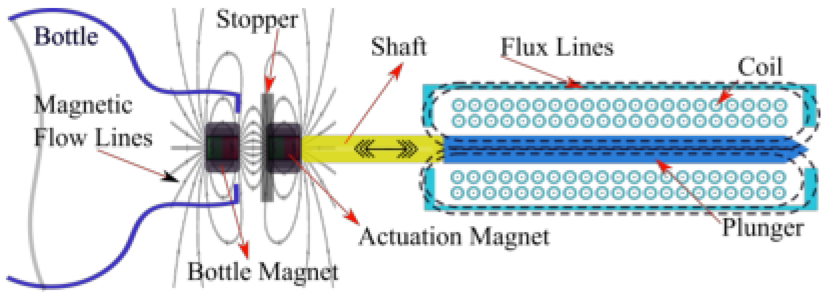

Figure 2.4: Sampler actuation mechanism [3]

Marine Vehicles (UMV) with the aim of collecting water samples for scientific campaigns in front of polar tidewater glaciers. Their main design considerations was the response time of the stopper since the MAWS were operated under water and at the risk of damage by glaciers. The actuation unit of the sampler is shown in figure 2.4.

When the coil in the solenoid is crossed by a current a strong magnetic field is generated that attracts the ferromagnetic plunger connected to the sealing stopper and opens the bottle allowing water to flow into the bottle's neck. As the current stops the two permanent magnets attract each other and the stopper seals the bottle [3].

2.3.2 Pneumatic Control

Pneumatic actuators utilizes the power of compressed air to impart motion on objects. Sangmin, and Joonwon [4] did a design of cartridge-type pneumatic dispenser with a back flow stopper. The system used a membrane covering a discharge hole. The membrane was opened and closed using negative and positive pneumatic pressure respectively as shown in figure 2.5.

The application was able to do precise dispensation of 100nL to 400nL droplets.

2.4 Summary

Every fluid flow experiment done on the Synthetic Hydro-Experimental machine involves the collection of discharge and the measurement of its properties. The most common experiment is the determination of the coefficient of discharge of the Venturi and the

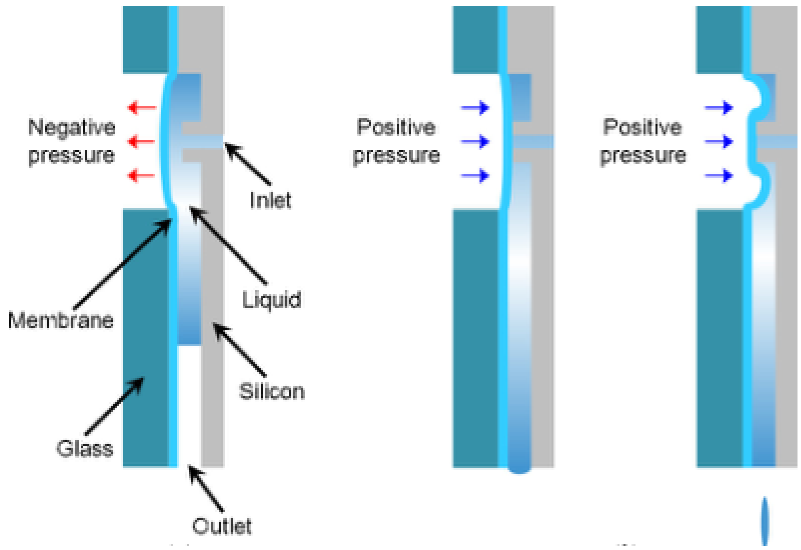

Figure 2.5: Dispensing mechanism [4]

Orifice. In this literature, other techniques such as CFD and analytical methods have been found to be effective as alternatives to this machine. These techniques have been proven to produce results with a difference of less than 1% from the experimental results obtained from a physical setup. Such results can also be obtained from the fluids rig currently used in JKUAT by automating the discharge collection unit. With regard to this, the literature has also covered discharge collection techniques that have proven to be effective in other applications and can be adapted for this automation. This techniques include the application of pneumatics and electromagnetism.

2.5 Gap analysis

1. The use of the CFD method or the analytical method undermines the credibility of the fluid flow experiments. This two techniques are rather used for the design of fluid flow measuring devices.

2. CFD method can also be very resource intensive in terms of compute resources. Softwares used for this method requires a hefty license fee.

3. The application of the analytical method involves tedious calculations and several

assumptions which can produce untrustworthy results.

4. The use of the Synthetic Hydro-Experimental machine with a manual discharge collection unit often produce results with huge error margins.

This project proposal will be entirely focused on addressing gap number four with the application of techniques such as pneumatics or electromagnetism. This will close in the technological gap with the use of CFD, and simplify the use of analytical methods by providing data for the computation of fluid flow properties.

3 Methodology

3.1 Overview

This project consists of three main units: a discharge flow control unit, a discharge collection unit, and a main control unit.

3.2 Discharge flow control unit

This unit will be used for controlling the flow at the end of the pipe system. It will utilize a ball valve installed on the existing machine. It is required that the valve aperture is controlled in steps specified by the user. However, the ball valve will be controlled by a driver based on a micro-controller. Some of the actuation mechanisms that can be applied for this purpose include :

3.2.1 Stepper linear actuator

A stepper motor converts a full rotation to small equal steps. The step size vary from one motor to the other.It will be used in this case to drive the handle of the ball valve. A mechanical interface such as a level system will be used between the motor and handle.

3.2.2 Piezoelectric Actuator

A Piezoelectric actuator converts electrical energy to mechanical displacement. It can provide high precision displacements with a large output force. It will be mounted between the handle lever and a stationary surface. When energised, the actuator will displace the lever and hence turning the valve. It is responsive to small variation in voltage.
The choice between these mechanisms will depend on the following factors :

1. Torque requirements of the ball valve.

   The piezoelectric actuator is suited for higher torque requirements as compared to the stepper motor.

2. Step sizes

Stepper motors are restricted to step sizes above their step angle which is typically 0.9 °. Piezoelectric actuators have a positioning accuracy of 0.3 mm.

3.3 Discharge collection unit

This unit will form the core part in the automation of the discharge collection. It will consists of the following : a flow diversion sub-unit, a discharge collection tank, an outlet valve, weight and temperature measurement sub-units.

3.3.1 Flow diversion sub-unit

This unit will be responsible for diverting the flow of the discharge from the main pipe system to the discharge collection tank. It will be required to have a fast response time of about a few milliseconds. It is also expected to divert the flow with minimum splashes and leakages into the discharge collection tank. This unit will consist of a flap, and an actuation unit. The design of the flap will be based on the following factors :

1. Size

   The size of the flap should be considered such that it will be able to fully cover the inlet of the discharge collection pipe.

2. Shape

   The shape of the flap should be such that it can divert the discharge away from the discharge collection unit with minimum spillage into the collection pipe. A funnel-shaped flap will be considered for this case.

3. Material

   The flap will always be in contact with the discharge fluid. This necessitates the flap to be a resistant to rust. The flap will also be actuated by a driver, and in order to achieve a fast response, the material of flap should be light.

The following mechanisms will be considered for the actuation of the flap :

1. Electromagnets

   This mechanism generates a magnetic effect on application of voltage. This will attract the metallic flap and hence opening the discharge collection pipe. The flap will be returned by a spring system in order to close the pipe.

2. Motors

   This mechanism will operate by driving the lid back and forth through an interface. The interface between the lid and the motor can be either a screw or a nut and a bolt. As the motor rotates, it either screws in or out the screw or the bolt and hence opening or closing the pipe.

The choice between this two type of methods will depend on the following factors :

1. Force requirements

   This refers to the force required to maintain the flap and hence the pipe open or closed. This will be affected by the stream of the discharge landing on the flap. Electromagnets can be adapted to produce more force by increasing the supply voltage. However, the motor will have to be replaced by another motor with more torque.

2. Voltage requirements

   Electromagnets tend to require higher voltages to produce the same force as a motor.

3.3.2 Discharge collection tank

This unit will be used to collect the discharge temporarily at each step during the experiment. The weight and temperature of the discharge will be measured within the tank. The design of the tank will involve the consideration of the following factors :

1. Position

   The position of the tank will influence size of the collection pipe and also the positioning of the outlet valve. The tank will be required the elevated above the reservoir in order to eliminate the need for a pump for pump out the discharge.

2. Insulation

   Since the temperature of the discharge is taken in this tank, the influence of the external environment will have a negative impact on the readings. The tank is therefore required to maintain internal environment with minimal effect from the external environment.

3. Shape

   The shape of the tank will determine will influence weight measurement, and the positioning of the outlet valve.

3.3.3 Outlet valve

This valve will be responsible to emptying the discharge collection tank into the reservoir. The design of this valve will be based on the following factors :

1. Position

   The position of the outlet valve will be critical since it determines how fast the mini collection tank drains into the reservoir.

2. Size.

   The size of the valve will also determine how fast the tank empty to the reservoir.

3.3.4 Weight measurement sub-unit

This sub-unit will be used to measure the weight of the discharge in the collection tank. The following approaches will be considered for this unit :

1. Ultrasonic

   Ultrasonic waves will be used to determine the depth of the discharge in the tank. This will be used with the cross-sectional area of the tank, and the density of the tank to determine the weight of the discharge based on following equation.

2. Load cells

   This will utilize load cells distributed below the discharge collection tank. The average of the output of the load cells will be averaged.

The choice between these two approaches will depend on the following factors :

1. Resolution.

   The refers to the smallest unit that can be measured by the measurement device. The resolution of ultrasonic waves will depend on the pulse rate of the ultrasonic wave generator.

2. Reliability.

   The application of ultrasonic waves requires the consideration of other factors such as the cross-sectional area and the shape of the tank. This will not be the case with the load cells. This makes the measurements using the load cells more reliable than those utilizing ultrasonic waves.

3.3.5 Temperature measurement sub-unit

This sub-unit will be required to measure the temperature of discharge in the tank. The following types of temperature measurement methods will be considered in the choice of a suitable sub-unit:

1. Contact temperature measurement

   The measuring device will be placed inside the tank and thus it will come into contact into contact with the discharge.

2. Contactless temperature measurement

   In the non contact type, the measuring device will not come into contact with the discharge.

The choice between the two technologies will be based on the following :

1. Sensitivity

   This refers to how responsive the device is to the smallest change in the environment.

A contact temperature measurement unit is predicted to have a higher sensitivity as compared to a contactless unit.

2. Reliability

   The application of a contactless temperature unit will require the consideration of the stimuli between the unit and the environment being probed. This is not the case with a contact temperature measurement unit as there is a direct interface with the environment being probed.

3.4 Interface and Control

This unit will take user input through an interface, and process the input with the data from the system using an application logic running in a micro-controller. The application logic will be as shown in figure 3.1. The results of the process will be displayed on the interface.

3.4.1 Processing sub-unit

This sub-unit executes the application logic, send instructions to the actuators, and reads inputs from sensors in the system. A micro-controller or a fully developed computer board such as Raspberry Pi may be considered for this application. The choice of a micro-controller or a computer chip will be determined by the following factors.

1. General Purpose Input Output (GPIO)s

   These form the primary interface between a micro-controller and the external circuitry. They can be used for several purposes such as analog signal I/O, counter/timer, digital signal I/O, and serial communication. A group of these pins forms a port. The number of pins and hence the size of the port are two important factors that are to be considered in the choice of a micro-controller.

   Some devices such as LCD displays with touch capability require bigger ports as many devices require many GPIOs to control them.

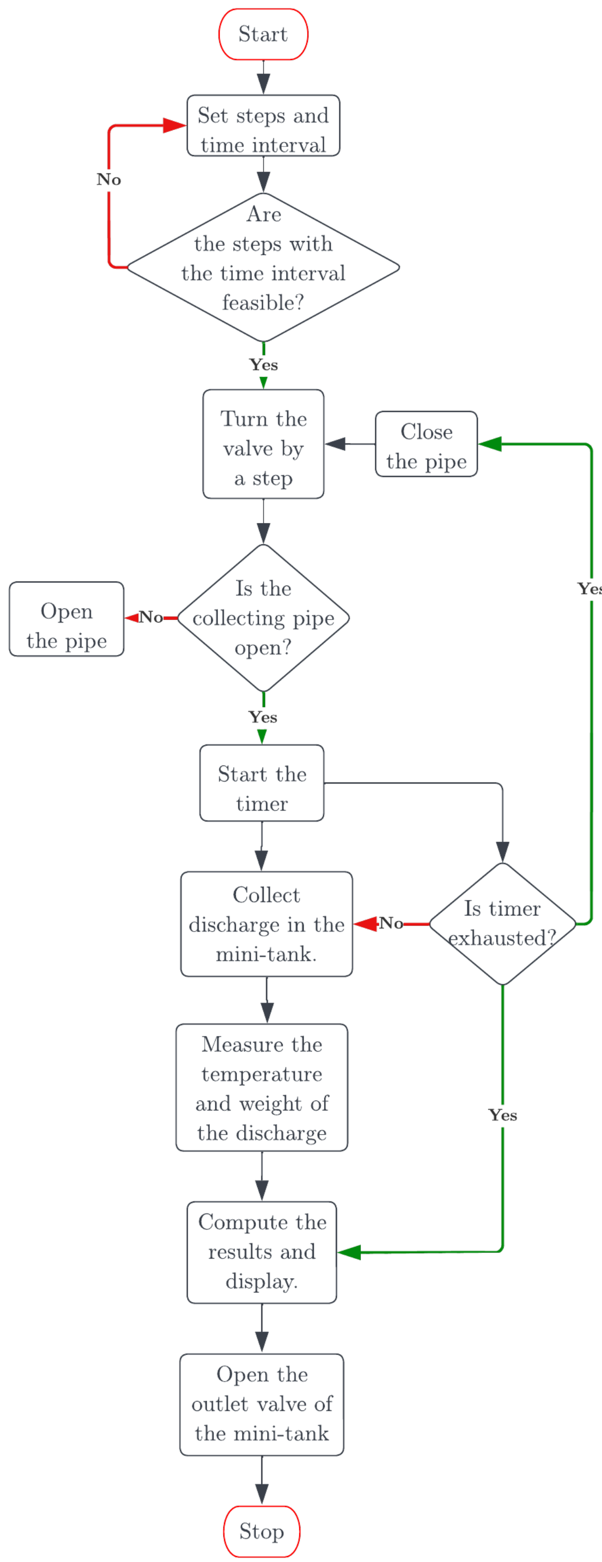

Figure 3.1: Application logic

2. Processing Power

   This refers to the processing capacity of a micro-controller. A multi-core processor is faster and consumes more power as compared to a single-core processor. A multi-core processor can also render intense graphics on displays. The amount of input processing will guide one in choosing the best micro-controller or microprocessor for the task.

3.4.2 Interface

This will provide for a human machine interaction. It will allow one to enter the required experiment parameters like start and stop or reset of the experiment, and read the processed results which will include parameters such as the weight and temperature of the discharge. Some of the interfaces that will be considered in this project are:

1. **LCD with Keypad**

   One can navigate, read and provide input where it is required on the LCD display using the keypad.

2. **LCD with touch capability**

   One can navigate the interface easily by touching and using a virtual keyboard to provide input.

3. **LCD with Knobs**

   The interface will be entirely controlled by knobs, navigation from page to page, and parameter input.

The choice of one of the three means to interface with the machine will entirely depend on the following factors.

1. Aesthetics

   This refers to the perception of the user while operating the interface. A touch screen is minimalistic, and its aesthetics can be improved easily by adding relatively beautiful graphics in the software. This might not be the case with the case of LCD with knobs. Any attempts to improve its aesthetics might require the addition of knobs. This might clutter the interface.

2. Ergonomics

   This refers to the impact of the interface on the user, and the ease of operation. LCD display with a keypad interface can be operated even in a moist environment. This might not be the case with an LCD display with touch capability.

3. Size

   This refers to the size of the display with regard to the size of the contents to be displayed. Fewer contents can fit any of the mentioned displays but the operability of the contents in the display should be considered.

4 Expected Outcomes

From the discussed methodology, the following are what are expected from this project :

4.1 Discharge flow control

A discharge flow control control mechanism that can turn the ball valve in precise steps is expected. The steps obtained from the division of the circumference of a full turn by the number of steps are also expected to be accurate to the nearest whole number.

4.2 Discharge collection unit

A discharge collection unit that can precisely collect the discharge within the specified time interval while taking its temperature and weight is expected. This can be expected if the expectations of the following sub-units are met :

4.2.1 Flow diversion sub-unit

A precisely sized diversion sub-unit, correctly positioned to collect the whole stream is expected. This will improve on the accuracy of the weight of the discharge and hence that of the experiment.

4.2.2 Discharge collection tank

A discharge collection tank whose shape can allow for accurate weight measurement is expected. It is also expected that this tank is positioned in such a way that flow into this tank utilizes gravity to eliminate the need for an extra pump.

4.2.3 Outlet valve

A sized outlet valve positioned at a point on the tank that it empties the tank the fastest way possible is expected.

4.3 Discharge weight and temperature measurements

It is expected these units measuring devices can measure to the smallest resolution.

4.4 Control and Display

It is expected that the control module can handle intense computations such as error approximation, immediate rendering of results and communicating with the sensors and transducers that will be used in the system. It is also expected that the user interface is slick and ergonomic.

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Week	1	2	3	4	5	6	7	8	9	10	11
Project proposal											
Continous Presentation											
Literature review											
Discharge flow control design											
Discharge collection unit design											
Interface and control design											
Assembly and testing											
Interim report											
Final presentation											

Table 4.1: Semester 1 timeplan

Item No.	Item	Quantity	Unit Cost	Cost
001	Flow Control valve	1	1000	1000
002	Motor	2	2500	5000
003	Limit Switch	2	150	300
004	Temperature Probe	1	300	300
005	Weight Sensors	3	500	1500
006	DC Power Source	1	1000	1000
007	Microcontroller	1	6000	6000
008	Interface	1	2000	2000
009	Heat foil	1	2000	2000
Total				19100

Table 4.2: Proposed Budget