جامعة الأمير محمد بن فهد
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

Fall 2020 - 2021

Senior Design Project Report

Design of Water Hammer Shock Absorber

In partial fulfillment of the requirements for the
Degree of Bachelor of Science in Mechanical Engineering

Team Members

	Student Name	Student ID
1	Sarah Mugbil Aldossary	201602298
2	Malak Abdullah Alnowaiser	201601292
3	Ghadeer Khalid AlMuslim	201600576

Project Advisors:

Dr. Esam Jassim

Abstract

In the piping system, water hammer or hydraulic shock is a major issue that engineers need to consider. Water hammer is a phenomenon that leads to shock waves in the fluid due to rapid closing and opening of the valve, which can affect pipes, valves and gauges in any water, gas, or oil applications due to the sudden transient event. It is there for every system that has a flow of fluid through pumping such as houses, hospitals, and influences major effectiveness in the power plant. It occurs when there is a pressure difference in the pipeline leading to a loud noise. Specifically, this project is aimed to design a pipeline system and develop solutions to reduce the water hammer using a shock absorber. The main idea of the design project is to design a water hammer system using a shock absorber in order to reduce the shock waves of the pipes.

Project objectives are:

1. Design a water hammer system to reduce water shock waves
2. Observe the effect of water hammer in copper coil pipe and PVC pipe
3. Produce a prototype of the design
4. Test and calculate the designing system

Acknowledgments

بِسْمِ اللَّـهِ الرَّحْمَـٰنِ الرَّحِيم

It is our honor to be the first female students to graduate with a Mechanical Engineering Bachelor’s degree at Prince Mohammad bin Fahd University (PMU). We are proud and grateful that PMU gave us the opportunity to stand for the community as female engineers in Saudi Arabia, Eastern Province with a highly qualified background in engineering and professional skills. We would like to express our deep gratitude to Supervisor Dr. Esam Jassim for his guidance, assistance, and encouragement throughout the entire project. We would like to thank Dr. Mohamed Elmehdi for his assistance. It is a pleasure to thank the team members for working as one soul from the beginning of this journey.

Finally yet importantly, our deep and sincere gratitude to our families for their continuous and unparalleled love, help, and support. We are forever indebted to our parents for giving us the opportunities and experiences that have made us who we are. This journey would not have been possible if not for them.

List of Acronyms (Symbols)

Symbol	Definition
ρ	Density
H_L	Head loss
K	Internal pipe roughness
Q	Flow rate
V	Velocity
Re	Reynolds number
μ	Viscosity
ε	Pipe roughness
f	Friction loss
g	Gravitational acceleration

K_L	Resistance coefficient
fc	Friction loss of coil
fs	Friction straight pipe
N_c	Number of turns of coil
Dc	Tube diameter
dc	Helix diameter
L_c	Length of pipe

List of Figures:

List of Tables:

Table of Contents

Chapter 1: Introduction

1.1 Project Definition

The aim of this project is to design and manufacture an entire pipeline system in order to reduce the water hammer phenomena by using a shock absorber, using appropriate components to observe and reduce the surge pressure. It will be a prototype to make optimization of how the pressure plays a role in the system. The design system consists of using proper types of pipes, valves, pressure gauges, and pumps. The main idea of the project is to add a Copper Coil to help us to reduce the surge pressure. The project is significant to many industrial applications through understanding the main features of designing, manufacturing, and economic aspects. This is very important from a safety perspective as this project will lead to increased safety and enhance the performance of pipes, valves, flanges, etc., as well as save the environment and humans from any sudden damage that can be caused by the water hammer phenomenon.

1.3 Project Specifications

Figure 1 presents the basic idea of our piping system and represents the cycle of water flow while having a water hammer. This is the first drawing of the project, and we have done the calculations of head losses to investigate whether our pipes lengths are suitable to each other, specifically, the length of the pipe that is parallel to the coil in order to achieve our target of reducing the surge pressure.

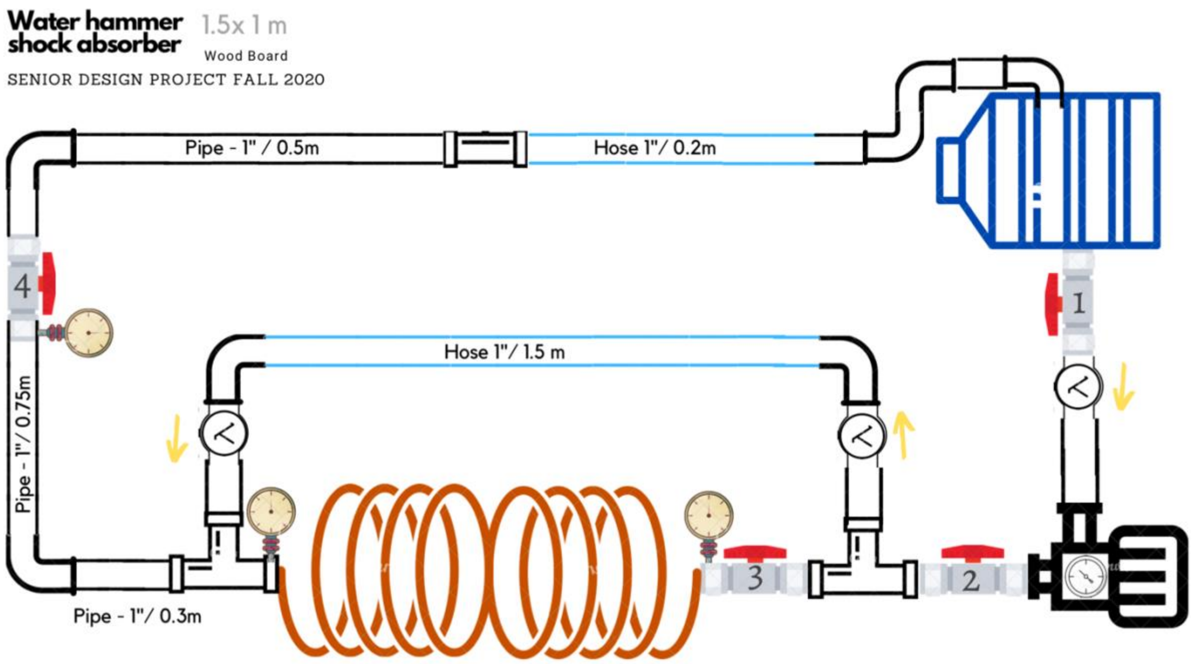

Figure 1 Drawing of water hammer flow cycle

1.3.1 Metrics and Marketing features

In this project, we seek to have a light-weight system and not a huge size because it is important for us to carry out and install competent flexibility while taking into full consideration the overall project budget and market availability. Using PVC pipes have many environmental advantages, as they are low carbon plastic, last long, easy to recycle, and require less energy due to low weight. Also, a water hammer can be an issue to some types of water supply pipes such as CPCV pipes, but PVC and copper coil prove good choices for this project. **Table 1** shows the specification for pump and coil selection.

Table 1 Product Specification

Pump Specification		**Coil Specification**	
Flow Rate Q_{max}	35 L/min	**Tube Diameter Dc**	0.5 in
H_{max}	32 m	**Helix Diameter**	14 in
Power	0.5 HP	**Pitch**	4.5 in
Operation Voltage	220V	**Height**	8 in
RPM	RPM	**Actual Length**	6 m
Fitted with Thermal Overload Protector		**Number of turns**	11

1.4 Applications

1. Fire Protection Systems

In fire protection systems, the pressure surges could be caused by various factors, for example, when opening or closing the valve very quickly or when the pump starts or shuts down abruptly.

Figure 2 Piping system in fire protection

2. Houses pipe system

In every house, there is a piping system for bathrooms, washbasin, and washing machine where water pressure surges can occur when the machine stops suddenly or when someone closes or opens the valve quickly.

Figure 3 Piping system in washbasin

3. Industrial pipe system

An industrial piping system consists of a variety of materials from metal to plastic and it is used for a variety of purposes, for example water, sprinklers, and standpipes which can cause water hammer.

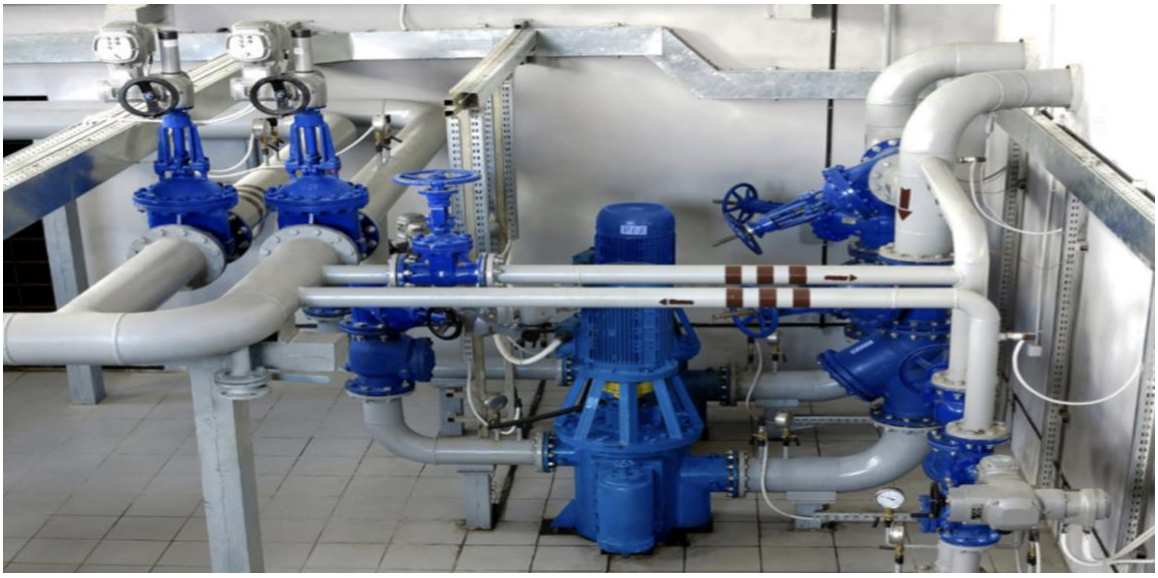

Figure 4 Water piping system in industrial

4. Farm pipe system

Even in farms, the piping system is necessary for providing water for agriculture. This system can lead to the water hammer in the pipe system as it can occur when the pumping of water stops suddenly.

Figure 5 Farms pining system

Chapter 2: Literature Review

2.1 Project background

Water hammer is a significant problem that exists in the pipeline system. Everyone now lives in a place where water flows with a piping system. Therefore, it is important to have the best piping system to prevent the damage that could happen due to high water pressure, which will cause the water hammer phenomenon. As known, water pipes usually have a quiet sound coming from them. When the water pipe emits a loud sound that means the phenomenon of a water hammer has occurred as shown in **Figure 6**. It happens because of an increase in surge pressure when the valve or faucet is abruptly closed. The water will start looking for a place to go and eventually it will hit the walls of the pipe or the valve in the water pipeline system, which will result in noise.

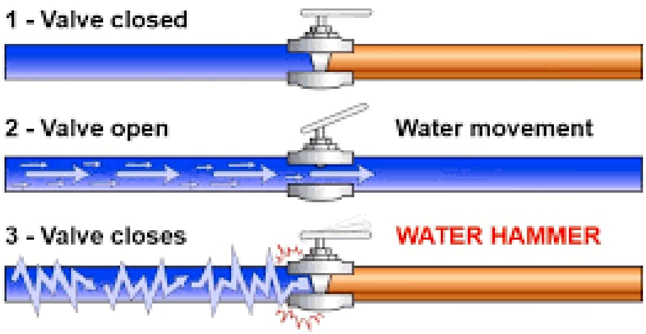

Figure 6 Water hammer phenomenon

It is important to adjust the water hammer immediately as it can cause damages to pipe and can lead to leaks. Water hammer is not only a system problem; it is a safety issue. Understanding the nature and intensity of a water hammer allows facilities to avoid its destructive force.

2.2 Previous Work

2.2.1 Investigation of Water Hammer effect

The hydraulic transient has been considered in both theoretical and practical interests for more than one hundred years. [1] There are many studies that have been employed to investigate the water hammer problems. One of the first investigations of the water hammer was reported by Lorenzo Allievi, who analyzed the water hammer using two different approaches: ignoring the compressibility of the fluid elasticity of the wall that is a rigid column theory, and analysis of elasticity [2]. However, prevention of the water hammer effect must be taken under consideration by analyzing the situations and methods of reduction. Research by the University of Malaysia has proven a prevention method that successfully reduces the water hammer effect by installing a bypass pipe with a non-return valve [3]. According to that, the analysis has been performed by capturing the vibration signal by using a data acquisition device and accelerator. According to the University of Malaysia, data successfully proved that by using this technology, the water hammer effect pressure is reduced 33.33%.

2.2.2 Water Hammer Analysis

Water hammer phenomena have been simulated and commercially modeled for numerical analysis purposes such as WaterGEMS and HAMMER [4]. The main objective of these programs was to analyze and predict the water hammer behavior in the Khobar-Dammam Ring Line (KDRL). The former code was used to simulate the hydraulics of the transmission pipeline under static conditions while the latter program was used to analyze the occurrence of water hammer phenomena and simulate the difference of the water hammer protection situations. The system modeling has several advantages starting with an accuracy of the system, easier representation compared to the real complexity application, analyzing several operational situations, and saving time and money [5].

2.2.3 Water Hammer in The Pump-Rising Pipeline System with An Air Chamber

As a result of the rapid change in velocity, hydraulic transients occur. The pressure inside the pipe decreases to the liquid vapor pressure when the pressure waves are propagating between the pumping station and the delivery reservoir, at which point a vapor cavity emerges, and eventually the column separation occurs. If the pressure in the pipe is lower than the pressure atmosphere, the pipe will collapse and destroy after rejoining the water columns separated by the vapor cavity. The pressure at the pumping station is so abnormally increased during the reverse flow that a flooding accident can occur due to system failure [6-9]. In a pressure vessel, the air chamber containing both the liquid and the compressed air or gas supplies the pipeline with the liquid in order to isolate the prevent column and efficiently suppress the upsurge. In addition, the air chamber will react continuously to any pressure changes, so that the system's stability will be greatly improved. The use of the air chamber as a surge suppression system at the pumping station [10] is becoming widespread for these reasons.

2. 3 Comparative Study

The study of reduction of water hammer has been investigated and developed using different technologies and computer model simulations for analyzing the water flow and automatic pressure control. The idea for our project is derived from a previous work done by PMU students in design and construction of a piping network system. Their objective study was designing a pipe network for the building and providing some methods for hydraulic transient problems. The design methodology of their project was achieved by using CAD for modeling the design using Solid working as shown in **Figure 7**.

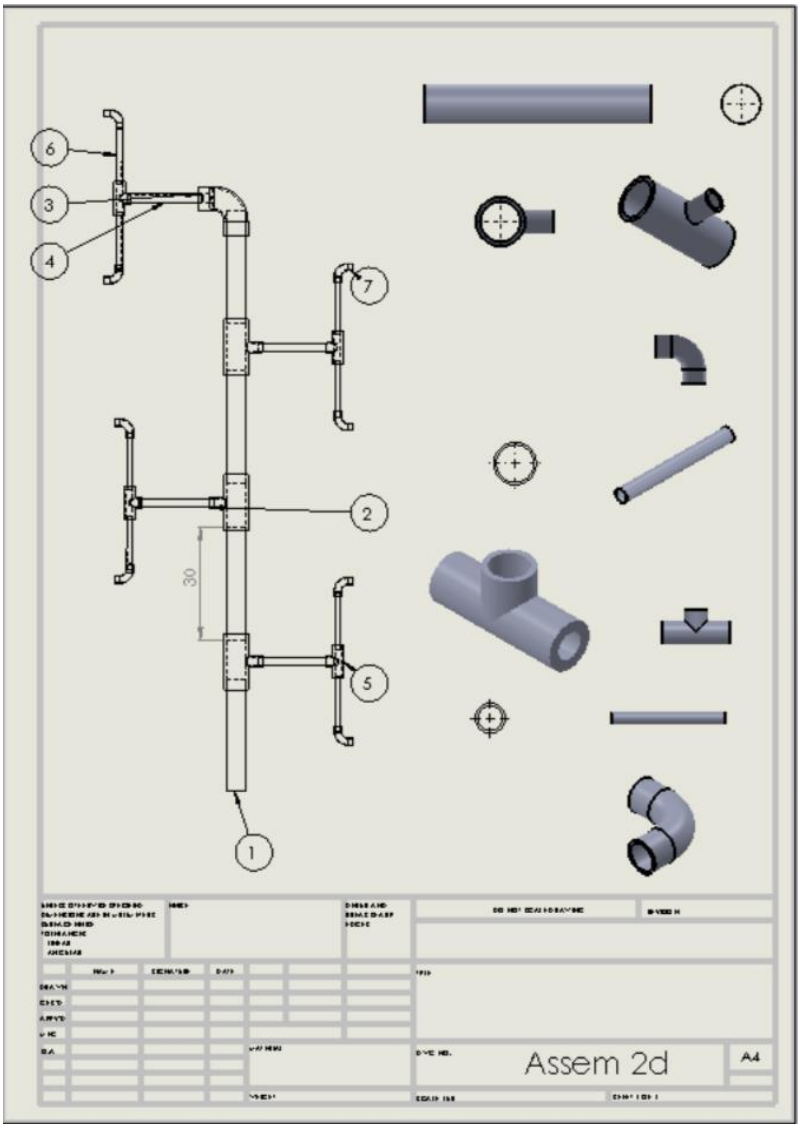

Figure 7 Design drawing using solidworks

After designing the piping system, they started to do theoretical calculations in order to calculate the head loss and determine the applicable measurements of the design. They selected standard materials such as PVC pipes, which handle more pressure than other types of pipes. The test of the project was done by testing the pressure through the pipe using a pressure gauge and digital flow rate in order to find the pressure difference in the distribution pipe design shown in **Figure 8**.

Figure 8 Final design prototype of PMU students' senior project

A second similar project was conducted by Palestine Polytechnic University at the college of engineering and technology. The project is focusing on analysis of the flow transient for AlDuhaish pumping station. Their main objective has been to study the performance of hydraulic transient systems with and without using protection devices. The methodology of their project is achieved by first collecting the data from the field and analyzing the water hammer in hydraulic systems using the protection device in order to improve the performance of AlDuhaish pumping station.

From the similar design projects applied by undergraduates' students, our project aims to study the reduction of surge pressure using shock absorber material such as copper coil and PVC pipes and determine the head losses of pipes and measure the pressure difference.

Chapter 3: System Design

3.1 Design Constraints

This designing system is analyzed by a numerous number of constraints corresponding to the main target of designing criteria. The system responses such as pipe size, pipe flow velocity, and junction pressures have been considered and implicated in the project:

3.1.1 Pipe Size Constraint

There are many pipe sizes in the market, but the main thing to consider is having a proper diameter to join the PVC pipe with the Copper coil. The available maximum diameter sizes of the coil are ½ inch and ¾ inch, which fit a PVC pipe with 1-inch diameter by using the fitting joints.

3.1.2 Pipe Flow Constraint

The design is also constrained by the pipe flow criteria, which gives us the maximum allowable flow velocity and maximum allowable hydraulic gradient.

3.13 Junction Pressures Constraint

Junction pressure is required to maintain the pressure levels to certify the water service, and to reduce the pressure rather than maintain the maximum pressure level in order to reduce the water leakage, and to prevent any sudden damage in the system.

3.4 Availability Market Constraint

We design the system with maximum availability parts, easily found in the local markets at less cost. We avoid ordering from online shops because during the COVID-19 Pandemic it has taken longer than before to receive shipped parts; therefore, local shops are the best choice to be on the safe side.

3.1.5 Budget Constraint

The budget of the entire project should not exceed 5000 Saudi Riyals. So, we should select the materials that are suitable to the requirement and benefit the design. Also, the costs of each part, which are available in the local markets, should be considered.

3.1.6 Design Methodology

The design of this project is concentrating on the piping system and fluid mechanics principles. The project has been implemented in four stages; first, collecting the information from the research papers and comparative studies that have been mentioned before. According to that, from calculating the information needed, we studied the issues and problems in the piping system and came up with the idea of developing the shock absorber using coil to reduce water hammer effect. The second stage was designing of the system and specified the parts and components of the system, including pipes, coil manufacturing, appropriate pump selection, joints, and sections. Furthermore, the third stage was categorized and subcategorized specifying the design components and formulas needed for calculations. Finally, we predict the theoretical data from using piping flow formulas with main consideration of Bernoulli's equation in order to measure the total head loss and estimate the length and number of turns of the coil, studying the effect of the coil to absorb the water hammer.

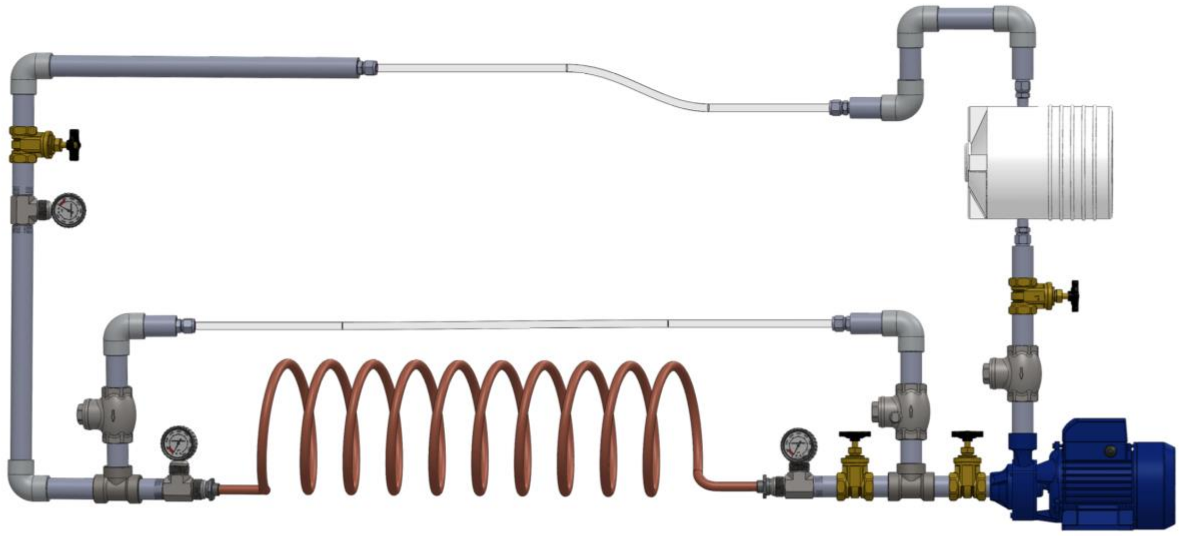

Figure 9 Front view of the piping system using solidworks

As shown in the above **figure 9**, the system contains several components. One of the main elements in the system is the pump. The pumping process is defined as giving liquid materials certain energy in order to move from one place to another. Another important element in the system is the non- return valve. In this system, we have three non-return valves used to determine the direction of flow and prevent backflow. Also, we have a four-gate valve that functions manually to stop the flow of liquid or its passage. There are seven-elbows in the system used when deflection of the mainline path is at a certain angle. Moreover, the system contains fitting pieces made from the same material as pipes or from other materials, and are used to connect pipes to each other at points of changing direction, making branches, changing diameter, or at the ends of pipes. A pipe tee is a connector used to join two or more plumbing pipes and in the system, we have two tee pipes. Also, there are three-pressure gauge devices used to measure water pressure. The copper coil pipe is used as a shock absorber to reduce the pressure. The hoses are used to transfer the water from the tank to the system.

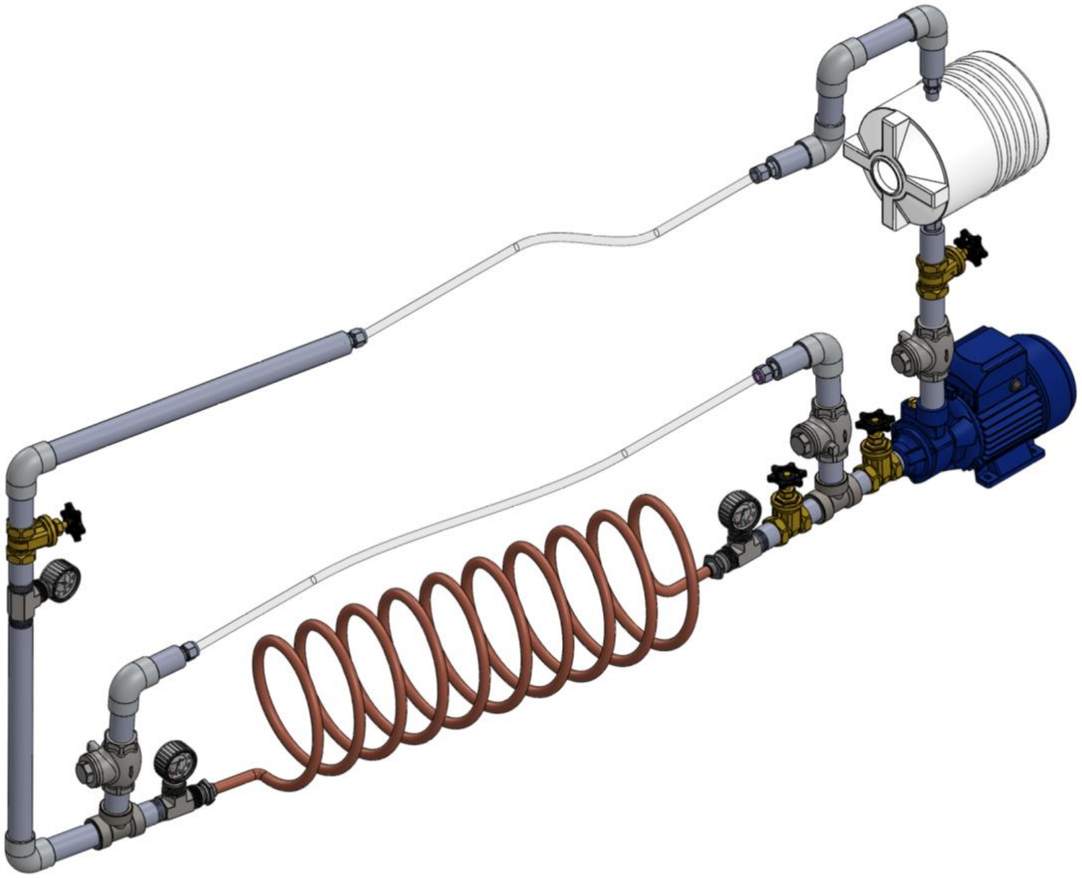

Figure 10 Isometric view of the piping system using solidworks

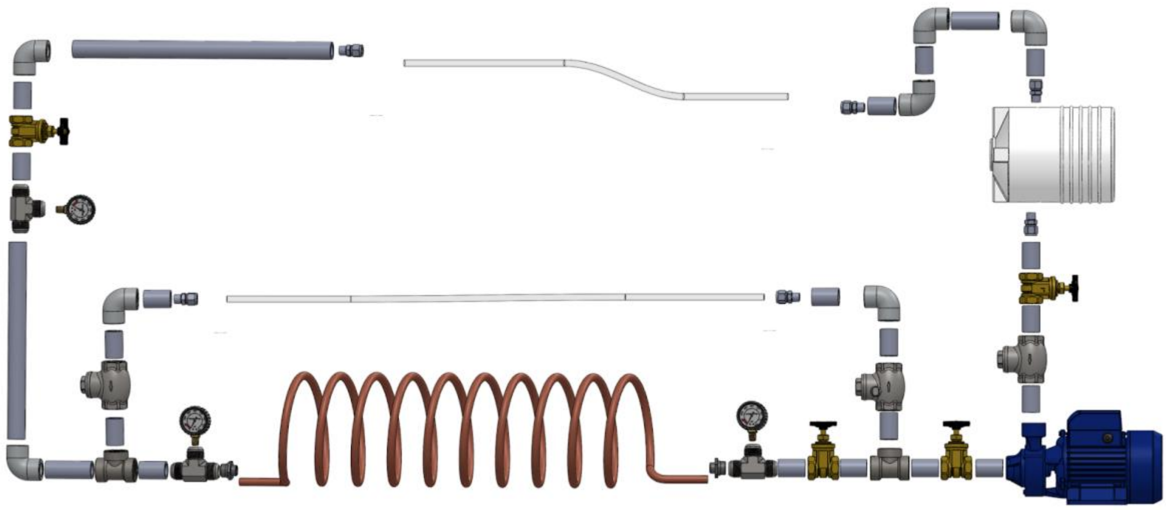

Figure 11 Exploded view of the piping system using solidworks

3.2 Engineering Design Standards

One of the most important criteria of designing a system is to follow the correct engineering standards that are related to the project. According to ISO, “A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.” However, the design of this project is based on the engineering standard of ASTM and ASME and are shown in the following **Table 2**:

Table 2 Engineering Standards

PVC Inert in Fittings	ASTM D2609
PVC Joining	ASTM D2564
PVC Pipes	ASTM D1785
Copper Pipe	ASTM B88M-20
Check Valve	ASME B16.34
Pressure Gauges	ASME B40.100
Centrifugal Pump	ASME B73.1

3.3 Theory and Theoretical Calculations

The main idea of the theoretical calculation is to predict the total head loss and flow rate velocity to measure the number of coil turns and length in order to study the efficiency of using the coil as a shock absorber of a water hammer.

1) Find the flow rate of the pump
2) Find the velocity of pipe in the section of coil
3) Find Reynolds number for one pipe & coil
4) Find the friction loss of the one pipe
5) Find the major head loss due to length of one pipe
6) Find the minor head losses for each elbow, tee section, check & gate valve
7) Find the total head loss
8) Find the length of the hose parallel to coil
9) Find the number of turns of coil
10) Find the pressure drop in coil
11) Estimate the value of pressure 2

3.3.1 Bernoulli equation

The Bernoulli effect is a state of conservation or of energy for flowing fluid where the reduction in pressure occurs when the fluid speed increases as shown in **Figure 12**.

$$P1 + \frac{1}{2}\rho V1^2 + \rho g h1 = P1 + \frac{1}{2}\rho V2^2 + \rho g h2 \qquad \textbf{Eqs 1.1}$$

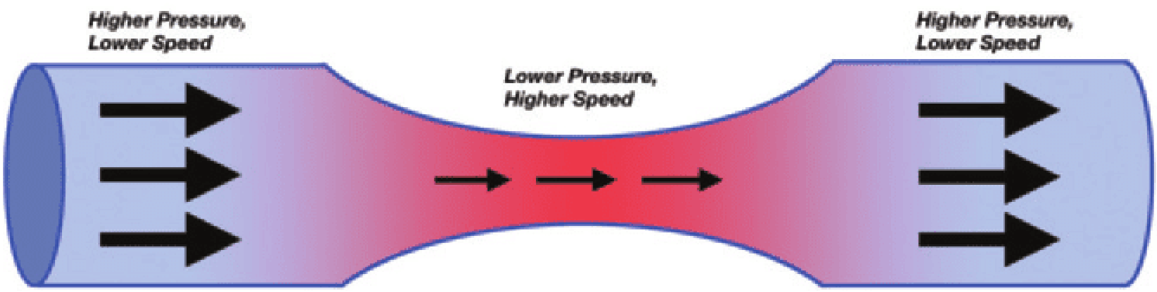

Figure 12 Diagram of bernoulli principle

3.3.2 Reynolds Number

A dimensionless parameter is controlling the behavior of flowing fluid, as it is the ratio of inertial forces to the viscous forces. This ratio helps to determine the flow type, i.e. laminar, transitional, and turbulent.

$$Re = \frac{\rho u L}{\mu} \qquad \textbf{Eqs 1.2}$$

Table 3 Flow Profile

Re ≤ 2300	**Laminar flow**
2300 ≤Re ≤ 10,000	**Transitional flow**
Re ≥ 10,000	**Turbulent flow**

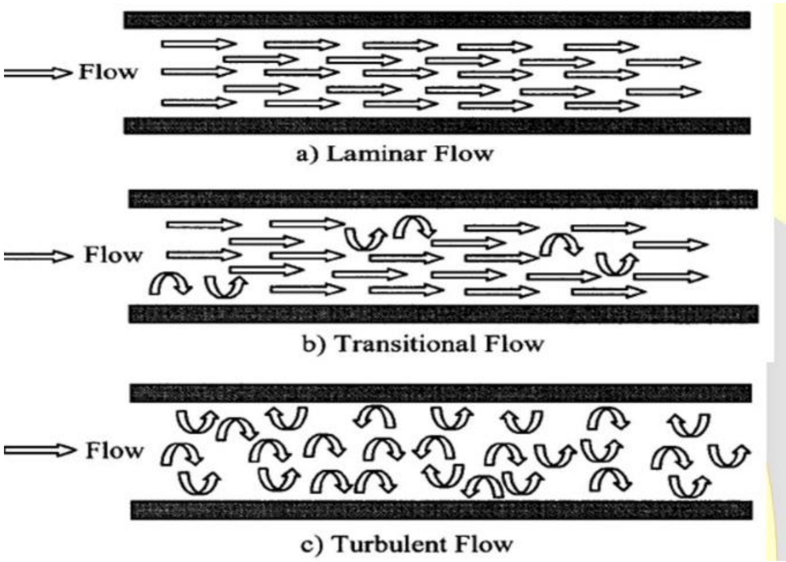

Figure 13 Flow profile types

3.3.3 Head Loss

It is a measurement of the reduction in the total head (sum of elevation head, velocity head, and pressure head) of the fluid as it moves through a fluid system. It occurs because of the friction between the fluid and walls of the pipe.

$$HL \frac{\Delta PL}{\rho g} = f \frac{L}{D} \frac{V^2}{2g} \qquad \textbf{Eqs 1.3}$$

3.3.4 Explicit Haaland Equation

$$\frac{1}{\sqrt{f}} = -1.8log[\frac{6.9}{Re} + \left(\frac{\frac{\varepsilon}{D}}{3.7}\right)^{1.1}]$$ **Eqs 1.4**

3.3.5 Minor loss

$$HL = KL\frac{V^2}{2g}$$ **Eqs 1.5**

3.3.6 Friction loss in pipe

$$\boldsymbol{f_s = 0.046(Re)^{-0.2}}$$ **Eqs 1.6**

3.3.7 Friction loss in coil

$$\boldsymbol{f_c = f_s[Re({}^{d_c}/_{D_c})^2]^{1/20}}$$ **Eqs 1.7**

3.3.8 Pressure drop in coil

$$\Delta\boldsymbol{p} = \frac{\boldsymbol{2f_cL_cu^2}}{\boldsymbol{d_c}}$$ **Eqs 1.8**

3.3.9 Number of turns of coil

$$\boldsymbol{L_c} = \mathrm{N}\sqrt{(\boldsymbol{2\pi R_c})^{\boldsymbol{2}} + \boldsymbol{P^2}}$$ **Eqs 1.9**

3.3. 9 Theoretical Calculations

The main parameters have been calculated using excel for the pump, pipe, coil, valves, and joints in order to estimate the pressure drop, length of coil, and number of turns.

1. **Pipe**

Table 4 Pipe (A)

Component	Unit
Pipe Diameter	1 in = 0.025400051 m

Pipe length	1m
ε	0.0000015 m
Velocity	1.1512 m\s
Reynolds number	29182.6419 > 2300 Turbulent flow
f	0.024816825
HL	0.06606 m
fs	0.00588482 m

2. Coil

Table 5 Coil (B)

Component	Unit
dc	0.5 in = 0.01270003 m
Dc	14 in = 0.35560071 m
Pitch	4.5 in = 0.11430023 m
Lc	1.12298461
Height	8 in = 0.20320041 m
ΔP	10817.323 Pa = 0.1081 bar
N	11.083
Velocity	4.7048 m/s
Reynolds number	58365.2838 > 2300 Turbulent flow
$\boldsymbol{fc}$	0.0.14603273

3. Elbow 90

Table 6 Elbow (C)

Component	Unit
Diameter	1 in = 0.025400051 m
K	0.75
HL	0.05071316 m

4. Non-return valve

Table 7 Non-return Valve (D)

Component	Unit
Diameter	1 in = 0.025400051 m
K	10
HL	0.67617547 m

5. Gate valve

Table 8 Gate Valve (E)

Component	Unit
Diameter	1 in = 0.025400051 m
K	0.9
HL	0.06085579 m

6. **Tee section**

Table 9 Tee Section (F)

Component	Unit
Diameter	1 in = 0.025400051 m
K	1
HL	0.06761755 m

7. **Total Head loss**

Table 10 Total Head Loss (G)

Design of the system	
Product	**Head loss**
Pipe	0.06606 m
Elbow 90º	0.050713 m
Non-return valve	0.67617 m
Gate valve	0.060855 m
Tee section	0.067617 m

3.4 Product Subsystem and Selection of Components

The components and materials selected on this project were based on their quality and availability in the market. As it is a mini project, it will be built in a wood board, the pipe size and length is 1 in and 1.5m maximum. The PVC pipe types were selected based on the ability to withstand high pressure. In addition, the joints have been used to connect the pipes together such as the tee section, elbows.

Figure 14 PVC pipe

The selection of pump is based on the power and flow rate (Q) which is 0.5HP and it includes a gauge pressure to measure the flow rate of the pump when it is operating.

Figure 15 Pump information

Figure 16 Joints (Union)

3.5 Manufacturing and assembly

The assembling of the elements is considered an easy process because we only need to assemble the pipes, tee sections, and elbow together using Weld-on CPVC. The picture of the item is shown in **figure 17**. It is like cement for the pipes and after application it is necessary to wait until it dries. Also, for the valves, hose, and copper coil, there is a piece called union as shown in **figure 18**, which allows joining of the valve with the pipe.

Figure 17 CPVC cement

Figure 18 Union

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors, and Data Acquisition System

The setup of the system depends on the number of valves, gauge pressure, the shock absorber, pump, and pipes. The system can be classified as an open system (cycle) that undergoes a steady flow process without change in the mass and energy of water.

In this project, we have used gate valves that are distributed in the three sections of the system in order to have a manual control of water flow through pipes as shown in **Fig. 20.** Gate valve 1 controls the flow of water through the pump. Gate valve 2 controls pumping water flow to enter the hose. Gate valve 3 prevents the water from entering the coil and directly flowing through the hose. Gate valve 4 is a valve for controlling the water hammer effect.

Another important valve that helps the working flow of the system is the non-return valve as shown in **Fig. 21.** The purpose of a non-return valve is to have only one direction of flowing water. In our research, we applied 3 valves, the first one, to prevent the water from flowing back into the tank when gate valve one is open. The second one is to prevent the water from entering the coil while gate valve 3 and 2 are open, and the last one is after exiting section 2. Moreover, the valve size was measured depending on the diameter of the PVC pipe.

The setup of the project cannot be completed without a pressure gauge. Three pressure gauges have been distributed at each section and are designed to measure pressure while running the tests. The type of a gauge that has been chosen is a hydraulic pressure gauge as shown in **Fig. 19**. It is installed in the PVC pipes in order to measure the pressure through the pipes.

Simultaneously, a pressure gauge can help to ensure that there is no leakage. As a final point, the shock absorber (coil) in **Fig 22** was installed to test if the reduction of water hammer occurs. As a result, we compare the calculated shock absorber with experimental observation.

Figure 20 Hydraulic pressure gauge

Figure 19 Gate valve

Figure 21 Non-return valve

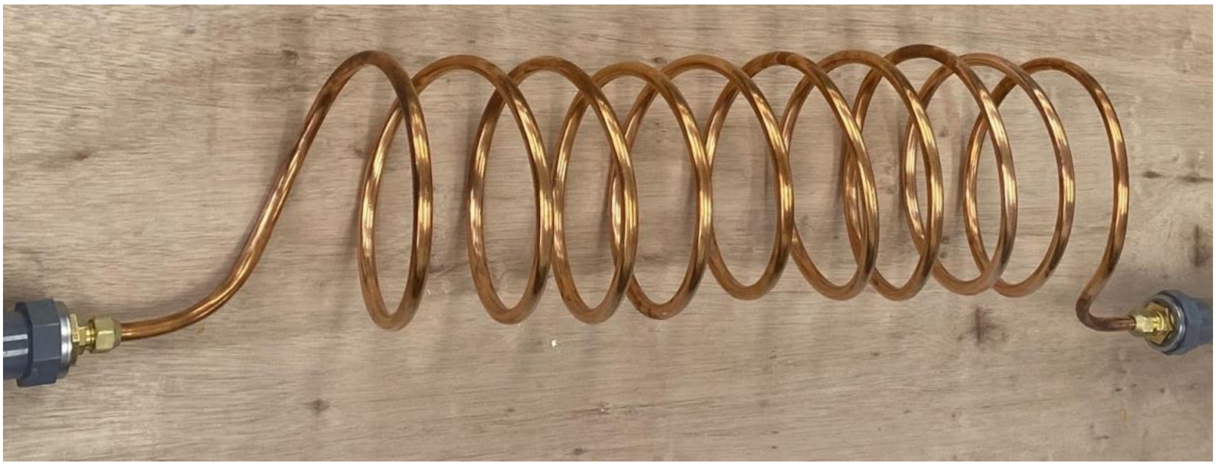

Figure 22 Copper coil

4.1.2 Working Mechanisms

Before running the experiment, we have to ensure no leakage and the system is working appropriately. The way this system is going to be tested is by starting to release air bubbles from water flow inbuilt to enable water pressure in pipes (venting). After that, gate valve 3 will be closed to prevent water flow through the coil. The system will continue to circulate while the power is on. Whereas the water hammer effect will occur when gate valve 4 is closed, resulting in increase in backpressure (P1) as it shows in **Fig. 23**, and shock wave flows in the coil. The pressure will be measured before (P3) and after (P0) entering the coil in order to observe the reduction of the water hammer. However, a non-return valve will allow the water to flow directly in the coil without entering the hose. The prototype of the system is shown in **Fig.24**

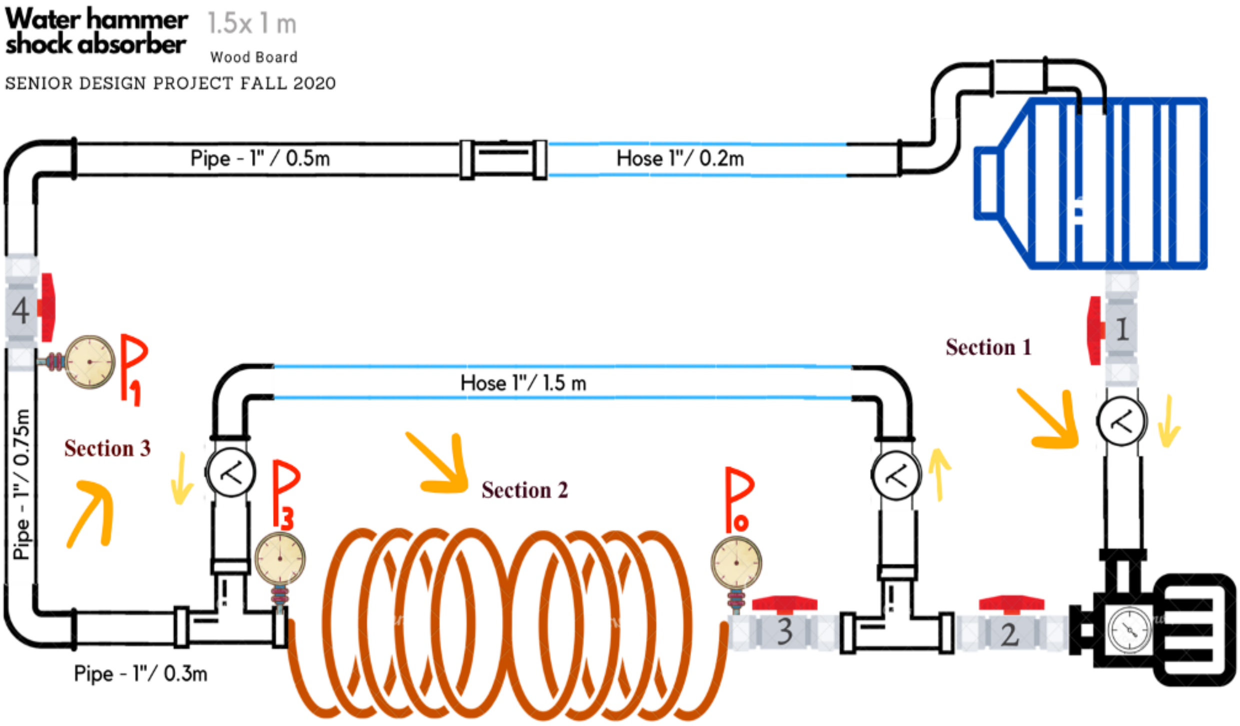

Figure 23 Detailed design drawing

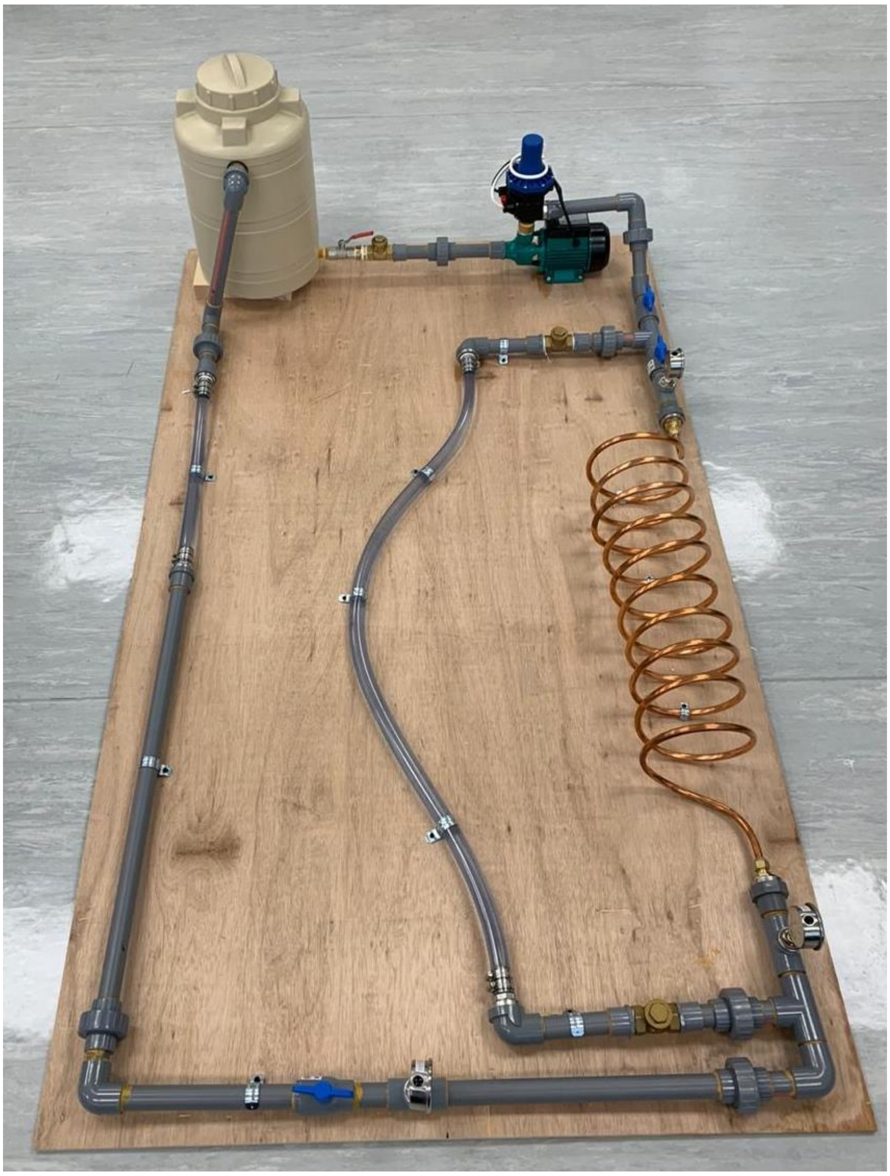

Figure 24 Prototype of the design project

4.2 Results, Analysis and Discussion

The system was tested four times with a closing gate valve 3&4 in order to measure the difference of water pressure across the coil caused by the water hammer effect. The test result can be shown in the below **Table 11**.

Table 11 Pressure Gauge Test

	Gate valve 1	**Gate valve 2**	**Gate valve 3**	**Gate valve 4**	**Po (bar)**	**P3 (bar)**	**P1 (bar)**
Test 1	Open		Close		2.2	2.4	2.6
Test 2					2.1	2.5	2.7
Test 3					2.3	2.4	2.8
Test 4					2.3	2.5	2.9
Average Pressure					2.225	2.45	2.75

Observing the data in the table, one can clearly prove that Po has the smallest pressure due to the excites of elbow and friction loss, and P1 has the largest pressure when valves are closed, resulting augmentation in the backward flow pressure.

4.3 Findings and Discussion

Table 12 Experimental Calculations

Parameter	value	unit
dc	**0.0127**	**m**
Dc	**0.35**	**m**
Density	**1000**	**kg/m^3**
Q	**0.00059**	**m^3/s**
Pitch (coil)	**0.115**	**m**
N	**11**	
dc/Dc	**0.036285714**	
μ	**0.001002**	
Po	**2.1**	**bar**
P1	**2.4**	**bar**
P3	**2.3**	**bar**
Velocity u	**4.65751957**	**m/s**
Reynolds number	**59032.43367**	
Coil length Lc	**12.16110341**	**m**
Friction factor Fs	**0.005111398**	**-**
Friction factor Fc	**0.006354301**	**-**
ΔP empirical	**0.274595852**	**bar**
ΔP Experimental	**0.3**	**bar**
% error	**8.468049217**	

To investigate the performance of the coil in terms of reducing the water hummer phenomena, we need to do several tests with different specifications of copper coil like number of turns, and size of pipe. But due to the limitation of time and shortage of manufacturing the coil, we did a comparison of coil pressure reduction (ΔP) between theoretical and experimental values for one coil with specification shown in the table above.

Empirical equations listed by [6] are employed to determine the pressure drop across the coil. The value obtained is then compared with the measured value. It was found that about 8% discrepancy in the coil pressure drop was determined. Such error is acceptable and in very good range, considering the uncertainty of the pressure gauges we used.

Chapter 5: Project Management

5.1 Project Plan

Segregating each task with its own start/end dates will help to manage and get better result of all project aspects:

Table 13 Tasks List

Task	Start	End
Milestone 1		
Project ideas	30 Aug, 2020	5 Sep, 2020
Group meeting	5 Sep, 2020	5 Sep, 2020
Advisor meeting	6 Sep, 2020	6 Sep, 2020
Project selection	7 Sep, 2020	9 Sep, 2020
Gantt chart preparation	9 Sep, 2020	11 Sep, 2020
Gantt chart submission	12 Sep, 2020	12 Sep, 2020
Finalized the Ideas	13 Sep, 2020	16 Sep, 2020
Search for materials	16 Sep, 2020	19 Sep, 2020
Group meeting	20 Sep, 2020	20 Sep, 2020
Discussing for the prototype	21 Sep, 2020	21 Sep, 2020
Initial project drawing	22 Sep, 2020	22 Sep, 2020
Searching for E-sources	23 Sep, 2020	25 Sep, 2020
Milestone 2		
Project Report Writing Chapter 1 Introduction		
Abstract	25 Sep, 2020	25 Sep, 2020

Acknowledgment	26 Sep, 2020	26 Sep, 2020
Table of contents	26 Sep, 2020	26 Sep, 2020
1.1 Project definition	27 Sep, 2020	28 Sep, 2020
1.2 Project objective	27 Sep, 2020	27 Sep, 2020
1.3 Project specifications	27 Sep, 2020	29 Sep, 2020
1.4 Application	28 Sep, 2020	28 Sep, 2020
Project Report Writing Chapter 2 Literature Review		
2.1 Project background	29 Sep, 2020	30 Sep, 2020
2.2 Previous work	29 Sep, 2020	1 Oct, 2020
2.3 Comparative study	29 Sep, 2020	2 Oct, 2020
Meetings for designing the project		
Group meeting	3 Oct, 2020	3 Oct, 2020
Advisor meeting	4 Oct, 2020	4 Oct, 2020
Milestone 3		
Project Report Writing Chapter 3 System Design		
3.1 Design constraints	5 Oct, 2020	5 Oct, 2020
3.1.1 Pipe size constrain	5 Oct, 2020	5 Oct, 2020
3.1.2 Pipe flow constraint	6 Oct, 2020	7 Oct, 2020
3.13 Junction pressures constrain	7 Oct, 2020	8 Oct, 2020
3.4 Availability market constrain	8 Oct, 2020	8 Oct, 2020
3.1.5 Budget constraint	8 Oct, 2020	9 Oct, 2020
3.1.6 Design methodology	9 Oct, 2020	11 Oct, 2020
3.1.6 Solidworks drawing	11 Oct, 2020	15 Oct, 2020

3.2 Engineering Design Standards	15 Oct, 2020	15 Oct, 2020
Meetings for design calculation		
Advisor meeting	16 Oct, 2020	17 Oct, 2020
Group meeting	18 Oct, 2020	24 Oct, 2020
Continue Project Report Writing Chapter 3 System Design		
3.3 Theory and Theoretical Calculations	24 Oct, 2020	25 Oct, 2020
3.4 Product Subsystem and Selection of Components	26 Oct, 2020	28 Oct, 2020
3.5 Manufacturing and assembly	29 Oct, 2020	29 Oct, 2020
Project Assembly		
Manufacture copper coil	19 Oct, 2020	20 Oct, 2020
Collection the equipment	20 Oct, 2020	23 Oct, 2020
Equipment & copper coil are ready to assemble	31 Oct, 2020	31 Oct, 2020
Assumable the project	5 Nov, 2020	5 Nov, 2020
Test the project	19 Nov, 2020	19 Nov, 2020
Milestone 4		
Preparing for the midterm presentation	9 Nov, 2020	11 Nov, 2020
Midterm presentation	12 Nov, 2020	12 Nov, 2020
Project Test		
Run the test	19 Nov, 2020	19 Nov, 2020
Observe the effect of water hammer	19 Nov, 2020	19 Nov, 2020
Investigate the performance	19 Nov, 2020	19 Nov, 2020
Reading the pressure values from the gauges	19 Nov, 2020	19 Nov, 2020
Milestone 4		

Prototype completion	29 Nov, 2020	29 Nov, 2020
Milestone 5		
Project Report Writing Chapter 4 System Testing and Analysis		
4.1 Experimental Setup, Sensors and data acquisition system	2 Dec, 2020	4 Dec, 2020
4.2 Results, Analysis and Discussion	4 Dec, 2020	5 Dec, 2020
Project Report Writing Chapter 5 Project Management		
5.1 Project plan	6 Dec, 2020	7 Dec, 2020
5.2 Contribution of team members	7 Dec, 2020	7 Dec, 2020
5.3 Project execution monitoring	7 Dec, 2020	8 Dec, 2020
5.4 Challenges and decision making	8 Dec, 2020	8 Dec, 2020
5.5 Project bill of materials and budget	8 Dec, 2020	8 Dec, 2020
Project Report Writing Chapter 6 Project Analysis		
6.1 Life-long learning	9 Dec, 2020	9 Dec, 2020
6.2 Impact of engineering solutions	9 Dec, 2020	10 Dec, 2020
6.3 Contemporary issues addressed	10 Dec, 2020	10 Dec, 2020
Project Report Writing Chapter 7 Conclusions and Future Recommendations		
7.1 Conclusions	11 Dec, 2020	12 Dec, 2020
7.2 Future Recommendations	12 Dec, 2020	12 Dec, 2020
Milestone 6		
Final presentation	16 Dec, 2020	17 Dec, 2020

5.2 Contribution of Team Members

Hand by hand with effort and contribution of each single individual of team members the project was conducted as follows:

Table 14 Team Members Contribution

#	Task Description	Team Members Assigned	Progress Made
1	Creating Gantt Chart	Malak Alnowaiser & Ghadeer Almuslim	100%
2	Report 1.1 Project definition	Sarah Aldossary	100%
3	Report 1.2 Project objective	Malak Alnowaiser	100%
4	Report 1.3 Project specifications	Sarah Aldossary	100%
5	Report 1.4 Application	Malak Alnowaiser	100%
6	Report 2.1 Project background	Malak Alnowaiser	100%
7	Report 2.2 Previous work	All group	100%
8	Report 2.3 Comparative study	Ghadeer Almuslim	100%
9	Material availability	Ghadeer Almuslim	100%
10	Design drawing	Malak Alnowaiser & Ghadeer Almuslim	100%
11	Design calculations	All group	100%
12	Material Standards	Sarah Aldossary	100%
13	Report 3.1 Design constraints	Sarah Aldossary	100%
14	Report 3.2 Engineering Design Standards	Sarah Aldossary	100%

15	Solidworks drawing	Malak Alnowaiser	100%
16	Report 3.3 Theory and Theoretical Calculations	Ghadeer Almuslim	100%
17	Report 3.4 Product Subsystem and Selection of Components	Ghadeer Almuslim	100%
18	Report 3.5 Manufacturing and assembly	Malak Alnowaiser	100%
19	Manufacture copper coil	Ghadeer Almuslim	100%
20	Collection the equipment	Ghadeer Almuslim	100%
21	Assumable the project	All group	100%
22	Design midterm presentation PowerPoint	Malak Alnowaiser	100%
23	Report 4.1 Experimental Setup, Sensors and data acquisition system	Ghadeer Almuslim	100%
24	Report 4.2 Results, Analysis and Discussion	Ghadeer Almuslim	100%
25	Setup the project	All group	100%
26	Running the system	All group	100%
27	Experimental calculation	All group	100%
28	Report 5.1 Project plan	Malak Alnowaiser	100%
29	Report 5.2 Contribution of team members	Malak Alnowaiser	100%

30	Report 5.3 Project execution monitoring	Sarah Aldossary	100%
31	Report 5.4 Challenges and decision making	All group	100%
32	Report 5.5 Project bill of materials and budget	Ghadeer Almuslim	100%
33	Report 6.1 Life-long learning	All group	100%
34	Report 6.2 Impact of engineering solutions	Ghadeer Almuslim	100%
35	Report 6.3 Contemporary issues addressed	Sarah Aldossary	100%

5.3 Project Execution Monitoring

The project monitoring involved various meetings with advisor Dr. Esam Jassem, either if we attended meetings at university or had an online meeting. Dr. Esam was very helpful and responsible in achieving the project with highly engineering quality and safety through obtaining different equations, and testing the project together. As group members had at least two meetings every week to complete the required tasks of calculating and writing the report. And also, to track the process of the work and making sure that every member is working efficiently. We assembled the prototype system together at university and we helped each other in understanding the entire system during different tests that were conducted in the project.

5.4 Challenges and Decision Making

Each project has its own difficulties and challenges that come up. Due to the current pandemic COVID-19 the communication with the team in regards to the project was one of the major difficulties that took place while conducting the project. Hence, there were limitations of physical meetings and online meetings were the alternative solution, which results to slow down the progress of the project. Despite the slow internet connection, we have been appealed to bridge the gap.

Another challenge faced during the current semester is that there are other senior programs requiring a lot of effort and work to be done at the same time which cause stress to get all of them done.

The first time we ran the project there was a leakage in the pipes which might cause a problem in the system. In that situation, we were able to figure out the cause of the leak and start solving the problem by indicating the leakage position and start working to solve it. Other challenges we faced, the shortage in manufacturers of coil that limits us with the specific size, and number of turns.

5.5 Project Bill of Materials and Budget

The estimated budget of our system was around 1800 SR. However, we were able to find most of the equipment in the market within high quality at a lower price, as the products are available in local markets, this helps us to maintain our project within not exceeding 1000 SR. The below **Table 15** shows the detailed cost:

Table 15 Bill of Material

Product	Specification	Quantity	Price (SR)
Water Pump	0.37 KW/ 0.5 HP	1	135 SR
Submersible Motor Pump	Regulate pump flow	1	100 SR
Pressure Gauge	Bar/ psi	3	108 SR
Refrigerated Tube Dehydrated (coil)	1/2 in	6 m, 10 turns	60 SR
Clear Flexible Hose	1 in	2 m	20 SR
Water Tank	30 L capacity	1	70 SR
Gate Valve	1 in & 3/4 in	4	90 SR
Hose Nipple	1 in	4	60 SR
Hose Clamp	1 in	8 m	16 SR
Plywet Wood	12 mm thickness	120* 220 cm	70 SR
PVC Pipe	1 in	5m	40 SR
Pipe Union	1 in	7	35 SR
Brass Non-Return Valve	1 in	3	75 SR
Tee Section	1 in	2	14 SR
Elbow	1 in	8	40 SR
Pipes connect	1 in	8	40 SR
Total Cost			973 SR

Chapter 6: Project Analysis

6.1 Life-long Learning

The project helps us to use our creativity in drawing design and enhance our software skills. Google Drive was one of the most important parts of our work as the senior design project requires lots of writing and collecting information. According to that, we were able to share the documents, edit, and comment at the same time. In addition, Excel plays a significant role in our calculations by applying several formulas for both experimental and theoretical calculations.

Taking online courses such as, Total Quality Management gave us an insight of designing our project through describing the management approach to long-term success of the project. Also, as group members that course helps us to improve the processes of designing the system as well as focusing on the strategic planning or strategic management to integrate quality as a core factor.

6.2 Impact of Engineering Solutions

The impact of the system in the engineering solution can be in the pipelines system where the water hammer occurs. Most of the industrial fields are seeking enhancement of technology and searching for advanced methods that help reduce water hammer. Our project presents a shock absorber method for the water hammer effect. However, the economic impact might be beneficial if the system was enhanced and developed for large industrial applications. Reduction of water hammer will reduce the cost of losses due to damages and rupture of pipelines caused by a raisin in pressure. Besides, this project might help future industrial fields such as water desalination, oil, and gas pipelines

6.3 Contemporary Issues Addressed

Water applications and supply in Saudi Arabia is characterized by challenges and achievements. One of the most challenges is to overcome water scarcity. Saudi Arabia substantial investments have been undertaken in seawater desalination, wastewater treatment, and water distribution. Water is an essential recourse of our life, so we as Saudi Engineers play a key role in supporting and development engineering solutions for the Kingdom's economy and as well as in improving the quality of citizen life. This project is concerned in designing an entire pipeline system in order to enhance the performance starting from small applications to huge applications related to water and oil applications. We are so proud that Saudi Arabia witnessed numerous achievements (vision2030) through institutional capacity and governances such as Saline Water Conversion Corporation (SWCC) and Saudi Aramco.

Chapter 7: Conclusions and Future Recommendations

7.1 Conclusions

The water hammer shock absorber here can be erected safely, and it is presented in this report fulfil the criteria specified in the project brief. This design has many advantages regarding safety and economy as it is economical to manufacture and maintain.

Overall, the objective of the system was achieved successfully. In this project, we were to do a mathematical calculation to measure the friction losses in PVC pipes, elbow, tee sections to estimate the length and number of turns in the coil. The system conducted four tests to observe the difference of pressure caused by a water hammer effect. However, the findings were obtained by a comparison of coil pressure reduction (ΔP) between theoretical and experimental values for one coil due to the limitation of time and shortage of manufacturing the coil, the comparison values obtained were in the acceptable range with an 8% error.

In this project, we were able to apply our knowledge and skills taken during our study in both communication and ME courses. According to that, the design of the project helps us to search and conduct studies related to water hammer effect, use different software programs which helped us to organize, draw, calculate the information needed such as Soildworks, Google drive, and Microsoft office programs. Last but not least, the project developed our mindset on engineering problems and helped us to think logically and search for a solution for any problem.

7.2 Future Recommendations

It is recommended in the future to test different coil configurations, helix diameters, tube diameters, and number of turns to sustain the conclusion with more accurate pressure gauges. It can study other shock absorber methods such as using Air chamber, check valve. However, the project can be developed using a simulation model of hydraulic transients of water hammer using MATLAB or CFD program. Also, the pressure can be controlled technologically.

Appendix A: Progress Reports

Progress report #1

Month: October 2020

ID Number	**Member Name**
Sarah Aldossary	201602298
Ghadeer AlMuslim	201600576
Malak Alnowaiser	201601292

List the tasks conducted this month and the team member assigned to conduct these tasks

#	**Task description**	**Team member assigned**	**Progress 0%-100%**	**Delivery proof**
1	Material availability	Ghadeer	100%	
2	Design drawing	Malak	100%	
3	Design calculations	All group	100%	
4	Material Standards	Sarah	100%	

List the tasks planned for the month of October and the team member/s assigned to conduct these tasks

#	**Task description**	**Team member/s assigned**
1	Local market availability of the materials (valves, pump, PVC pipe, coil manufacture, pressure gauge, tank.	Ghadeer AlMuslim
2	2D design of the piping system and 3D drawing using SolidWorks.	Malak Alnowaiser Ghadeer AlMuslim
3	Calculate the head losses, estimate the length of the pipe using fluid mechanics formula for internal pipe.	All group
4	Searching for engineering standards society for material and components used	Sarah Aldossary

Progress report #2

Month: November 2020

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Setup the project	All group	100%	
2	Running the system	All group	100%	
3	Experimental calculation	All group	100%	
4	Midterm presentation	Malak	100%	

List the tasks planned for the month of November and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Collect the products and equipment and start connecting the project together	All Group
2	Make sure that the project was set up appropriately without any problems and leakage in pipelines	All Group
3	After running the project, we measured the pressure from pressure gauges in order to do the experimental calculations	All group
4	Working on the design and the content of the midterm presentation	Malak Alnowaiser

Appendix B: Engineering standards (Local and International)

Table 1 Engineering Standards

PVC Inert in Fittings	ASTM D2609
PVC Joining	ASTM D2564
PVC Pipes	ASTM D1785
Copper Pipe	ASTM B88M-20
Check Valve	ASME B16.34
Pressure Gauges	ASME B40.100
Centrifugal Pump	ASME B73.1

Appendix C: CAD drawings and Bill of Materials

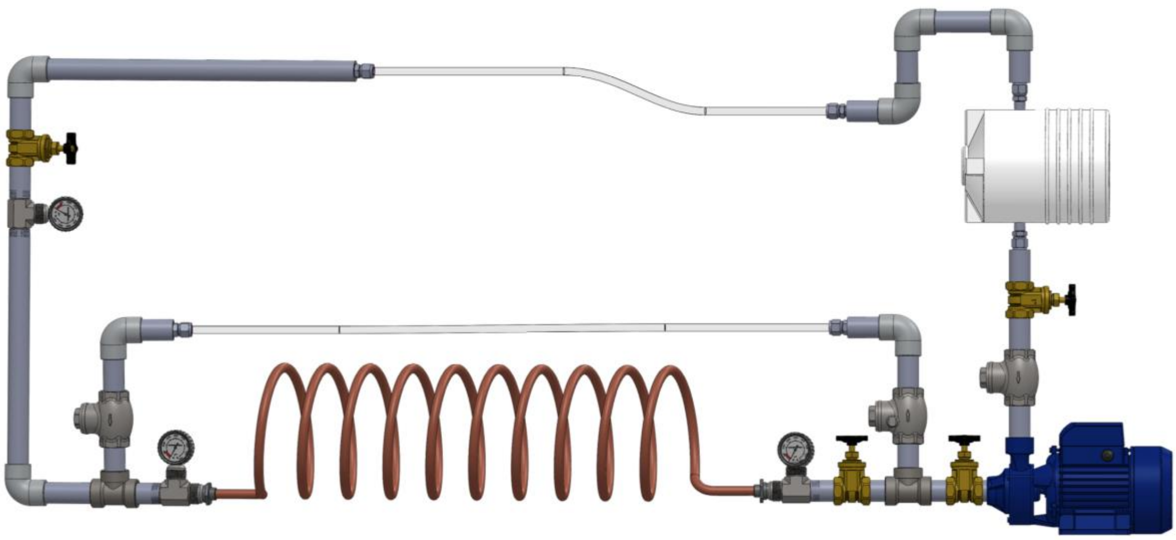

Figure 9 Front View of The Piping System Using Solidworks

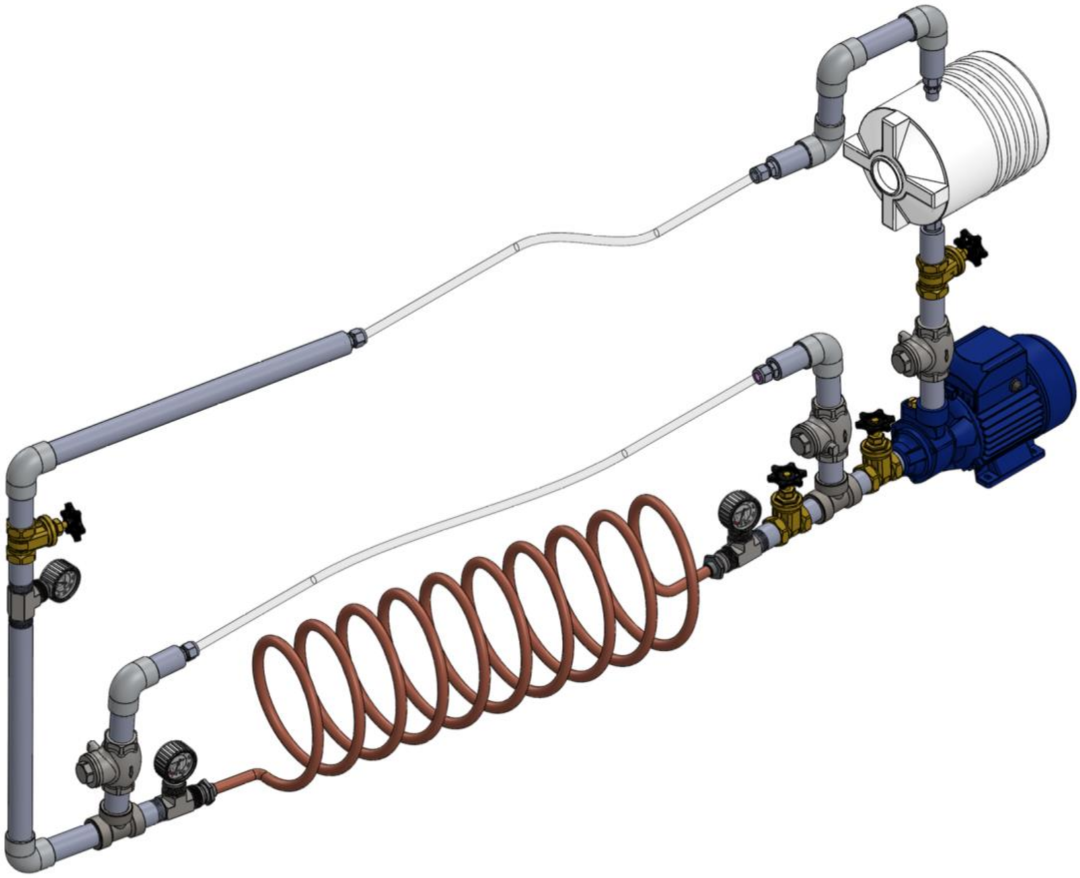

Figure 10 Isometric View of The Piping System Using Solidworks

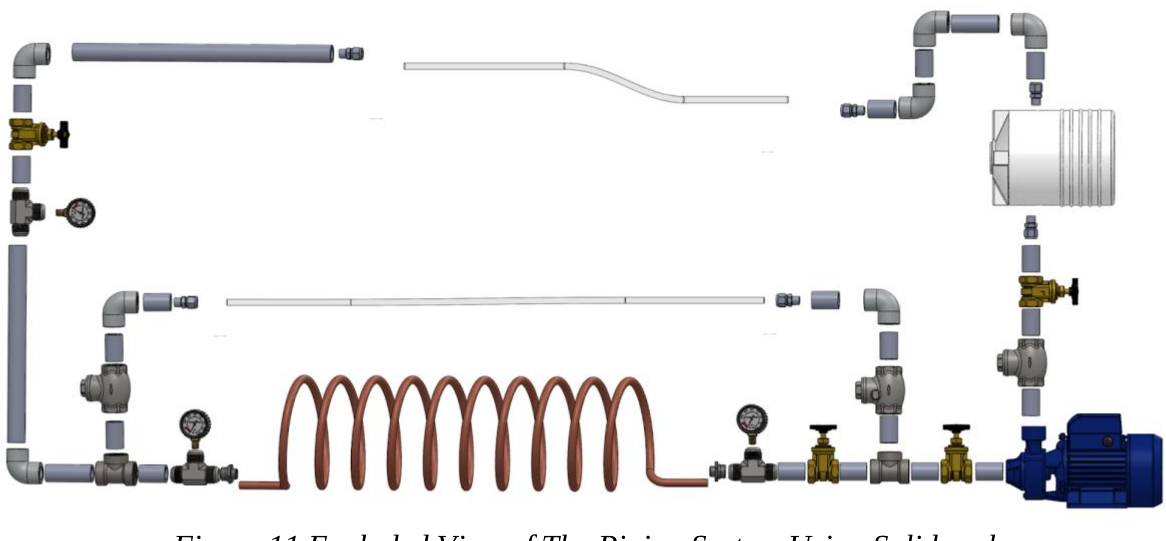

Figure 11 Exploded View of The Piping System Using Solidworks

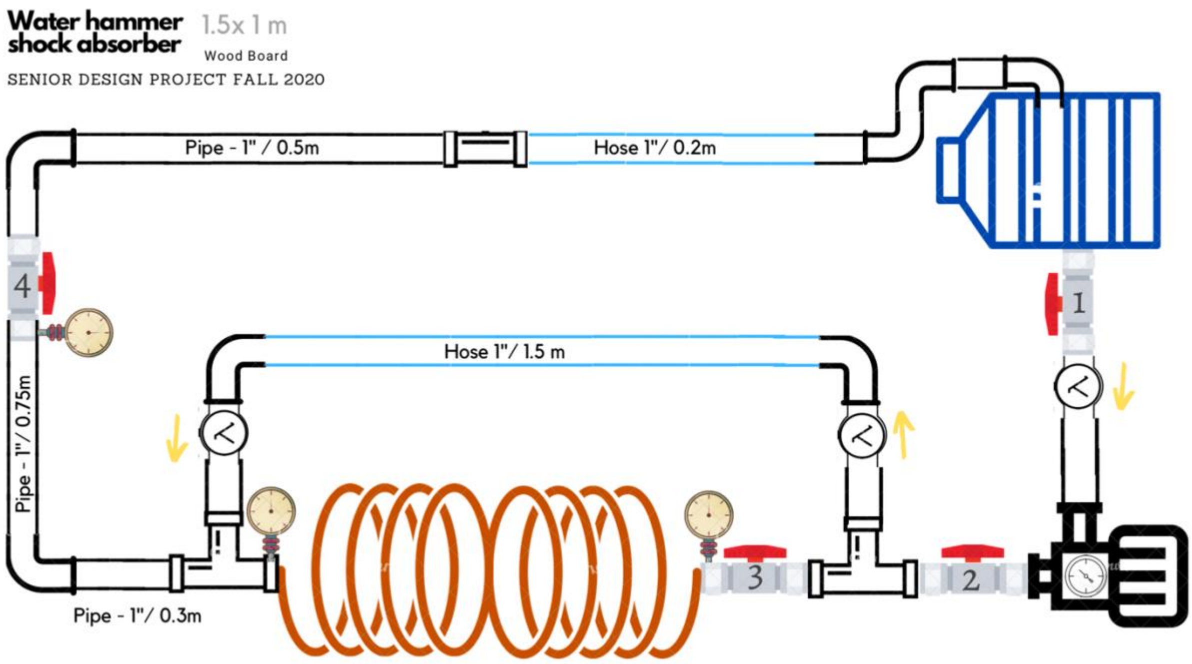

Figure 25 Drawing of water hammer flow cycle

Table 13 Bill of Material

Product	Specification	Quantity	Price (SR)
Water Pump	**0.37 KW/ 0.5 HP**	**1**	**135 SR**
Submersible Motor Pump	**Regulate pump flow**	**1**	**100 SR**
Pressure Gauge	**Bar/ psi**	**3**	**108 SR**
Refrigerated Tube Dehydrated (coil)	**1/2 in**	**6 m, 10 turns**	**60 SR**
Clear Flexible Hose	**1 in**	**2 m**	**20 SR**
Water Tank	**30 L capacity**	**1**	**70 SR**
Gate Valve	**1 in & 3/4 in**	**4**	**90 SR**
Hose Nipple	**1 in**	**4**	**60 SR**
Hose Clamp	**1 in**	**8 m**	**16 SR**

Plywet Wood	**12 mm thickness**	**120* 220 cm**	**70 SR**
PVC Pipe	**1 in**	**5m**	**40 SR**
Pipe Union	**1 in**	**7**	**35 SR**
Brass Non-Return Valve	**1 in**	**3**	**75 SR**
Tee Section	**1 in**	**2**	**14 SR**
Elbow	**1 in**	**8**	**40 SR**
Pipe’s connect	**1 in**	**8**	**40 SR**
Total Cost			**973 SR**

Appendix D: Theoretical calculations

1. **Pipe**

Table 3 (A)

Component	**Unit**
Pipe Diameter	1 in = 0.025400051 m
Pipe length	1m
ε	0.0000015 m
Velocity	1.1512 m\s
Reynolds number	29182.6419 > 2300 Turbulent flow
f	0.024816825
HL	0.06606 m
fs	0.00588482 m

2. **Coil**

Table 4 (B)

Component	**Unit**
dc	0.5 in = 0.01270003 m
Dc	14 in = 0.35560071 m
Pitch	4.5 in = 0.11430023 m
Lc	1.12298461
Height	8 in = 0.20320041 m
ΔP	10817.323 Pa = 0.1081 bar
N	11.083
Velocity	4.7048 m/s
Reynolds number	58365.2838 > 2300 Turbulent flow

fc	0.0.14603273

3. Elbow 90

Table 5 (C)

Componen t	**Unit**
Diameter	1 in = 0.025400051 m
K	0.75
HL	0.05071316 m

4. Non- return valve

Table 6 (D)

Component	**Unit**
Diameter	1 in = 0.025400051 m
K	10
HL	0.67617547 m

5. Gate valve

Table 7 (E)

Component	**Unit**
Diameter	1 in = 0.025400051 m
K	0.9
HL	0.06085579 m

6. Tee section

Table 8 (F)

Component	**Unit**
Diameter	1 in = 0.025400051 m
K	1
HL	0.06761755 m

Table 9 (G)

Design of the system	
Product	**Head loss**
Pipe	0.06606 m
Elbow 90º	0.050713 m
Non-return valve	0.67617 m
Gate valve	0.060855 m
Tee section	0.067617 m

Appendix E: Experimental Result

Table 9 Pressure Gauge Test

	Gate valve 1	**Gate valve 2**	**Gate valve 3**	**Gate valve 4**	**Po (bar)**	**P3 (bar)**	**P1 (bar)**
Test 1	Open		Close		2.2	2.4	2.6
Test 2					2.1	2.5	2.7
Test 3					2.3	2.4	2.8
Test 4					2.3	2.5	2.9
Average Pressure					2.225	2.45	2.75

Appendix F: Experimental Calculations

Table 16 Experimental Calculations

Parameter	value	unit
dc	0.0127	m
Dc	0.35	m
Density	1000	kg/m^3
Q	0.00059	m^3/s
Pitch (coil)	0.115	m
N	11	
dc/Dc	0.036285714	
µ	0.001002	
Po	2.1	bar
P1	2.4	bar
P3	2.3	bar
Velocity u	4.65751957	m/s
Reynolds number	59032.43367	
Coil length Lc	12.16110341	m
Friction factor Fs	0.005111398	-
Friction factor Fc	0.006354301	-
∆P empirical	0.274595852	bar
∆P Experimental	0.3	bar
% error	8.468049217	

Appendix G: Figures of prototype

Figure 14 PVC Pipe

Figure 15 Pump Information

Figure 21 Non-return valve

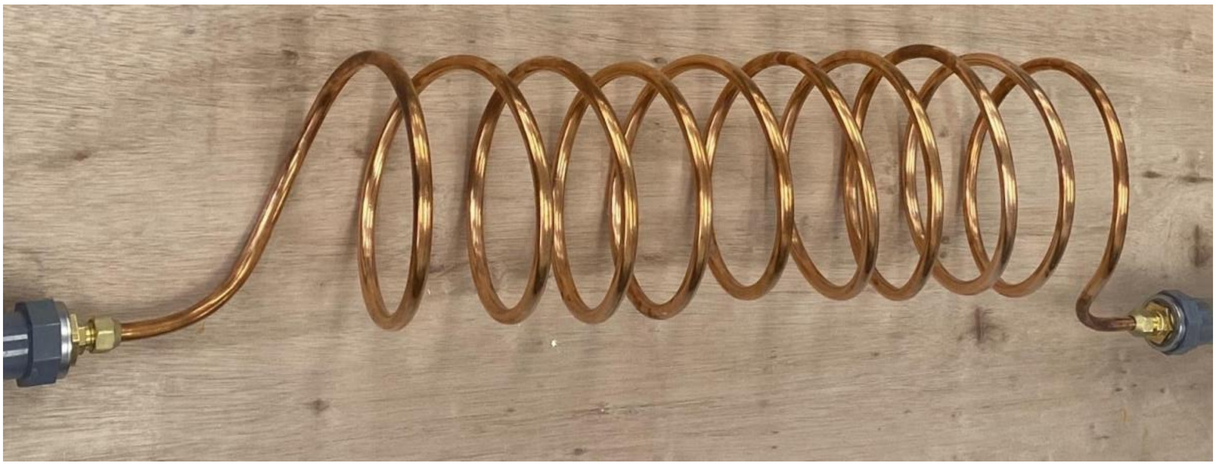

Figure 16 Copper Coil

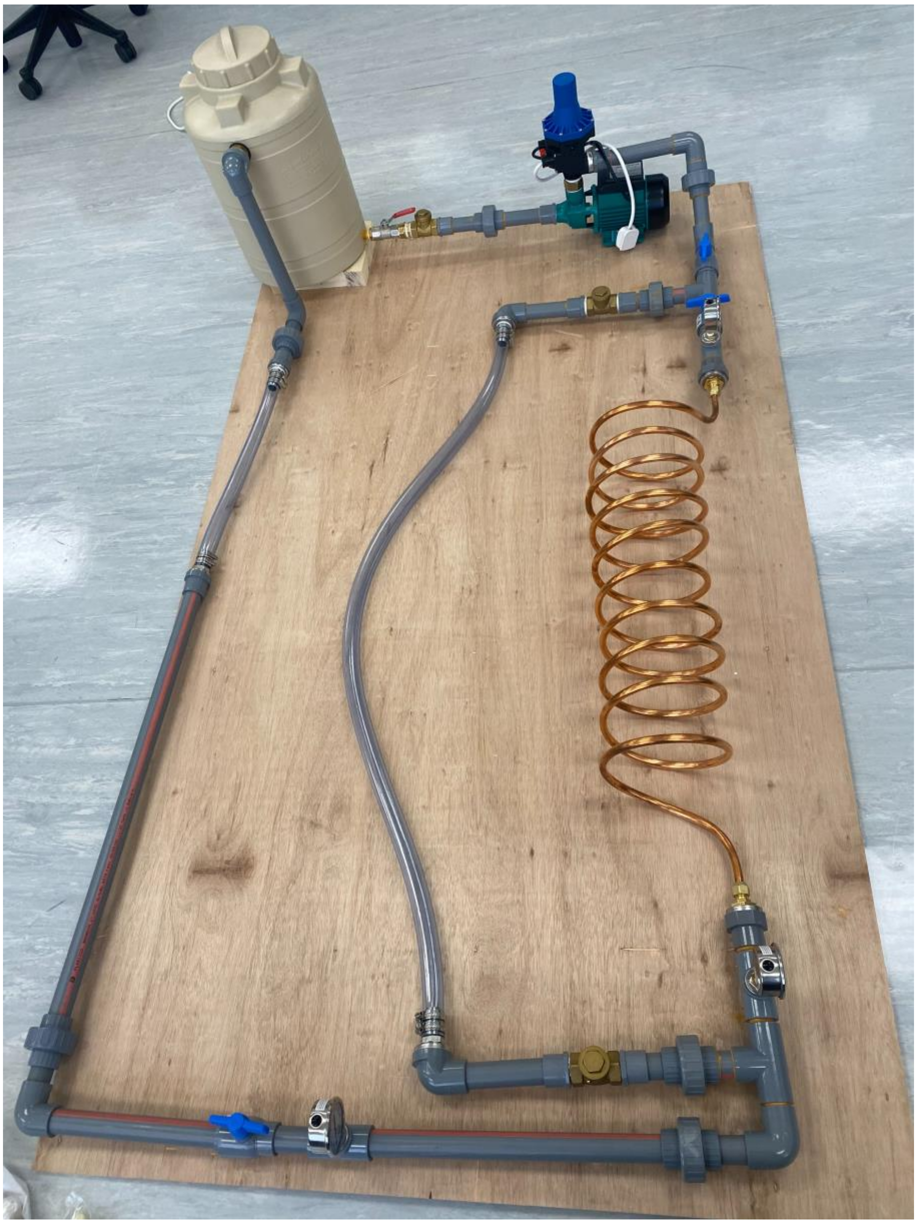

Figure 26 Prototype of the design project

Appendix H : Design specifications

Table 17 Product Specification

Pump Specification		Coil Specification	
Flow Rate Q_{max}	35 L/min	**Tube Diameter Dc**	0.5 in
H_{max}	32 m	**Helix Diameter**	14 in
Power	0.5 HP	**Pitch**	4.5 in
Operation Voltage	220V	**Height**	8 in
RPM	RPM	**Actual Length**	6 m
Fitted with Thermal Overload Protector		**Number of turns**	11

References

[1] K.R.Allaev,V.A.Khokhlov,R.A.Sytdykov,andZh.O.Titova, *Electromechanical and Hydromechanical Processes in Hydro- electric Power Plants* [in Russian], Fan va texnologiya, Tashkent (2013).

[2] A. V. Khokhlov, V. A. Khokhlov, and Zh. O. Titova, *Modes of Operation of the Pumping Stations of the Karshinsky Cascade* [in Russian], Navruz, Tashkent (2015).

[3] Wood, D.J.; Lingireddy, S.; Boulos, P.F.: Pressure Wave Analy- sis of Transient Flow in Pipe Distribution System. MWHsoft, Pasadena, California (2005)

[4] Chaudhry, M.H.; Hussaini, M.Y.: Second-order accurate explicit finite-difference schemes for waterhammer analysis. J. Fluids Eng. **107**, 523–529 (1985)

[5] Afshar, M.H.; Rohani, M.: Water hammer simulation by implicit method of characteristic. Int. J. Press. Vessel. Pip. **85**(12), 851– 859 (2008)

[6] MITOSEK M. Study of transient vapor cavitation on series pipe systems[J]. Journal of Hydraulic Enginee- ring, ASCE, 2000, 126(12): 904-911.

[7] ISMAIER A., SCHLUCKER E. Fluid dynamic intera- ction between water hammer and centrifugal pumps[J]. Nuclear Engineering and Design, 2009, 239: 3151- 3154.

[8] KIM S. Impulse response method for pipeline systems equipped with water hammer protection devices[J]. Journal of Hydraulic Engineering, ASCE, 2008, 134(7): 961-969.

[9] NIKPOUR M. R., NAZEMI A. H. and HOSSEINZA- DEHDALIR A. et al. Experimental and numerical si- mulation of water hammer[J]. Arabian Journal for Science and Engineering, 2014, 39(4): 2669-2675.

[10] STEPHENSON D. Simple guide for design of air vesse- ls for water hammer protection of pumping lines[J]. Journal of Hydraulic Engineering, ASCE, 2002, 128(8): 792-797.

[11] Bonafoni, G., & Capata, R. (2015). Proposed Design Procedure of a Helical Coil Heat Exchanger for an Orc Energy Recovery System for Vehicular Application.

[12] Záruba, J. (1993). *Water hammer in pipe-line systems*. Elsevier.

[13] Kim, S. G., Lee, K. B., & Kim, K. Y. (2014). Water hammer in the pump-rising pipeline system with an air chamber. *Journal of Hydrodynamics*, *26*(6), 960-964.

[14] Asli, K. H., Naghiyev, F. B. O., & Haghi, A. K. (2010). Some aspects of physical and numerical modeling of water hammer in pipelines. *Nonlinear Dynamics*, *60*(4), 677-701.

[15] Azoury, P. H., Baasiri, M., & Najm, H. (1986). Effect of valve-closure schedule on water hammer. *Journal of Hydraulic Engineering*, *112*(10), 890-903.

[16] Xu, J., Xie, J., He, X., Cheng, Y., & Liu, Q. (2017). Water drop impacts on a single-layer of mesh screen membrane: Effect of water hammer pressure and advancing contact angles. *Experimental Thermal and Fluid Science*, *82*, 83-93.