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

Final year project proposal

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Declaration

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List of Abbreviations

GPIO General Purpose Input Output

STM STMicroelectronics

SKE Single Kernel Estimate

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.

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 flow control valve 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 of the study

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 differential pressure, mass flow rate, fluid velocity and conductivity coefficients, and they are altered and the change measured by flow measuring devices such as the Venturi, the Orifice, turbine flow meters and rotameters [7]. The measurements are finally related to the flow.

The synthetic hydro-experimental machine employs the venturi and the orifice meters in fluid flow measurements. Besides flow properties measurements, fluid flow experiments involve collecting small amount of discharge whose weight and temperature is to be recorded. Discharge also referred to as flow rate refers to the amount of fluid passing a section of a stream in unit time. A commonly applied methodology for measuring, and estimating, the discharge of a fluid is based on a simplified form of the continuity equation. The equation implies that for any in-compressible fluid, such as liquid water, the discharge (Q) is equal to the product of the stream's cross-sectional area (A) and its mean velocity [8], and is expressed equation 2.1:

$$\mathbf{Q} = \mathbf{Av} \tag{2.1}$$

where Q is the discharge in m^3/sec, A is the cross sectional area of the flow in m^2 and V is the mean velocity of flow in m/sec .

The discharge collection unit for the synthetic hydro experimental machine comprises of a flow control valve, a diverter and a weight measurement unit. The process involves controlling the discharge using flow control valves and using a diverter to direct the discharge into the weight measurement unit. All this is done in tandem with time and temperature measurement which are taken simultaneously with discharge collection.

2.2 Existing Technologies

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 [9]. It can be used to model fluid flow in a process. This method has been used in the modelling of fluid 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.

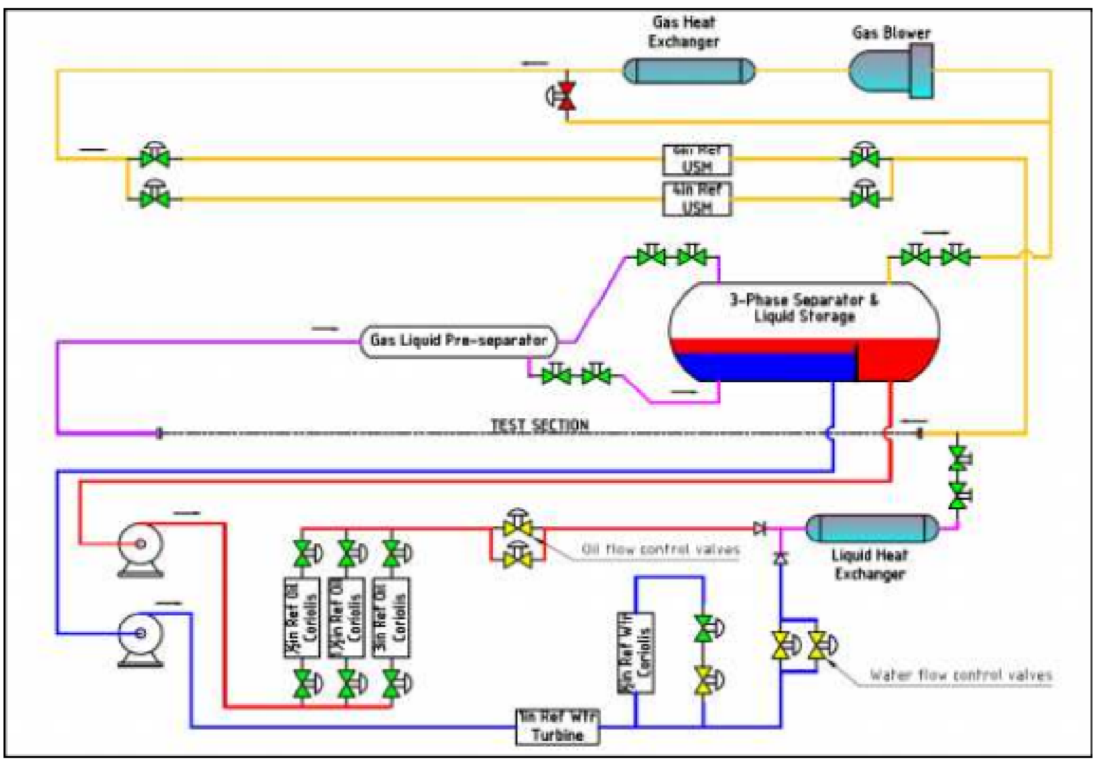


Figure 2.1: Test loop schematic [1]

The CFD model was designed using ANSYS Design Modeller software. The model consists of a Venturi tube designed according to the standards ISO 5167:2003 [10], and both a

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

Table 2.2: Results

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

liquid and gas system. The physical experiment was done in a specific test matrix which was included in the numerical simulation model. Finally the coefficient of discharge of the venturi was calculated using equation 2.2.

$$Cd = \frac{4m\sqrt{1-\beta^4}}{\pi\varepsilon d^2\sqrt{200000Dp_1\rho_1}} \tag{2.2}$$

The results obtained in 2.1 were found to have a difference of less than 1%.

Tamhankar et al [2] also did a similar experiment using a CFD model 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.

Table 2.2 shows the results obtained from the experiment

The study concluded that difference in values of the coefficient of discharge obtained from the model and the ones obtained experimentally was within 5% .

2.2.2 Analytical Predictions

This technique utilizes the Bernoulli's equation to establish an analytical correlation for 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

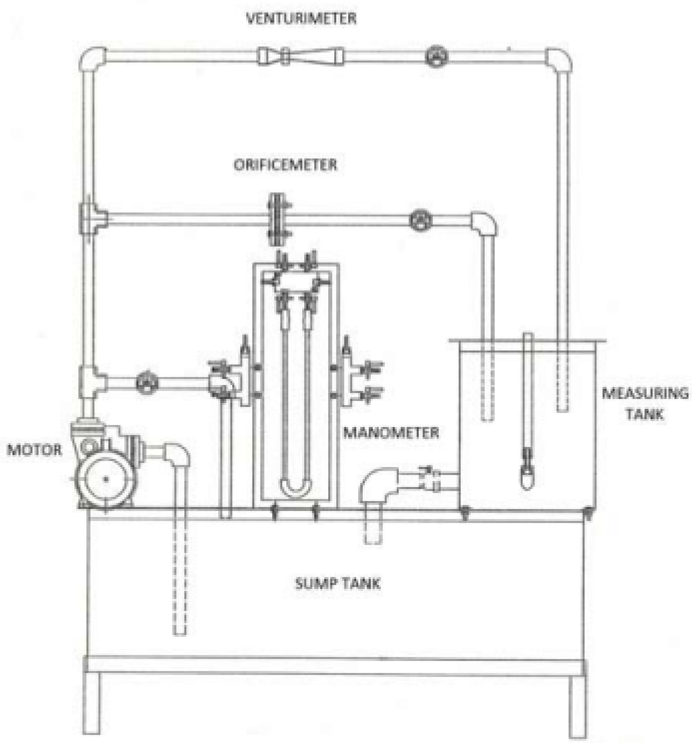


Figure 2.2: Experimental setup [2]

equation before and after the contraction,

$$
\begin{aligned}
&\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 \\
&\text{But } Z_1 = Z_2, \\
&\frac{(p_1 - p_2)}{\rho} = \frac{(v_2^2 - v_1^2)}{2} \\
&\frac{(p_1 - p_2)}{\rho} = \frac{v_2^2}{2}\left(1 - \frac{A_2^2}{A_1^2}\right) \\
&\frac{\Delta p}{\rho} = \frac{v_2^2}{2}\left(1 - \beta^4\right) \\
&v_2 = \frac{1}{\sqrt{1-\beta^4}}\sqrt{\frac{2\Delta p}{\rho}}
\end{aligned}
\tag{2.3}
$$

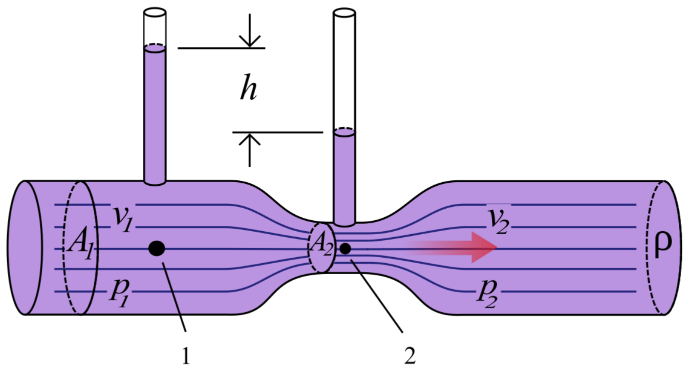


Figure 2.3: Venturi meter

Applying the continuity equation,

$$Q_{th} = A_1 v_1 = A_2 v_2$$
$$Q_{th} = A_2 v_2 = \frac{1}{\sqrt{1-\beta^4}} \frac{\pi d^2}{4} \sqrt{\frac{2\Delta p}{\rho}} \tag{2.4}$$

The above equation 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 [11].

$$\mathrm{Q_{act}} = \frac{\mathrm{C_{dstd}}}{\sqrt{1-\beta^4}} \frac{\pi \mathrm{d}^2}{4} \sqrt{\frac{2\Delta \mathrm{p}}{\rho}} \tag{2.5}$$

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

$$\mathrm{H_L} = \frac{(\Delta \mathrm{p})_{\mathrm{viscous}}}{\rho \mathrm{g}} = \mathrm{f} \frac{\mathrm{v}^2}{2\ \mathrm{g}} \frac{\mathrm{D}}{\mathrm{D}} \tag{2.6}$$

where 'f' is the friction factor.

Coefficient of discharge equation 2.8 where is for laminar flow 'f' is given by equation 2.7 . This equation is derived from both the Darcy's law equation and the Bernoulli's equation.

$$f = \frac{64}{R_{ed}} \tag{2.7}$$

$$C_{\mathrm{d}} = 0.995\sqrt{\frac{1}{(1+3f)}} \tag{2.8}$$

Arun et al [11] did a comparision of the C_d obtained by this method and the obtained from CFD. The study concluded that the results from the two methods had an uncertainity of 0.9%.

2.3 Related Works

Discharge collection process and techniques have existed over a long time and finds application in various sectors.

2.3.1 Pressure Control

To solve the problem of sludge deposits accumulating in storage tanks, Liu et al, [3] proposed a new set of an automatic adjusting underwater sludge discharge collector and regulator as shown in figure 2.4 . The regular employs the use of a check valve to

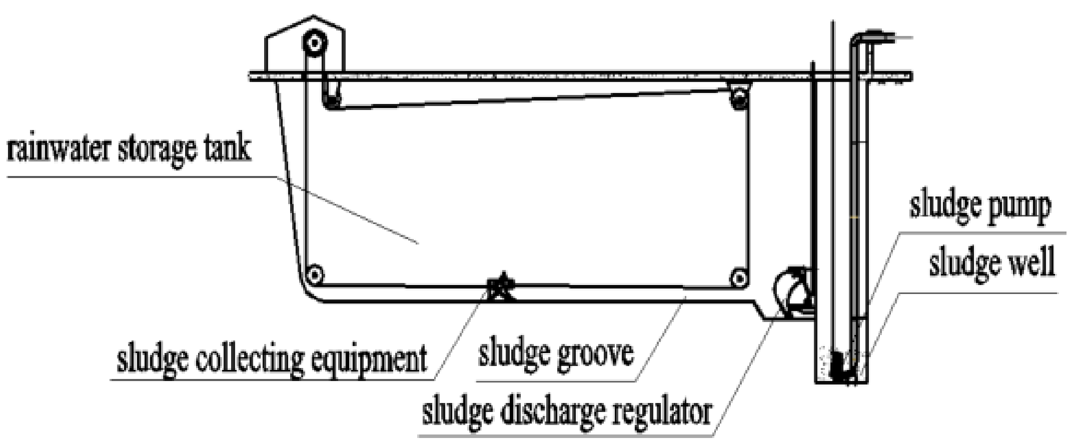


Figure 2.4: The Principle of Underwater Sludge Discharge and Collection System [3]

adjust the water pressure inside the water chamber as shown in figure 2.5. Blockage in the discharge port reduces the flow in the sludge channel thus lowering the pressure of the sludge channel as to that of the water chamber. This causes a drop a water level drop

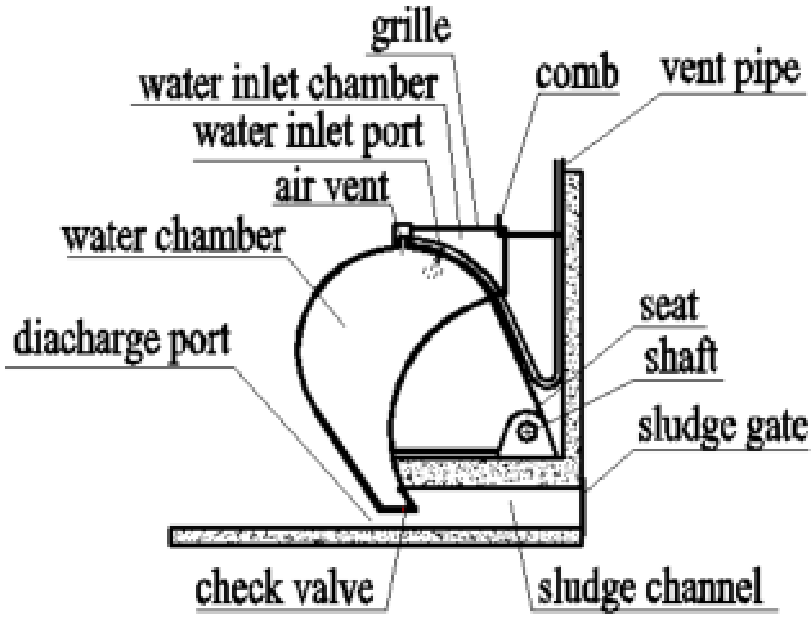


Figure 2.5: The Structure and Principle of the Sludge Discharge Regulator [3]

in the water chamber reducing the weight of the regulator. A reduction in the regulator weight, enlarges the discharge port and thus the blocked sludge is released and collected.

2.3.2 Electromagnetic activation

Angelo et al [4] implemented this technique in the design and testing of an Modular Automatic Water Sampler (MAWS). They designed MAWS and mount them on Unmanned 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 MAWS were operated under water and at the risk of damage by glaciers. The actuation unit of the sampler is shown in figure 2.6 .

When the coil in the solenoid is crossed by a currrent a strong magnetic field is generated that attracts the ferromagnetic plunger connected to the sealing stopper and opens the bottle allowing water flowing into the bottle's neck. As the current stops the two permanent magnets attract each other and the stopper seals the bottle [4].

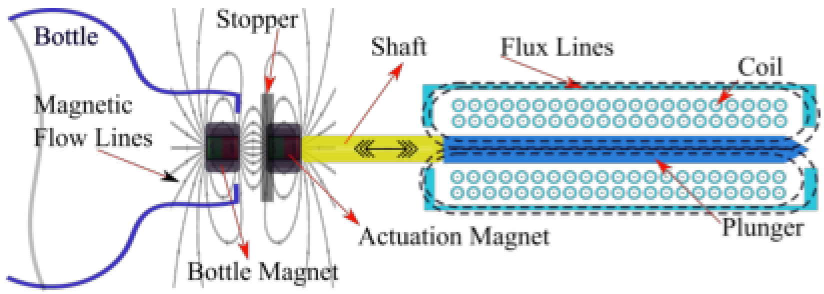


Figure 2.6: Sampler actuation mechanism [4]

2.4 Summary

Every fluid flow experiment done on the Synthetic Hydro-Experimental machine involves collecting the discharge and its properties. The most common experiment is the determination of the coefficient of discharge of the Venturi and the Orifice. In this literature, other techniques such as CFD and analytical methods have been found to be effective in this experiment. Both techniques have been proven to produce results with a difference of less than 1% from the experimental results. Such results can also be obtained by the fluids rig currently used in JKUAT by automating the discharge collection unit. The literature has also covered techniques that also be used to achieve this such as the application of pneumatics and electromagnets.

2.5 Gap Analysis

1.

3 Methodology

3.1 Overview

This automation will entail three main subsystems namely: mechanical, electrical, and control modules. To effectively ensure consistency in this experiment, it will be imperative that the following are taken into consideration: synchronism in time and temperature measurement with discharge collection, and precision in controlling the flow rate in steps.

3.2 Mechanical Module

3.2.1 Flow Control Valve

This is located at the discharge collection end of the machine. It is required that this valve has an adjustable aperture for one to be able to control the flow of the fluid in steps. The torque requirement for turning the valve should also be considered for sizing the motor for turning the valve. Once an experiment starts, this valve is to be left flowing after each step until the last step then it closes. Subsequent steps are incremental to the first step.

3.2.2 Discharge collection unit

This sub-unit will be used to collect the discharge from the valve within the time interval set. This unit can be slid in and out below the discharge valve to collect the discharge within the set time interval. It can also be fixed below the discharge valve with a lid to open when the timer starts to collect the discharge and close when the timer stops. Both approaches should be highly responsive to ensure only the quantity of the fluid flowing within the time interval is collected and not a drop more.

1. **Mini Collection tank**

   The discharge collection unit will also have a mini collection tank. Within this tank, the weight of the collected discharge is measured and its temperature recorded. This tank should be resistant to sudden environmental changes. It should also be light enough in case the discharge collection approach of sliding the tank in and out below the discharge flow is considered.

2. **Outlet valve**

   The collected discharge is to be emptied before the next step of discharge is initiated. This is to be done through an outlet valve that opens to the reservoir. This valve should be large enough to be able to empty the collection tank within the shortest time possible. The location of this valve is also an important factor to be considered to reduce the time for emptying the discharge.

3.3 Electrical and Electronic Module

The electrical module will comprise a motor, limit switch, valves, an immersible temperature probe, weight measurement unit, and a power source as the main components.

3.3.1 Motor

The motor is the main actuation unit in this setup. They will be used in the following sections

1. **Flow rate control**

   The motor in this section will be used for flow rate control from the orifice and the venturi flow meters into the mini collection tank. This motor will be required to open a valve attached to the discharge collection unit in small and precise steps computed from the size of the pipe and the number of steps required by the user. The choice of the motor in this section will depend on the following factors.

   (a) **Precision**

   The flow rate is controlled in small precise steps. This requires a motor that can produce the steps with a very small tolerance.

   (b) **Torque requirement**

   This will be determined by the flow rate control valve operated by the motor. The amount of torque required to turn the valve handle will be considered for sizing the motor.

(c) **Control**

The directions that the motor can cover will be considered. The flow control valve requires a motor that can open and close it therefore a motor that can rotate both clockwise and anticlockwise will be considered.

2. **Discharge collection channel Operation**

This sub-unit uses a pipe to cut the flow into the discharge collection tank. The motor in this section will be used for sliding the pipe in and out below the flow control valve to collect the discharge at specified time intervals. The choice of the motor in this section will depend on the following factors

(a) **Speed**

In order to boost precision in this experiment, the pipe has to be slid into and out of the flow fast enough to ensure only the correct amount of the fluid is collected. This requires a motor with relatively higher speeds.

(b) **Direction**

The pipe is slid into and out of the flow. This operation can only be achieved by a motor that can rotate in both directions.

3.3.2 Limit Switch

The pipe will be moved by a motor that can move back and forth. To ensure that the discharge collection pipe is at the right position, limit switches will be used to detect the pipe and act as a feedback control to operate the motor. The location of the limit switches will be considered to ensure precision.

3.3.3 Immersible temperature probe

An immersible temperature probe will be attached to the mini collection tank for measuring the temperature of the collected discharge within the set time interval. This information is then sent to the user interface after each step in the experiment. The location of the temperature probe within the tank is to be considered to ensure reliable measurement. It is expected that it should be submerged.

3.3.4 Weight measurement unit

Two approaches for weight measurement are to be considered. One approach will involve the use of ultrasonic waves to determine the depth of the empty tank. The depth of the fluid, its density, and the known surface area of the tank will be used to calculate the weight of the fluid. Another approach will involve the use of load cells strategically distributed below the collection tank to measure the weight of the tank at all times. The choice between the two approaches will be made considering the reliability and the precision of the measurement.

3.3.5 Power Source

Most of the units in this prototype will be operating on DC power. An AC-DC converter can be used to provide up to a 24V main DC source. Buck converters can be used to step down this value to a value specific to each unit.

3.4 Control Module

3.4.1 Processing Unit

This unit is responsible for executing the application logic, sending instructions to the actuators, and reading inputs from sensors in the system. A microcontroller or just a microprocessor can be used. A fully developed computer board such as Raspberry Pi or an M7 series STMicroelectronics (STM)32 microcontroller can also be used. The choice of a microcontroller, a microprocessor, 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 microcontroller or a microprocessor with 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 microcontroller or a microprocessor.

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

2. **Processing Power**

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

3.4.2 Interface

This provides a means of interaction with the machine. It can allow one to enter required experiment parameters, start and stop or reset the experiment, and read the processed results. 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

An automated discharge collection unit that can be used to perform fluid flow experiments with minimized human error through synchronization of the discharge collection with time and temperature measurement while maintaining the credibility of the experiment.

References

[1] A. Tukimin, M. Zuber, and K. Ahmad, "Cfd analysis of flow through venturi tube and its discharge coefficient," in *IOP Conference Series: Materials Science and Engineering*, vol. 152, no. 1. IOP Publishing, 2016, p. 012062.

[2] N. Tamhankar, A. Pandhare, A. Joglekar, and V. Bansode, "Experimental and cfd analysis of flow through venturimeter to determine the coefficient of discharge," *International Journal of Latest Trends in Engineering and Technology (IJLTET)*, vol. 3, no. 4, pp. 194–200, 2014.

[3] Z. Liu, J. Cheng, and Y. Zhu, "Research of automatic adjusting underwater sludge discharge regulator," in *2018 8th International Conference on Manufacturing Science and Engineering (ICMSE 2018).* Atlantis Press, 2018, pp. 422–426.

[4] A. Odetti, G. Bruzzone, M. Caccia, R. Ferretti, E. Spirandelli, and G. Bruzzone, "Design, development and testing at field of a modular mini automatic water sampler (maws) based on magnetic activation," in *OCEANS 2019-Marseille.* IEEE, 2019, pp. 1–8.

[5] M. Pereira, "Flow meters: part 1," *IEEE Instrumentation and Measurement Magazine*, vol. 12, no. 1, pp. 18–26, 2009.

[6] R. W. Miller, "Flow measurement engineering handbook," 1983.

[7] P. Nandagopal and S. Nuggenhalli, "Fluid flow measurements," in *Fluid and Thermal Sciences.* Springer, 2022, pp. 137–147.

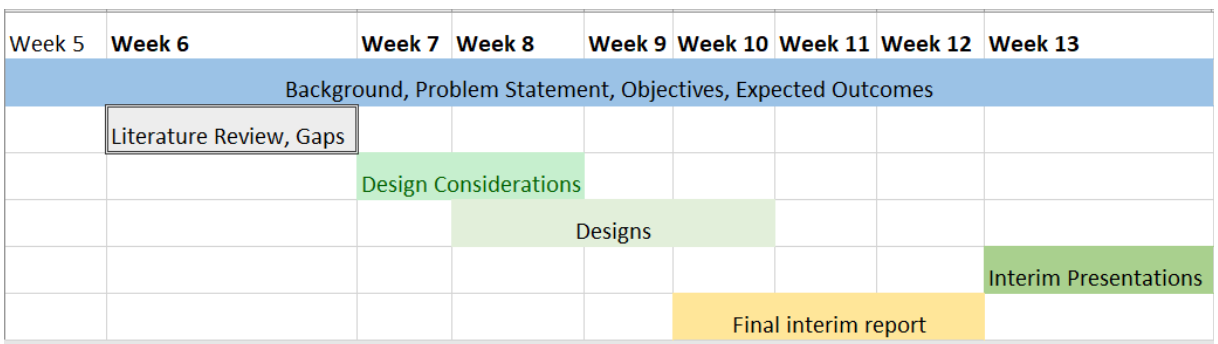
[8] L. Davidson *et al.*, "Fluid mechanics, turbulent flow and turbulence modeling," *Chalmers University of Technology, Goteborg, Sweden (Nov 2011)*, 2018.

[9] M. J. Kuntz and H. J. Klein, "Pre-occupancy planning, commission, qualification and validation testing," in *Planning and Designing Research Animal Facilities.* Elsevier, 2009, pp. 45–51.

[10] E. ISO, “5167: Measurement of fluid flow by means of pressure differential devices,” *International Organization of Standards, Genève*, 2003.

[11] R. Arun, K. Yogesh Kumar, and V. Seshadri, “Prediction of discharge coefficient of venturimeter at low reynolds numbers by analytical and cfd method,” *International Journal of Engineering and Technical Research (IJETR) ISSN*, pp. 2321–0869, 2015.

Appendix A: Time plan



Appendix B: Budget

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 4.1: Budget