**ME 450 F09**

# Power Plant Fluid Simulator

**Team 25**

**Owen Ali**
**Anthony Bingei**
**Elwin Ho**
**Yudie Soenjoto**

**Prof. Gordon Krauss**

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**FINAL REPORT**

**EXECUTIVE SUMMARY**
The goal of our sponsor, Sargent & Lundy (S&L), is redesigning an existing Power Plant Fluid Simulator (PPFS). PPFS main function is to pre-calibrate instruments that are used in actual power plant. Also, it is being used to train technicians in calibrating the instruments. In order to achieve those functions, PPFS replicate the flow parameter of working fluid of an actual Power Plant. Then, the flow is then channeled to the instruments to activate, and served the parameters as standard values to calibrate these instruments. S&L needs an improved design that is smaller in size, compared with the current design, while still maintaining the basic functionality of it: Technician training, Accuracy, Robustness, Ease of use, Smaller Size, ability to test varieties of instruments, and Cost. Please Refer to Table 5 for complete listings.

In order to better understand the requirements, we constructed a functional decomposition for the simulator.  Combining this knowledge with the customer requirements and engineering specifications, we set a list of functional level for the simulator. Then, we brainstormed for concepts on how to satisfy this functional level individually. Finally, we combined these concepts to come up with several complete simulator concepts. Also, we utilized scoring matrices (Pugh Chart) to help us determine the winning (alpha) concept of our project. The same process was then repeated to generate the alpha design of our demo model. The alpha design of our simulator consists a standard layout for the components, a parallel I arrangement for the test slots, and combination of PLC and dual pump power source to fulfill the required flow parameters. Our final selected alpha design satisfied all the required customer requirements and engineering specifications. The final concept of Demo model validates the customer requirement in level control, size, cost, and weight. The selected concept is considered also due to budget constraint.
The list of materials and costs for building both of them are done and fabricaton costs are included in Table 26 and Table 29. From this point on, we will focus on working on the prototype.

In manufacturing the prototype, 90% of the parts are obtained off the shelf and the remaining is fabricated in Home Depot, in which the Safety Report provides a great detail of the fabrication plan. The total cost of building the material adds up to $431.32. After completing the prototype components, the assembly takes place at the X50 lab, where the first test is performed with the Section Professor and GSI.

From the test results, the prototype is safe to be shown as a demo for the public. The purpose of the test is first to show the safety aspect and functionalism of the prototype. In addition, it succeeds to validate the full scale function of level control, size, robustness, and cost. During the process, we test for the logic of the prototype in leveling the working fluid inside stand pipe; Then, components performance and mechanical connection (leaking) are checked for safety purposes.  The test is performed by running the pump at lower speeds to start the process safer. Critiques for the prototype involved the need in safety for the mechanical connection and electrical connection such as leaking and numerous electrical wires.

Overall, we conclude that the water fluid simulator project was effective in delivering the function that validates the full scale simulator, level control. In addition, the prototype is safe and meets the requirement in size and cost. With further research and experimentation, the mechanical connection problem such as leaking could be better solved for safety. Furthermore, the result shows that the prototype is capable for future improvements such as introduction of new instruments to be installed in the components.

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**NOMENCLATURE**

| | |
|---|---|
| Components | Standpipe, Pumps, Storage tank, Pipes, Control Valves, Orifices, Gate Valves, Pumps. |
| Flow Loop | Area of the simulator where instruments can be calibrated in terms of flow rate, consists of several test slots |
| H | Height of the testing slot |
| L | Length of testing slot, parallel to the direction of the flow |
| Level Control Loop | Area of simulator to test the logic of level control, consist of one stand pipe, a pressure transmitter |
| Test Loops | Same as flow loop |
| Test slots | Area of the simulator where the instruments can be attached to the simulator |
| W | Width of the testing slot, perpendicular to the directon of the flow |

## INTRODUCTION

According to the US government, 69.4 % of the electricity generated in the US in 2008 was generated by thermal power plants [1]. Thermal power plants can be divided by the type of fuels that is used to generate heat, either fossil fuel or nuclear powered. However, both thermal power plants still use water/steam as the working fluid to transform the heat energy into mechanical energy and in the end, electrical energy. These power plants rely heavily on valves and instrumentation to operate effectively and reliably. That being said, power plants require regular maintenance, calibration, and parts replacement regularly, without shutting the plants down, to keep their economic viability.

S&L is a company that provides energy business consulting and project services for new and operating power plants and power delivery system. Currently, S&L client has an existing power plant fluid simulator that can mimic the behavior of water (flow rate, pressure and level) in a working power plant. The fluid simulator is being used to train technicians on how to calibrate instruments that is being used in the actual power plant. That way the technicians will be able to familiarize themselves with the instruments before actually handling it in the power plant. It is also being used to calibrate instruments and calibrate level control logic.

Through feedback from S&L's customer, the existing simulator is deemed too big. By reducing the size, the simulator will be able to fit in more power plants, thus reducing the time wasted on transporting technicians that need training and instruments that need calibration, from power plants that do not have a simulator to the ones that have the facility.

Our goal is to improve the design of the simulator so that it is smaller in size, compared with the current design, while still maintaining the basic functionality of it. The project deliverable is to design a new Piping and Instrument Diagrams, to come up with a system to control and set the flow parameter, develop a hydraulic model of the flow, and build a working mini demo model of the simulator.

Table 1a and 1b summarizes the customer requirements for the actual simulator and the demo model.

| **Table 1a: Simulator Customer Requirement** |
|---|
| Technicians training |
| Accurate |
| Robust |
| Easy to use |
| Small size |
| Able to test variety of instruments |
| Cost |

| **Table 1b: Demo Model Customer Requirement** |
|---|
| Able to replicate calibration function |
| Able to test the logic of the system |
| Size |
| Weight |
| Cost |

## INFORMATION SOURCES

We reviewed critical points and knowledge from recent Patents and Company Methodologies that focused on the Fluid Simulator system. The information sources are found using Google search and Patent Storms search. Some of these references might not be fully relevant to our goals of the project; however, they will help in building a solid foundation for the project knowledge.

### Patents

**US-Patent #4977529** [2] (Training Simulator for a Nuclear Power Plant): The article describes training simulator for the full scope-real-time dynamic operation of a nuclear power plant as shown in Figure 1 below. A digital computer configuration is connected to a control console device and performs dynamic real-time simulation calculation. An instructor console is connected to the computer configuration to initialize and replaying selected operational states. When the computer is initialized and replayed, it provides indications on the power plant devices that do not normally correspond to the plant status. The terms initialized and replayed are terminologies used for input and feedbacks to the programmed logic control. As the current simulator uses a PLC to control the valves, testing loops, and level loop, this patent would give information to our simulator in terms of how the PLC controls the devices in the simulator. The patent provides big picture ideas from a blank situation, where the team members are alien to the process of a power plant simulation.

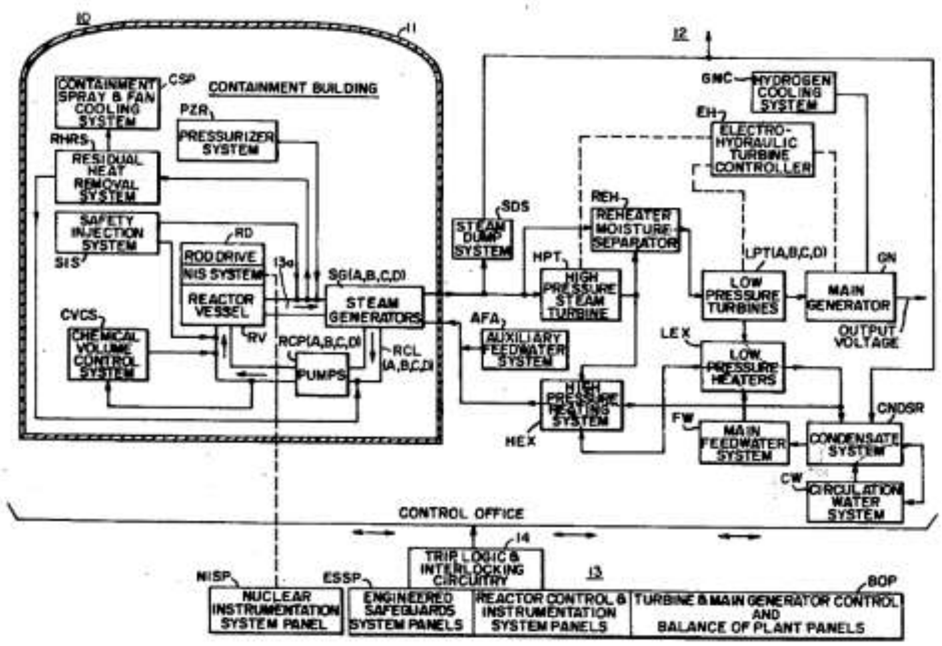



**Figure 1. Schematic block diagram of a Nuclear Power Plant for Simulation. [3]**

**US-Patent #4064392** [3] (Engineered safeguard system and method in nuclear power plant simulator): A method and system of a real-time dynamic operation in a Nuclear Power Plant, where remote control devices provide quantifiable physical values to a digital computer. The calculated physical values monitor the real-time physical condition of the plant. This patent refers to the Figure 1 above as well. Also, it relates to our project in defining the programmed logic control operation, in controlling the valves and parameters measuring devices. This general explanation provides a big picture in how PLC is used in a simulator. The information from the patent builds up for better understanding in system logic control process.

**Digital Simulators**

**Labview Program in Drum-Level Control** [4]**:** As shown below in Figure 2, a DCS (Drum-level control system), which has the actual control logic and MMI (Man Machine Interface), and the real-time dynamic simulator, which has the process model, provide a hardware-in-the-loop simulator configuration. In other words, it is called a stimulated system. Because this configuration uses the actual DCS connected to the simulator, the real control system of the LNGC (Liquefied Natural Gas Carrier) can be easily verified and debugged during the test without exhibiting the failures of the LNGC equipment. This LabView program has the function to control flow parameters, which is similar to what we want. Thus, it may became useful if we decide on using LabView.

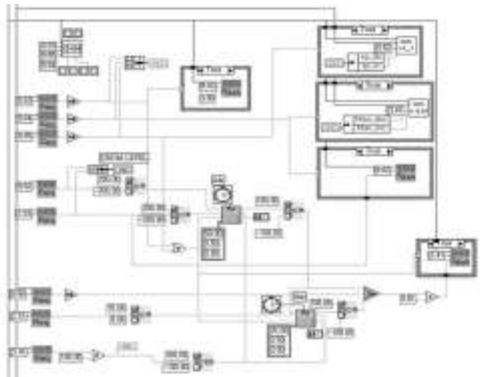


**Figure 2. Labview program for the drum-level control [4]**

**Instrumental Devices**
This section provides our research on the instruments that are being calibrated using current simulator or they are part of the current simulator itself.

**Pressure Regulating Valves** [5]**:** The pressure regulating valve shown in Figure 3 below is manufactured by Watson McDaniel Company. It's used for reducing pressure in air and water systems. These regulators are commonly found in industrial plants, apartment buildings and water supply system. The regulator insures accurate control even when the pressure coming in fluctuates. It also senses the pressure internally. This valve is being used to control the water pressure in the current simulator.

**Figure 3. Pressure Regulating Valves B Series [5]**

**Industrial Glass Tube Variable Area Flowmeters [6]:** Figure 4 below shows an industrial glass tube variable flowmeter, The Brooks® GT 1000 combines ruggedness and simplicity in design to provide a versatile glass tube flowmeter suitable for a wide range of applications. The GT 1000 O-ring construction minimizes process downtime by allowing for convenient in-line removal of the glass tube for cleaning and maintenance. This flowmeter is used to measure the flow rate of water in the current simulator.

**Figure 4. Variable Area Flowmeters Brooks® GT1000 Series. [6]**

**Pressure Transmitter [7]:** Figure 5 below shows a pressure transmitter; Rosemount 1511, it offers a variety of configurations for differential, gage, absolute and liquid-level measurements including integrated solutions for pressure, level and flow. High pressure models allow static line pressures up to 4500 psi. Multiple wetted materials, as well as alternative fill fluids ensure process compatibility. Smart, analog and low-power electronics are available to meet specific application requirements. This transmitter is used to measure the flow of water, and the level of standpipe in the current simulator.

**Figure 5. Pressure Transmitter Rosemount 1511. [7]**

**Pressure Gauge [8]**: Figure 6 below shows a pressure gauge; an Ashcroft Pressure Gauge Type 1279 that is offered in 4.5" phenolic case for superior chemical and heat resistance. Solid-front case design with blow-out back for safety. All case styles provide full temperature compensation. We will also use this gauge to measure the pressure of water in our simulator. The difference between this pressure gauge and the previously mentioned pressure transmitter is that the transmitter can be electronically wired to the PLC for controls. The gauge is cheaper in cost too, thus being used more in the simulator where a PLC is not required.

**Figure 6. Duragauge® Pressure Gauge Type 1279. [8]**

**Signet Magmeter [9]:** Figure 7 below shows a magmeter; a Signet 2551 Magmeter that is versatile, simple-to-install sensors which deliver repeatable flow measurement over a wide dynamic range in pipe sizes ranging from DN15 to DN200, satisfying the requirements of many diverse applications. We will also use this magmeter to measure the flow rate of water in our simulator. The difference between this and previously mentioned industrial flow meter is that the magmeter has digital output. It is also easier to install although it has a lot of obstructions in the setup.

**Figure 7. Signet 2551 Magmeter. [9]**

**Control Valves [10]:** Figure 8 below shows a control valve; a Fisher 21000 Series Control Valve that are designed with built in versatility making them well-suited to handle a wide variety of process applications. This control valve is used to control the flow rate of water in the current simulator.

**Figure 8. Fisher Control Valve [10]**

**Actuators [11]:** Figure 9 below shows an actuator; a Fisher Type 37/38 Actuator, type 37 is direct acting and type 38 is reverse acting. Their features includes providing maximum strength and rigidity, thrust capability that provides a wide range of applications, diaphragm with fabric insert for strength, long life and high sensitivity. This actuator is used to control the pressure of water in the current simulator.

**Figure 9. Masoneilan® Type 37/38 Actuator [12]**

**Centrifugal Pump:** Figure 10 a and b below show two different centrifugal pumps; a Fristam Type FM Series is able to provide 1250 psi pressure and 600 gpm flow rate. The Sundyne P3000 provides 500 psi pressure with 1000 gpm flowrate. Both pumps with motor included would cost approximately $50,000 to $60,000 per pump. We are planning on using one of this high pressure centrifugal pump for our dual pump energy source concepts.

**Figure 10a. Fristam FM Series Centrifugal Pump[12]**

**Figure 10b. Sundyne P3000 Centrifugal Pump [12]**

**High Pressure Centrifugal Pump:** Figure 11 below show a heavy duty centrifugal pump, Sundyne type BMP. The high pressure centrifugal pump provides pressure of 1440 psi and 1100 gpm flow rate. This pump can be used for our single pump energy source concept.

**Figure 11. High-pressure Centrifugal Pump type BMP [13]**

**P&ID**

This section will provide the basic concept of the current simulator

**Benchmark: Sargent & Lundy Flow Loop P&ID [14]:** Figure 12 shown below is the current Piping & Instrumentation Diagram of the current simulator. The current simulator is a water flow simulation that mimics the Nuclear Power Plant simulation in the industry. The existing simulator consists of four loops with several valves on each to increase reliability in flow parameters measurement. The overall simulator covers a relatively large amount of space. Due to the large devices and space imbedded in the simulator, it has issues in the ease of use the simulator itself. This design will be a benchmark in designing our fluid simulator.

The way it works, the water from the storage tank will flow through the pump section due to gravitational force, the water storage tank has a higher elevation compared with the pump. The pump will then be switched on to pump the water into the maximum flow rate and pressure rate. From there the water will flow through until it reaches a control valve which is hooked to system logic, this logic will control how much valve opening is needed in order to achieve the desired flow parameter. From there the flow can be directed to either the test loop (flow loop) or to the level control loop. In the test loop, instruments will be attached to the testing slots, from there the technicians will calibrate those instruments manually, by using the desired flow parameter. Level control loop consist of one standpipe attached to level transmitters. Power plants can test and calibrate their program logic for level control in this section. The water will be turned back to the storage tank after it passed the loop where they were intended to flow.

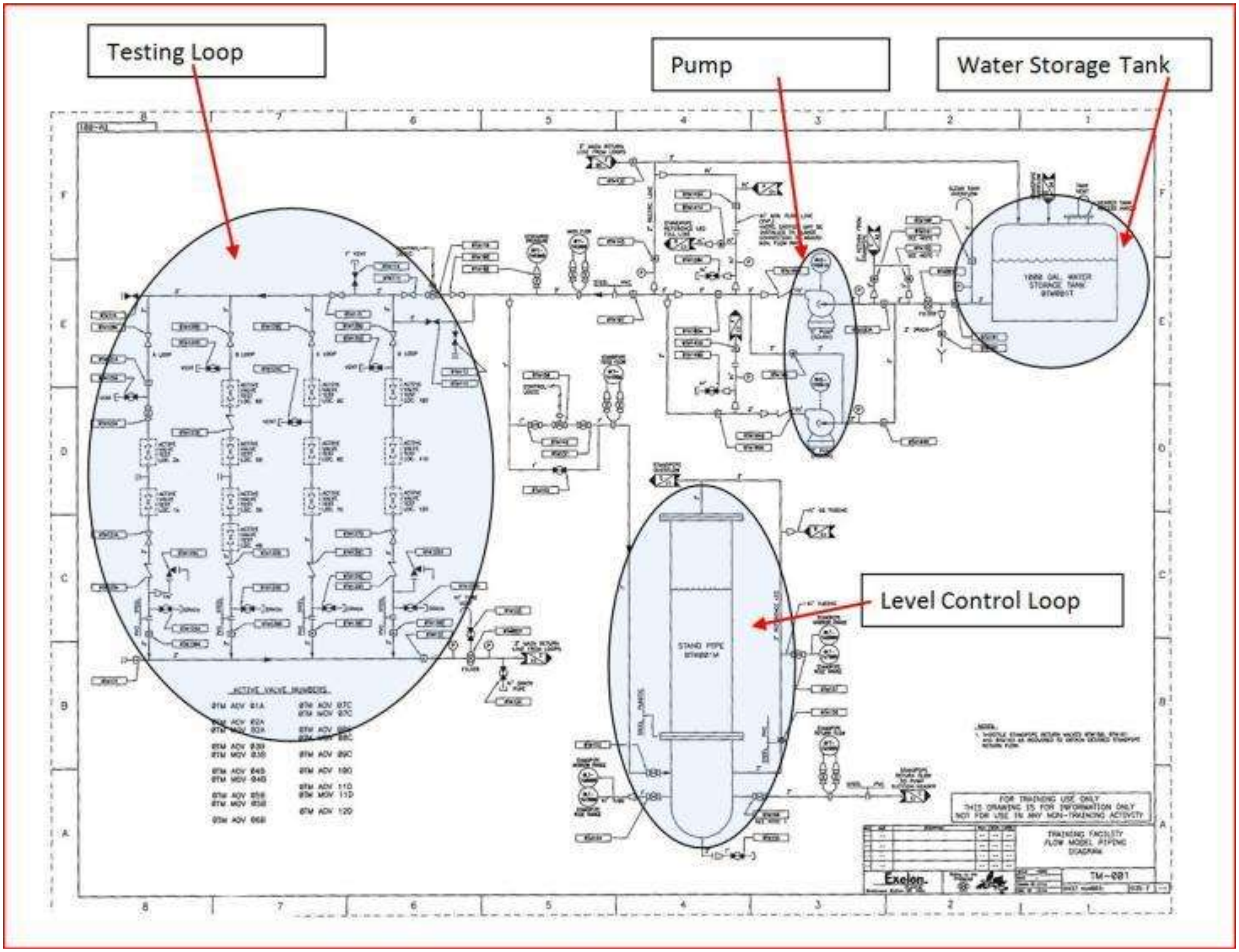



**Figure 12. Piping & Instrumentation Diagram (P&ID) of existing Simulator in Sargent & Lundy [14]**

**CUSTOMER REQUIREMENTS**

In order to derive a set of engineering requirements, which will be used to guide the design process and design selection, the needs and wants of the customer had to be determined. Based from our meeting with S&L, we came up with the customer requirements of this project. We gather as much information as possible regarding the customer requirements and how they fulfill the goal of the project. Based on this information and our understanding of the project, we came up with weight for each customer requirement. Then, we re-confirm this customer requirement-weight relation with S&L to ensure that we are moving in the right direction. Table 3a and 3b summarize the customer requirement and their weight, while table 4 summarizes the definition of each customer requirement.

**Table 2a: Customer requirement**

| Customer Requirement | Weight |
|---|---|
| Technicians training | 5 |
| Accurate | 5 |
| Robust | 5 |
| Easy to use | 4 |
| Small size | 4 |
| Able to test variety of instruments | 4 |
| Cost | 3 |

**Table 2b: Customer weight scale**

| Customer Weight Scale | |
|---|---|
| 5 | Essential |
| 4 | Very Important |
| 3 | Important |
| 2 | Less Important |
| 1 | Secondary |

**Table 3: Description of each customer requirements**

| Customer Requirement | Description |
|---|---|
| Technicians training | Train the technician on how to calibrate instruments, and how to shut instrument off in case of emergency |
| Accurate | Accuracy of the actual flow compared to the flow parameter that had been set in control |
| Robust | System that is robust enough that it can function well, and consistently |
| Easy to use | Ability to control the system parameter, better way to connect the system |
| Small size | Smaller floor size occupied |
| Able to test variety of instruments | Ability to test, to use and to provide training on a variety of different instruments |
| Cost | Minimum cost to achieve above mentioned requirement |

The top area of concern for S&L is the 'Technician training' feature; technicians should be able to learn on how to calibrate the instruments, and how to shut them off during emergency. These are the main intended functions of the simulator. In order to do this, the simulator must be able to work properly without breaking down and deliver the correct flow parameter so that the instruments can work properly. Thus, 'Technicians training', 'Accurate' and 'Robust' are assigned the maximum weight of importance.

'Easy to use', 'Small Size', and 'Able to test a variety of instruments' are rated as 4 (very important), because these are the areas that are very important for the improvement of the simulator. However, they are not directly affecting the main intended functions that the new simulator needs to achieve.

In particular,' Small size' is one of the driving factor for this project. As of now, the current simulator is too big that not all power plant has this facility. With smaller simulator, more power plants can have this kind of simulator. This will minimize the time wasted to carry instruments from one power plant to another power plant that has the simulator facility.

'Cost' is being rated as 3 (Important). We tried to design our simulator with the least amount of cost while still achieving the above mentioned customer requirements. However, based on our conversation with our sponsor, we are not given a set amount of budget for this project and our sponsor does not seem to mind any number for the cost. That is why we rated low cost as the lowest customer requirement since it is more of a "would be nice to have" feature.

**ENGINEERING SPECIFICATIONS**
After the customer requirements were defined, the engineering specification has to be determined. In order to do this, we looked at each individual customer requirement and thought about how it could be met. Table 5 shows the engineering specifications which will achieve each customer requirements.

**Table 4: Relation between Customer Requirement and Engineering Specification**

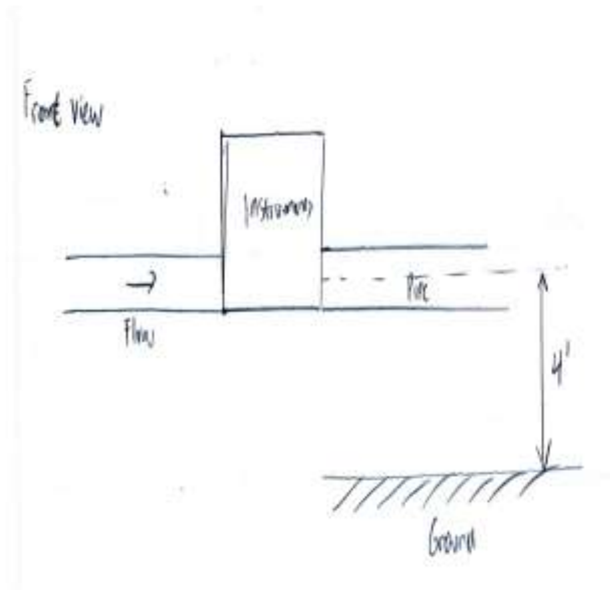
| Customer Requirement | Engineering Specification |
|---|---|
| Technicians training | Height of the testing slot |
| | Working space area |
| | Operating Pressure |
| | Operating Flow Rate |
| Accurate | Difference between flow parameter and actual flow |
| | Steel Material for all the piping |
| | Able to extract free air from testing flow loop |
| Robust | Safety factor for maximum pressure in the pipe |
| Easy to use | System to control and vary the flow parameter |
| | Able to drain instruments |
| | Accessible path to the testing slots |
| | Minimum turning radius in the path |
| | Minimum width of the path |
| Small Size | Floor Size |
| | Number of Testing Flow Loop |
| | Number of Level control Loop |
| Able to test variety of instruments | Total Number of testing slot per flow loop |
| | Types of instruments that can be tested |
| | Testing slot size |
| Cost | Low cost |

We also created quantitative targets/limits that we wanted each engineering specification to meet (table 5).

**Table 5: Engineering Specifications and the target value**

| Engineering Specification | Target | Unit |
|---|---|---|
| Height of the testing slot | 3-4 | ft |
| Working space area | >4x4 | ft |
| Operating Pressure | 0-1000 | PSI |
| Operating Flow Rate | 0-660 | GPM |
| Difference between flow parameter and actual flow | <3% | difference |
| Steel Material for all the piping "Customer specification" | yes | |
| Able to extract free air from testing flow loop | no air bubble | |
| Safety factor for maximum pressure in the pipe | >1.5 | N/A |
| System to control and vary the flow parameter | yes | |
| Able to drain instruments | yes | |
| Accessible path to the testing slots | yes | |
| Minimum turning radius in the path | >36" | inch |
| Minimum width of the path | >36" | inch |
| Floor Size | <500 | ft^2 |
| Number of Testing Flow Loop "Customer specification" | 2 | N/A |
| Number of Level control Loop "Customer specification" | 1 | N/A |
| Total Number of testing slot per flow loop | 3 | N/A |
| Types of instruments that can be tested | 5 | N/A |
| Testing slot size | >50" L x 30" W x 60" H | inch |

In order to train the technicians, the technicians must be able to physically interact with the instruments while they are being run in the simulator. Therefore, we must ensure that the technicians can work comfortably in our simulator. Initially, we set the ‘Height of testing slot’ to be around 4 ft so that the technicians can work on the instruments without having to crouch or stretch up. We determined the targeted number by taking into consideration the average height of US men, 5’9” [15]. The eye level will then be around 5’ region, we then subtract the value with 1’ (the ideal reading distance from the eye to the object [16]) which gives us our target height of testing slot at 4’. The target height allowed the technicians to read the control panel of the instruments properly while also reaches the instrument’s control panel without crouching or stretching. We measure the height of the testing slot as the distance from the floor to the center of the pipe that is connected to the instrument in the testing slot, as can be seen in figure 13. Based from our research of the instruments that is going to be calibrated in the simulator. We found out that some instruments reaches the height of 60” and their control panel is located at the 12” from the bottom of the instruments. Meaning, with our current 4’ height, the control panel of the instruments will be at 5’ height of the ground. Taking that into consideration, we updated our ‘Height of testing slot’ specification to range from 3’ to 4’. We also checked our target values with our sponsor to make sure they were satisfied with the specification.



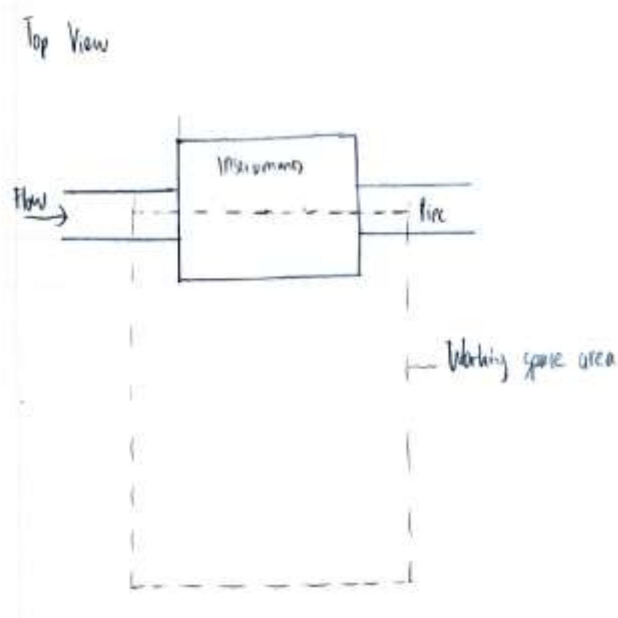




**Figure 13: Height of testing slot**

**Figure 14: Working space area**

Furthermore, we also need to ensure that the technicians will have enough space to stand while they are working with the instruments. We set the 'working space area' to be at least 4' x 4'. Initially we proposed working space area of 3' x 3', but our sponsor specifically determined 4' x 4' to be more appropriate. Since the instruments' control panels are located at the right side of the instruments, we don't need to provide working space area at the other side of the instruments. Figure 14 illustrate our definition of 'working space area'

In order to be able to train the technicians on how to calibrate the instruments, the simulator needs to be able to operate at the required pressure and flow rate needed to calibrate the instruments. 'Operating pressure' and 'Operating flow rate' were set at the range of 0-1000 PSI and 0 – 660 gallon per minute respectively. These values were determined by looking at the operating range of the instruments that our simulator needs to calibrate.

We want to make sure that our simulator will be able to calibrate the instruments accurately per industry standard. Based on our research and conversation with S&L, we set 'Difference between intended flow parameter and actual flow' to be at most 3% difference. Intended flow parameters are the values (flow rate and pressure) that we set in the system control, while the actual values are the values measured in the testing slots. The 3% value came from the tolerance standard that is being used by S&L. One of the way to measure the actual value of the flow is to put a calibrated instruments into the testing slot to measure the actual flow and compare it with the value that we set in our control.

Furthermore, actual power plant uses steel pipe for their water flow, while the current simulator uses combination of steel and PVC pipes. Our sponsor requires us to use steel pipe for our simulator. This is to ensure that our simulator can provide a more similar environment for the water flow, since PVC pipe has a considerably different friction factor compared with steel pipe.

Next is the 'Ability to extract free air from the flow'. Free air, in form of water bubble, in the water flow will disturb the accuracy of the flow in our simulator and can also potentially damage the instruments that are being calibrated. We want to ensure that our simulator would be able to extract free air from the flow before it reaches the instruments in the testing slots. Based from our conversation with the vendors that produce the instruments, we set the target value of 0 % of free air before the flow enter the testing slots, because any number greater than that will damage the instruments

We want to make sure that our simulator can work at the maximum flow parameter properly without breaking down. In order to achieve that feature, we need to set a safety factor for our simulator. We set ‘Safety factor for pressure in the pipe’ to be ≥ 1.50, which means the piping in our simulator must be able to at least hold pressure 1.5 times bigger than the maximum operating pressure. The safety factor of 1.5 was determined from the industry standard that our customer requires.

S&L also requires our simulator to have a system that can control and vary the flow parameter. By having this control system, the operator will be able to easily set the flow parameter value to whatever value that is needed to calibrate the instruments.

In order to increase the ease of use of our simulator, we also need to make sure our simulator is capable of draining the instruments after they are done. Once the work on the simulator is done, the pumps need to be shut off first while water is still running through them, this is to prevent dry-running that can damage the pumps. In doing so, there will still be water left in the flow loops, test slots and instruments. If the technicians try to directly take off the instruments from the flow loops, the excess water will drips all over the area. Thus, our sponsor requires us to built a drain system that can accommodate every test slots

Equally important for ease of use of our simulator is the ‘Accessible path to testing slots’. From the list of instruments that our simulator needs to be able to calibrate, we found out that one of the instruments weight 150 lb. Thus, it requires some sort of cart to transport it from the storage to the testing slots in our simulator. We need to ensure that there is accessible path to the testing slots that can be accessed by the cart. By taking into account that the biggest instrument size is 20” L x 30” W and the average size for market cart is 29” L x 19” W [17], we specify that the minimum width of the path to be 36”. We also specify the minimum turning radius for all the corners in the path to be at least 36”. This is more than adequate, because most of the cart in the market can rotate their front and rear wheel sets, effectively giving them “zero” turning radius.

Small floor size is an essential requirement, because with smaller simulator, more power plants can have this simulator. This will minimize the time wasted to carry instruments from one power plant to another power plant that has the simulator facility. In our design, we target the new simulator to take about ≤500 $ft^2$ of floor space. The current simulator takes up 40 ft x 20 ft or 800 $m^2$ of floor space. S&L specify us to just use 2 flow loops instead of 4 flow loops, with each control loop takes up 50 $ft^2$ of floor space. S&L then ask us to further reduce the size of the old simulator by around 20 %, thus we get 500 $ft^2$ of floor space as our target.

‘Number of flow loops’ and ‘Number of testing slots per flow loops’ directly influence the size of our simulator. ‘Number of flow loops’ was set to be 2 (the current simulator has 4), as per our sponsor requirement. ‘Number of testing slots per flow loops’ was set to be 3 (the current simulator ranges from 2-4). Based from our conversation with S&L, there is no application which requires more than 3 instruments arranged in series connection, as in our flow loop.

‘Number of level control loop’ also directly influence the size of our simulator. Level control loop in the simulator is being used to calibrate the level control logic before it is being implemented in the actual power plant. We set the number of level control loop to be 1(the current simulator has 1) because it is a customer specification from our sponsor

Furthermore, our sponsor also requires our simulator to be able to test and calibrate 5 different instruments (same as current simulator): transmitter, sensor, valves, control, and level sensor. In order to properly calibrate those instruments, we need to make sure that they fit perfectly in our simulator test slots. We set the 'testing slot size' to be 50" L x 30" W x 60" H .The width and height of the testing slot value was determined by taking into consideration the biggest instrument's width and height that our simulator need to be able to calibrate. However, the length of the testing slot was determined from the minimum straight pipe run needed for the instrument to work properly, since their value exceed the length of the instruments itself. Straight run of pipe requirements are based on the inner diameter (ID) of the process piping, not the length of the sensor. For example, if we have 1.5" piping and the sensor requires 10 diameters straight run upstream, then we need 15" length. As explained in the customer requirement section, we don't have a set budget for this project. That is why we didn't set any target value for our cost.

To further help us understand the relationship between each customer requirements to the engineering specification and between each engineering specifications to one another we constructed QFD diagram (Figure 15). The QFD diagram shows that many of the engineering specifications relate to several customer requirement in a strong = 9, moderate = 3, and weak way = 1. For example, we created the minimum 'Working space area' engineering specification with 'Technicians training' customer requirement in our mind. However, this engineering requirement also directly affects the small size.

The QFD diagram also shows us the relationship between one engineering specifications to the other. These engineering specifications generally have a positive relationship with one another, which means they support the existence of the one another. However, the maximum 'Floor size' specification contradicts with 'Working space area', 'Number of testing slots per flow test loop', 'Number of flow loop', and 'Testing slot size'. Because we want to minimize the floor size but we still need to ensure that we achieve minimum requirements in the above mentioned specifications

## System QFD

| Project: | Project |
|---|---|
| Date: | date |
| | Input areas are in yellow |

| # | Technical Requirement | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Height of the testing slot | | | | | | | | | | | | | | | | | | | |
| 2 | Working space area | | | | | | | | | | | | | | | | | | | |
| 3 | Operating Pressure | -1 | | | | | | | | | | | | | | | | | | |
| 4 | Operating Flow Rate | -1 | | 9 | | | | | | | | | | | | | | | | |
| 5 | Difference between flow parameter and actual flow | | | 3 | 3 | | | | | | | | | | | | | | | |
| 6 | Steel Material for all the piping | | | | | | | | | | | | | | | | | | | |
| 7 | Able to extract free air from testing flow loop | | | | | | | | | | | | | | | | | | | |
| 8 | Safety factor for maximum pressure in the pipe | | | | | | | | | | | | | | | | | | | |
| 9 | System to control and vary the flow parameter | | | | | | | | | | | | | | | | | | | |
| 10 | Able to drain instruments | | | | | | | | | | | | | | | | | | | |
| 11 | Accessible path to the testing slots | | | | | | | | | | | | | | | | | | | |
| 12 | Minimum turning radius in the path | | | | | | | | | | | 9 | | | | | | | | |
| 13 | Minimum width of the path | | | | | | | | | | | 9 | 9 | | | | | | | |
| 14 | Floor Size | | -9 | | | | | -1 | | -1 | | -9 | -9 | -9 | | | | | | |
| 15 | Number of Testing Flow Loop | | | | | -1 | | | | | | | | | -9 | | | | | |
| 16 | Number of Level control Loop | | | | | -1 | | | | | | | | | -9 | | | | | |
| 17 | Total Number of testing slot per flow loop | | | | | | | | | | | -1 | -1 | -1 | -9 | | | | | |
| 18 | Types of instruments that can be tested | | | 9 | 9 | | | | | | | | | | | | | | | |
| 19 | Testing slot size | | | | | | | | | | | -3 | -3 | -3 | -9 | 9 | | | 9 | |
| 20 | Low Cost | -3 | -3 | | | | -9 | -3 | -3 | -3 | -1 | -3 | -3 | -3 | | -1 | -1 | -9 | | |

| Survey Legend | |
|---|---|
| A | Our Simulator |
| B | Current Simulator |
| C | |

**Technical Requirements** — **Customer Opinion Survey**

| # | Customer Needs | Customer Weights | Kano Type | Height of the testing slot | Working space area | Operating Pressure | Operating Flow Rate | Difference between flow parameter and actual flow | Steel Material for all the piping | Able to extract free air from testing flow loop | Safety factor for maximum pressure in the pipe | System to control and vary the flow parameter | Able to drain instruments | Accessible path to the testing slots | Minimum turning radius in the path | Minimum width of the path | Floor Size | Number of Testing Flow Loop | Number of Level control Loop | Total Number of testing slot per flow loop | Types of instruments that can be tested | Testing slot size | Low Cost | 1 Poor | 2 | 3 Acceptable | 4 | 5 Excellent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Technicians training | 5 | | 9 | 9 | 9 | 9 | | | | | 3 | | 3 | | 3 | | 3 | 1 | 3 | 9 | 3 | | | | | | AB |
| 2 | Accurate | 5 | | | | | | 9 | 9 | 3 | | | | | | | | | | | | | | | | | AB | |
| 3 | Robust | 5 | | | | 3 | 3 | | | 3 | 9 | | | | | | | | | | | | | | | | AB | |
| 4 | Easy to use | 4 | | | | | | | | | | 9 | 9 | 9 | | | | | | | | | | | | B | A | |
| 5 | Small size | 4 | | | 9 | | | | | | | | | | 9 | 9 | 9 | 9 | 9 | 9 | | 9 | | | | B | | A |
| 6 | Able to test variety of instruments | 4 | | | | 9 | 9 | | | | | | | 1 | | | | | 9 | | 9 | 9 | | | | | AB | |
| 7 | Low Cost | 3 | | 1 | | | | | 9 | | | | | 1 | 1 | 1 | 1 | | | | | | 9 | | | B | | A |
| 8 | | Raw score | | # | 81 | # | # | # | # | # | # | 51 | # | # | # | # | # | 51 | # | 51 | 81 | # | # | | | | | |
| 9 | | Scaled | | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | | | | | |
| 10 | | Relative Weight | | 4% | 7% | 8% | 8% | 4% | 6% | 3% | 4% | 4% | 3% | 5% | 3% | 5% | 3% | 4% | 7% | 4% | 7% | 7% | 2% | | | | | |
| 11 | | Rank | | 13 | 4 | 1 | 1 | 14 | 7 | 19 | 14 | 10 | 18 | 8 | 16 | 9 | 16 | 10 | 6 | 10 | 4 | 3 | 20 | | | | | |

| # | Requirement Benchmarking | | Height of the testing slot | Working space area | Operating Pressure | Operating Flow Rate | Difference between flow parameter and actual flow | Steel Material for all the piping | Able to extract free air from testing flow loop | Safety factor for maximum pressure in the pipe | System to control and vary the flow parameter | Able to drain instruments | Accessible path to the testing slots | Minimum turning radius in the path | Minimum width of the path | Floor Size | Number of Testing Flow Loop | Number of Level control Loop | Total Number of testing slot per flow loop | Types of instruments that can be tested | Testing slot size | Low Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | Requirement Benchmarking | Best in Class | | | | | | | | | | | | | | | | | | | | |
| 13 | | AVE | | | | | | | | | | | | | | | | | | | | |
| 14 | | Worst in Class | | | | | | | | | | | | | | | | | | | | |
| 15 | | Kano | | | | | | | | | | | | | | | | | | | | |
| | | Direction | | | | | | | | | | | | | | | | | | | | |
| | Technical Requirement Units | | ft | ft | PSI | GPM | difference | | | N/A | | | | inch | inch | ft^2 | N/A | N/A | N/A | N/A | inch | |
| | Technical Requriement Targets | | 4 - 4.5 | >4x4 | 0-1000 | 0-660 | <3% | yes | no air | >1.5 | yes | yes | yes | >36" | >36" | <500 | 2 | 1 | 3 | 5 | .x30W | none |
| | Technical Requriement USL | | | | | | | | | | | | | | | | | | | | | |
| | Technical Requriement LSL | | | | | | | | | | | | | | | | | | | | | |

**Figure 15: QFD diagram**

**FUNCTIONAL DECOMPOSITION**
In order to produce a flow simulator that meets all the requirements, we broke down the specific functionality of the flow simulator. Table 7 shows a text based functional decomposition. Additionally, this information has been adapted to a graphical flow chart in figure 16.

**Table 6: Text based functional decomposition**

Design Problem: Create a device that can calibrate power plants instrument and also train technician on how to calibrate those instruments

1. Drives water to the required flow parameter
    - Uses power and system control to drives water from the storage tank to the flow testing slots, at the required flow rate and pressure (based on the instruments)
    - Drives water to the flow loop or level control loop

2. Calibrate instruments and train technicians to calibrate the instruments
    - Instruments should be attached properly to the flow simulator
        - Detachable connections between simulator and instruments
        - Connection for the simulator should be able to accommodate all the different type of instruments
    - Technicians should be able to work on the instruments while it is attached and running
        - Enough clearance in the surrounding area of testing slot so that a technician can adjust the instrument while it is still running
        - When attached, the height of the instruments must be comfortable to work with

3. Overall design should minimize the floor area occupied

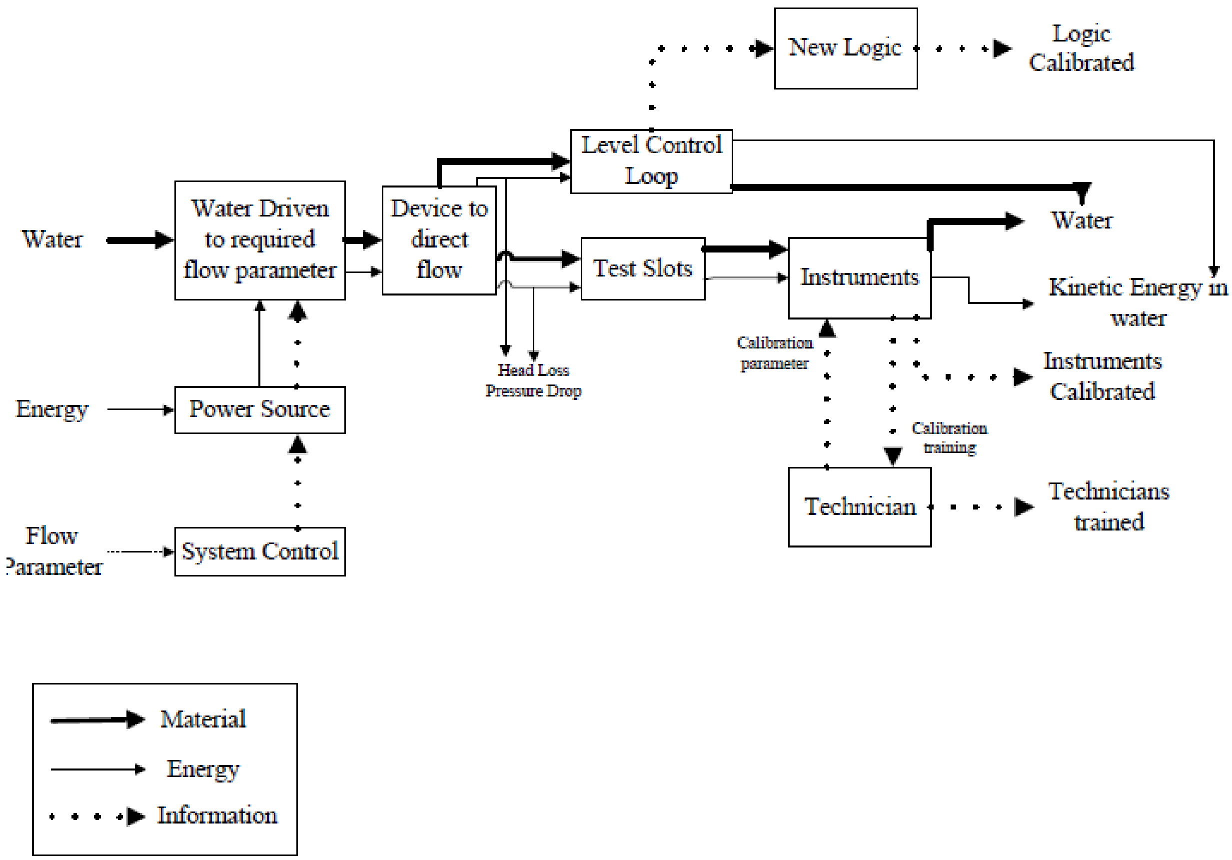



**Figure 16: Flowchart based functional decomposition**

This functional decomposition helped us to understand what kind of designs we had to focus on. Using the main functions to create our initial concepts, we then used the sub-functions to iterate into more refined concepts. Furthermore, we created an 'Element Decomposition' to further help us in understanding the individual functions of each element in the simulator (Appendix A). Combining this analysis with our customer requirements and engineering specifications, we determined that we need to focus on redesigning the following features:

- Test slots arrangement
- Test loops and component arrangement
- Flow directing method
- Power source
- Control method
- Pipe support

**CONCEPT GENERATION**

With the functional decomposition in mind, concepts for the individual features were brainstormed individually by team members. We came together after the session to present our ideas to the rest of the team. Initially, no idea was thrown out for being too impossible. After we finished compiling all the generated concepts, we compiled them and put them into separate Pugh chart analysis for each function. The purpose of the Pugh chart in this section is mainly to separate the feasible concepts from the infeasible ones, and to judge which concept is the best for each functions.

**Concept Generation - Test slots arrangement**
As per our customer specification, our simulator needs to have three test slots per flow test loops. As we mentioned in the engineering specification section, the test slot size is dictated by the specification of the instruments that need to be calibrated. Furthermore, the test slots needs to be arranged in such way that the minimum working space area, test slots height, and accessible path to the test slots are achieved while still ensuring the floor area occupied is minimum.

From the process, we came out with nine different concepts, on which five design concepts are considered as unfeasible. The feasible designs are the Parallel U, Nested U, Parallel I, and Parallel E; the unfeasible designs are the stacked U, Stacked I, Parallel O, Stacked E, and Vertical E. Please refer to Apendix B for detail description of each design concepts that is deemed infeasible.

**Parallel U loop:** Figure 17 below shows the design concept of a Parallel U loop. This design concept consists of two U shape testing loops that are located next to the other. There are three testing slots available on each testing loop that is connected by 90° elbow pipes. The advantage of this design it minimized the unoccupied area on the other side of the test slots, where clearance area is not needed.

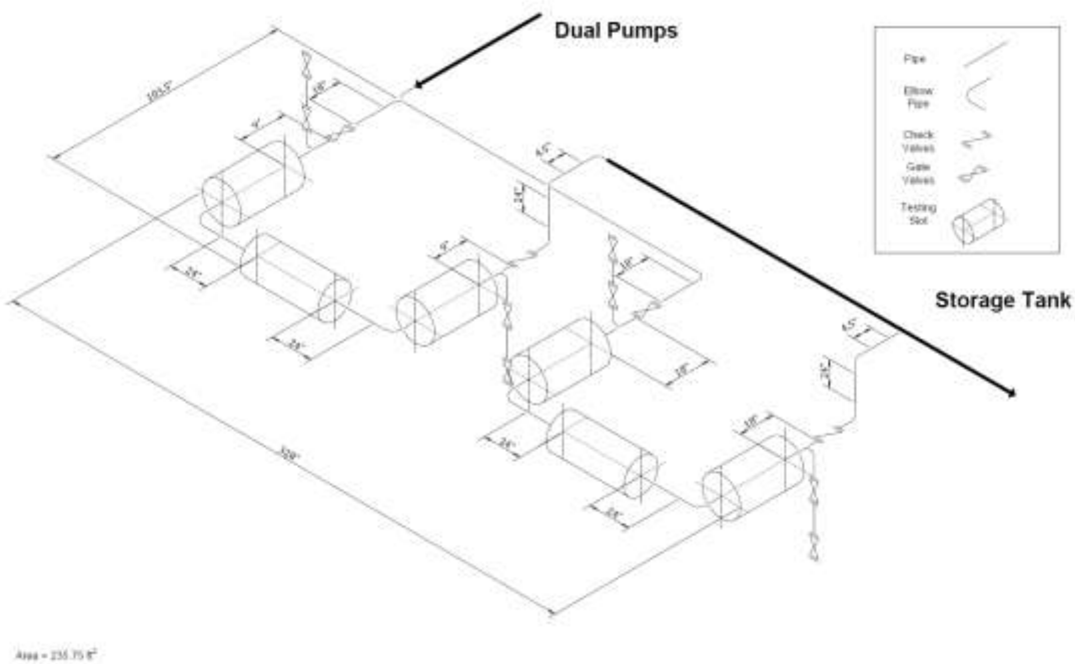



**Figure 17: Schematic Diagram of Nested U Test Loop**

**Parallel I loop:** This design includes two straight testing loops with three testing slots on each side. The two loops are parallel to each other with straight pipes connecting each testing slots. The advantage of parallel I loops includes accessible flat path and working space area for the instruments.

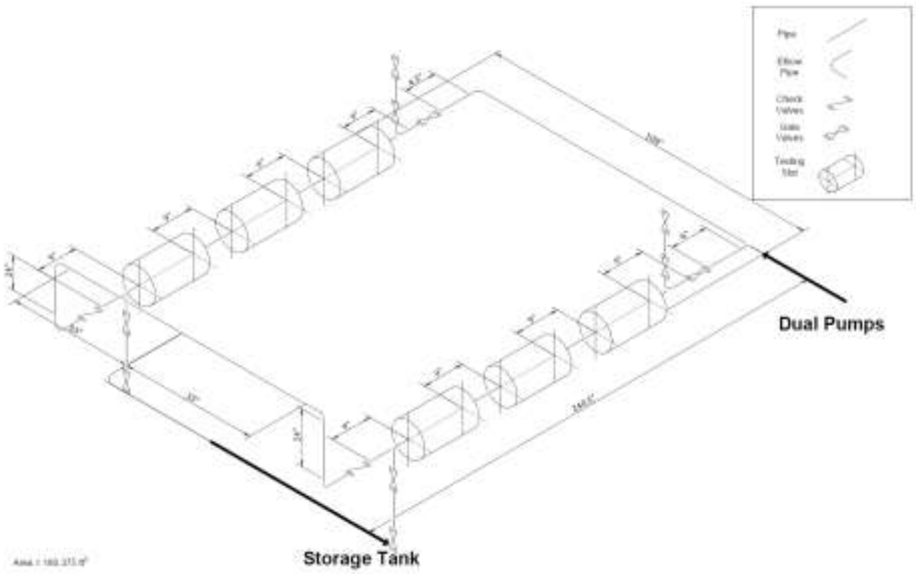



**Figure 18. Schematic Diagram of Parallel I Test Loop**

**Parallel E loop:** This concept consists of two E-shaped testing loops that are in parallel configuration. There are three testing slots on each testing loop with the 90° elbow pipe connecting them making the E shape structure. The advantage of this design it minimized the unoccupied area on the other side of the test slots, where clearance area is not needed. The disadvantage of this concept is that it needs to have an additional clearance area. Figure 19 below shows a schematic diagram of a parallel E testing loop.

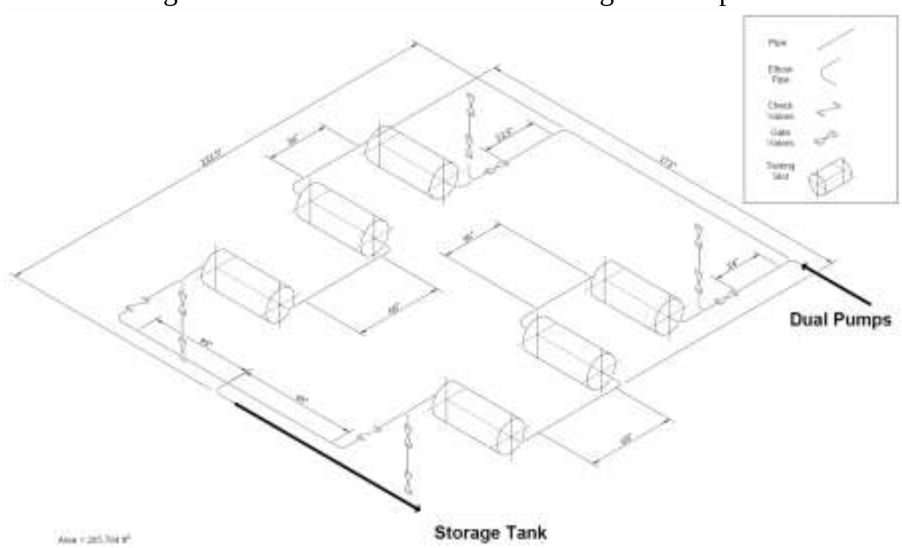



**Figure 19: Schematic Diagram of Parallel E Test Loop**

**Nested U loop:** The nested U loop illustrates a smaller U-shaped loop surrounded by a larger U-shaped loop. Having three testing slots on each U-loop, the testing slots are connected by 90° elbow pipes and straight pipes. The disadvantage for this loop is the huge amount of space wasted in having clearance areas around each side of the loop, ending up with a floor size that is bigger than our initial model.

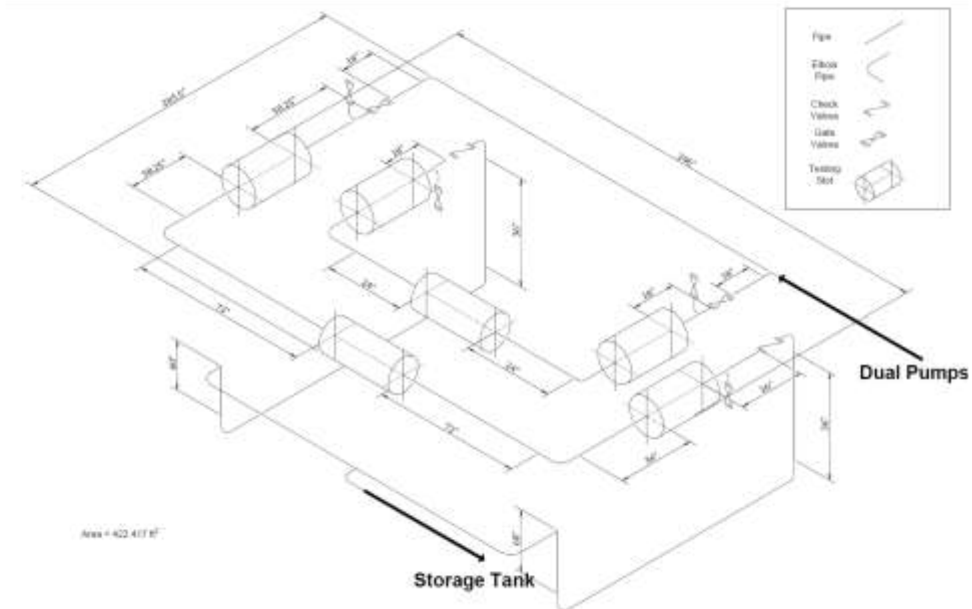



**Figure 20. Schematic Diagram of Nested U Test Loop**

**Table 7: Pugh Chart for Testing Slots**

| Selection Criteria | | Weight | Parallel U | | Nested U | | Parallel I | | Parallel E | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Customer Requirement* | *Engineering Specification* | | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Technicians training | Height of the testing slot | 0.04 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 |
| | Working space area | 0.04 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 |
| | Operating Pressure | 0.04 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 |
| | Operating Flow Rate | 0.04 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 |
| Accurate | Steel Material for all the piping | 0.08 | 4 | 0.33 | 4 | 0.33 | 4 | 0.33 | 4 | 0.33 |
| | Able to extract free air from testing flow loop | 0.08 | 4 | 0.33 | 4 | 0.33 | 4 | 0.33 | 4 | 0.33 |
| Robust | Safety factor for maximum pressure in the pipe | 0.17 | 4 | 0.67 | 4 | 0.67 | 4 | 0.67 | 4 | 0.67 |
| Easy to use | Able to drain instruments | 0.03 | 4 | 0.13 | 4 | 0.13 | 4 | 0.13 | 4 | 0.13 |
| | Accessible path to the testing slots | 0.03 | 4 | 0.13 | 4 | 0.13 | 4 | 0.13 | 4 | 0.13 |
| | Minimum turning radius in the path | 0.03 | 4 | 0.13 | 4 | 0.13 | 4 | 0.13 | 4 | 0.13 |
| | Minimum width of the path | 0.03 | 4 | 0.13 | 4 | 0.13 | 4 | 0.13 | 4 | 0.13 |
| Small Size | Floor Size | 0.04 | 3 | 0.13 | 1 | 0.04 | 4 | 0.18 | 3 | 0.13 |
| | Number of Testing Flow Loop | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| | Number of Level control Loop | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| Able to test variety of instruments | Total Number of testing slot per flow loop | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| | Types of instruments that can be tested | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| | Testing slot size | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| Cost | Low cost | 0.10 | 3 | 0.30 | 3 | 0.30 | 5 | 0.30 | 4 | 0.30 |
| Total Score | | 1 | | **3.86** | | **3.77** | | **3.90** | | **3.86** |
| Ranking | | | | **2** | | **4** | | **1** | | **3** |

Referring to table 8 above, we will next clarify how each of the concepts are quantified using the Pugh Chart. For the customer requirement technicians training, rating four is given to all four testing slots concepts as they are able to fulfill the four engineering specification.

For customer requirement regarding accuracy, rating four is given to all concepts as the piping for testing slots are all steel in material. For the ability to extract air from the testing flow loop, all of the concepts are equipped with air vent that drain the air bubble. Thus, rating four are given for the four concepts.

All four concepts fulfill the customer requirements of robust and ease of use. Therefore, rating four is given all four concepts. For the small size customer requirement, there are the same number of testing flow loop and number of level control loop for all testing loops concepts. Therefore, they are rated four. For floor size, the four concepts have different dimensions. Parallel U is rated three for floor size as the design area comes out to be 235.75 $ft^2$; having an area of 422.42 $ft^2$, nested U is rated one; The area of Parallel I and Parallel E are 175.87 $ft^2$ and 265.76 $ft^2$ respectively. Therefore, Parallel E is rated four and parallel I is rated three. In terms of cost, Parallel I ranked as the best since it uses the least amount of piping compared with the other concepts. In addition, labor cost contributes to the Cost in the customer requirement. The labor cost is higher on concepts with more piping components for installation.

**Concept Generation - Test loop and component arrangement**
As per our customer specification, our simulator needs to have two flow test loops, and one control loop (which consist of one standpipe). Adding this with the storage tank, and power generation equipment, we need to generate concepts on how to arrange these components to ensure that they occupy minimum floor area while still satisfy the other engineering specifications.

**Standard Layout***:* The standard layout idea has the storage tank and stand pipe next to one another on the higher elevation. The energy source is located under the storage tank on ground level. For the testing loops, it is located on an elevation higher than the energy source while still lower than storage tank. The reason why we placed the storage tank at a higher elevation than the pumps is to ensure that water will flow down smoothly from the tank and into the pumps. For the same reason, a higher elevation stand pipe will allow water to flow from the standpipe to the tank without the use of any pumps. Figure 21 below shows the schematic diagram of a standard layout.

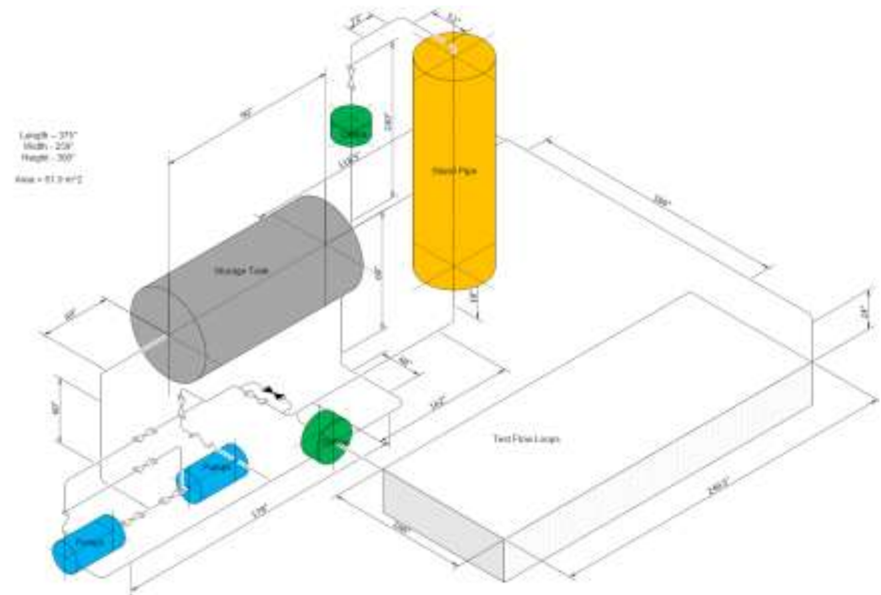


**Figure 21. Schematic Diagram of Standard Layout**

**Vertical Stack Layout :** The vertical stack concept has the testing loops and energy sources on ground level, storage tank on level 1, and stand pipe on level 2. This idea creates a smaller floor size and a very high structure. The advantage of the vertical stack layout will be in decreasing floor size that meets the customer requirement. The major disadvantage is the height of the vertically stacked components. It will create difficulties for users for reaching devices that are too high for human. From the team discussion, the concept is considered unfeasible.

**Spread-out Layout:** This design has the storage tank and stand pipe on level 1. The energy source and testing loops are located on ground level between the storage tank and stand pipe. The advantage of a spread layout is its simple layout which allows maximum clearance space between each individual parts of the simulator. The disadvantage of this design is that huge spread of pipelines and space consumption which is in contradiction with our customer requirement. Figure 22 below shows the schematic diagram of the spread-out layout.

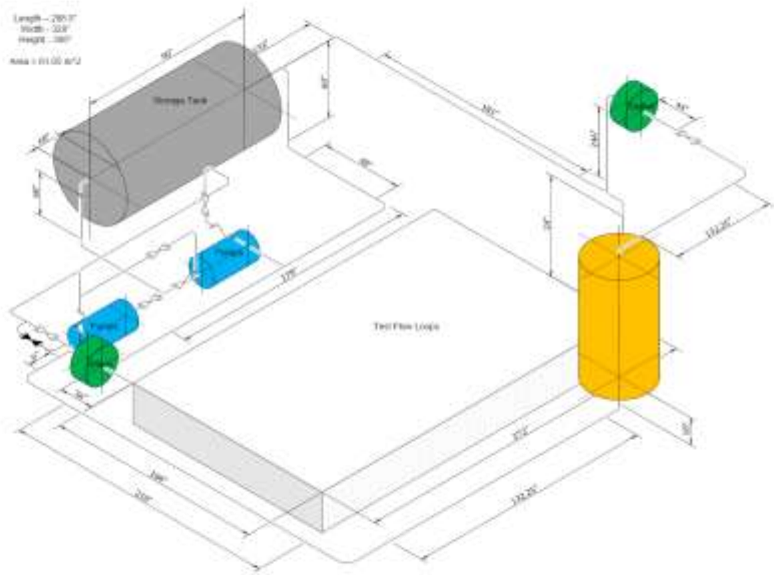


**Figure 22. Schematic Diagram of Spread-Out Layout**

**Square Layout***:* This design is similar to the Standard Layout. The only difference is that instead the testing loop is located in the middle of the storage tank, the stand pipe and the dual pumps. The advantage of this concept includes ease of use. The disadvantage is that is impossible to place all four subsections in a square formation due to head loss. When there is head loss, the simulator will not operate normally due to insufficient pressure calculated from our hydraulic analysis. Therefore, this concept is not feasible. Figure 23 below shows the schematic for square layout.

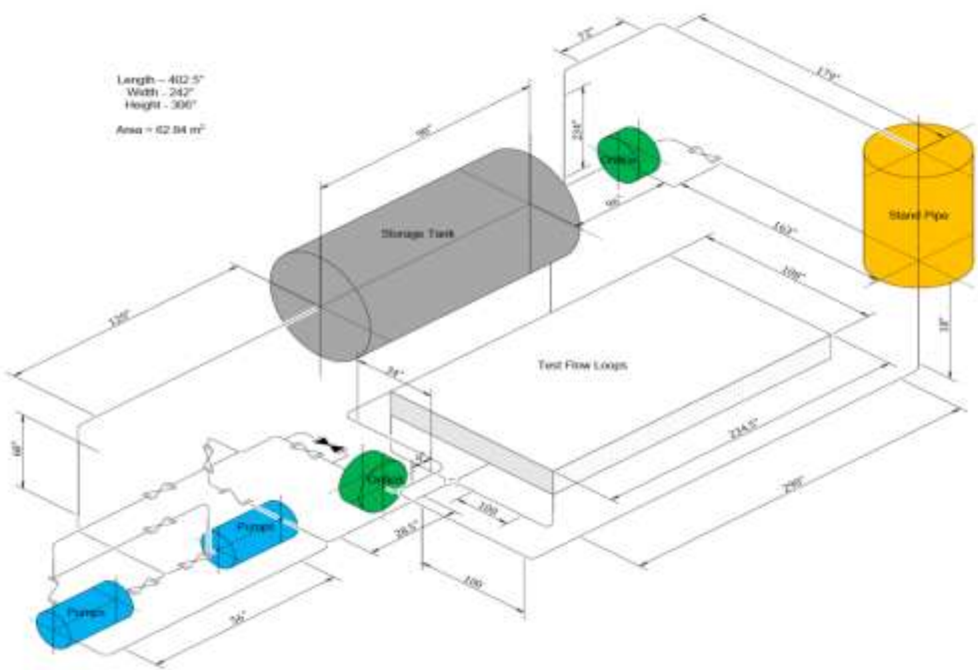



**Figure 23. Schematic Diagram of Square Layout**

**Table 8: Pugh Chart for Test loops and component arrangement**

| Selection Criteria | | Weight | Standard Layout | | Vertical Stack Layout | | Spread Layout | | Square Layout | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Customer Requirement* | *Engineering Specification* | | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Technicians training | Height of the testing slot | 0.04 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 |
| | Working space area | 0.04 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 |
| | Operating Pressure | 0.04 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 |
| | Operating Flow Rate | 0.04 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 | 4 | 0.17 |
| Accurate | Difference between flow parameter and actual flow | 0.06 | 4 | 0.22 | 4 | 0.22 | 4 | 0.22 | 4 | 0.22 |
| | Steel Material for all the piping | 0.06 | 4 | 0.22 | 4 | 0.22 | 4 | 0.22 | 4 | 0.22 |
| | Able to extract free air from testing flow loop | 0.06 | 4 | 0.22 | 4 | 0.22 | 4 | 0.22 | 4 | 0.22 |
| Robust | Safety factor for maximum pressure in the pipe | 0.17 | 4 | 0.67 | 4 | 0.67 | 4 | 0.67 | 4 | 0.67 |
| Easy to use | System to control and vary the flow parameter | 0.03 | 4 | 0.11 | 4 | 0.11 | 4 | 0.11 | 4 | 0.11 |
| | Able to drain instruments | 0.03 | 4 | 0.11 | 4 | 0.11 | 4 | 0.11 | 4 | 0.11 |
| | Accessible path to the testing slots | 0.03 | 4 | 0.11 | 4 | 0.11 | 2 | 0.05 | 4 | 0.11 |
| | Minimum turning radius in the path | 0.03 | 4 | 0.11 | 4 | 0.11 | 4 | 0.11 | 4 | 0.11 |
| | Minimum width of the path | 0.03 | 4 | 0.11 | 4 | 0.11 | 4 | 0.11 | 4 | 0.11 |
| Small Size | Floor Size | 0.04 | 3 | 0.13 | 5 | 0.22 | 3 | 0.13 | 3 | 0.13 |
| | Number of Testing Flow Loop | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| | Number of Level control Loop | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| Able to test variety of instruments | Total Number of testing slot per flow loop | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| | Types of instruments that can be tested | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| | Testing slot size | 0.04 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 | 4 | 0.18 |
| Cost | Low cost | 0.10 | 4 | 0.40 | 3 | 0.30 | 3 | 0.30 | 3 | 0.30 |
| Total Score | | 1 | | **3.96** | | **3.94** | | **3.80** | | **3.86** |
| Rank | | | | **1** | | **2** | | **4** | | **3** |

After performing the feasibility studies, we have selected the standard and spread out layout. The standard layout is easy to use, accurate, robust, and able to train technician. The spread layout also meets the design criteria except working space area and accessibility of flat path. As shown from the Pugh chart above, the standard layout is ranked the highest from the Pugh chart analysis. Although Spread-out layout is ranked last in the Pugh chart, it is selected because of its feasibility. Based on our team discussions, the vertical stack layout and the square layout are considered unfeasible, even if they do satisfy the design criteria. The issue in a vertical stack layout is due the height of the layout that greatly creates size and budget constraint. Secondly, the square layout is unfeasible because the process in placing all subsections in a square shape would create head loss for the system. A head loss would not provide enough pressure in operating fluid throughout the simulator.

Referring to the Table 9 above, we will next clarify the Pugh chart analysis on the four layout concepts. Under customer requirement, the ability to train technician encompasses four different engineering specifications. The four layout concepts meets all four engineering specification well and therefore, they are rated four.

Under the customer requirement accuracy design, all layouts are rated four as each is able to satisfy all engineering specifications: the difference between flow parameter and actual flow, steel material, and the ability to drain air from the test flow loops. In addition, all the design concepts are considered robust relates to the safety factor for maximum pressure. Therefore, all concepts are rated four.

Rating four is given to all layout concepts under customer requirement ease of use. Because, all engineering specifications in ease of use customer requirement are met when brainstorming the concepts. With that in mind, the ratings are the same for all the concepts for ease of use.
In the small size customer requirement, it is being divided into floor size, number of testing flow loop, and number of level control loop. All four designs are rated four on number of testing flow loop and number of level control loop as each concepts fulfill the functions. The standard layout floor size is rated three because its area of 40.8 $m^2$ is very close to the customer requirement floor size of 46.4 $m^2$. A Rating five is given to the vertical stack layout as it encompasses a small floor size of 26.4 $m^2$. Both Spread out layout and square layout are rated two because they have a larger floor space than the customer requirement of 61.05 $m^2$ and 62.84 $m^2$ respectively.

All layout concepts are rated four in their ability to test varieties of instruments, as all layout concepts are able to meet the engineering specification. As cost is unable to be quantified, the standard layout is to be made a datum for the other layout concepts in terms of cost. Vertical stack layout is rated three for cost because, stronger and longer supports will be needed to withstand the simulator components in vertical structure; stronger supports would then be more expensive. Square layout and Spread layout are rated three because, these designs cover a larger space that needed longer pipes. Longer pipes are considered more expense.

**Concept Generation - Flow directing method**

As per our customer requirement, our simulator will consist of 2 flow loops and 1 level control loop. When water flow is going through 1 loop, to ensure the accuracy of the flow, we need to find a method so that the flow will not go through the other 2 loops. We've decided to use valves to direct the flow; the valves are placed right before each loop. When the flow needs to be directed to one loop, the valve in front of that loop will be completely opened while the valves corresponding to the other loops will be completely closed to ensure that the water will not flow to the other loops.

Since the scope and timeline of our project does not allow us to custom design a valve that will meet our requirement, we researched a number of common valve types that are available in the market and best suit our project. The valves that we consider in this section exclude the control valve (which will be connected to the PLC) which is being used to throttle the flow of water to match the required flow parameter. Thus the valves in this section only need to be able to be fully opened or fully closed.

Figure 24 illustrates the three types of valves considered (Ball, Gate, and Poppet/Globe valve). Ball Valve (Figure 24a) is a valve that opens by turning a handle attached to a ball inside the valve. The ball has a hole, or port, through the middle so that when the port is in line with both ends of the valve, flow will occur. When the valve is closed, the hole is perpendicular to the ends of the valve, and flow is blocked. Gate Valve (Figure 24b) uses a round or rectangular gate/wedge perpendicular to the direction of the flow. When the valve is closed, the gate completely fall and block the flow of water through the valve. Poppet/Globe Valve (Figure 24c) has an opening that forms a seat onto which a movable plug, connected to the stem, can be screwed in to close (or shut) the valve

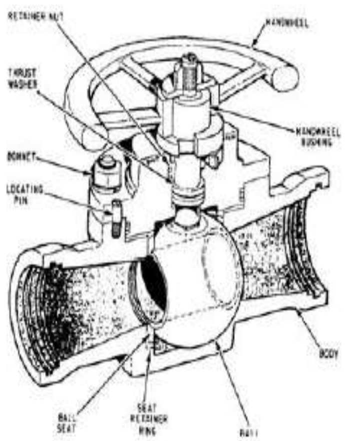


Fig. 24a: Ball Valve [18]

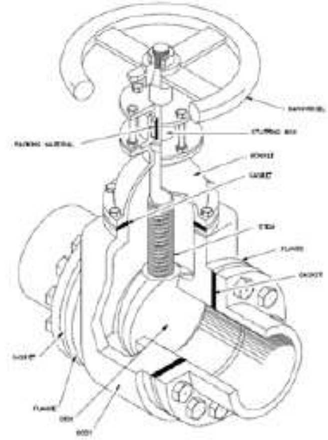


Fig. 24b: Gate Valve [19]

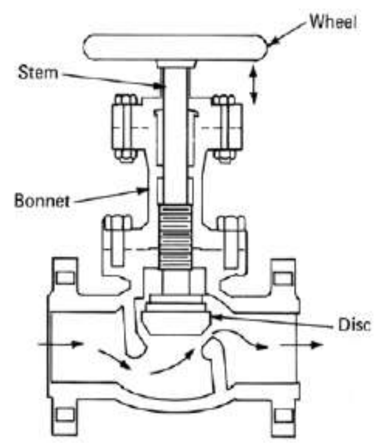



Fig.24c: Globe valve [20]

**Table 9: Pugh Chart for flow directing method**

| **Selection Criteria** | **Weight** | **Ball valve** | | **Gate valve** | | **Globe valve** | |
|---|---|---|---|---|---|---|---|
| | | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Easy to use | 0.14 | 5 | 0.70 | 5 | 0.70 | 5 | 0.70 |
| Small | 0.14 | 5 | 0.70 | 5 | 0.70 | 5 | 0.70 |
| Able to test a wide range of instruments | 0.14 | 5 | 0.70 | 5 | 0.70 | 5 | 0.70 |
| Robust | 0.18 | 5 | 0.90 | 4 | 0.72 | 3 | 0.54 |
| Accurate | 0.18 | 5 | 0.90 | 4 | 0.72 | 1 | 0.18 |
| Technicians training | 0.10 | 3 | 0.30 | 3 | 0.30 | 3 | 0.30 |
| Cost | 0.12 | 3 | 0.36 | 3 | 0.36 | 3 | 0.36 |
| | | | | | | | |
| Total Score | 1.00 | | **4.56** | | **4.20** | | **3.48** |
| Rank | | | **1** | | **2** | | **3** |

Our Pugh analysis (Table 9) showed that Poppet/Globe valve is not suitable to direct the water in our simulator. Globe valve received a rating of 1 in terms of accuracy because its inner construction will restricts the flow path; therefore they are not recommended in application where full unobstructed flow is required [21]. Ball valve and Gate valve are feasible for this purpose because they can work properly at fully opened or closed condition. Ball valve received higher score in ‘Robust’ and ‘Accuracy’, because they typically has higher operating pressure range and lower pressure drop compared with Gate valve

[22]. The cost of these valves are pretty identical to one another, and they are relatively small compared with the cost of other parts.

**Concept Generation - Power Source**

In order to drive the water from stationary to the required flow parameter, we need to find a way to generate energy for the drive. The concepts generated for the energy source involves four concepts generated: two pump source, one pump source, an elevated storage tank, and substituting the working fluid. The goal of an energy source is to provide the required flow parameters of 1000 psi operating pressure and a flow rate of 660 gpm.

**2 Pump source:** The fluid simulator requires an operating max pressure of 1000 psi in order to deliver enough flow rate to cycle the whole loop. Therefore, an idea of using two pumps with Operating pressure of 580 psi each will provide the operating flow parameters to run the simulator. The two pump sources may be configured in series or parallel; the type of pump used provides 1250 psi maximum working pressure and a flow rate of 600 gpm.

One of the advantages of using two pumps is that when one pump stopped working, the other pump would still work and able to operate flow parameters for the simulator. In addition, two pumps can be configured to a series or parallel, depending on the operation needs in meeting the required flow parameters. The disadvantage of two pump source is that it covers more space near the storage tank, which also adds more piping and valves needed for the installation. Therefore, it would increase floor space. Please refer to Appendix C for cost analysis for the dual pump.

Furthermore, the dual pump energy source is able to operate on different configuration (parallel or series). For two pumps in a parallel configuration, the flow rate will be twice the flow rate of a single pump with the same head. For two pumps connected in series configuration, the head will be twice the head of a single pump with the same flow rate. Figure 26a and b below show how two pumps behave in different configurations. Therefore, dual pumps configuration is also flexible for different conditions and needs.

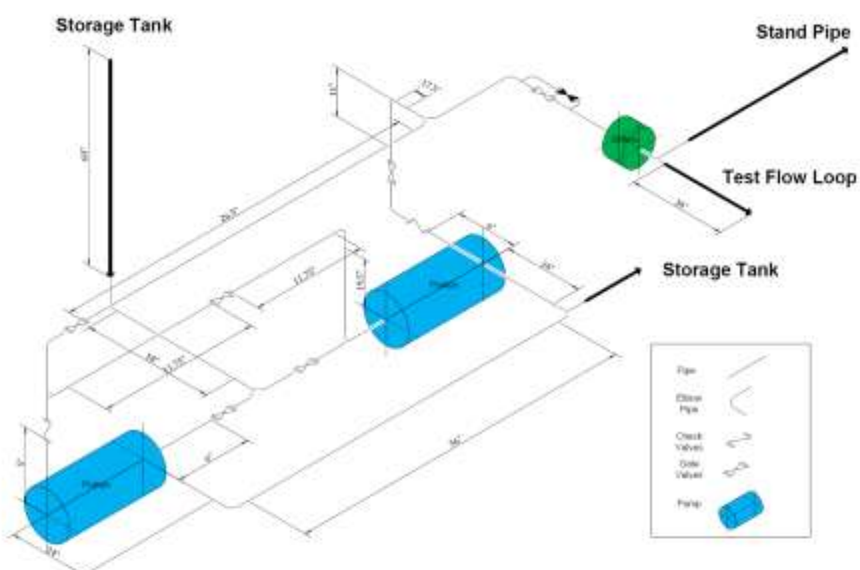



**Figure 25. Schematic Diagram of Dual Pump Energy source**

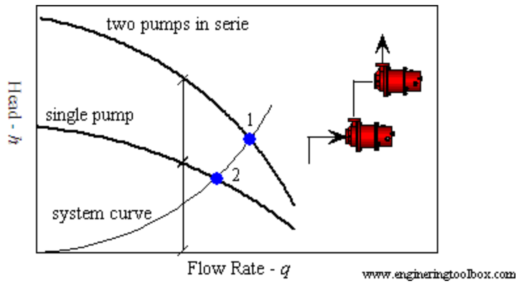



**Fig 26a: Pump in series curve [23]**

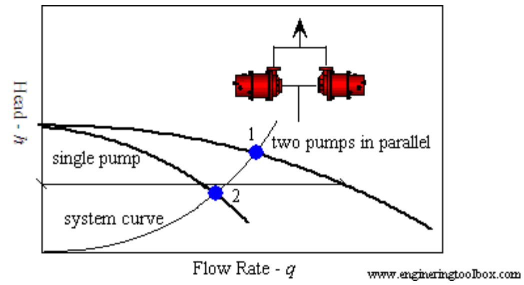



**Fig 26b: Pumps in parallel curve [23]**

**1 Pump Source:** To generate the required flow parameters (1000 psi and 660 gpm), a single high-pressure centrifugal pump can be used to operate the simulator The single pump here provides a 1100 gpm flow rate and a maximum working pressure of 1440 psi. Please refer to Appendix X for the detail of the single high-pressure centrifugal pump source.

One the advantage of using one very high pressure centrifugal pump is in terms of space. As the energy source is powered by one pump instead of two, there will be less area needed for the simulator. In addition, the cost of one high pressure pump will be more cost efficient compared to two pumps, as less pipes and valves are needed to accommodate the flow parameters. One of the disadvantages with the pump is in term of cost. One package of pump with motor included will cost up to $150,000. Also, if a downtime occurred on the pump, the whole simulator will have no energy source for normal operation. Please refer to Appendix C for cost analysis of the single pump.

**Elevated Storage Tank:** The concept here defines the initial height of the storage height. The height is the Bernoulli's equation parameter in the equation shown below:

$$vP_1 + \frac{1}{2}V_1{}^2 + gH_1 = vP_2 + \frac{1}{2}V_2{}^2 + gH_2 \qquad \text{(Equation 1)}$$

V1 is the inlet velocity, V2 is the exit velocity, g is acceleration due to gravity (9.816 $m/s^2$), P2 is Pressure exit, P1 is inlet pressure, H1 is the initial height, and H2 is the final height. From the stated equation above, the initial height H1 is directly proportional to the outlet pressure. Therefore, an increase in storage tank height will produce higher outlet pressure that will provide the required flow parameters of the fluid simulator.

The advantage of using an elevated storage tank is that it provides more energy from the height to increase pressure output for the required flow parameters. Nevertheless, this concept generation is not feasible as the weight of the storage tank itself would be very heavy (18408 lbs). The disadvantage of this concept is that it will need a tremendous height condition. From a theoretical calculation, an elevated storage tank would reach an elevation of 2000 ft, which becomes impossible. In addition, circulating the working fluid back to the elevated tank would be harder, as the piping from the stand pipe need to be longer. Therefore, this concept is considered unfeasible.

**Working Fluid Substitute:** The concept in different types of working fluid is based on the Bernoulli's Equation theory. Several simplified equations derived below will describe a conceptual explanation in changing types of working fluid.

$$\frac{V_1{}^2 - V_2{}^2}{2g} = \frac{P_2 - P_1}{\rho} \qquad \text{(Equation 2)}$$

$$P_2 = \frac{\rho V_2}{2g} \qquad \text{(Equation 3)}$$

V1 is the inlet velocity, V2 is the exit velocity, g is acceleration due to gravity (9.816 $m/s^2$), P2 is Pressure exit, P1 is inlet pressure, and ρ is the density of the working fluid. The equation above shows that density is proportionally related to the exit pressure. Therefore, a working fluid with higher density will produce a larger pressure that can sufficiently provide energy to operate the simulator. An example of a high density fluid is a refrigerant, which has one if its function is for cooling purposes. The disadvantage of applying a substitute working fluid is that it will have different fluid parameters, behaviors, and conditions. Such circumstances would be unsuitable for a fluid simulator that is specified for water as the working fluid. Therefore, the working fluid substitute concept is not feasible.

**Table 10: Pugh Chart for power source**

| Selection Criteria | | Weight | Single Pump | | Dual Pump | | Elevated Storage Tank | | Another Working Fluid | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Customer Requirement* | *Engineering Specification* | | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Technicians training | Operating Pressure | 0.15 | 4 | 0.59 | 4 | 0.59 | 2 | 0.29 | 2 | 0.29 |
| | Operating Flow Rate | 0.15 | 4 | 0.59 | 4 | 0.59 | 3 | 0.44 | 3 | 0.44 |
| Accurate | Difference between flow parameter and actual flow | 0.29 | 4 | 1.18 | 4 | 1.18 | 2 | 0.59 | 1 | 0.29 |
| Small Size | Floor Size | 0.24 | 3 | 0.71 | 4 | 0.94 | 5 | 1.18 | 5 | 1.18 |
| Cost | Low Cost | 0.18 | 2 | 0.35 | 3 | 0.53 | 4 | 0.71 | 4 | 0.71 |
| Total Score | | 1 | | **3.41** | | **3.82** | | **3.21** | | **2.91** |
| Rank | | | | **2** | | **1** | | **3** | | **4** |

Referring to Table 10, the technicians training under customer requirement relates to the engineering specification of operating pressure and operating flow rate; The single pump and dual pump power source are rated four on operating pressure and operating flow rate as they are able to meet the required performance; Elevated storage tank is rated two for operating pressure and flow rate because, a reasonable elevation of storage tank would not satisfy the flow parameters; The working fluid is rated two because, a different working fluid would be unstable in providing the specified flow parameters that operates normally with water.

Under customer requirement regarding accuracy, it relates to the engineering specification of steel material and the difference between flow and actual parameter. In rating the dual pump and single pump power source, they are rated four on the accuracy of delivering actual flow as the both products are deemed high-end products from the information sources. Elevated storage tank is rated two because the source of power is theoretically calculated using Bernoulli thermo. Therefore, there would be uncertainties in Bernoulli theorem that leads to difference between flow parameter and actual flow. The working fluid substitute is rated one because it is not water in the first place. Thus, there would also be uncertainties between flow parameter and actual flow.

For the size, it relates to engineering specification of floor size. The dual pump is rated 3 because it covers an area of approximately 2.64 $m^2$. The single pump is rated three because it has an area of 6.60 $m^2$. Both elevated storage tank and working fluid are made datum. As they do not affect the floor size, they are both rated zero. Also, we have the assumption that height of the elevated storage tank does not affect the floor size.

For cost, we cannot quantify the engineering specification as there is no target cost. However, we rate the power source concept by making working fluid as the datum. The single pump power source is rated two because from the information source, a single high pressure centrifugal pump would cost $150,000. Also, the dual pump is rated three, as two pumps would cost $50,000 to $60,000. An elevated storage tank is rated four because, the cost for increasing the height is only by installing higher and stronger supports. A stronger steel sports with expansion pipe would costs approximately $70 to $100 each. An expansion pipe is used to extend the support higher. For working fluid, it is rated four because it will cost about $700 for changing to a different working fluid. The type of working fluid substitute we are considering is a refrigerant.

We have selected the double pump and single pump; First, because they are feasible. The double pump is robust, flexible, accurate, small, and low cost. As specified by a centrifugal pump manufacturer, Corrosion Fluid Corporation, a single high pressure pump would cost $150,000. The dual pump concept would be considered the best selection as it reasonably satisfies all the design criteria including cost, as each pump in the dual pump concept costs $50,000 to $60,000. Although the single pump is more expensive, it still meets the design criteria to be robust, flexible, accurate, small size. As shown in the table above, the Pugh chart analysis shows that the double pump source showed the best score rating and the single pump ranked second. The elevated storage tank and working fluid substitute concepts are considered unfeasible. The elevated storage tank would need a very high elevation of 2000 ft to create sufficient head for the operating pressure. The height creates dimensional constraint that would be inapt. Secondly, a different working fluid would have different fluid behaviors. Therefore, applying a working fluid substitute would not be suitable for our simulator that normally runs on water.

**Concept Generation -Control Method**
Control method is used to regulate the flow that is going through our simulator. The control method needs to be able to adjust the flow parameter within the range of operating pressure and flow rate

**PLC (Programmed Logic Control):** This is the current control system used by current simulator. The PLC will be used to control the valve and calibrate the transmitter. The PLC is connected to the control valve, level and flow transmitter, and pump. In the PLC controller there will be a display and we could program the logic to control the valve. Advantage of this choice includes flexibility to control many machines. Moreover, the PLC has a lower cost where it is possible to make more functions into smaller and less expensive packages. Disadvantages of this choice will be fixed program where it only has a single-function applications.

**Figure 27: PLC device illustration [24]**

**VFD (Variable Frequency Drive)***:* Applying VFD on the pump is one of the major design ideas. The VFD controls the rotational speed of the motor in the pump by using different range of frequencies. First, the VFD retrieves signals in electric current or voltage, from the pressure transmitter by the pump. Then, it converts the signals to frequency, which could be altered to different values for operating the motor. One of the advantages of a VFD is that we could modulate flow by changing the frequency. Therefore, one pump (pump with operating pressure that satisfies 1000 psi or more) would be required instead of two pumps. In addition, the VFD replaces valves that function to throttle the flow, which results in cost saving. The advantage of using this to control the pump will give higher life time for the pump. Moreover, it will rise up the efficiency of the plant itself. The disadvantages of using VFD will be complicated engineering assembly might be needed. The operator must have certain knowledge to operate the VFD. Also, In order to operate a high pressure pump, the CFD must a have a high capacity as well. Therefore, having a high power VFD will result in a very high cost ($16,490 for a 350 Hp VFD).

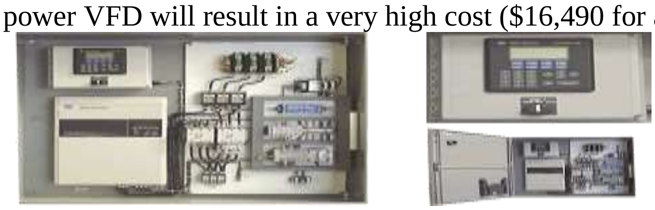


**Figure 28: Sample VFD Component [25]**

**Relay:** Relay is simple component that is connected to control applications. For example, a relay could be used to turn on or off the pump. The advantages of using this will be having a less costly system and easier to troubleshoot. However, this relay has no monitor control and also it is only for more simplified system with no extension possibility.

**MicroController***:* A microcontroller is essentially a very small, lower power computer that can fit onto a single chip. It is programmable to control valves. These chips must generally be used with a development/programming board in order for them to interact with other components. Microcontroller is good for simple open valve system. The disadvantage of using micro controller is for a complex system, it will be troublesome to program using microcontroller.


**Figure 29. Sample Microcontroller chip [26]**

**Manual Adjustment: M**anually adjust the valve to control the flow rate will be another alternative. Operator will have to manually shut off the necessary valve to control the desired flow rate. Advantages of using this are saving space and less expensive in terms of building the simulator. Disadvantages of this will be inaccuracy of flow rate adjustment. Moreover manually adjustment will have human error involve in the system.

**Table 11: Pugh Chart on Control System**

| **Selection Criteria** | | **Weight** | **PLC** | | **VFD** | | **Relay** | | **MicroController** | | **Manual Adjustment** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Customer Requirement* | *Engineering Specification* | | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Technicians Training | Working space area | 0.08 | 4.00 | 0.32 | 4.00 | 0.32 | 4.00 | 0.32 | 4.00 | 0.32 | 5.00 | 0.40 |
| | Operating Pressure | 0.08 | 4.00 | 0.32 | 4.00 | 0.32 | 4.00 | 0.32 | 4.00 | 0.32 | 2.00 | 0.16 |
| | Operating Flow Rate | 0.08 | 4.00 | 0.32 | 4.00 | 0.32 | 4.00 | 0.32 | 4.00 | 0.32 | 2.00 | 0.16 |
| Accurate | Difference between flow parameter and actual flow | 0.24 | 5.00 | 1.19 | 5.00 | 1.19 | 3.00 | 0.71 | 3.00 | 0.71 | 1.00 | 0.24 |
| Easy to use | System to control and vary the flow parameter | 0.19 | 5.00 | 0.95 | 5.00 | 0.95 | 3.00 | 0.57 | 3.00 | 0.57 | 2.00 | 0.38 |
| Small Size | Floor Size | 0.19 | 4.00 | 0.76 | 4.00 | 0.76 | 4.00 | 0.76 | 4.00 | 0.76 | 5.00 | 0.95 |
| Cost | Low Cost | 0.14 | 4.00 | 0.57 | 3.00 | 0.43 | 4.00 | 0.57 | 4.00 | 0.57 | 5.00 | 0.71 |
| Total Score | | | | **4.43** | | **4.28** | | **3.57** | | **3.57** | | **3.00** |
| Rank | | | | **1** | | **2** | | **3** | | **4** | | **5** |

From the Pugh chart analysis, we could see that PLC is rated highest of all. We choose plc because it is able to handle complex programming system and also it gives a flexibility to extend the based system with affordable price. Manual adjustment has the lowest score where it actually ranks lowest in the two most important requirements the accuracy and technician trainings. Although the relay has a pretty high rank on the technician training and costs, it has a problem where it might be difficult for the operator to operate and vary the flow in which similar to microcontroller. Although it might serve as different function in our simulator, VFD falls into our control system category. VFD actually rates second here in the Pugh chart where it is rated high in accuracy on controlling flow since it will control the pump and vary the flow parameter easily.

**Concept Generation - Pipe Support**
We are considering different type of supports for the whole piping system. Choices of this might be critical; we need to consider whether the support could handle the weight needed and also the required pipe size

**Bolt on:** This piping support bolts directly to the flange. The support designed for all flanged piping needs with adjustability function. We could adjust the height that we want for the support. The supports also have corrosion resistant and galvanized finish. This is really critical for a water pipe since it will rust easily if not finished with protective coating. It might not take up a lot of space for the piping.


**Figure 30. Schematic of bolt on piping support (27)**

**Clamp Style***:* This is a clamp style for the pipe. It tightens the two halves of the clamp with the included bolts for a snug hold. It actually tightens up the pipe and reduces the movement of the pipe itself. This design also has adjustability design. It is good for installations where seismic activity might occur. However, it might take longer time to attach the support.


**Figure 31. Schematic of Clamp Style piping support (28)**

**Saddle Style***:* This type is not feasible because it is not robust enough to hold the piping system. The saddle comes in direct contact with half of the pipe's circumference for secure support. This model is the cheapest price of all. This model is not good for the piping with a lot of vibration. This support is easy to assemble into the system since it has less bolting attachment compare to other choices we have.


**Figure 32. Schematic of Saddle Style piping support (27)**

**Pipe Hangers: T**his type of hanger is good for outdoor usage. It is good resistance for harsh weather piping supports. It absorbs thermal expansion and contraction of pipes thus preventing damage to the roof membrane. However, it is not feasible to use this because it might takes up more space and have less adjustability. Moreover, it costs more than the other choices.

**Figure 33. Schematic of Pipe Hangers piping support (28)**

**Table 12. Pugh Chart on Piping Support.**

| Selection Criteria | | Weight | Bolt On | | Clamp Style | | Saddle | | Pipe Hangers | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Customer Requirement* | *Engineering Specification* | | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Technicians training | Height of the testing slot | 0.12 | 4.00 | 0.48 | 4.00 | 0.48 | 4.00 | 0.48 | 3.00 | 0.36 |
| | Working space area | 0.12 | 4.00 | 0.48 | 4.00 | 0.48 | 4.00 | 0.48 | 3.00 | 0.36 |
| Robust | | 0.24 | 5.00 | 1.19 | 5.00 | 1.19 | 3.00 | 0.71 | 4.00 | 0.95 |
| Easy to use | Accessible path to the testing slots | 0.06 | 4.00 | 0.19 | 4.00 | 0.25 | 4.00 | 0.25 | 3.00 | 0.19 |
| | Minimum turning radius in the path | 0.06 | 4.00 | 0.25 | 4.00 | 0.25 | 4.00 | 0.25 | 3.00 | 0.19 |
| | Minimum width of the path | 0.06 | 4.00 | 0.25 | 4.00 | 0.25 | 4.00 | 0.25 | 3.00 | 0.19 |
| Small Size | Floor Size | 0.19 | 4.00 | 0.76 | 4.00 | 0.76 | 4.00 | 0.76 | 3.00 | 0.57 |
| Cost | Low Cost | 0.14 | 4.00 | 0.57 | 4.00 | 0.43 | 5.00 | 0.72 | 4.00 | 0.57 |
| Total Score | | 1.00 | | **4.17** | | **4.17** | | **3.90** | | **3.38** |
| Rank | | | | **1** | | **1** | | **3** | | **4** |

As shown on table 12 above, we could see that the bolt-on and clamp style are ranked the highest among the choices. They essentially offer the same benefit; the only difference is in term of applications. Whereas, 'Bolt on' can only be used in flange connection, 'Clamp' can be used in smooth pipe but cannot be used on a flange connection. As our design will mature, and we've decided on the areas that need pipe support, we'll decide which pipe support type we're going to use for our design

The pipe hanger ranks the lowest where it actually takes up space and will hinder ease of use of the simulator. it also takes up more space than the other choices. Although the other requirement rated highly among the other choices the saddle support actually ranked lowest in robustness, since it is not suitable to support piping that might involve a lot of vibrations.

**Complete Concepts Generation**

From the Pugh charts' results of the above mentioned individual functions, we can combine the winning concepts of each function and come up with one complete design that incorporates all the winning concepts. However, we acknowledge that some of the concepts in each function only loose by a small margin. These concepts, when combined with the other concepts from other functions, may have the potential to be a better complete design compared with the design that combines all the winning concepts of each function.

In order to help us to generate more complete concepts, we constructed a concept generation tree (Figure 34) which gives us a better overall view of all the concepts generated for each function.

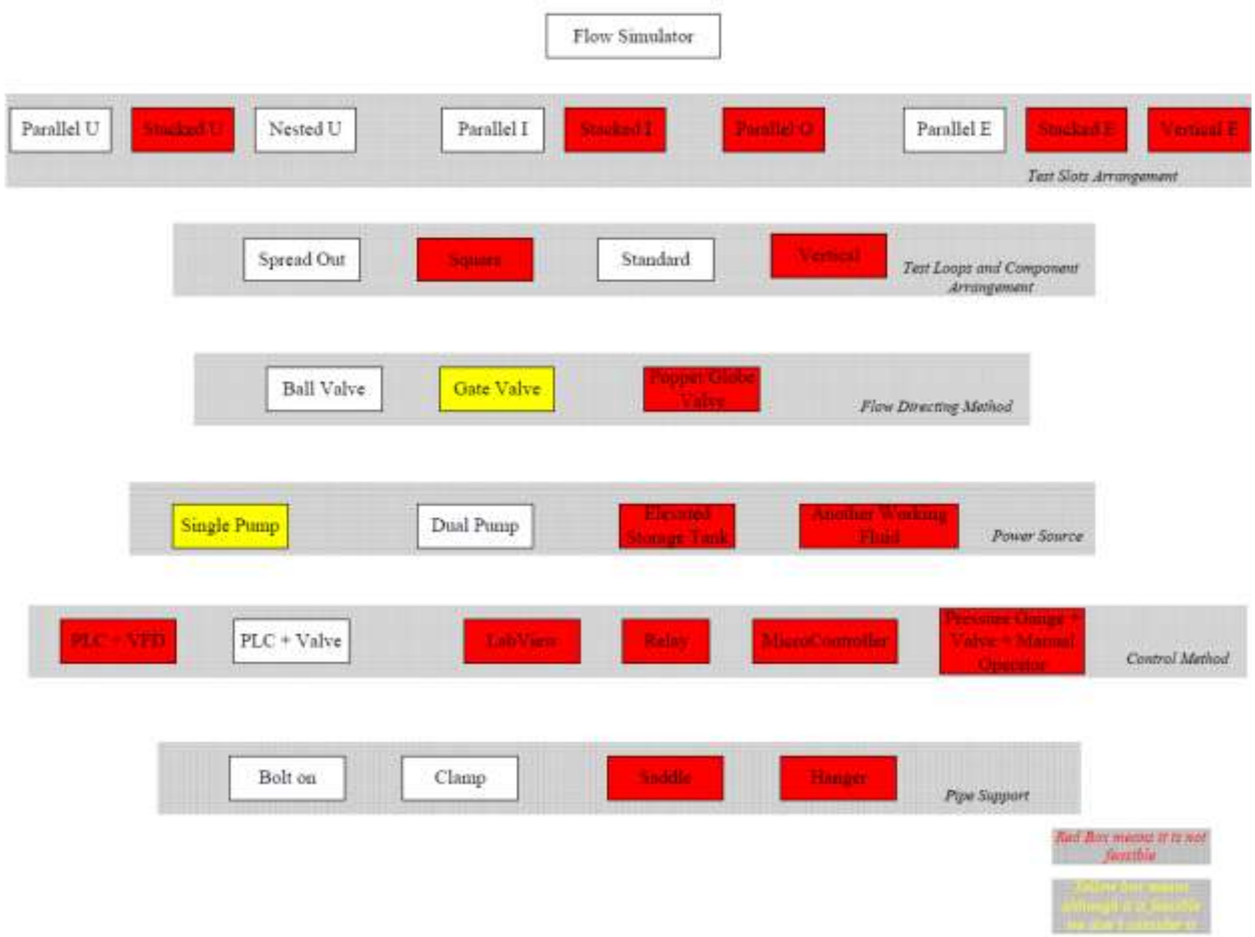



**Figure 34: Concept generation tree**

In Figure 34, the red box indicates the concepts that were deemed not feasible, thus they are not considered for our complete concept generations. Please refer back to the individual concept generations sections for explanation on why these concepts were deemed not feasible.

The yellow box indicates the concept that are still feasible for our project, however they are deemed to be completely inferior to the winning concept in the same functions even after combined with the other concepts from other function level. Thus they are also not considered for our complete concept generations.

For example, in the 'Flow Directing Method' function level, the 'Gate valve' concept is deemed completely inferior compared with 'Ball valve'. As can be seen in Table 10, the 'Ball valve' is superior in terms of 'Robust' and 'Accurate'. If we interchange these two concepts in the same set of complete concept, the 'Ball valve' will always be better than 'Gate valve'. For example, if we compare "Gate valve + Parallel U + Spread out + Dual pump + plc and valve + Bolt on" complete concept with "Ball valve + Parallel U + Spread out + Dual pump + plc and valve + Bolt on", the concept with 'Ball valve' will always win, no matter what's the selection for the other function level as long as they are the same for the two complete concepts. This is because 'Robust' and 'Accurate' for the valve is independent of outside factors.

Meanwhile, in the 'Energy source' function level, the 'Single pump' is always inferior to 'Dual pump' because the cost of single pump is much greater compared with dual pump.

Based from the above mentioned analysis and concept generation tree, we came up with five different complete concepts:
Concept 1: Parallel I – Standard – Ball valve – Dual Pump – PLC+Valve – Clamp
Concept 2: Parallel I – Spread Out – Ball valve – Dual Pump – PLC+Valve – Bolt on
Concept 3: Nested U – Spread Out – Ball valve – Dual Pump – PLC+Valve – Bolt on
Concept 4: Parallel U – Standard – Ball Valve – Dual Pump – PLC+Valve – Clamp
Concept 5: Parallel E – Standard – Ball Valve – Dual Pump – PLC+Valve – Clamp

Based from the concept generation tree, we can still come up with more complete concepts. However, the remaining concepts are not as good or too close to the main five concepts. Thus we are not going to discuss them in details for this report. Please refer to Appendix D for their descriptions.

**Concept 1**: Concept 1 (Fig. 35) utilizes combination of 'Parallel I' and 'Standard' as the arrangement for the test slot and test loop + components. 'Parallel I' has 2 equal sized 'I-shaped flow loops' parallel to each other. There are 3 test slots on each loop and they are connected in a straight connection to each other. Both of the test loops are on the same height relative to the ground. 'Standard' test loop and component arrangement places the test loop on one side of the area and the rest of the components clustered side by side of the test loop. Concept 1 also utilizes 'clamp' as support for the pipes in the flow loops, to ensure that the testing slot height requirement is fulfilled

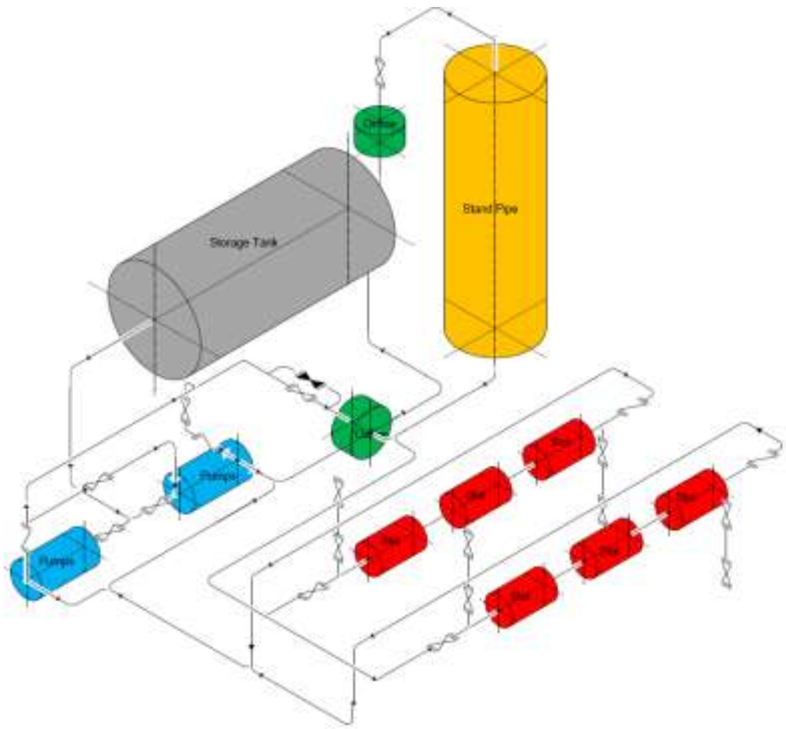



**Figure 35: Concept 1**

**Concept 2**: Concept 2 (Fig. 36) utilizes combination of 'Parallel I' and 'Spread out' as the arrangement for the test slot and test loop + components. 'Parallel I' has 2 equal sized 'I-shaped flow loops' parallel to each other. There are 3 test slots on each loop and they are connected in a straight connection to each other. Both of the test loops are on the same height relative to the ground. 'Spread out' test loop and component arrangement places the flow loop on the center of the simulator, with storage tank and pumps at the left side of the flow loops and  the level control loop on the right side of the flow loops. Concept 2 also utilizes 'Bolt on' as support for the pipe in the flow loops, to ensure that the testing slot height requirement is fulfilled.

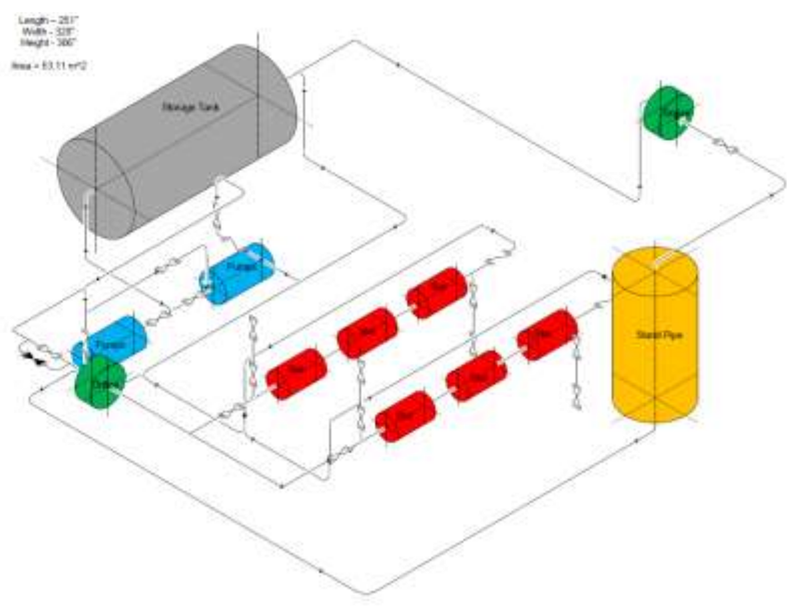



**Figure 36: Concept 2**

**Concept 3**: Concept 3 (Fig. 37) utilizes combination of 'Nested U' and 'Spread out' as the arrangement for the test slot and test loop + components. 'Nested U' has two 'U-shaped flow loops'. One of the 'U-shaped flow loops' is smaller than the other one, and fits inside the cavity of the bigger loop. There are 3 test slots on each loop and they are connected with one horizontal $90^0$ elbow connection between each other, hence the U-shape. Both of the test loops are on the same height relative to the ground. 'Spread out' test loop and component arrangement places the flow loop on the center of the simulator, with storage tank and pumps at the left side of the flow loops and the level control loop on the right side of the flow loops. Concept 3 also utilizes 'Bolt on' as support for the pipe in the flow loops, to ensure that the testing slot height requirement is fulfilled.

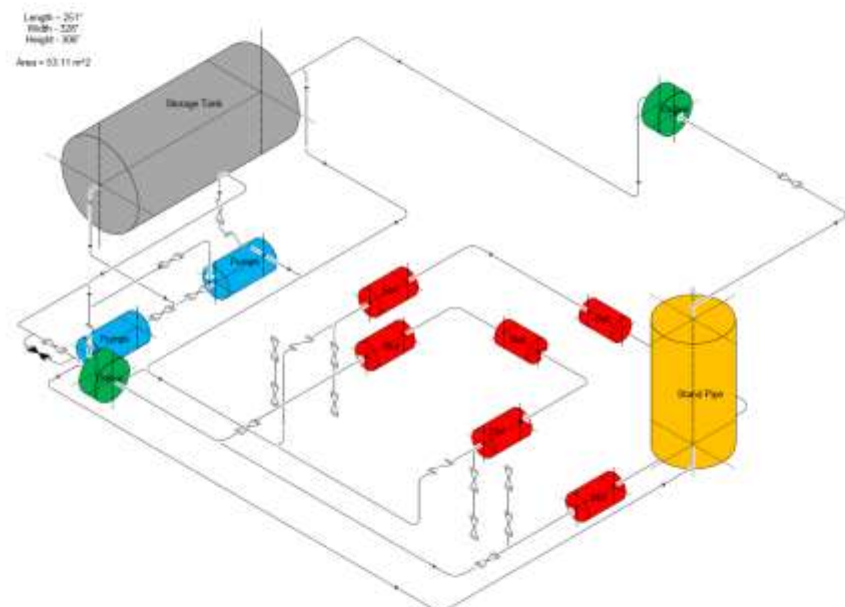


**Figure 37: Concept 3**

**Concept 4**: Concept 4 (Fig. 38) utilizes combination of 'Parallel U' and 'Standard' as the arrangement for the test slot and test loop + components. 'Parallel U' has two equal sized 'U-shaped flow loops' parallel to each other. There are 3 test slots on each loop and they are connected with one horizontal $90^0$ elbow connection between each other, hence the U-shape. Both of the test loops are on the same height relative to the ground. 'Standard' test loop and component arrangement places the test loop on one side of the area and the rest of the components clustered side by side of the test loop. Concept 4 also utilizes 'clamp' as support for the pipes in the flow loops, to ensure that the testing slot height requirement is fulfilled

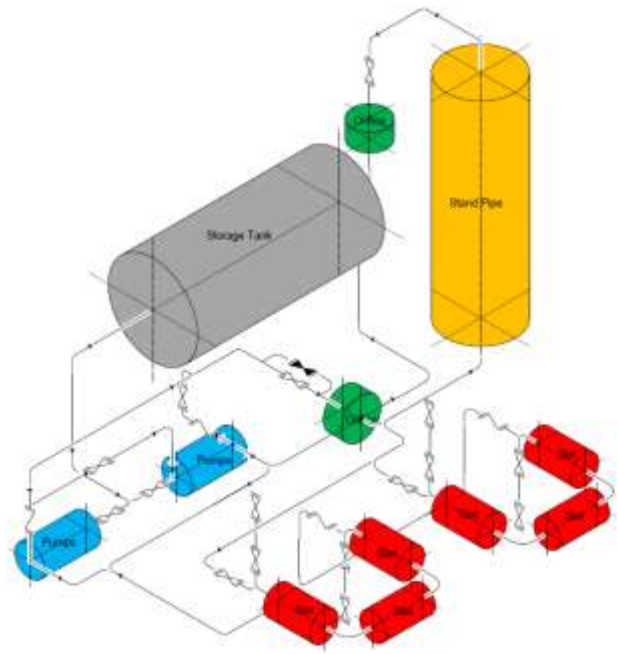



**Figure 38: Concept 4**

**Concept 5**: Concept 5 (Fig. 39) utilizes combination of 'Parallel E' and 'Standard' as the arrangement for the test slot and test loop + components. 'Parallel E' (Figure 1d), where it has two 'E-shaped flow loops'. It has two equal sized 'E-shaped flow loops' parallel to each other. There are 3 test slots on each loop and they are connected with two countering $90^0$ elbow connections between each other, hence the E-shape. Both of the test loops are on the same height relative to the ground. 'Standard' test loop and component arrangement places the test loop on one side of the area and the rest of the components clustered side by side of the flow loop. Concept 5 also utilizes 'clamp' as support for the pipes in the flow loops, to ensure that the testing slot height requirement is fulfilled

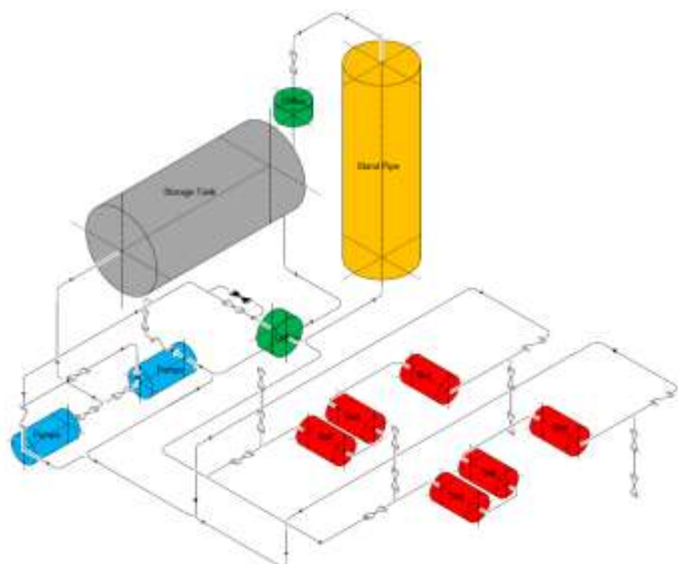


**Figure 39: Concept 5**

All of the concepts utilize combination of 'Ball valve', 'Dual pump' and 'PLC + Control valve' to control and direct the flow of water. The ball valve is used in application where the valve needs to be either completely closed or completely open. For example, to change the settings of dual pump from parallel connection to series connection, and also to completely close the other 2 loop when 1 loop is being used. Meanwhile, the control valve that is connected to the PLC will be Globe valve. Based from our research, this valve is the most suitable valve for throttling job that the control valve will need to do.
All of our concepts also implement a vent and a drain at the beginning and at the end of each flow loops. This is to satisfy the specification that our simulator must be able to extract free air and drain the instruments.

As mentioned earlier, the selection of pipe support depends on their placement in our simulator. As they both offer similar support but 'Bolt on' can only be placed on flange connection and 'Clamp' cannot be placed on flange connection. As our design mature, we may decide to use the combination of both pipe supports in our simulator. Thus, currently, we rated both methods equally so they won't be a deciding factor between design selections.

**CONCEPT SELECTION**

We utilized Pugh Chart (Table 13) in order to help us in choosing the best concept design for our simulator. The selection criteria for this Pugh chart is based from our customer requirement, while the relative weight of each selection criteria was determined from the cross relation of each engineering specification, which we acquired from our QFD diagram (Figure 15).

In our Pugh chart, for each selection criteria a concept was rated from scale 1 to 5. When a selection criteria has a lowest or highest limit that can be further improved, meaning that the target value is not a 'dead stone' target value, a score of 3 means the concept just satisfy the minimum requirement and 5 means the concept did better than the requirement. For example, in the 'Working space area' criterion, the target is a 4' x 4' space, however this is the lowest limit of the requirement, if a concept is able to provide even bigger space, that concept will score greater than 3.

**Table 13: Pugh chart for our concept selection showed that concept 1 is the best concept**

| **Selection Criteria** | **Weight** | Concept 1 | | Concept 2 | | Concept 3 | | Concept 4 | | Concept 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Technicians training | | | | | | | | | | | |
| Height of the testing slot | 0.041237 | 5 | 0.21 | 5 | 0.21 | 5 | 0.21 | 5 | 0.21 | 5 | 0.21 |
| Working space area | 0.069588 | 3 | 0.21 | 3 | 0.21 | 2 | 0.14 | 3 | 0.21 | 3 | 0.21 |
| Operating Pressure | 0.082474 | 5 | 0.41 | 5 | 0.41 | 5 | 0.41 | 5 | 0.41 | 5 | 0.41 |
| Operating Flow Rate | 0.082474 | 5 | 0.41 | 5 | 0.41 | 5 | 0.41 | 5 | 0.41 | 5 | 0.41 |
| Accurate | | | | | | | | | | | |
| Difference between flow parameter and actual flow | 0.03866 | 4 | 0.15 | 4 | 0.15 | 4 | 0.15 | 4 | 0.15 | 4 | 0.15 |
| Steel Material for all the piping | 0.061856 | 5 | 0.31 | 5 | 0.31 | 5 | 0.31 | 5 | 0.31 | 5 | 0.31 |
| Able to extract free air from testing flow loop | 0.025773 | 5 | 0.13 | 5 | 0.13 | 5 | 0.13 | 5 | 0.13 | 5 | 0.13 |
| Robust | 0.03866 | 5 | 0.19 | 5 | 0.19 | 5 | 0.19 | 5 | 0.19 | 5 | 0.19 |
| Easy to use | | | | | | | | | | | |
| System to control and vary the flow parameter | 0.043814 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 |
| Able to drain instruments | 0.030928 | 5 | 0.15 | 5 | 0.15 | 5 | 0.15 | 5 | 0.15 | 5 | 0.15 |
| Accessible path to the testing slots | 0.049828 | 5 | 0.25 | 3 | 0.15 | 2 | 0.10 | 4 | 0.20 | 4 | 0.20 |
| Minimum turning radius in the path | 0.033505 | 5 | 0.17 | 3 | 0.10 | 1 | 0.03 | 4 | 0.13 | 4 | 0.13 |
| Minimum width of the path | 0.046392 | 5 | 0.23 | 3 | 0.14 | 2 | 0.09 | 4 | 0.19 | 4 | 0.19 |
| Small Size | | | | | | | | | | | |
| Floor Size | 0.033505 | 5 | 0.17 | 2 | 0.07 | 1 | 0.03 | 2 | 0.07 | 3 | 0.10 |
| Number of Testing Flow Loop | 0.043814 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 |
| Number of Level control Loop | 0.066151 | 5 | 0.33 | 5 | 0.33 | 5 | 0.33 | 5 | 0.33 | 5 | 0.33 |
| Able to test variety of instruments | | | | | | | | | | | |
| Total Number of testing slot per flow loop | 0.043814 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 | 5 | 0.22 |
| Types of instruments that can be tested | 0.069588 | 5 | 0.35 | 5 | 0.35 | 5 | 0.35 | 5 | 0.35 | 5 | 0.35 |
| Testing slot size | 0.074742 | 5 | 0.37 | 5 | 0.37 | 5 | 0.37 | 5 | 0.37 | 5 | 0.37 |
| Cost | 0.023196 | 5 | 0.12 | 3 | 0.07 | 2 | 0.05 | 4 | 0.09 | 4 | 0.09 |
| Total Score | 1.00 | | **4.82** | | **4.42** | | **4.13** | | **4.57** | | **4.60** |
| Rank | | | **1** | | **4** | | **5** | | **3** | | **2** |

In the ‘Working space area’ selection criteria, concept 3 rank the lowest. All of our concepts still satisfy the minimum ‘Working space area’ specification, however concept 3 did not satisfy the requirement, its working space area is only 3’x 2’.

Meanwhile, for the ‘Accessible path to the testing slots’, ‘Minimum turning radius in path’, and ‘Minimum width of the path’, Concept 1 scored the highest point, while concept 2 and 3 scored the lowest point. Concept 2 and 3 scored below “3” because the ‘Spread out’ layout implemented in these concepts placed components all around the flow loops, thus preventing easier access to the test slots. Meanwhile, ‘Standard layout’ placed the components on one side of the flow loops, thus the other side of flow loops is wide open, giving an easier access to it. Furthermore, Concept 1 scored higher points compared with concept 4 and 5 because concept 1 utilizes ‘Parallel I’ test slots arrangement. This practically eliminates any turns when going from one testing slot to another. The other arrangement still requires turns when going from one testing slot to another. Thus, concept 1 scores the highest point in this criterion.

Concept 1 again scores the highest point in the ‘Floor size’ criteria. Based on our estimation of the total area (table 14), concept 1 is the only concept that satisfy the maximum allowable floor area of 500 $ft^2$. That is why concept 1 is the clear winner in this criterion.

**Table 14: Concept 1 occupies the smallest area and uses the least amount of pipes compared with the other concepts**

| Concept | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Area (ft^2) | 439.2 | 571.6 | 923.4 | 596.3 | 533.9 |
| Total length of pipe (ft) | 30.625 | 40.5 | 51 | 36.25 | 35.5 |

Since the components for all the five concepts are essentially the similar to one another, the deciding factor for the ‘Cost’ criteria is the amount of pipe that we need to use for each design. Concept 1, came out with the highest score, since it uses ‘Standard’ layout which uses less pipe compared with the ‘Spread out’ layout. “Parallel I” test slot arrangement also uses the least amount of tube compared with the other test slot arrangement. Please refer to table to see the total length of pipe used in every concept.

From these results, it is clear to us that concept 1 is the alpha design for our project. Table summarizes how elements of concept 1 satisfy each engineering specification and customer requirement.

**Table 15: How Concept 1 satisfies each Engineering Specification and Customer Requirement**

| Customer Requirement | Engineering Specification | Element of Concept 1 that satisfy the specification |
|---|---|---|
| Technicians training | Height of the testing slot | Bolt on/Clamp pipe support |
| | Working space area | Parallel I test slot arrangement |
| | Operating Pressure | Dual pump |
| | Operating Flow Rate | Dual pump |
| Accurate | Difference between flow parameter and actual flow | PLC + Control valve |
| | Steel Material for all the piping | Usage of steel pipe |
| | Able to extract free air from testing flow loop | Vent |
| Robust | Safety factor for maximum pressure in the pipe | Usage of steel pipe |

| | | |
|---|---|---|
| Easy to use | System to control and vary the flow parameter | PLC + Control valve |
| | Able to drain instruments | Drain |
| | Accessible path to the testing slots | Parallel I and Standard Layout |
| | Minimum turning radius in the path | Parallel I and Standard Layout |
| | Minimum width of the path | Parallel I and Standard Layout |
| Small Size | Floor Size | Parallel I and Standard Layout |
| | Number of Testing Flow Loop | Parallel I and Standard Layout |
| | Number of Level control Loop | Parallel I and Standard Layout |
| Able to test variety of instruments | Total Number of testing slot per flow loop | Parallel I and Standard Layout |
| | Types of instruments that can be tested | Dual pump + Parallel I |
| | Testing slot size | Parallel I |
| Cost | Low cost | Combination of everything |

'Bolt on and/or Clamp' pipe support will be used to elevate the flow loop section into the required testing slot height. There will be several pipe supports, strategically placed to ensure adequate support for the whole section. We've also pre-screened some pumps that will work to achieve the operating pressure and flow rate. Please refer to Concept Generation- Energy Source for the detail of the pumps.

In terms of 'Difference between flow parameter and actual flow', to ensure the values of the flow parameter coming to the test slots are accurate compared to the values set in the control system, we need to adjust the control system to accommodate the energy loss due to travel from the control system sensor to the test slots. We shall determine the exact distance from the control valve to the test slots, the head loss and pressure drop shall be determined by paper calculations and it will be taken into account when we set the program for our PLC control system.

In order to be 'Able to extract free air from testing flow loop' and 'Able to drain instruments', concept 1 will utilize Vent and Drain that is similar to the current simulator. The details on their concept shall be discussed in the First Concept Description section.

For 'Floor size', table shows that concept 1 clearly satisfies the maximum floor area requirement. Concept 1 also satisfy the 'Testing slot size' requirement, combining this with the operating pressure and flow rate, concept 1 will be able to satisfy the 'Types of instruments that can be tested' requirement.

Concept 1 is able to satisfy all of our engineering specifications and customer requirements, furthermore it also rated the best when compared with the other concepts that we've generated. For that reason, we choose concept 1 as our Alpha Concept.

## FIRST CONCEPT – ALPHA DESIGN

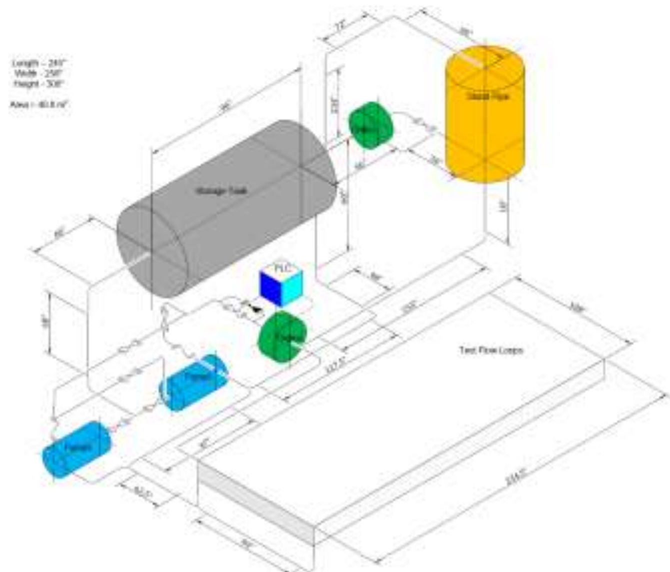



**Figure 40. Simulator Layout**

After going through our concept generation and concept selection, we have concluded that the simulator layout shown in Figure 1 is the most feasible to our sponsor's requirements. The isometric drawing is a simple layout design consisting of the storage tank, stand pipe, dual pumps and the testing flow loops. We have chosen the Parallel I Test Loop to be installed in our simulator due to its high ranking in our concept analysis. Due to a straight flow, we are able to minimize waste of space for the clearance area between each testing slot for the installation or removal of calibrated components. We have chosen to install dual pumps generally due to our cost analysis in our other concepts. With the same efficiency, we are able to minimize its cost with our conclusion. We have also installed the PLC into our system that would be connected to both the control valve that will operate the flow of water digitally and also the orifice in that pipeline.

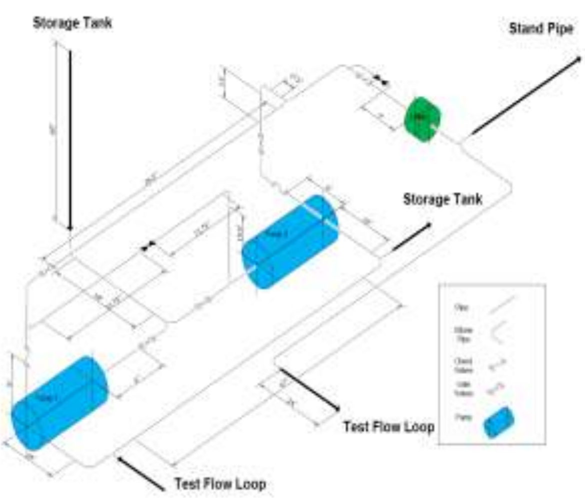



**Figure 41a. Parallel Pumps**

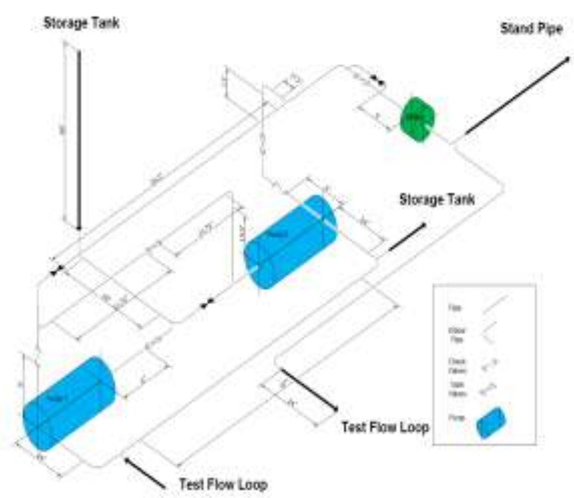



**Figure 41b. Series Pumps**

Shown in Figure 41 is our pump layout that was designed with the engineering aspect of having enough pressure to pump the water through the testing flow loop and to the stand pipe. We have also specially designed it so that the pump would be able to work in both parallel and series if required, as shown in Figure 41 a and b. The current drawing is how the dual pump would work in parallel, the black valve between the two pumps indicate that it is closed. When the simulator requires the pump to work in series, the black valve would be open and the valve outside the inlet to pump 2 would be close.

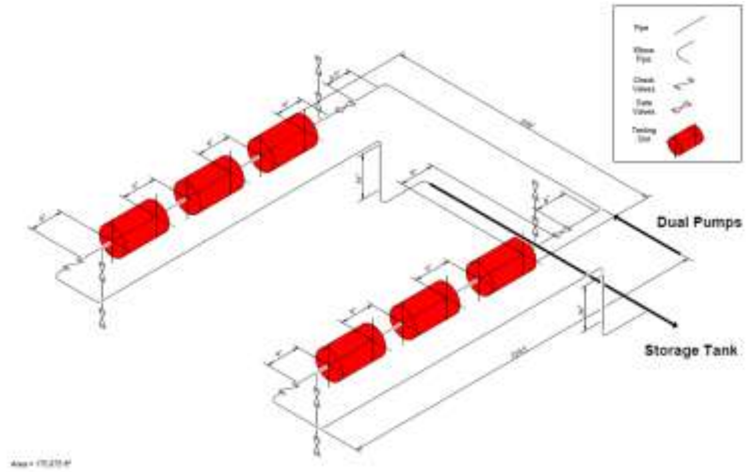



**Figure 42. Parallel I Test Loop**

The layout shown in Figure 42 is the test loop that we have chosen to be in our simulator. During the concept selection phase, we chose this design mainly due to its small floor space. This particular design is operated in a straight flow, minimizing wasted space for clearance area. Before we calibrate our components, air ventilation before the testing slots is necessary to prevent damage to the instruments. We have installed a two valve ventilation system to remove air from our simulator. The first valve would stabilize pressure in the system and as the water slowly fills in, air will escape into the pipe between the first valve and the closed valve. When the water level has started to rise into the pipe, we can determine that there is no longer air in our simulator. At this moment, we will close the first valve and open up the second to release stored air. For the draining system that we installed after our testing slots, it works the same way as air ventilation. The only difference is that the flow will go downwards to remove all water from the system.

The other main concepts that we picked out from our concept generation tree are the flow directing method, control method and pipe support. Although it is part of our concept generation, we have determined most of our choices to be unfeasible and therefore ending up with a concluded decision. We will be using ball valves for our flow directing method as it is easily adjustable to allow water into the system with the ability to limit the amount of flow rate. For our control method, we decided to choose the dual pumps over a single pump and VFD due to a few problems that we encountered. First of all, having to install and operate the VFD would take up more learning time for technicians therefore reducing the ease-of-use customer requirement. Also the cost of a single pump having to operate at the desired pressure and flow rate is a lot more expensive than using a dual pump. For our alpha design simulator, we would be using bolt-on pipe supports. Bolt-on is used to support pipes and clamp style is used to support flanges. Two reasons why we chose this would be a cheaper choice compared to clamp styles and the other would be that we will be using way more pipes than flanges, thus having more flexibility on the location of pipe supports.

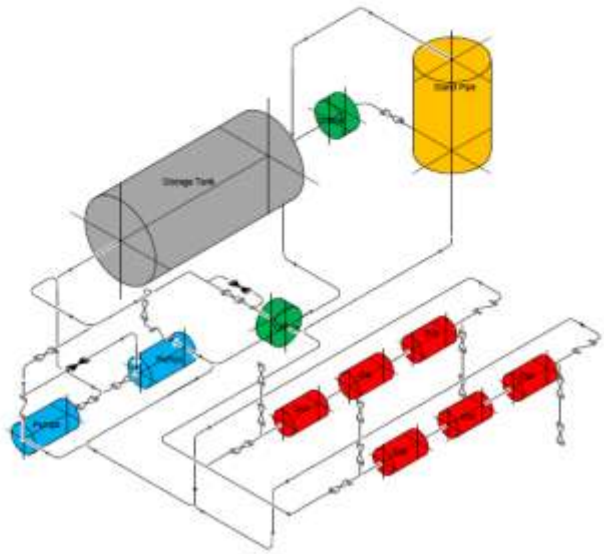


**Figure 43. Alpha Design**

A dimensionless drawing, Figure 43, would be used to illustrate the flow of water from the storage tank, through the pumps, calibrating the instruments and into the stand pipe. This cycle of flow would start off from the storage tank at a higher elevation than the dual pumps. This is to allow the water from the storage tank to have a smooth flow to the pumps. Initially the pump would be set at a low frequency to allow the ventilation of air within the pipe system. As previously mentioned the air ventilation system has to be installed at the highest elevation of the flow loop pipelines to remove all air. The orifice component between the pumps and flow loops would allow us to be more flexible in adjusting the flow rate of the water flow into the loops. The water will flow through the loops and back into the storage tank with enough pressure to rise up the elevation. A different route after the orifice would direct water to the stand pipe initially to fill it up. Two exits from our stand pipe have been designed. The lower pipe would allow us to release water into our storage tank when need as we have a valve and orifice installed. The upper pipe is placed in case of emergency overflow that would lead to flooding of the stand pipe.

Regarding the safety issues in our simulator, we realized that we are dealing with a large amount of water and electricity. Despite knowing that electricity has to go through pipelines to be connected to valves and instruments, we have come up with a simple safety measurement to prevent any danger hazards. In every flow loop, there is a control box that allows the instruments to be connected to the control system of our simulator. We will install a safe waterproof cover around the control box that will prevent any spills or leakages from reaching the wires. In our control system we will also design a program that will enable emergency shut off for all power source and instruments. This is to ensure that if any accidents were to happen, we are able to cut off all electricity in an instant.

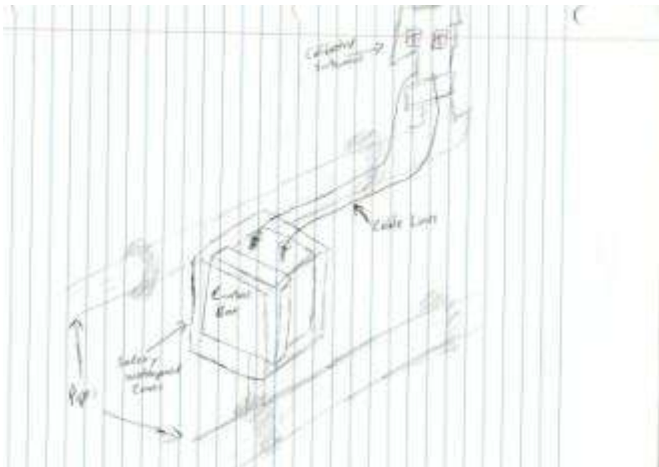


**Figure 44: Safety cover for the power supply**

**DEMO MODEL**

Due to cost and time constraint, we will not be able to build the actual simulator that we design. In order to present our project in the design expo, a much smaller and cheaper demo model needs to be designed and built. In order to generate and select concepts for our demo model, we followed the same methodology that we use to generate the design for the simulator. The following sections will elaborate our approach in designing our demo model.

**CUSTOMER REQUIREMENT – DEMO MODEL**

Since our primary customer for the demo model is Professor Gordon Krauss (our section instructor) instead of S&L, we met him to determine the aspects of the actual simulator that the demo model needs to show. Based on our meetings and understanding, we came up with customer requirement and their individual weight. Table 16a and 16b summarize the customer requirement and their weight

**Table 16a: Customer Requirement**

| Customer Requirement | Weight |
|---|---|
| Able to replicate calibration function | 5 |
| Able to test the logic of the system | 5 |
| Size | 4 |
| Weight | 4 |
| Cost | 4 |

**Table 16b: Customer weight scale**

| Customer Weight Scale | |
|---|---|
| 5 | Essential |
| 4 | Very Important |
| 3 | Important |
| 2 | Less Important |
| 1 | Secondary |

**Table 17: Definition of each customer requirement**

| Customer Requirement | Description |
|---|---|
| Able to replicate calibration function | The demo model should at least be able to show how the instruments are being calibrated in the real simulator |
| Able to test the logic of the system | The demo model should be able to show how the simulator adjust the flow parameter |

| | |
|---|---|
| Size | It should fit in our allocated expo space |
| Weight | It should be able to be placed on top of the provided table |
| Cost | Cost should stay within the budget of ME 450 |

The top area of concern is ‘Able to replicate calibration function’. Since the main function of the actual simulator is to calibrate instruments and train technicians, it is essential for the demo model to give the audience on how the instruments are being calibrated in the actual simulator. Thus, ‘Able to replicate calibration function’ is rated as 5 (essential). ‘Able to test the logic system’ is also being rated as 5 (essential) because control logic testing is also a function expected from our simulator

‘Size’ and ‘Weight’ are rated as 4, since we need to fulfill these requirements in order to be able to show our demo model during the design expo. ‘Cost’ is rated as 4 (very important) because we need to stay on our ME 450 budget of $400, and it is hard for us to get any additional budget since what we are building is essentially a miniature, not the actual device. However, S&L has been able to contact the vendor to lend us these components: Control Valve, PLC, Pressure Transmitter. These will ease our financial burden, since none of these parts are within the range of our budget.

**ENGINEERING SPECIFICATION – DEMO MODEL**

After defining the customer requirement, the next step is to define engineering specification. Table 18below shows the engineering specifications that will achieve the customer requirements.

**Table 18: Relation between customer requirement and engineering Specification Demo Model**

| Customer Requirement | Engineering Specification |
|---|---|
| Able to replicate calibration function | Number of Testing slots |
| | Operating Flow Rate |
| Able to test the logic of the system | Number of level control loop |
| | System to control the flow parameter |
| Size | Maximum allowable area |
| Weight | Maximum allowable weight |
| Cost | Maximum allowable cost |

We also created quantitative targets/limits that we wanted each engineering specification to meet (table 18).

**Table 19: Engineering Specifications and the Target Value**

| Engineering Specification | Target | Unit |
|---|---|---|
| Number of testing slot | ≥1 | |
| Operating Flow rate | 1.1 - 12 | GPM |
| Number of level control loop | 1 | |
| System to control the flow parameter | Yes | |
| Maximum allowable area | ≤8x3 | ft |
| Maximum allowable weight | ≤150 | lb |
| Maximum allowable cost | ≤400 | US $ |

One of the main functions of the simulator is to perform calibration function. Therefore, number of testing slots is required to perform the calibration. The number of testing slots is set to be at least 1.

An operating flow rate is needed to carry out the calibration function. The target in our engineering specification is set to 1.1 – 12 GPM. These values are obtained from the data in Control Valves, Fisher Control Valve [11], under the condition of 1" valve size.

In order for users to be able to test the logic of the system, the demo model needs to have a level control loop. A Level control loop in the simulator is being used to calibrate the level control logic; it maintains the level of water on the standpipe. We set the number of level control loop to be 1, as the required number to test the level control logic in the real simulator would also be 1.

In addition, a system to control the flow parameter is needed to perform the test logic of the system. The control system that will be installed in order for users to be able to change the flow parameters that is required for the calibration of instruments.

The maximum allowable area refers to the area of the table that will be used to support the demo model. The table dimension is 8x3 ft. With that in mind, we will have to design the demo model that does not exceed the target allowable area. Nevertheless, we could still placed the demo model components under the table or on the floor, thus giving us more room to play with.

Maximum allowable weight is related to the maximum weight a table for the demo expo is able to withstand. From the information provided by the ME 450 Graduate Student Instructor, the table maximum weight is 150 lbs. Therefore, it is important to make a demo model concept that does not exceed this engineering specification. However, if the weight would exceed the engineering specification for weigh, we could place the components on the floor.

Maximum allowable cost is essential for the demo model to stay within the given budget. The University of Michigan is endorsing the project with $400 for project expense. Therefore, our project expense should not exceed the given budget.

To understand better the relationship between each customer requirements to the engineering specification, and between each engineering specifications to one another, we constructed a QFD diagram as shown in Appendix E.

**FUNCTIONAL DECOMPOSITION – DEMO MODEL**

The functional decomposition of our demo model is essentially the same as our simulator's functional decomposition.

**CONCEPT SELECTION – DEMO MODEL**

After going through our engineering specifications and customer requirements, we have come up with three types of demo drawings for our concept selection. With the basic equipments of a storage tank, pump, valves and control systems, a few transmitters are also installed to ensure the desired parameters were met. Some of our particular functions are having a stand pipe and/or a testing slot included in our model to show the calibrating ability that would mirror our simulator's primary objective.

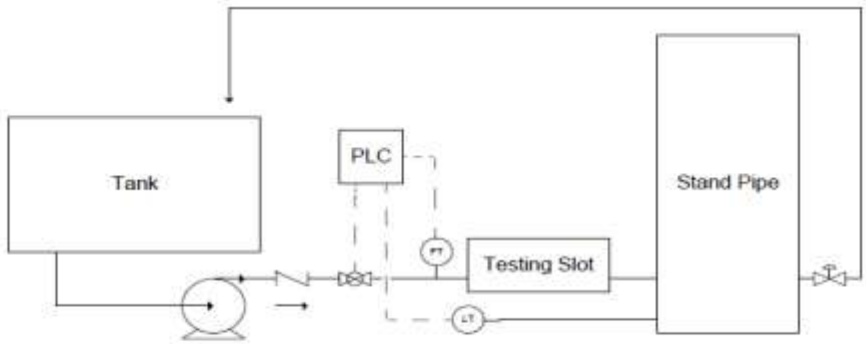



**Figure 45: Concept 1 – Complete Demo**

**Concept 1:** This particular design consists of both the testing slot and the standpipe, shown in Figure 45. With a flowmeter transmitter to indicate the flow rate of the water entering the testing slot and a level transmitter to measure the water level of the stand pipe, we are able to show the calibration of the instrument in our demo simulator. With the additional stand pipe in the set, we are also able to test our control system to ensure that the flow of water in our simulator runs smoothly and to prevent the flooding of the storage tank and stand pipe.

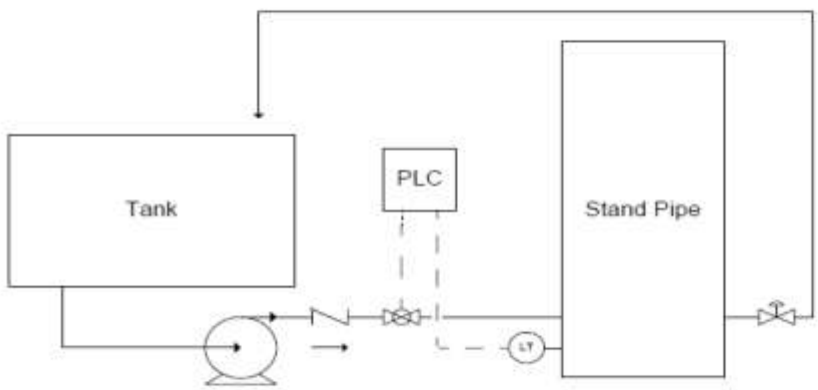



**Figure 46: Concept 2 – Level Control Demo**

**Concept 2:** This particular design consists of a standpipe only, shown in Figure 46. With this design, we would be able to adjust the exit of the standpipe. The purpose of this design would be to show our control system rather than our calibration chamber. We would be able to manually control the globe valve at the exit of the standpipe and the level transmitter, enable our control system to open up the control valve when the maximum water level in our storage tank has been exceeded. Thus, allowing the water to travel back to the stand pipe.

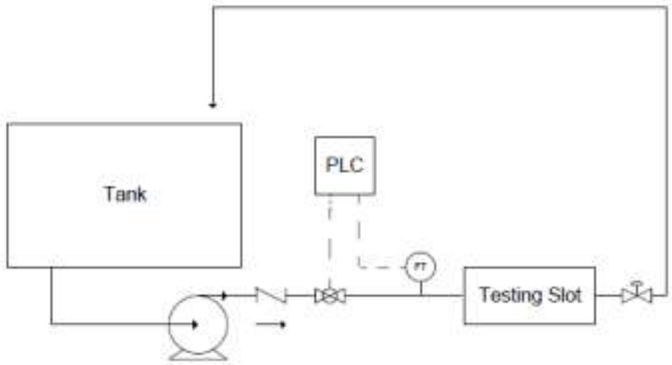



**Figure 49: Concept 3 – Calibration Demo**

**Concept 3:** This particular design consists of a testing slot to calibrate instruments suited for power plant usage, shown in Figure 49. With the flow meter at the entrance of our testing chamber, we are able to adjust the control valve and measure the flow rate of water running through the system to calibrate our instrument.

**CONCEPT SELECTION – DEMO MODEL**

We used Pugh chart (Table 20) to help us on selecting the best demo model. Based on the results, it is clear that concept 1 is the best design that satisfies our customer requirement. However due to budget constraint, since we don't have the money to buy the necessary components, we have decided to proceed with concept 2 as our alpha design concept of the demo model.

We're still trying to negotiate with S&L to inquire whether we can get more instruments so that we can actually build concept 1, but as if now the chances are very small.

**Table 20: Pugh chart for our demo model**

| **Selection Criteria** | **Weight** | **Concept 1** | | **Concept 2** | | **Concept 3** | |
|---|---|---|---|---|---|---|---|
| | | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Able to replicate calibration function | 0.23 | 5 | 1.14 | 0 | 0.00 | 5 | 1.14 |
| Able to test the logic of the system | 0.23 | 5 | 1.14 | 5 | 1.14 | 0 | 0.00 |
| Size | 0.18 | 3 | 0.55 | 4 | 0.73 | 5 | 0.91 |
| Weight | 0.18 | 2 | 0.36 | 3 | 0.55 | 4 | 0.73 |
| Cost | 0.18 | 1 | 0.18 | 5 | 0.91 | 1 | 0.18 |
| | | | | | | | |
| Total Score | 1.00 | | **3.36** | | **3.32** | | **2.95** |
| Rank | | | **1** | | **2** | | **3** |

**FIRST CONCEPT DEMO MODEL**

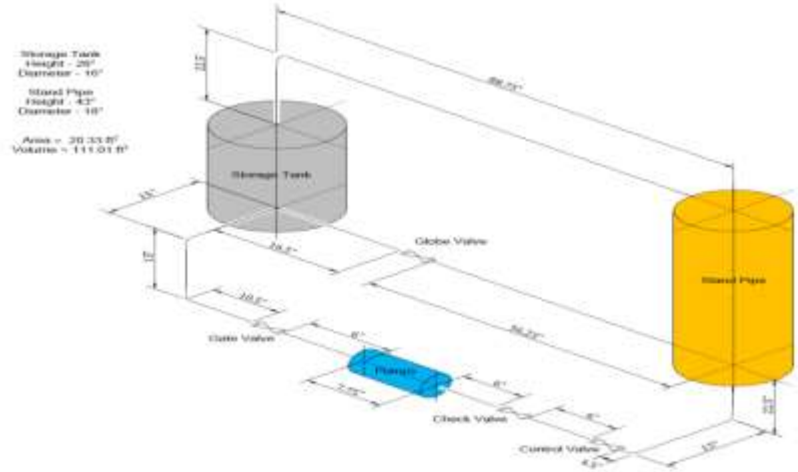



**Figure 50 Alpha Design Model**

After analyzing our pugh charts and discussing with our sponsor, we have decided to proceed to the alpha design with the level loop in mind, shown in Figure 50. Although our pugh charts state that concept 1 is the best suited, we are unable to retrieve another instrument to be an example of our calibration instruments. Due to that factor, we concluded upon concept 2 to be our prototype. With the simple fundamentals of piping, water flows down from the storage tank at a higher elevation and is then pumped back into our stand pipe. A necessary installment of check valves to ensure that backtracking of water will not be present as it will damage our pump. As previously mentioned, the purpose of this demo simulator is to manipulate the water level in both tank compartments. In doing so, we are able to test our control system in its accuracy and sensitivity from the level transmitter installed beneath the stand pipe.

The pump used in the demo model is a compact Pump that have a mounting flange of 0.15 inch diameter holes with a dimension of 6" x 6.5 x 7.75". The power supplied by this pump is 1/6 horsepower. Also, it can supply up to 20 ft head under 17 GPM flowrate. Regarding the electrical power source, this pump could be connected to a 120 VAC at 60 Hz power supply [29].

building both of them are done and included in the Appendix XX. From this point on, we will focus on working on the prototype. The major challenges that we see is writing the logic for PLC controller. Furthermore, we would start with the fabrication plan, assembling plan, and validating plan. We will go through several testings and finalizing our prototype before the design expo.
Lastly, the safety aspect of the prototype is also performed. This stage involves plan assessing the hazards in experimentation, designing, assembling, and fabrication.

**Final Design for Full Scale Simulator**

**ENGINEERING ANALYSIS**

With the final design selected, the next step in the design process is to thoroughly analyze the design and set all of the engineering parameters. The following section describes in detail what engineering calculations were done in order to set all of the engineering parameters of the design.

**Hydraulic Analysis - Pump Selection**

The purpose of this analysis is to determine the required head of pump needed to deliver the water to the test slots at the required flow parameters. The pump configuration in our simulator must be able to deliver water from storage tank to the testing slots at the maximum pressure of 1000 psi and maximum velocity of 25 ft/s (which translates to 550 GPM for 3" schedule 40 pipe). In order to achieve these specifications at the test slots, the pump configuration needs to be powerful enough to overcome the total head, *H*, that the water undergoes during the travel from pump outlet to the test slots. *H* is any resistance to the flow of the water.

**Total Discharge Head:** The total head (H) is defined as:

$$H = positive\ vertical\ length + h_L \quad \text{(Eq. 1) [crane]}$$

*Positive vertical length* is the amount positive vertical distance (going up) that the flow needs to cover, and $h_L$ is the head loss. $h_L$ is defined as:

$$h_L = K\frac{v^2}{2g} \quad \text{(Eq. 2) [crane]}$$

where *K* is the resistance coefficient, *v* is the velocity of fluid, and *g* is gravitational constant. The value of K itself depends on the geometry of the component (whether it's a straight pipe, pipe bend, valve, etc).

| | | |
|---|---|---|
| Straight pipe | $K = f_T\frac{L}{D}$ | (Eq.3) [c] |
| T pipe - Flow through run | $K = 20\ f_T$ | (Eq.4) [c] |
| T pipe - Flow through branch | $K = 60\ f_T$ | (Eq.5) [c] |
| $90^o$ elbow pipe | $K = 30\ f_T$ | (Eq.6) [c] |
| Gate valve | $K = 8\ f_T$ | (Eq.7) [c] |
| Globe valve | $K = 340\ f_T$ | (Eq.8) [c] |
| Check valve | $K = 50\ f_T$ | (Eq.9) [c] |

where $f_T$ is friction factor in zone of complete turbulence, $f_T$ is 0.018 for 3" schedule 40 pipe [c], L is the length of the pipe, and D is the internal diameter of the pipe.

By considering all the pipes and valves from the pump outlet to the test slot inlet and back to the storage tank, the value of *H* can then be determined. Since the simulator will only run one loop at a time, we determined the minimum total discharge head for all three loops. Table 1 showed us that the flow which requires biggest *H* is the flow through Flow Loop B. Therefore, our pump configuration must be able to satisfy the minimum *H* of 628.57 feet.

**Table 21: Flow Loop B requires the biggest head at 628.57 feet**

| | Stand pipe Loop | Flow Loop A | Flow Loop B |
|---|---|---|---|
| Total Head (Ft) | 380.71 | 615.13 | 628.57 |

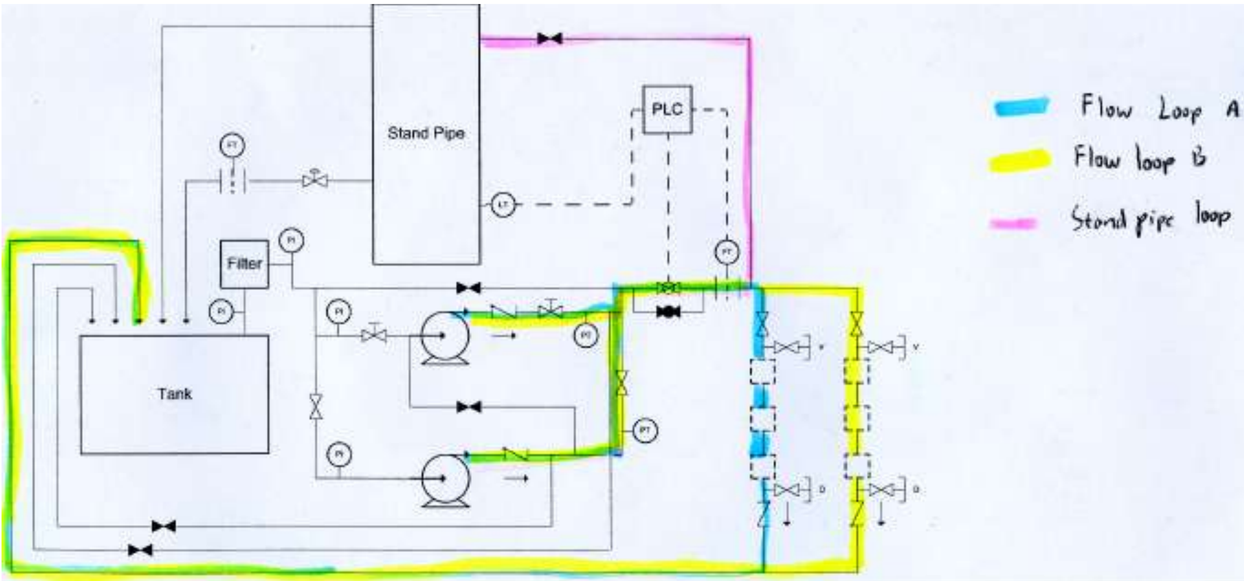



**Figure 51: Path for each loop**

We based our pump selection from the head requirement that we calculated. Figure 51 shows us that our selected pumps will be able to deliver water at required head with 550 gpm flow rate , when both of them are running parallel (parallel run will add the number of flow rate).

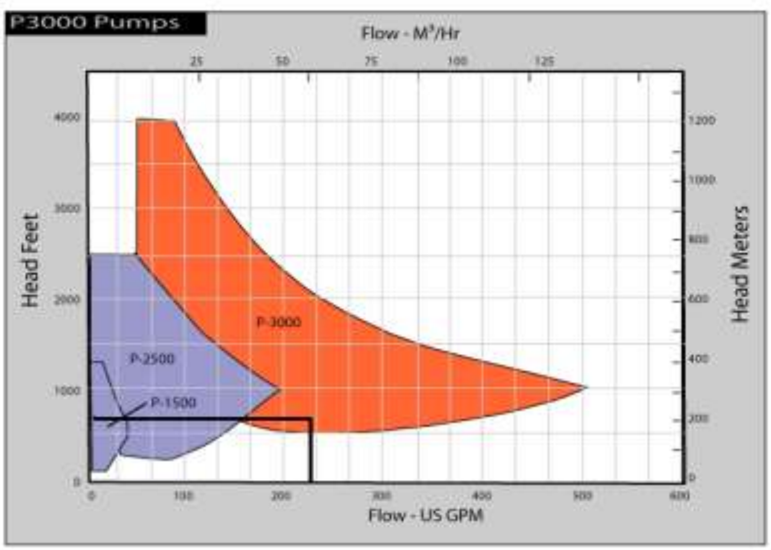



**Figure 52: Our pump selection satisfy the head requirement**

Table 21 shows us that the amount of water that can be contained in the simulator (excluding the storage tank) is 294.6 gallon. Considering our storage tank has the capacity of 1000 gallon, we won't have to fill the storage tank into its full capacity thus avoiding the risk of overflowing the storage tank.

**Table 22: The maximum volume of water in the simulator (excluding storage tank)**

| | Level Loop (up to storage tank) | Storage tank | Flow Loop A | Flow Loop B | Total |
|---|---|---|---|---|---|
| Volume (US gal) | 17.2 | 165 | 52.4 | 60 | 294.6 |

**Static Analysis - Maximum Pressure in our System**

Since our simulator must be able to deliver pressurized water until up to 1000 PSI to the test slots, we must ensure the piping system will be able to withstand such pressure. By utilizing Bernoulli Equation (Eq. 1), and the head loss, $h_L$, that we've determined in hydraulic analysis section, we were able to determine the maximum internal pressure, $P$, that our piping system must withstand.

$$Z_1 + \frac{144P_1}{\rho} + \frac{{V_1}^2}{2g} = Z_2 + \frac{144P_2}{\rho} + \frac{{V_2}^2}{2g} + H_L \qquad \text{(Eq. 1) [crane]}$$

Where $P_2$ is the internal pressure of water at the entrance of test slots, which is 1000 PSI, and $P_1$ is the internal pressure of water at the pump outlet. Due to valves and fittings, there will be pressure drop from the $P_1$ to $P_2$. Thus, $P_1$ must be greater than 1000 PSI. $P_1$ is the maximum internal pressure in our simulator, which we are going to use for further analysis, which is 1088 PSI.

**Static Analysis - Pipe Failure Analysis**

When designing our simulator, we have to keep in mind that failure in our piping system can be caused by three factors:

- Failure due to internal pressure
- Failure due to tension
- Failure due to shear

**Failure due to Internal Pressure**: The internal pressure in the pipe will cause normal stress in the hoop direction, $\sigma_1$, and longitudinal direction, $\sigma_2$.

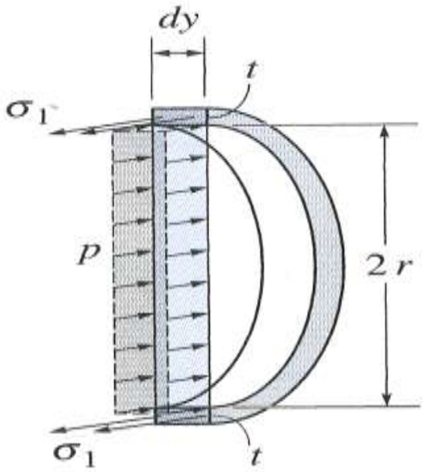



Fig. 53a: Normal stress in the hoop direction, $\sigma_1$ [31]

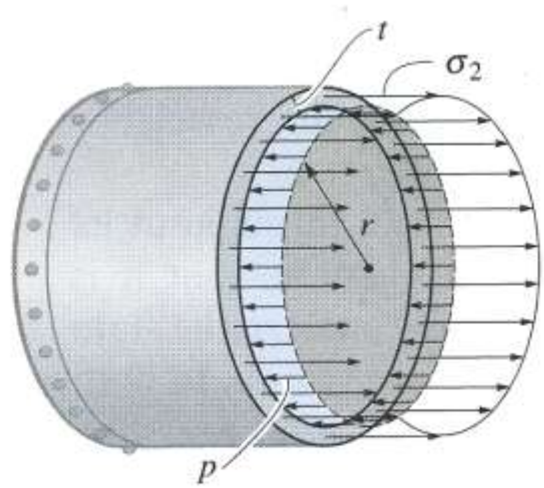



Fig. 53b: Normal stress in the longitudinal direction, $\sigma_2$ [31]

By using equation 2 and 4, $\sigma_1$ is determined to be 643.98 PSI while $\sigma_2$ is 321.99 PSI.

$$\sigma_1 = \frac{Pr}{t} \qquad \text{(Eq. 2) [2]} \qquad\qquad \sigma_2 = \frac{Pr}{2t} \qquad \text{(Eq. 3) [31]}$$

In our piping, internal water pressure is the only factor that would affect the stress at the hoop direction. Since we've already determined $\sigma_1$, we can now determine the safety factor of the pipe for hoop stress by using equation 4.

$$SF = \frac{\sigma_{fail}}{\sigma_{allow}} = \frac{\tau_{fail}}{\tau_{allow}} \qquad \text{(Eq. 4) [31]}$$

Where $\sigma_{allow}$ is $\sigma_1$, and $\sigma_{fail}$ is 2500 psi, which is the allowable hoop stress of ASTM A53 pipe [30]. SF in the hoop direction for our simulator is determined to be 3.88, which satisfy our minimum SF of 1.5.

**Failure due to tension:** Meanwhile, the normal stress in the longitudinal direction (tension) is affected by, not only the internal pressure of the pipe, but also the stress caused by the bending moment. This is due to the placement of pipe supports on some of our piping to ensure they are at the correct height. Ideally, pipe supports should be placed throughout the entire pipe length. However, this is not economically effective, thus pipe supports are strategically placed on certain points to ensure they can support the weight of the pipes and waters, while ensuring the normal stress caused by the pipe supports is still within the limit of the pipe strength itself. Bending moment is caused by the load that acted on the pipe; this includes the weight of the pipe itself, the weight of water, the weight of the valves and other instruments attached to it.

$$\sigma_{total} = \sigma_{internal\ \ pressure} + \sigma_{bending\ \ moment} \quad [31] \quad \text{(Eq. 5)}$$

By using equation 4, where the allowable SF in the longitudinal direction is 1.5, and $\sigma_{yield}$ for our pipe is 35,000 psi [1], the allowable $\sigma_{total}$ is 23,333 psi. Since we've already determined the maximum $\sigma_{internal\ \ pressure}$ , which is $\sigma_2$ = 321.99 psi, the maximum allowable normal stress due to bending moment, $\sigma_{bending\ \ moment}$ , is 23,011 psi.

Furthermore, by combining equation 6 and 7, the maximum bending moment allowed in our pipe, *M*, is determined to be 3,317.04 lb-ft. Due to pipe supports, additional bending moment will arise in our system. This maximum allowable bending moment is one of the biggest factors that we take into consideration when placing the pipe supports in our simulator. Even though a single pipe support would be able to hold up to 10,000 lbs, we may need to place more than one pipe supports to ensure the bending moment would not exceed maximum limit.

$$\sigma_{bending\ \ moment} = \frac{Mc}{I} \quad \text{(Eq. 6) [31]} \qquad I_x = \frac{\pi r^4}{4} \quad \text{(Eq. 7) [31]}$$

**Failure due to shear**: Loading on the pipes (due to weight of the pipe, weight of the water, and weight of instruments attached to it) and placement of pipe supports also causes shear stress, $\tau$, on the piping. By utilizing equation 4, with SF = 1.5 and $\tau_{yield}$ = 19,950 psi [30], the maximum allowable shear stress in our pipe is determined to be $\tau_{allow}$ = 13,300 psi. Which translates to maximum allowable shear force of $V_{max}$ = 95,000 lb, considering our 3" diameter with schedule 40 pipe.

**Maximum allowable pipe deflection**: Based from our consultation with a graduate student in the Civil Engineering department, the allowable standard for maximum deflection in a piping system is determined to be 5% of internal diameter [32], which translates to 0.15". We've also re-confirm this number to our sponsor to make sure it is up to the industry standard. Equation 8 is used to calculate the pipe deflection.

$$v_{max} = \frac{-5wL^4}{384EI} \quad \text{(Eq. 7) [31]}$$

Where $v_{max}$ is the maximum deflection, L is the length of the pipe, w is the loading acting on the pipe, and E is the modulus of elasticity for steel = 29,000 ksi [31].

We utilized pipe supports to give the required elevations for our piping. Ideally, the pipe support should support the entire length of the pipe, thus minimizing bending moment in our piping system. However, this method is not the most economical; our goal is to minimize the amount of pipe support that we use, while still ensuring the bending moment, shear force, pipe deflection, and the amount of weight that is being supported by one pipe support (one pipe support can support up to 10,000 lbs) to be below the allowable limit.

We decided to only place the supports only on the pipe, and not on the instruments and the valves. While the instruments and the valves weigh more per unit length compared with the pipe, their unique geometry requires different shape of support for one another, which can only be achieved through custom made support. In the future these valves and instrument might be changed to different types, thus if we used a custom made support, the support will not fit the new valves.

**Table 23: Summary of the maximum bending moment, shear force, pipe deflection**

| | Bending moment (lb-ft) | Shear force (lb) | Deflection (in) |
|---|---|---|---|
| Allowable (for SF=1.5) | 3317.04 | 95000 | 0.15 |
| Max value in simulator | 2456.329 | 3533.187 | -0.134 |

Table 23 showed us that the maximum bending moment, shear force and deflection in our simulator is bellow the allowable limit that we've discussed previously.

The placement of these pipe supports will be described in the next section, while the validation can be seen in Appendix A.

**Static Analysis – Flange and Bolt connection**

There are 8 bolts that hold one flange to another. The total maximum shear force that these bolts see is going to be 3,533 lb. Meaning, each bolt will see 441 lb of shear force. Since the cross section area of each bolt is 0.442 $in^2$, the shear stress that each bolt will see is 998 psi. The yield strength of ASME B18.2.1 bolt is 70,000 psi, so these bolts will not fail and they have a safety factor of 70

Furthermore, we also ensure that all the valves that we use (gate, check and control valve) can withstand the maximum pressure with safety factor of at least 1.5. Our gate and check valve are rated ANSI 900 [33], thus they have a safety factor of 2 for our system. Meanwhile, our control valveis rated ANSI 600 [33], thus they have a safety factor of 1.5 compared to our system

## FINAL DESIGN DESCRIPTION

### Parameter Analysis

All pipes not dimensioned are 6" pipes used only for connection adapters for flange and couplings.

### Parameter Analysis-Storage Tank Loop

This section will go over analysis on the storage tank loop. Figure 53 shows the detail consideration of the storage tank loop. Table 24 shows the reasoning behind the parameter that we choose for the storage tank loop.

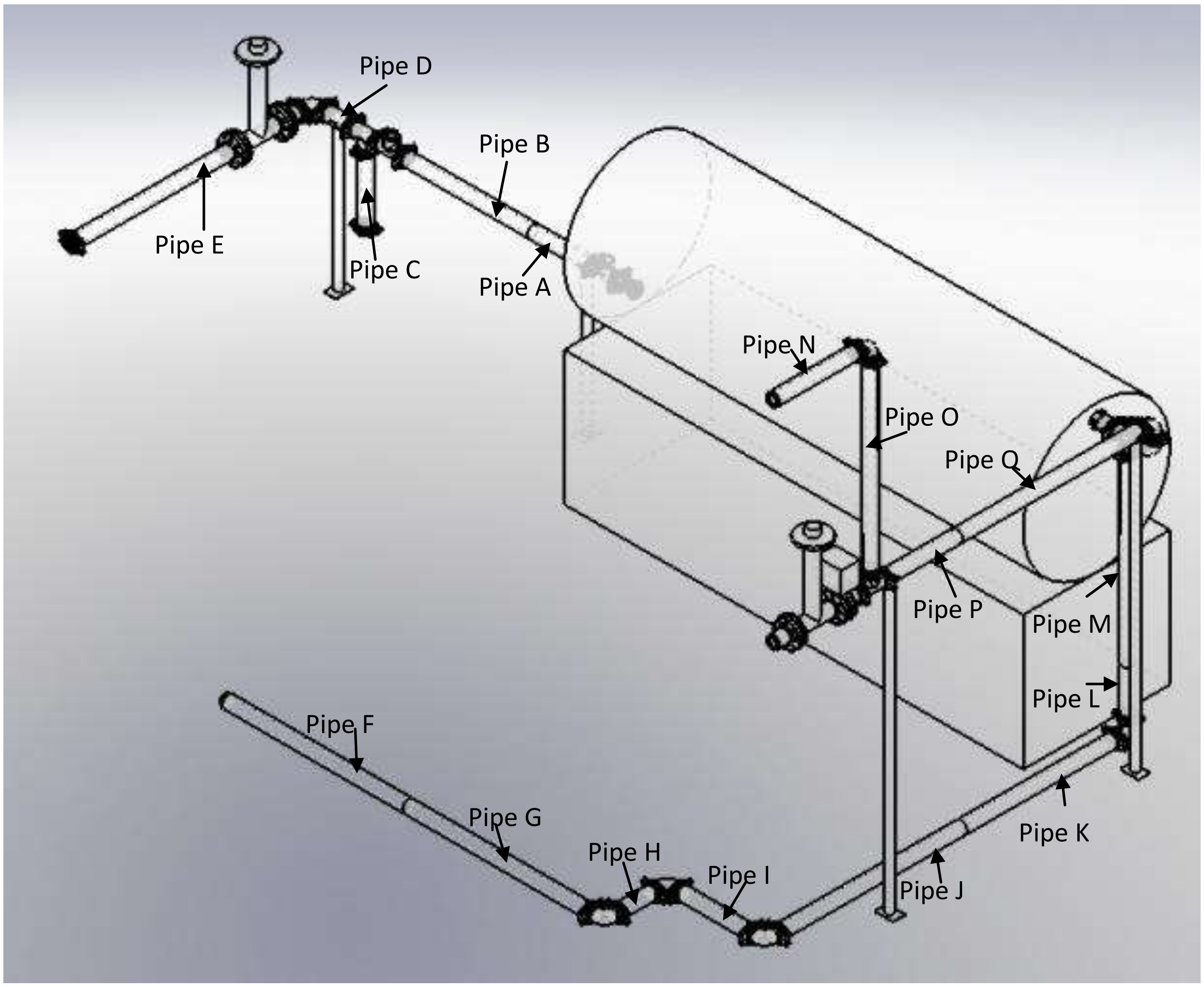



**Figure 53: Storage Tank Loop**

Table 24: Analysis of Storage Tank Loop

| Pipe # | Length (Inch) | Reason |
|---|---|---|
| A | 19.67 | Requires 61.67" to reach Pipe C, Max pipe length 60" |
| B | 42 | |
| C | 21.94 | Requires 21.94" to reach pump loop |
| D | 8.93 | Requires 8.93" to reach Pipe D |
| E | 53.04 | Requires 53.04" to reach pump loop |
| F | 60 | Requires 265.43" to reach Pipe L, Max pipe length 60", Turn was made to bypass clearance for Stand Pipe |
| G | 60 | |
| H | 12 | |
| I | 23.42 | |
| J | 60 | |
| K | 50.01 | |
| L | 14.84 | Requires 64.84" to reach Storage Tank, Max pipe length 60" |
| M | 50 | |
| N | 27.93 | Requires 27.93" to reach Pipe O |
| O | 60 | Requires 60" to reach Pipe P |
| P | 24.05 | Requires 84.05" to reach Storage Tank, Max pipe length 60" |
| Q | 60 | |

**Parameter Analysis - Dual Pump Loop – Lower**

Figure 54 shows the lower dual pump loop configuration. The parameter chosen and reasoning behind it is included in table 25.

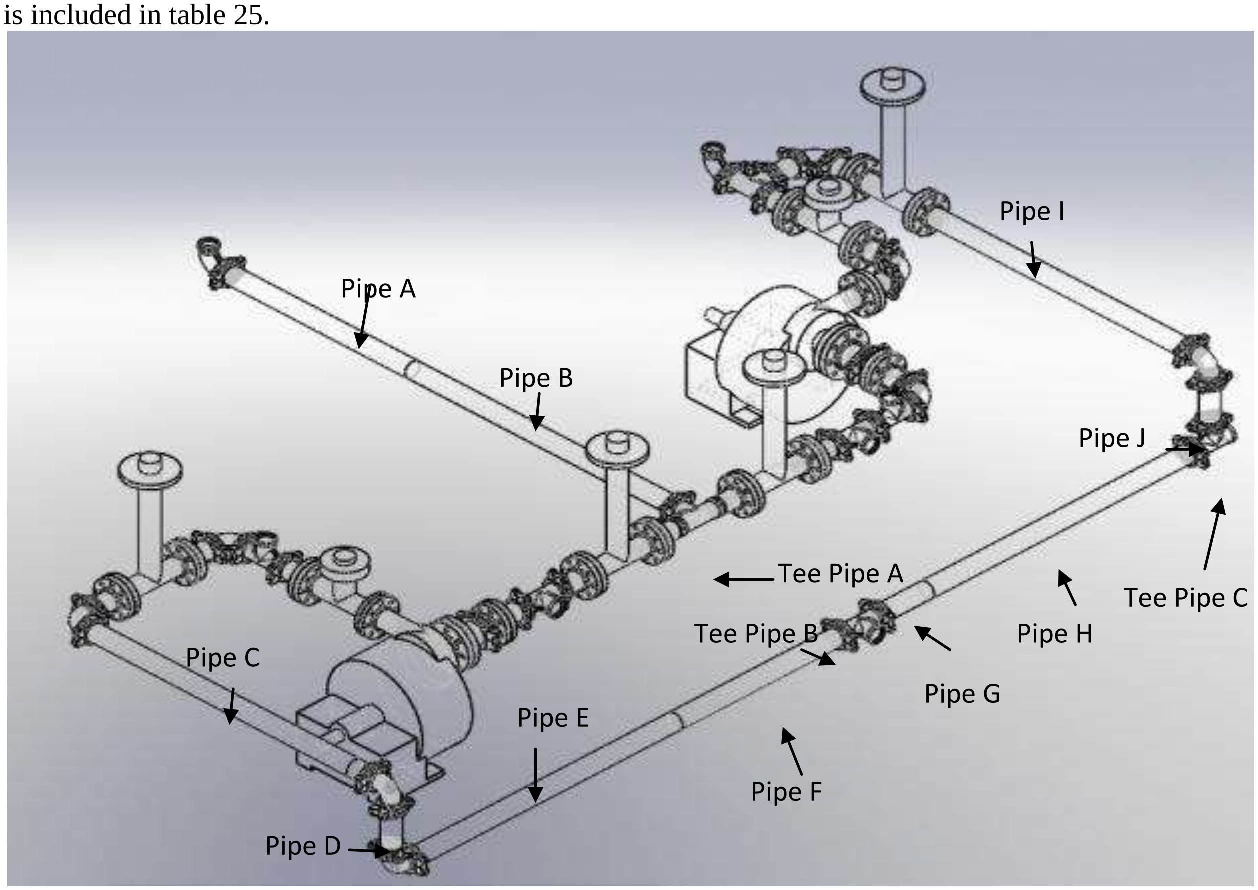



**Figure 54: Storage Tank Loop**

**Table 25: Analysis of Dual Pump Loop-Lower**

| Pipe # | Length (Inch) | Reason |
|---|---|---|
| A | 42 | Requires 102” to reach Tee Pipe A, Max pipe length 60” |
| B | 60 | |
| C | 60 | Requires 60” to reach Pipe D |
| D | 9.28 | Requires 9.28” to reach Pipe E |
| E | 60 | Requires 97.39” to reach Tee Pipe B, Max pipe length 60” |
| F | 37.39 | |
| G | 11.14 | Requires 77.14” to reach Tee Pipe C, Max pipe length 60” |
| H | 60 | |
| I | 60 | Requires 60” to reach Pipe J |
| J | 9.28 | Requires 9.28” to reach Tee Pipe C |

**Parameter Analysis-Dual Pump Loop – Upper**

Figure 55 shows the dual pump loop upper configuration. The parameter chosen and reasoning behind it is included in table 26.

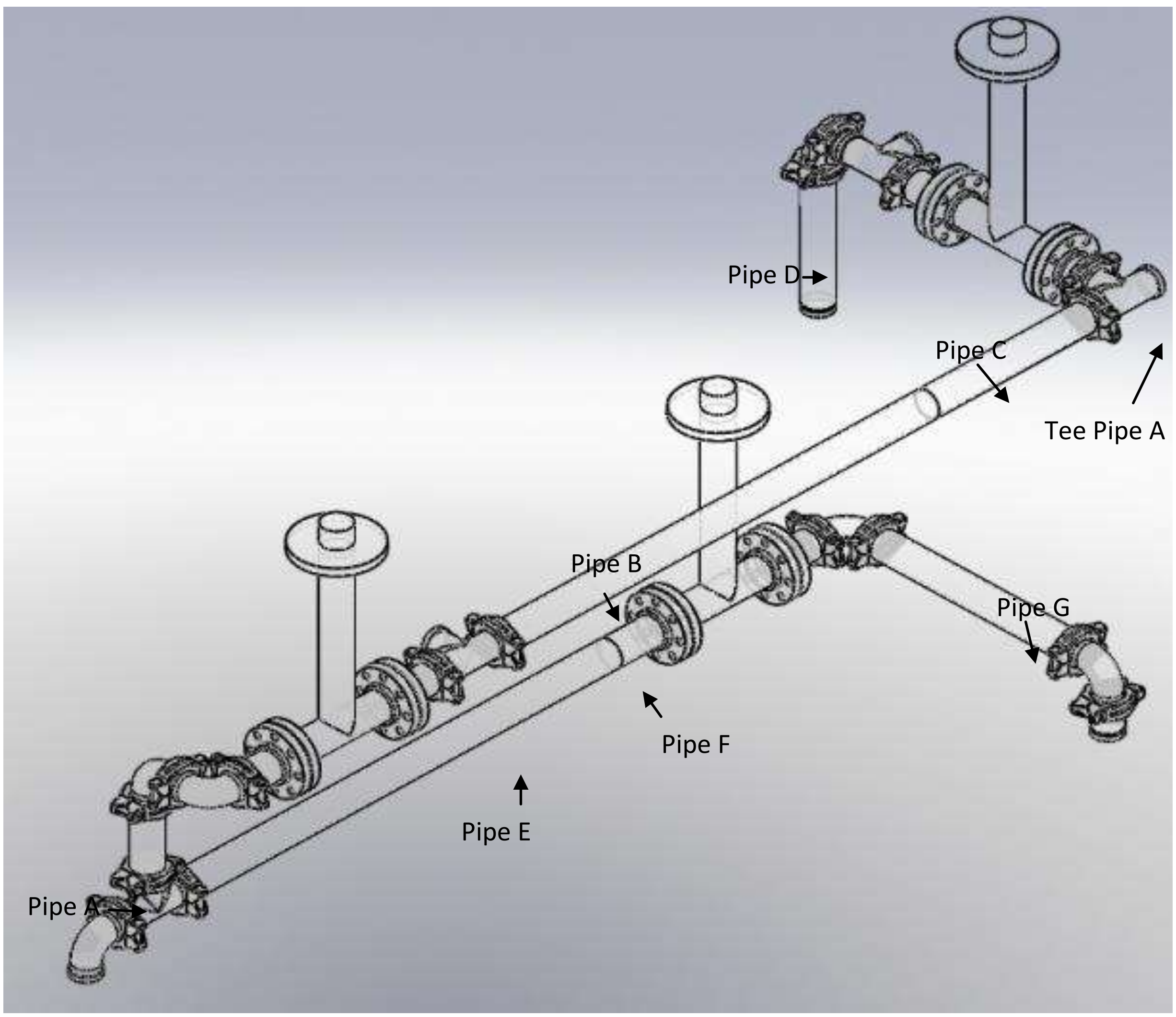



**Figure 55: Dual Pump Loop- Upper**

Table 26: Analysis of Dual Pump Loop-Upper

| Pipe # | Length (Inch) | Reason |
|---|---|---|
| A | 9.34 | Requires 9.34” to reach Pipe B |
| B | 60 | Requires 92.8” to reach Tee Pipe A, Max pipe length 60” |
| C | 32.8 | |
| D | 18.19 | Requires 18.19” to reach Tee Pipe A |
| E | 60 | Requires 67.53” to reach Pipe G, Max pipe length 60” |
| F | 7.53 | |
| G | 27.84 | Requires 27.84” to reach lower level of pump |

**Parameter Analysis-Stand Pipe Loop**

The full design of stand pipe loop is shown in Figure 56.The detail reasoning of why each parameter is chosen is shown in table 27.

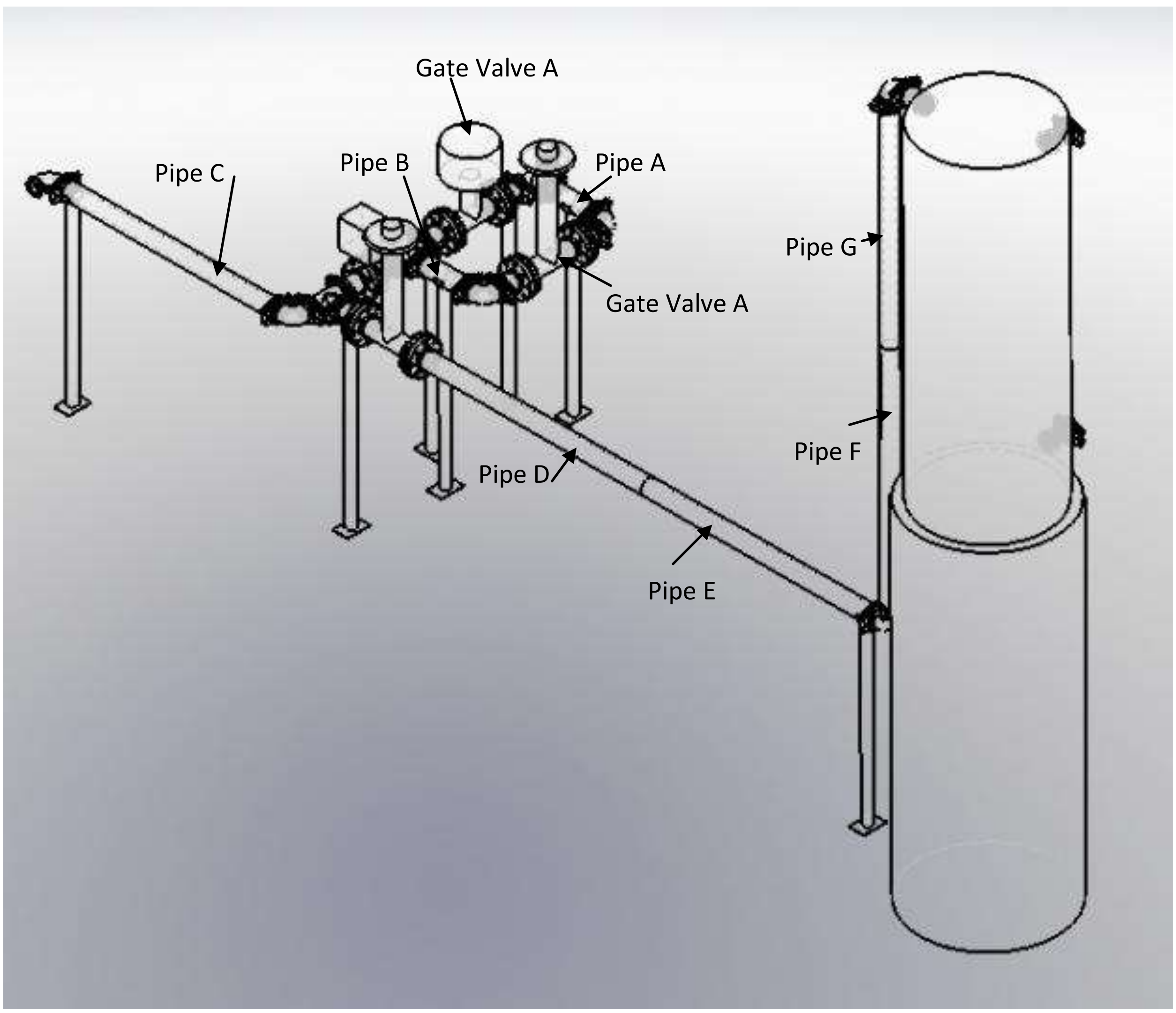



**Figure 56: Stand Pipe Loop**

**Table 27: Analysis of Stand Pipe Loop**

| Pipe # | Length (Inch) | Reason |
|---|---|---|
| A | 12 | Requires 12” for clearance between Gate Valve A and Control Valve A |
| B | 12 | |
| C | 56 | Requires 56” to reach testing flow loop |
| D | 60 | Requires 120” to reach Pipe F, Max pipe length 60” |
| E | 60 | |
| F | 60 | Requires 115.37” to reach stand pipe, Max length 60” |
| G | 55.37 | |

**Parameter Analysis-Testing Flow Loop**

The testing flow loop is shown in the figure 57. The detailed explanation on parameter chosen is in table 28.

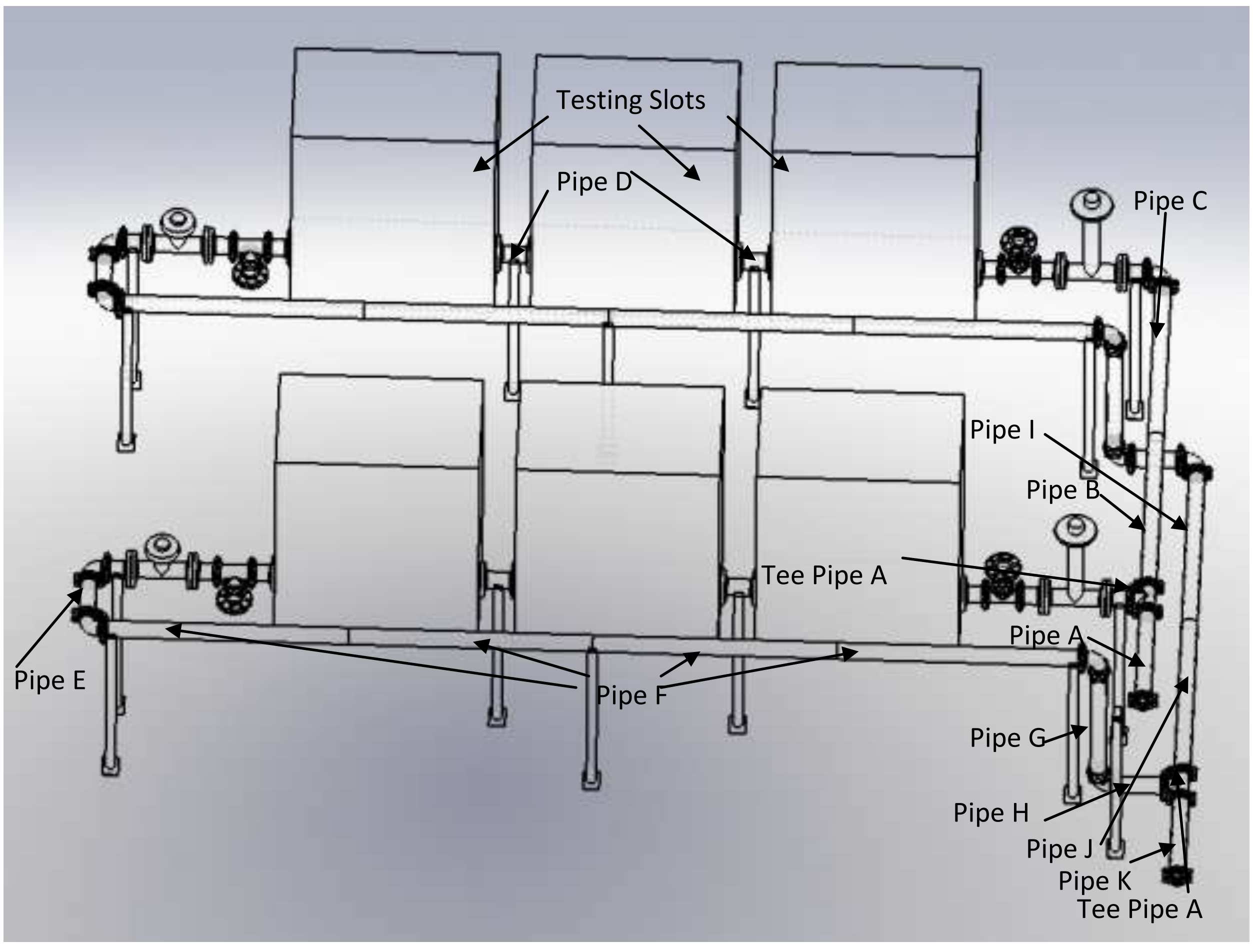



**Figure 57: Testing Flow Loop**

**Table 28: Analysis of Testing Flow Loop**

| Pipe # | Length (Inch) | Reason |
|---|---|---|
| A | 30 | Requires 30" to reach Tee Pipe A |
| B | 51 | Requires 102" to reach Testing Slot |
| C | 51 | |
| D | 9 | Requires 9" between Testing Slots due to: pipe support (2"), flanges (3.5") and clearance for flange installation (3.5") |
| E | 12 | Requires 12" for clearance between Testing Slots and Pipe F |
| F | 60 | Requires 240" to reach Pipe G, Max pipe length 60" |
| G | 36 | Requires 36" to reach Pipe H |
| H | 12 | Requires 12" to reach Tee Pipe B |
| I | 51 | Requires 102" to reach Tee Pipe B |
| J | 51 | |
| K | 26.61 | Requires 26.61" to reach lower level of pump |

**Pipe support placement**

Figure 58 provides the details on the spacing for the pipe supports in our simulator. As mentioned in engineering analysis section, the pipe supports are placed to ensure the pipes will not fail statically, but still maintain the required minimum elevation and use the minimum amount of pipe supports possible. For the sake of clarity, figure 1 shows only the spacing between each pipe support to one another.

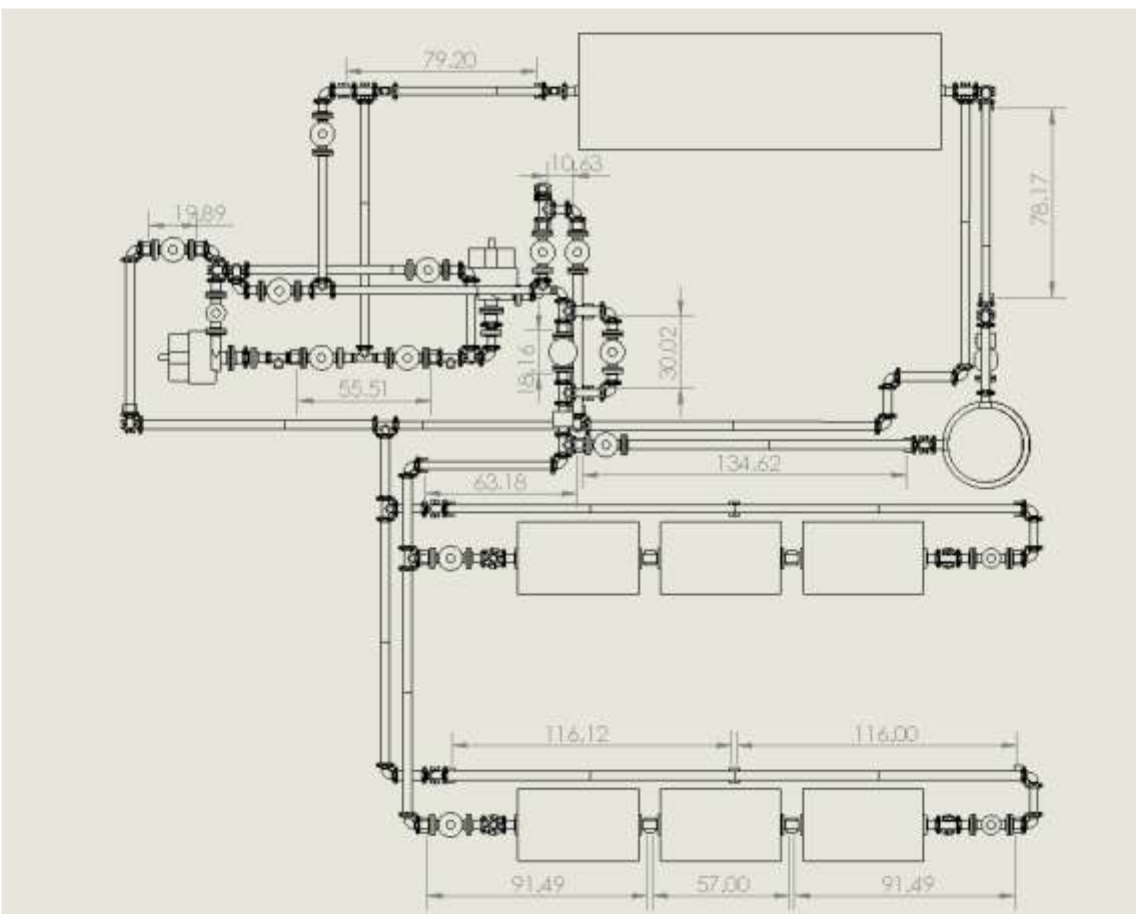



**Figure 58: Piping Support Placement**

### Connection for the instruments in the test slots

Figure 59 shows us how the instruments will be connected to the test slots. There will be two adapter pipes with flange on both ends that bridges the gap between simulator and instruments in the test slot. This is due to the length of test slots (50”) that is much greater than the length of the instrument itself. One end of the pipe adapter will be connected to the simulator, and the other end will be connected instrument. Both connections will utilize combination of flange, bolts and nuts.

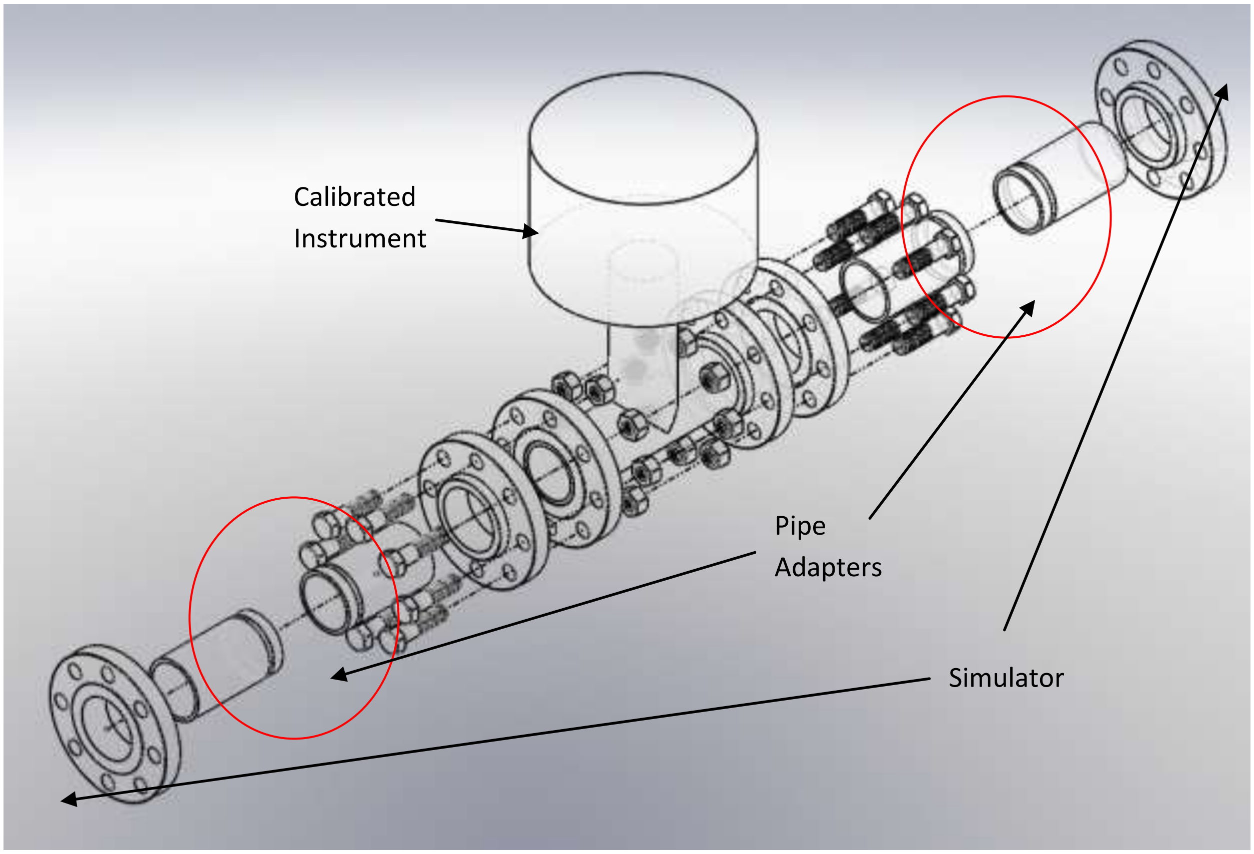



**Figure 59: Connection for test slots**

**Flow Analysis**

**Storage Tank Loop**

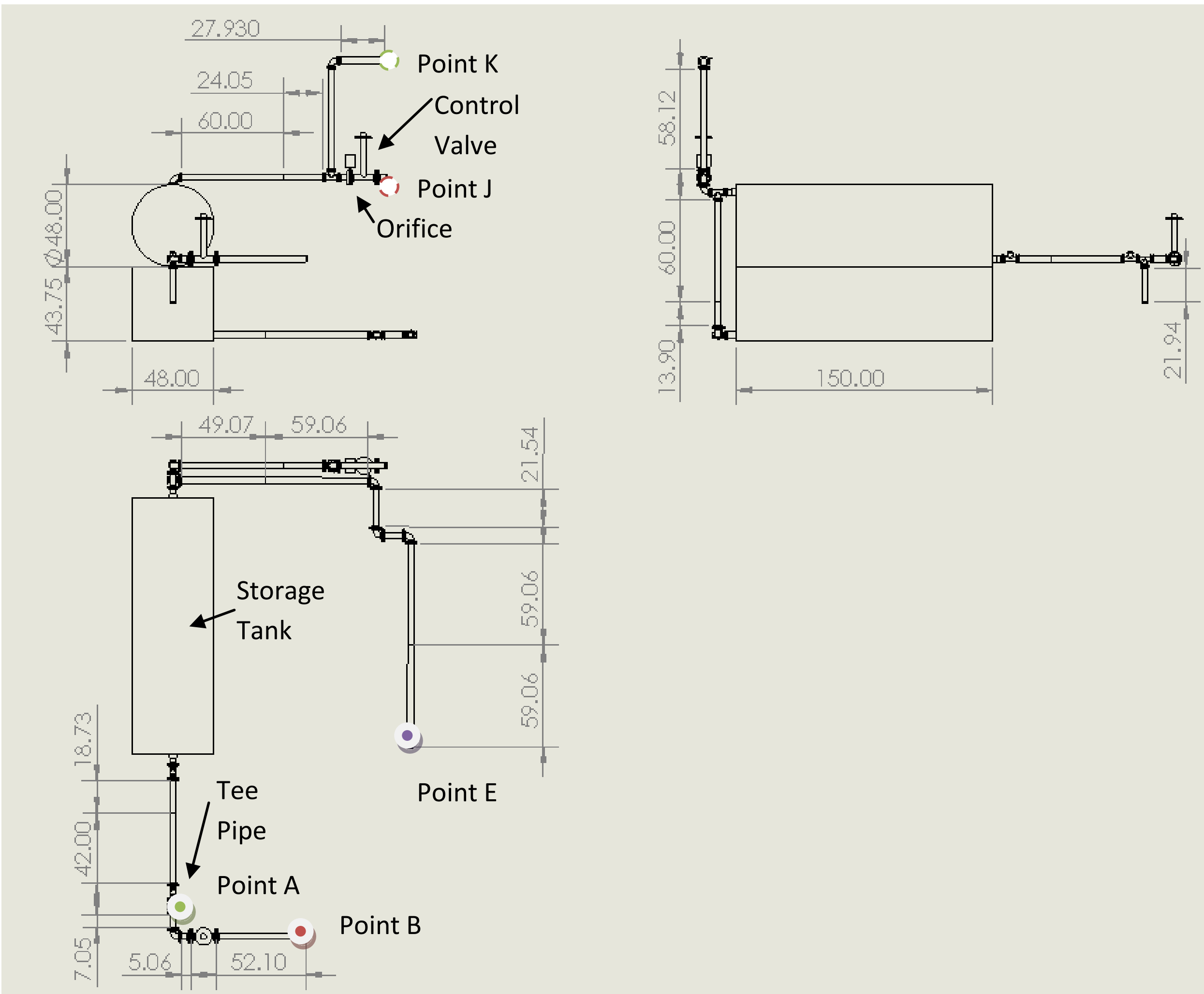



**Figure 59: Storage Tank Loop**

The flow of the water will be starting from the storage tank through a 5' pipe leading onto a tee pipe that goes straight to the stand pipe or the dual pump. From the tee pipe, the water flow would drop vertically 22" into point A. The tee pipe also leads through a valve and 52" of pipe into point B, disregarding the pump and into the rest of the system for draining purposes. Point E is where the excess water will flow after being pumped in the dual pump loop – lower. This amount of water would flow back to the storage tank. Point J at the stand pipe would be used to drain out the stand pipe to re-fill water back to the storage tank. It will flow through a valve and orifice that will allow the logic system to control and adjust the required flow rate. Point K would also be used to drain out the water from the stand pipe in cases of overflowing; these would prevent the water from piling up and disrupting the system.

**Dual Pump Loop – Lower**

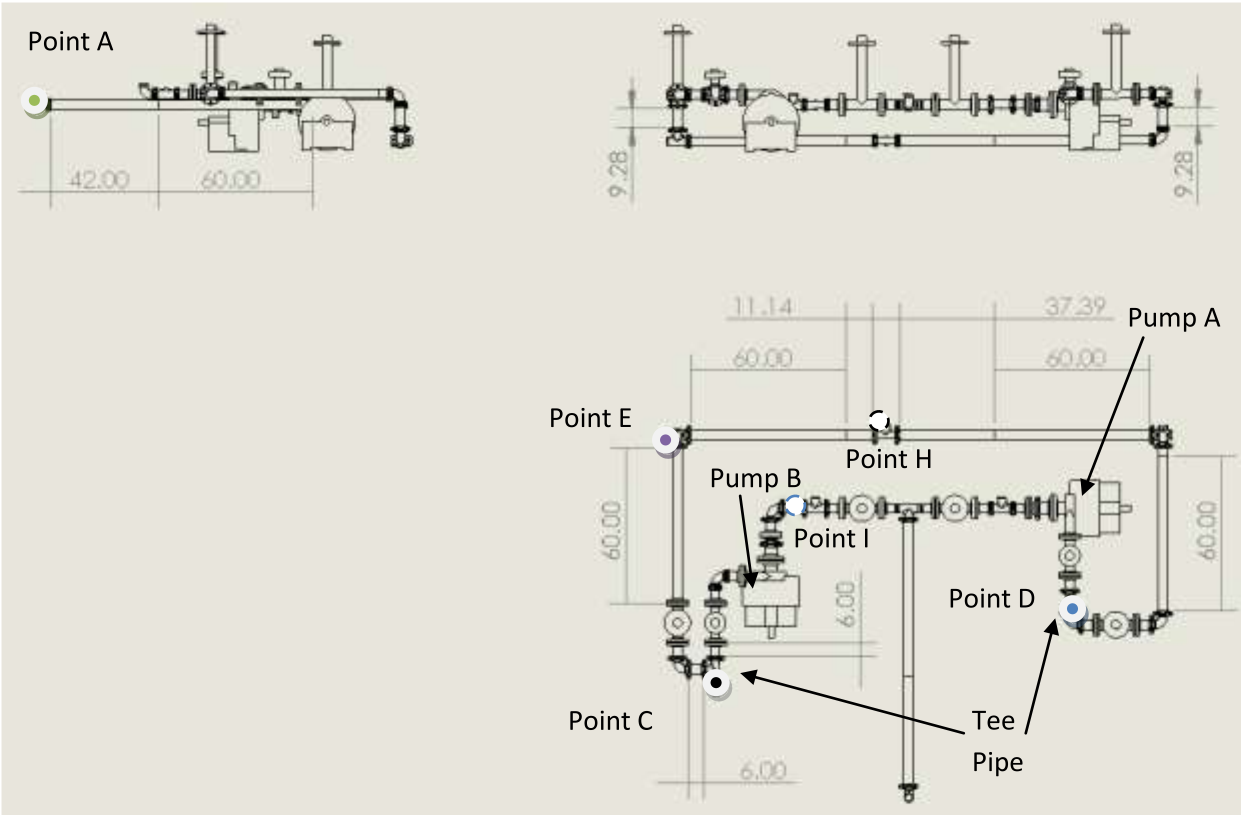



**Figure 60: Dual Pump Loop - Lower**

From Point A, the water travels horizontally through 8.6' of pipe into a tee pipe before the entrance of each pump. The water is then pumped to point C and point D from both pumps. Before the two points, a tee pipe is set to drain excess water back to the storage tank via point D. Point H would allow water coming from back from the testing flow loops to enter the storage tank. Having the ability to operate the pumps in series to boost water pressure and head, water flow from pump A would enter point D to the upper section of the loop and then back down to point I, re-entering pump B with initial flow rate.

**Dual Pump Loop – Upper**

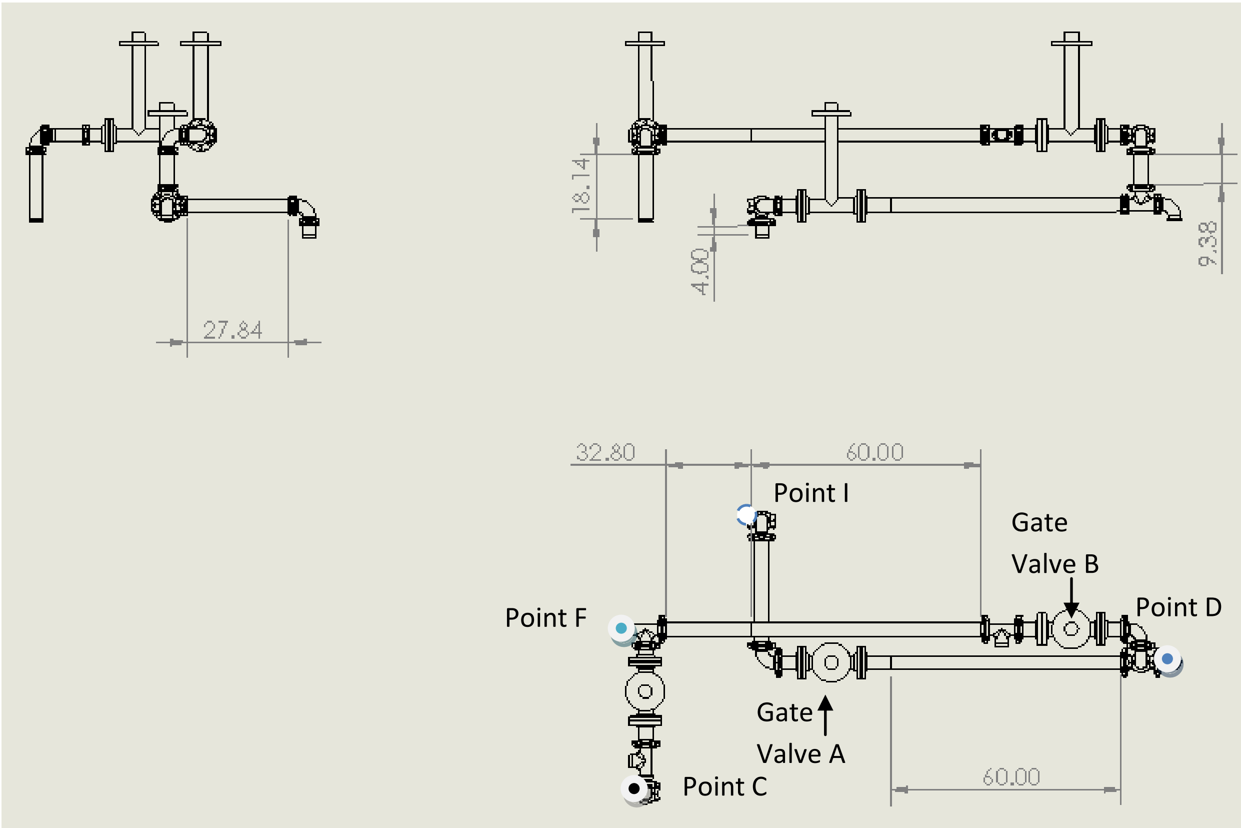



**Figure 61: Dual Pump Loop-Upper**

Water is being pumped from the lower level of the pump loop and into points C & D. From this water will then flow into Point F and into the stand pipe loop. Gate valve A would normally be closed. It would only be opened to allow the pump to operate in series, closing gate valve B. Water will then flow through gate valve A and into point I.

**Stand Pipe Loop**

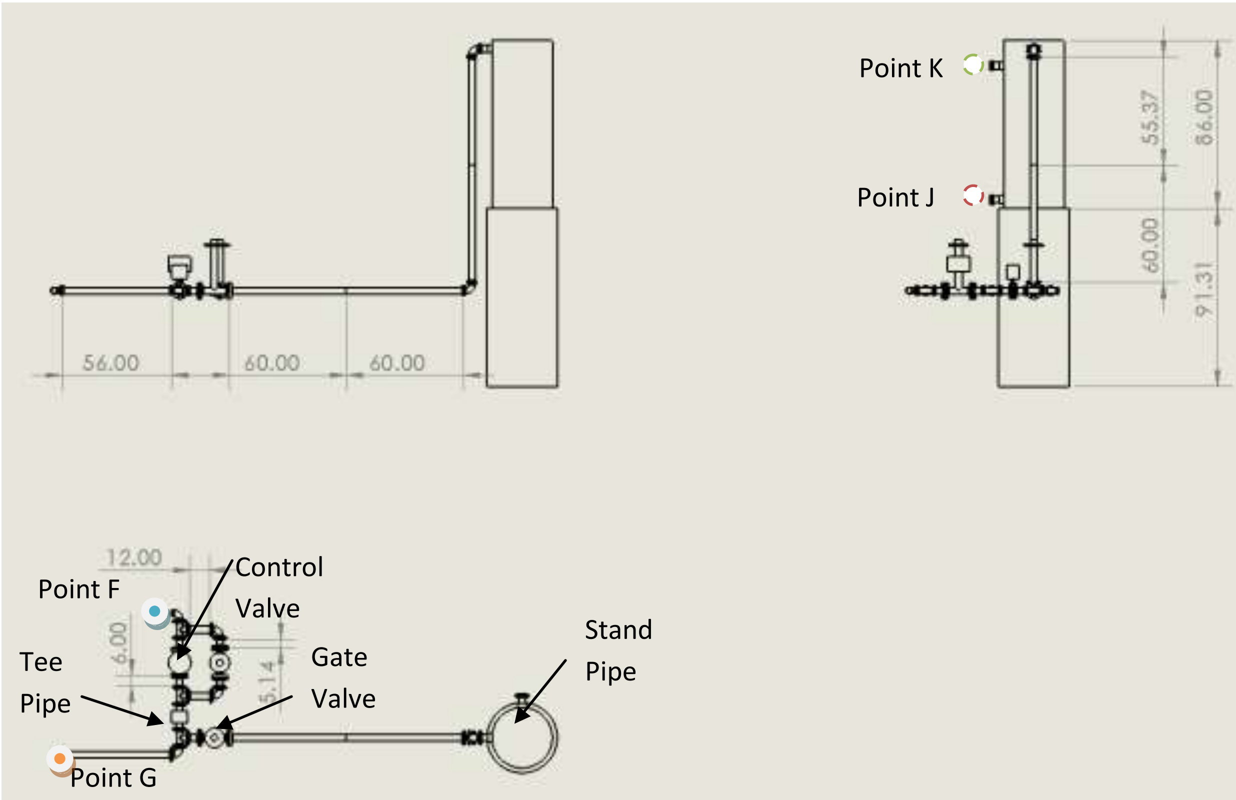



**Figure 62: Stand Pipe Loop**

As water is being pumped up from the dual pumps running in parallel to point F, the water flow rate will then be controlled through the control valve to adjust the flow rate required to calibrate the instruments at the testing flow loop. This new water flow will be directed at the next tee pipe depending on the situation of calibration, whether it would be the instruments at point G or the logic system. If level calibration is being tested, the gate valve will be opened to let flow of water into the stand pipe. A level transmitter will be installed at the bottom of the stand pipe to measure the water level in it.

**Testing Flow Loop**

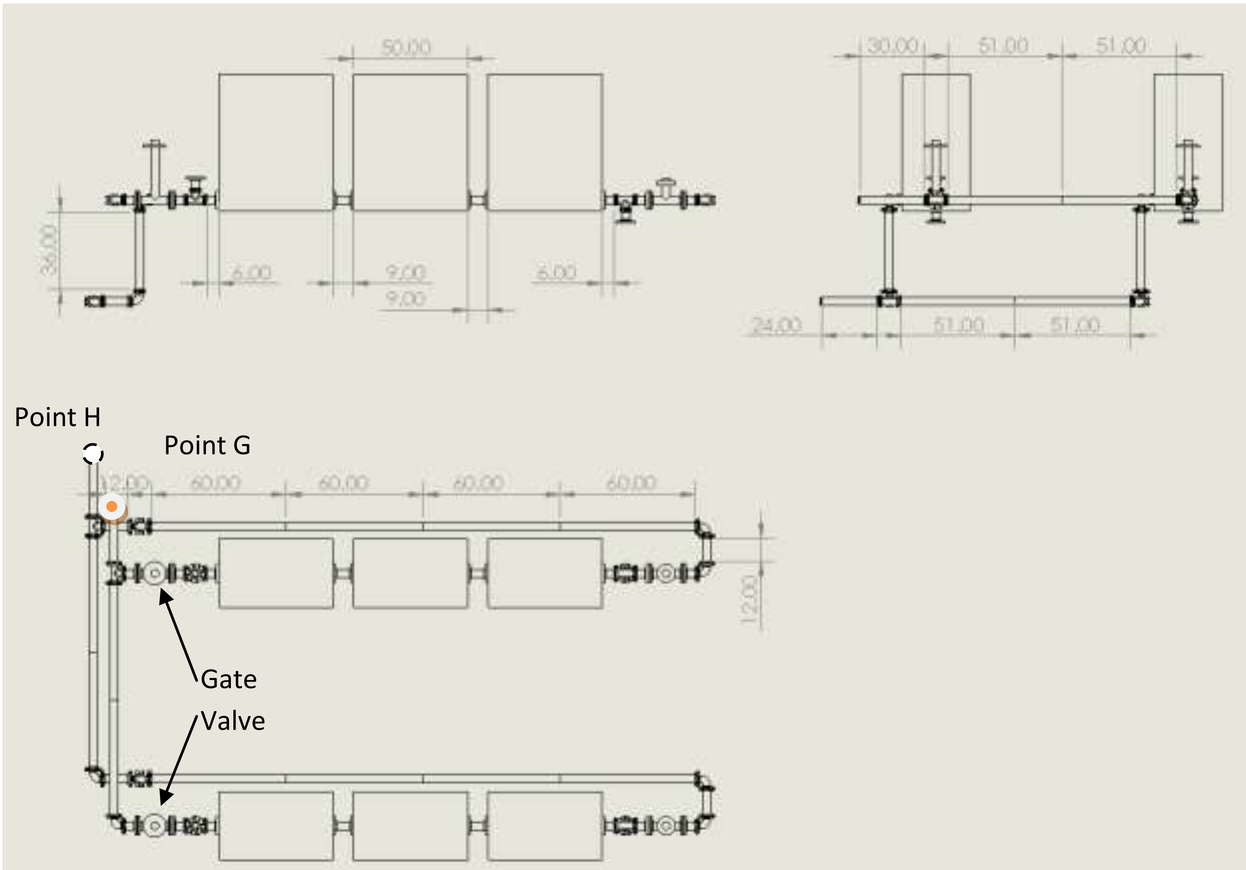



**Figure 63: Testing Flow Loop**

Water flow from Point G onto the two flow loops through the gate valves to calibrate instruments. A vent and drain system has been installed before and after the testing flow loops respectively. The vent system would remove all air before starting the calibration to prevent any damage to the instruments. The drain system would be used to remove all water when the testing and calibration has been completed. After the flow of water reached through all three testing slots, the flow would be reversed back for 250" and then drop vertically 3' before returning to point H, which will be connected back to the lower section of the pump loop.

**Design Analysis**

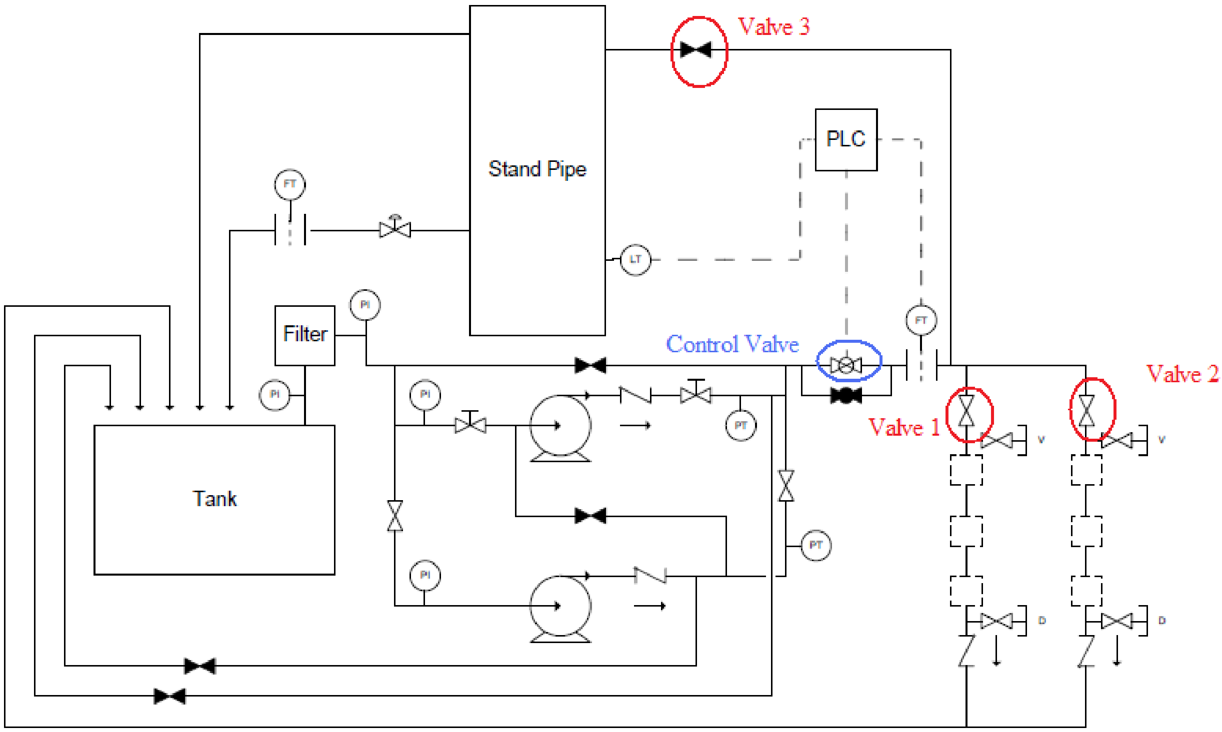



**Figure 64: Valves that are being used to direct the flow of water**

1. The water from storage tank will flow to the pumps due to gravity
2. Pumps drive water to the maximum flow rate as possible based on flow path(s) and system resistances (at start up the control valve will be closed and the pump(s) will operate on minimum flow)
3. Once the water reaches control valve and stable operating conditions are achieved (pump(s) up to speed and aligned), the PLC will adjust the opening of the control valve depending on the control logic and required flow parameter(s) to achieve the desired test condition
4. When a loop is going to be used, the respective valve will be opened while the other two will be closed. For example, when flow loop 1 is being used, valve 1 will be open while valve 2 and 3 will be closed. Note that valve 1 is on flow loop A and valves 2 and 3 are on loops B and Stand pipe loop, respectively.
5. The water will then be channeled back to the storage tank

**Cost Analysis**

The total cost of our simulator has been summarized to be approximately $137,435.86. For further details, please refer to the appendix.

**Table 29: Summary of cost for Full Scale Design**

| Part Name | Qty | Price per unit | Total price |
|---|---|---|---|
| **Testing Flow Loop** | 1 | $7,289.70 | $7,289.70 |
| **Dual Pump Loop** | 1 | $115,274.65 | $115,274.65 |
| **Stand Pipe Loop** | 1 | $8,372.98 | $8,372.98 |
| **Storage Tank Loop** | 1 | $6,395.13 | $6,395.13 |
| **3"D Coupling** | 5 | $20.68 | $103.40 |
| | | | **$137,435.86** |

**Prototype**

**Parameter and Engineering Analysis of Prototype**

**Fluid Dynamics Analysis**

In order to verify that our design is functional, we did theoretical calculations of the fluid dynamics inside our system. The calculations are used to select pump required for the prototype.

For simplicity, we made the following assumptions:

1. The system is overall steady-state
2. The fluid is inviscid, and the material of the tubing is plastic with smooth inner surface.
3. The fluid is incompressible
4. Pressure in the tank is equal to the atmospheric pressure

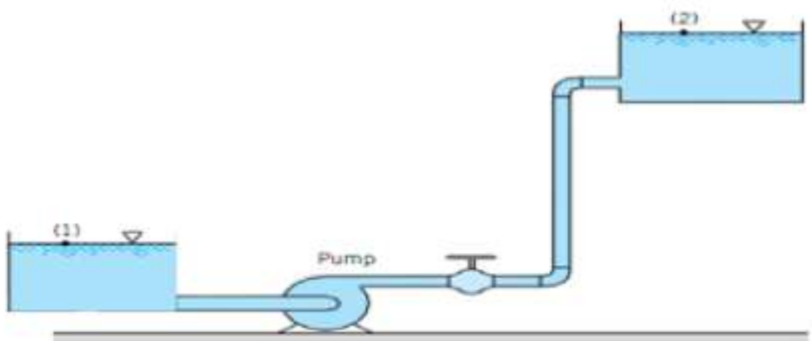



**Figure 65. Reference point of Hydraulic Analysis**

**Storage Tank to Stand Pipe**

The required flow rate for the demo model is 1 – 12 GPM. All of the following calculations are done using the maximum range of required flow rate and one inch pipe size. As shown in figure 65 point 1 and point 2 is our reference point for calculating the system dynamic from tank 1 to tank 2. The velocity of the system could be obtained from Eq.1 by plugging in the flow rate and pipe diameter. The velocity is plugged into Eq.2 and obtains the Reynolds number. Reynolds number is used to determine whether the flow is laminar or turbulence. The flow appears to be laminar flow from the calculations and we could use Eq.3 to obtain the entrance length. Entrance length is defined as a distance from an entrance to a tube in which the flows become fully developed. If we do not have enough lengths for the flow to become fully develop, we might have turbulence flow coming into the system. Thus, the entrance length is used to determine minimum pipe length required for the system.

$$Q = V * A \quad \text{Eq.1}$$

$$Re = \frac{\rho v D}{\mu} \quad \text{Eq. 2}$$

$$le = 0.06 * Re * D \quad \text{Eq.3}$$

*Where Q is the flow rate of the water, $V$ is the velocity of the water in the pipe, $A$ is area of the pipe, D is the pipe diameter, $\mu$ is the water viscosity, the RE is the Reynolds number and le is the entrance length*

Then, we proceed to calculate the required head pump of using Eq.4. We assume that the two tanks are open tank so pressure is equal to atmospheric pressure. The velocity from entering the pipe and coming out of stand pipe is the same. Those assumptions will reduce Eq.4 into Eq.5. After obtaining the total head we could calculate the power needed to pump the system using Eq.8.

$$\frac{P1}{\gamma} + \frac{V1^2}{2g} + Z1 + \hbar p - \hbar l - \hbar lminor = \frac{P2}{\gamma} + \frac{V2^2}{2g} + Z2 \quad \text{Eq.4}$$

$$\hbar p = \hbar l + \hbar lminor + Z1 - Z2 \quad \text{Eq.5}$$

$$\hbar l = f \frac{l}{d} \frac{V^2}{2g} \quad \text{Eq.6}$$

$$Hlminor = K \frac{V^2}{2g} \quad \text{Eq.7}$$

$$HP = \frac{GPM * Head}{3960} \quad \text{Eq.8}$$

*Where P is the pressure,Z1 is the height of water in point 1, hp is the head of the pump, hl is the major loss , hlminor is the minor loss*

**Net Positive Suction of Head Available**

To prevent cavitations which could lead to lower efficiency of the pump we need to calculate the net positive suction of head available. This value should be higher than the Net positive suction head required by the pump. This is calculated and compare to the head of the pump stated at the required flow rate. Net positive suction of head is calculated from Eq. 9

$$\text{NPSHA} = \text{Static head} + \text{surface pressure head} - \text{vapor pressure} - (\text{hl} + \text{hlminor}) \quad \text{Eq.9}$$

**Stand Pipe to Storage Tank**

There is no pump used to flow the water from stand pipe to storage tank. Therefore, gravity will drive the water. For this to be possible, we have to calculate the minimum level of the water required to be maintained in the stand pipe. We used this as a reference for the level transmitter to maintain the water at certain height. In order to obtain the required flow rate, Eq.4 is reduced to Eq.10 to find the minimum level of water needed to maintain in the stand pipe. We also need to check if the required flow rate is sufficient to overcome friction from standpipe to storage tank, thus, we calculated the minimum velocity from Eq.11. The height determination is compared to the velocity value from Eq.10 to ensure that water velocity could flow from stand pipe to storage tank. The flow rate from the stand pipe is essential, because this flow rate needs to be larger than the incoming flow rate in order to prevent overflow in the stand pipe.

$$V = \sqrt{2gH} \qquad \text{Eq.10}$$

$$Z1 - Z2 = \hbar l + Hlminor \text{ Eq. 11}$$

**STATIC ANALYSIS**

The static analysis in the prototype involves cylindrical vessel pipe analysis, bending moment theorem, and basic static analysis of rigid structure.

**Cylindrical vessel pipe**

To obtain the pressure acting on the walls of the pipes and the longitudinal direction, we utilized the two formulas below called the cylindrical vessel analysis.

$$\sigma_1 = \frac{pr}{t} \text{ Eq. 12 } \sigma_2 = \frac{pr}{2t} \text{ Eq. 13}$$

where $\sigma_1$ is the circumferential pressure acting on the wall, $\sigma_2$ is the longitudinal pressure, p is the pressure of the working fluid which is 4 psi, and t is the thickness of the wall with 0.133 in. The calculated value of $\sigma_1$ and $\sigma_2$ came out to be 8.75 psi and 4.38 psi respectively. The calculation is still within the specification of the pipe with 450 psi of tensile strength.

**Structural Analysis**

The structural analysis is used to calculate the weight on supports. Two basic static formulas are used as shown below:

$$\sum F_x = 0$$
$$\sum F_y = 0$$

**Failure due to Tension analysis**

The bending moment analysis is performed on the straight long pipe connections from the stand pipe back to the storage tank. The formula used in the calculation is shown below:

$$\sigma_2 = \frac{pr}{2t}$$

$$\sigma_{bending\ \ moment} = \frac{Mc}{I_x}$$

$$I_x = \frac{\pi r^4}{4}$$

$$\sigma_{total} = \sigma_{internal\ \ pressure} + \sigma_{bending\ \ moment}$$

Where M is the moment, c is the perpendicular distance to neutral axis, $I_x$ is the area moment of inertia, and r is the radius if the pipe.

**Material selection and Summary of Findings**

The following section will provide summary of findings from the above calculations. The calculations values are the reference for the prototype material selection. It was ensured to not fail under all of the conditions listed in the following sections before it was ordered.

**Table 30: Hydraulic Analysis Summary of findings**

| | |
|---|---|
| Total Head (ft) | 9.13 |
| Power Required (HP) | 0.027 |
| Height Needed (inches) | 4.49 |
| Entrance Length (Inches) | 2.27 |
| Net Positive Suction Head (ft) | 21.5 |

**Table 31. Static Analysis Summary of findings**

| Forces | Value |
|---|---|
| Longitudinal Stress ($\sigma_1$) | 8.75 psi |
| Circumferential Stress ($\sigma_2$) | 4.38 psi |
| Bending Moment stress ($\sigma_{bending\ moment}$) | 30.34 psi |
| Maximum stress ($\sigma_{total}$) | 34.72 psi |
| Stand pipe section weight | 101 lbs |
| Control Valve weight | 48.5 lbs |

**Tension Stress on PVC Pipe**

Maximum tension stress is performed on the 24" pipe length of the stand pipe back to the storage tank. From the bending moment calculation, the maximum Moment is 0.1712 lb-ft, area moment of inertia is $4.31 * 10^{-6}$ $ft^3$, and c of 0.11 ft. The maximum bending moment stress is calculated to be 30.34 psi. For the normal stress, it is as calculated as in the cylindrical vessel analysis, which comes out to be 4.38 psi. Therefore, the total stress is added up and become 34.72 psi. Comparing with the maximum yield strength of the PVC used in the prototype of 6500 psi, the analysis showed that the PVC pipe meets the requirement.

**Stand Pipe and Table**

As all prototypes are mounted on the floor except the stand pipe, structural analysis is calculated on the table support. The stand pipe overall force is derived from the stand pipe stock mass, mass of water inside the stand pipe, and the pressure transmitter that is attached on the stand pipe side. The maximum weigh the table could handle is 150 lbs. From the calculation, the pipe overall force weighs 101 lbs, which is still under the capacity of the table.

**Control Valve and Support**

The control valve total weight is 58.5 lbs. Therefore, a support will be mounted directly under the control valve. Using two U-bolts down mounting supports clamped to the ground, each support will withstand 29.25 lbs of weight exerted by the control valve. From the analysis, the support is capable to withstand 3,817 lbs of support, which is far larger than the exerted Force.

**PVC Pipe selection**

We choose to use PVC pipe in our prototype because it is a light weight and less expensive material. Besides that based on our head calculation the total pressure needs to be withstand by the pipe will be around 4 PSI. The PVC we choose has strength of 450 PSI which is larger than the pressure in our system. Moreover from the static stand point, the maximum bending moment stress is calculated to be 30.34 psi. For the normal stress, it is as calculated as in the cylindrical vessel analysis, which comes out to be 4.38 psi. Therefore, the total stress is added up and become 34.72 psi. Comparing with the maximum yield strength of the PVC used in the prototype of 6500 psi, the analysis showed that the PVC pipe meets the requirement.

**Height of water need to be maintained in stand pipe**
The minimum height required to maintain in stand pipe appeared to be 4.5” of water. This height is needed to ensure that the water flowing out of the stand pipe is higher than the required velocity to overcome the piping friction and minor losses. The water from the stand pipe has to pump out more water than from the storage tank in order to prevent overflow in the stand pipe. Moreover, the height is calculated as a set point for the level transmitter to send the required signal to PLC to turn on or off the control valve.

**Pump Selection**
After obtaining the head of the system, we compare to the pump chart in figure 66. Our head on the system shows that the pump is able to pump up water around 9-10 GPM in high speed for the prototype. We choose this pump because it is able to work on our system and it is less expensive. We could also calculate required power from the total head loss of the system from storage tank to stand pipe. The horse power calculated is for the pump to overcome the frictional loss and height. The pump horse power required for the system is calculated to be 0.027 in which lower than the pump power available 1/25 HP.

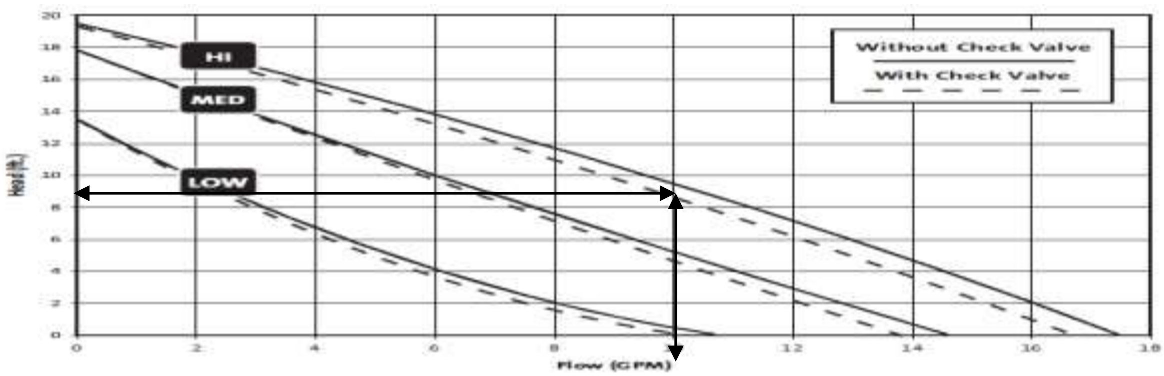



**Figure 66. Pump characteristic chart**

**Pipe Length Selection**
We choose the pipe length to be at least 3” long since based on our calculation we need to have at least 2.27”.The pipe length is determined from the entrance length calculation in which the calculation shows the minimum length that required for the water to be fully developed. We used three sizes of PVC pipe in our prototype, 2’, 6” and 3” pipes. In the connection between storage tank and ball valve we actually used the 3” pipes for the design. We choose to do those configurations of pipe lengths because the vendor provides us with 2’ length of pipe. To save complexity of cutting and save the waste of pipe, we decided to use in three sizes. Those pipe lengths are also chosen to layout appropriately on the table. The size of pipe length is also considered for space in attaching instruments for the prototype. The length is also adjusted according to the height of the table since it will be the support for the stand pipe.

## PROTOTYPE DESCRIPTION

### Prototype Functions

The purpose of the prototype is firstly, to demonstrate that the final design could perform following functions. The prototype will show that our final design will be able to operate the level control loop. Furthermore, ability to detect the decreasing level of water in stand pipe and open up the control valve and pump to maintain the water back to reference level. It will also demonstrate that the final design will be able to attach instruments on the system. A pressure gauge that is the simulator common instrument used to show pressure difference on pipe. In addition, the control valve, pump, and ball valves demonstrate their specific functions and importance for the water circulation in the full-scale simulator. Not all of the function of the full design scale will be validated due to budget and size constraint.

**Prototype Differences**

The prototype is a downscale of the full simulator; however, it still demonstrates several main function of the full scale simulator. The main differences between the full scale simulator and prototype are in the material selection, operating flow parameters (pressure and flow rate), availability of testing slots in full scale simulator to calibrate variety of instrument at once, and the significant size reduction of the prototype. The change in material used is due to cost reduction and weight consideration. Besides that much smaller material strength is required by the much smaller water flow rate when compared to the final design. Reduction in flow parameters magnitude is necessary just to meet the required needs for the prototype function. In addition, absence of testing slots in the prototype is due to budget constraint. Simplifications from the final design in the prototype are needed to aid the manufacturing process and building the prototype in which will take up less space.

**Materials**
the prototype used different materials than the full scale simulator; however, several main instruments are the same component used in the actual full-scale simulator: control valve, PLC, and level transmitter. The prototype will have the storage tank made of PVC, straight pipe and elbow pipe of PVC, stainless steel pump, and a plastic stand pipe. Firstly, PVC for storage tank is chosen due to its cost and durability that match our required needs for the prototype, PVC for piping is selected as it is low cost, suitability for water operating in the prototype flow parameters, and ease of use for manufacturing. In addition, steel pump material is selected as it is corrosion resistance.

**Simplification**

The section below explains several simplifications made to the prototype prior to design review 3 to reduce cost, create ease of manufacturability, and reduce complexity in the prototype system.

**Testing Slots**
The idea of having a testing slot in the prototype has been pulled out due to budget constraint. As the installation of a testing slot requires additional instrument such as pressure transmitter, which costs approximately US$2,600, it would exceed the budget provided by the University and Sponsor.

**A Drain Pipe**
Previously, the piping connection that serves the purpose of draining water from the stand pipe was an idea. However, for simplification, the drainage pipe and manual valves pipe connections are combined into one piping.

**Prototype Components**

The following section is going to explain each material that we are putting into our prototype. It is including both the off-the-shelf parts and parts from sponsor.

**Ball Valves**
As shown in Figure 67 below, the ball valves are used to restrict or discharge flow of working fluid. The PVC schedule 40 the ball valve is chosen as it is the most cost effective and best for flow of working fluid (Please refer to Engineering Analysis section for material selection explanation). It could withstand pressure up to 100 PSI.

**Figure 67. PVC Ball Valves**

**PVC Straight Pipe**
The PVC 40 straight pipe is used for connections between different components: storage tank, stand pipe, pump, check valves, ball valves, and control valves. Six PVC straight pipes are purchased with a 1" size and 2 feet length for each pipe; Six pipes are adequate to provide the necessary length of approximately 45.5" from storage tank to stand pipe (we will band several PVC straight pipes to match the required length). Figure 68 below shows the actual straight pipe that is purchased off the shelf. This pipe could withstand internal pressure up to 450 PSI.

**Figure 68. PVC Straight Pipe**

**PVC Elbow Pipe**
A 1" size PVC elbow pipe is purchased to connect the stand pipe back to the storage tank (Hole B' to Hole B). In addition, it is used to lower the height of the working fluid from the stand pipe to the storage tank. The purpose of the height decrease is to create potential energy for the working fluid to be able to flow back to the storage tank. The Figure 69 below shows an actual PVC elbow pipe that is used for the prototype.

**Figure 69. PVC Elbow Pipe**

**Coupling**
The PVC schedule 40 Coupling is used to join two PVC pipe together. It is joined with the PVC cement and before that it requires the primer before cementing. It is the socket weld x socket weld pipe to pipe connection. Figure 70 shows the actual PVC coupling that we are going to use in the prototype.

**Figure 70. PVC Coupling**

**Tank Fitting**
Figure 71a below shows a male PVC adapter that is used for tank fittings, which connects the storage tank to a straight PVC pipes. It is a PVC schedule 40 Male adapter MIPT x Slip. We will join the threaded part with female adapter Figure 71b to create a pipe fittings for the hole drilled in the storage tank. The female adapter is also a PVC schedule 40 adapter. The male PVC adapter will also use to join the threaded part of the flange of the pump and control valve with the PVC pipe.


**Figure 71a. PVC Female adapter** **Figure 71b. PVC Male adapter**

**Circulating Pump**
The Circulating pump is used for the prototype power source that provides the flow rate to circulate water from the storage tank to the stand pipe. It has a 1/25 hp power and an adjustable motor speed (low, medium, and high). In addition, it has a built-in check valve that prevents back flow of water back to the pump. Figure 72 below shows the Grundfos Series Up pump that is purchased off the shelf.

**Figure 72. Grunfos Series Up Circulating Pump**

**Pump Flange Fitting**
The pump flange fitting is used to create connection point on both sides of the circulating pump hole (inlet and outlet). It provides a 1" size threaded hole for the PVC pipe to be connected on both sides of the pump. Figure 73 below shows the pump flange Fitting used for the pump.

**Figure 73. Grundfos Pump Flange Fitting**

**Electric Cable**
As there is no electrical connections provided when purchasing the circulating pump, We decided to manually connect an electrical cable from the pump to the electric source. The electric cable consists of the positive wire, negative wire, and the ground wire.

**PVC Cement**
The PVC Cement is a chemical construction material that acts as a sealant. The purpose of this sealant is to prevent water leakage occurring on open gaps between connection points and as a thermal insulation.

Caulk is used between connection points such as storage tank fittings, valves fittings, stand pipe fittings, and pipe fittings. The PVC Cement has lap shear strength of 250 psi after 2 hour curing time and strength of 500 psi after 4 hour curing time. Therefore, it would provide high enough strength to prevent leakage of working fluid with maximum working pressure of 3.2 psi. Figure 74 below shows the sealant that is used on connection points on the prototype. Please refer to the safety report for detail explanation about the PVC Cement (MSDS).


**Figure 74. PVC Cement**

**Air Compressor**
The air compressor is borrowed from the GSI. The function of this device is to provide a compressed air supply to operate the actuator imbedded in the control valve. The air compressor is capable to output up to 150 psi of pressure. Figure 75 below shows the air compressor used for the prototype.

**Figure 75. Porter Cable air compressor**

**Table**
We actually requested two tables during the design expo. One of the tables is used as a support for the stand pipe and the other one PLC components. We separated the table due to safety reason in case there is a water spillage out of the stand pipe. The height of the table is 30" and 8' x 30" in length and width. The table will be able to support up to 150 lb.

**Clamp**
The Control valve weight is around 58.5 lb and it is connected to the pipe on the both end. To avoid shear stress on the pipe, we need to have support on the both end of the control valve. We chose to use the dual clamp as the control valve support. It has a capacity of withstanding 3,817 lbs of which far than enough for our control valve. The bottom of the clamp will be bolted to a piece of wooden block to make it a rigid structure. Figure 76 shows the sample of the clamp that we are using for the control valve.

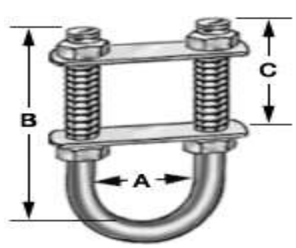



**Figure 76. Dual Clamp**

**Materials from Sponsor**

**Control Valve**
Figure 77 below shows the control valve that is provided by our sponsor. It is the 24000CVF series of Fisher control valve. The main function of the control valve is to control the level of working fluid on the stand pipe after the manual valve is open. The actuator imbedded in the control valve is the component that operates the open or close of the control valve. Furthermore, the control valve is connected to a control logic that detects the level change. We need to have a compress air supply to the control valve to move the actuator. We need the ½" threaded connection from the air compressor to the control valve.

**Figure 77. Control Valve**

**Pressure Transmitter**
The pressure transmitter we are getting is the Rosemount 3051 S level transmitter. It is connected to the PLC to read off pressure difference inside the stand pipe. When there is an indicated change inside the stand pipe, the control logic catches the signal of a level change of working fluid inside the stand pipe that is performed by the pressure transmitter. It needs to be connected to the bottom of the stand pipe to detect the changes in level of water. The level transmitter than can send the signal of pressure changes to PLC. In the market, this unit will cost about USD 1500 a unit. Figure 78 below shows the control valve used in our protototype.

**Figure 78. Rosemount 3051S**

**PLC Controller**
The PLC controller we are getting from sponsor is the SIMATIC PCS 7 AS 417 H. Programmed control logic is connected to the pump, control valve, and pressure transmitter. The pressure transmitter senses the pressure difference and sends the signal to the PLC. The PLC will then decided whether to cut the flow or not by turning on and off the control valve. Using a dedicated computer, the software in the PC is equipped with a preset coding script and adjustable interface that match the Piping and Instrumentation Diagram of the prototype. For PLC connection to the pump, a relay is used to downgrade electric current capacity of the PLC to match the pump; the purpose of this connection is to turn on or off for the pump,

when a flow circulation is needed.  Figure 79 below shows the PLC used for the control logic in the prototype.

**Figure 79. PLC**

**Descriptions**

The prototype is designed to demonstrate functionality of the final design. It will show that our final design, through PLC, will be able to fill up the stand pipe when the level of water decrease and stop filling the water once it reached the required level by shutting down the control valve and pump. The level of water is sensed through signal from level transmitter send out to the PLC and the PLC will read the signal and open or close the control valve accordingly. The water will be drained out from the stand pipe using manual ball valve in which connecting the stand pipe to the storage tank. We also wish that the final design is capable of attaching instruments on the system. This is done in our prototype by attaching pressure gauge on the piping between control valve and stand pipe. Besides that, to be able for the user to monitor the water level, we used the clear polyethylene stand pipe for the prototype.

**Initial Fabrication Plan**

This section will go over our prototype difference, manufacturing and assembly plan. In the following section, it will also show the bill of materials for the prototype.

**Comparison with final design**

The main differences of prototype and full scale design will be the different materials due to different parameters run on the system. The prototype is a scaled down version of a full size design which resembles functions of level control loop in the full scale level control. A pressure gauge will also be included in the prototype to resemble the ability of instrument calibrations. The prototype will only be tested in small fraction of flow rate of the full scale simulator therefore the prototype piping material will be made of smaller and less expensive materials such as PVC. The geometry of the prototype and final design will be another obvious difference. Since the prototype only mimic some parts of the full scale simulator, the prototype has a significantly smaller floor sized occupied than the final design simulator.

**Bill of Materials**

The instruments used in the prototype are borrowed from our sponsor. The table below shows the detail bill of materials for the prototype.

**Table 32: Bill of Materials for Prototype**

| Part Name | Qty | Material | Color/Finish | Price per unit | Total price | Manufacturer |
|---|---|---|---|---|---|---|
| Centrifugal Pump | 1 | Stainles Steel | | $119.99 | $119.99 | Grundfos |
| Pump Flange Fitting | 1 | | | $14.99 | $14.99 | Grundfos |
| Electric Cable | 1 | Rubber/Brass | | $0.00 | $0.00 | n/a |
| Storage Tank | 1 | PVC | | $29.97 | $29.97 | Rubbermaid |
| PVC Male Adapter | 6 | PVC | Gray | $0.94 | $5.64 | Dura Plastic Products |
| PVC Female Adapter | 2 | PVC | White | $1.09 | $2.18 | Dura Plastic Products |
| Stand Pipe | 1 | Plastic | | $102.00 | $102.00 | Plastic Mart |
| PVC Cement | 1 | | White/Green | $11.98 | $11.98 | Oatey |
| PVC Ball Valve | 2 | PVC | | $4.92 | $9.84 | Mueller Industries |
| Clamp Support | 1 | Zinc/Steel | Gray | 12.41 | 24.82 | McMasterr |
| PLC | 1 | | | $0.00 | $0.00 | Siemens |
| Control Valve | 1 | | | $0.00 | $0.00 | Fisher |
| Pressure Transmitter | 1 | | Blue | $0.00 | $0.00 | Rosemount |
| PC set | 1 | | Black | $0.00 | $0.00 | Dell |
| PVC Straight Pipe | 9 | PVC | White | $1.60 | $14.40 | Charlotte Pipe |
| PVC Elbow Pipe | 4 | PVC | White | $0.44 | $1.76 | Dura Plastic |
| Pressure Gauge | 1 | | Black | $4.99 | $4.99 | Brady |
| Air Compressor Rent | 1 | | Red | $0.00 | $0.00 | n/a |
| Threaded Flange | 2 | Steel | Black | $28.56 | $57.12 | McMasterr |
| **Subtotal** | | | | | | **$399.68** |

**Manufacturing Plan**

In our project, we have less manufacturing processes since most of the parts are off the shelf and borrowed from sponsor. To save complexity, we do not do any machining in the university machine shop. The machining is done by our vendors since we purchased the materials from them. The section below will cover manufacturing of storage tank, stand pipe, and PVC pipe.

**Manufacturing of Storage Tank**

The manufacturing of the Storage Tank would be outsourced as our Vendor Home Depot had proposed their assistance in the machining processes.

Below are the procedures of manufacturing steps we will perform:

1. Put the storage tank on a vise and tighten it with enough force to hold it in place.

2. Select a drill bit made of iron with ¾” size, then place the drill bit on the drill motor.

3. Use a double tape on the section of the storage tank where drilling process will be done. Then mark the drilling spot with a permanent marker.

4. Set the drilling speed to 250-600 RPM and start the drilling process deep enough to penetrate the wall of the storage tank.

5. After then, clean up the burrs on the wall of the holes using a knife and clean up for good surface finish.

Figure 80 below shows the engineering drawing used to manufacture hole for outlet port in the storage tank.

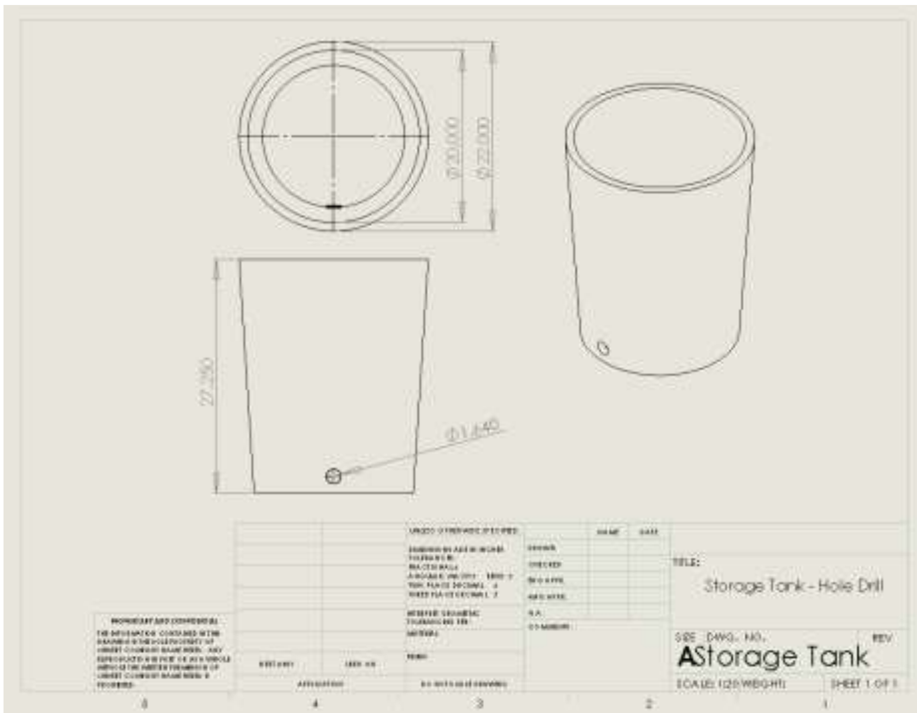



**Figure 80. Storage tank engineering drawing (all of the dimensions are manufacture in +/- 0.05 tolerances -not shown in the drawing-)**

**Manufacturing of Stand Pipe**

The manufacturing of stand pipe would be outsourced at Home Depot. A 0.5" hole would be drilled on the stand pipe with a height from the bottom of stand pipe of 1". Below are the steps in drilling the stand pipe hole:

1. Put the stand pipe on a vise, and then tighten the vise strong enough to hold the stand pipe in place.

2. Choose a drill bit size made of iron with size 0.4531" and place the drill bits on a drill motor.

3. Use a double tape to the section where drilling will be performed, and mark an exact location using a permanent market where the drill bit is going to be in contact initially.

4. Start the drilling process and deep enough to penetrate the wall of the stand pipe. Use a drilling speed of 250-600 RPM, and feed of 0.006.

5. After finished with the drilling process, remove the burrs on the wall in the hole using a knive.

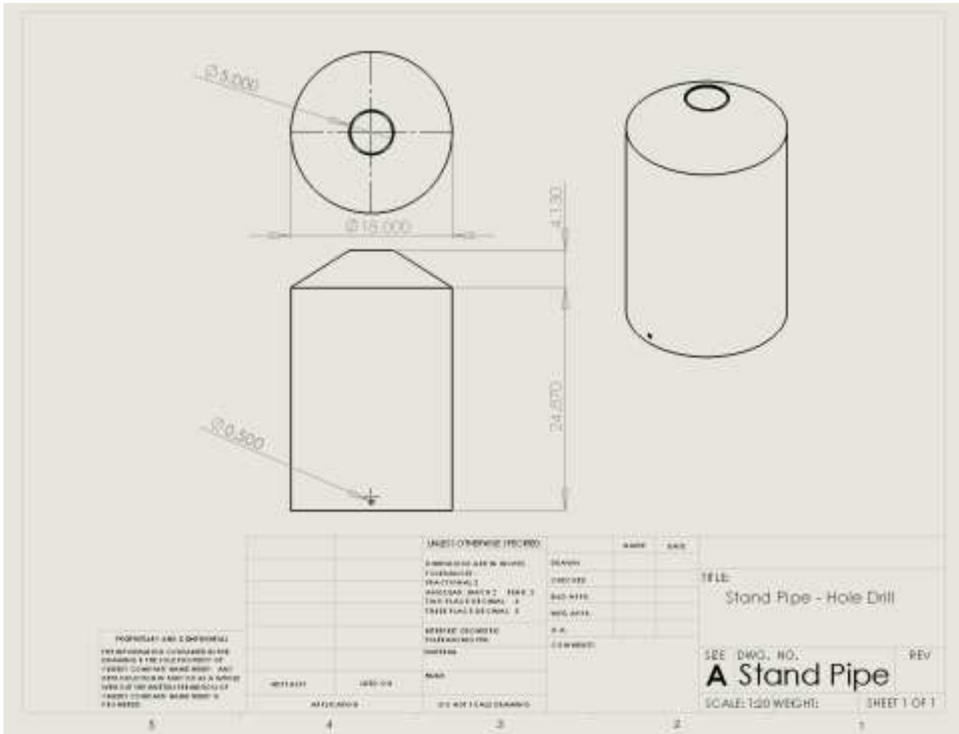



**Fig 81. Stand Pipe Engineering Drawing (all of the dimensions are manufacture in +/- 0.05 tolerances -not shown in the drawing-)**

Figure 81 above shows the engineering drawing that would be used to manufacture the hole for the stand pipe and pressure transmitter connection.

**Manufacturing of Thread hole on PVC Pipe for Pressure Gauge**

The machining of the thread hole will also be performed in Home Depot shop. The shop provides us with drill bits to machine a ¼" threaded NPT connection for later installation of Pressure Gauge. Below is the step of drilling the PVC Pipe.

1. Use a double tape and mark the double tape with a permanent marker to indicate where drilling will be performed.
2. Select a 5/16" drill bit and insert it to a drill motor. For the PVC pipe, tighten it to a vise, enough pressure for holding the PVC pipe rigid enough is good without exerting too much pressure (might crack the PVC pipe instead).
3. Center the drill bit and face the PVC pipe perpendicularly to it. Drill the hole tenderly and deep enough to create a nice hole on the PVC pipe.
4. Lift up the drill bit and clean up the burr using a knive.

Below is a Table 30 that explains how to determine the correct drill bit material used for drilling a hole on a PVC pipe and the cutting speed of the drill bits. Also, figure 82 below shows the engineering drawing for drilling the PVC pipe.

**Table 33. Speed and Feed for drilling PVC material**

| Material | Rec. Drill Sizes | Speed (RPM) | Feed Range (Inch/Revolution) for each Drill Diameter | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1/16 | 1/8 | 1/4 | 1/2 | 3/4 | 1 |
| Plastics | **225** | **250-600** | 0.0015 | 0.0030 | **0.0040** | 0.0060 | - | - |
| | **240** | | 0.0030 | 0.0050 | **0.0120** | 0.0160 | - | - |
| | 223 | | - | - | - | - | - | - |

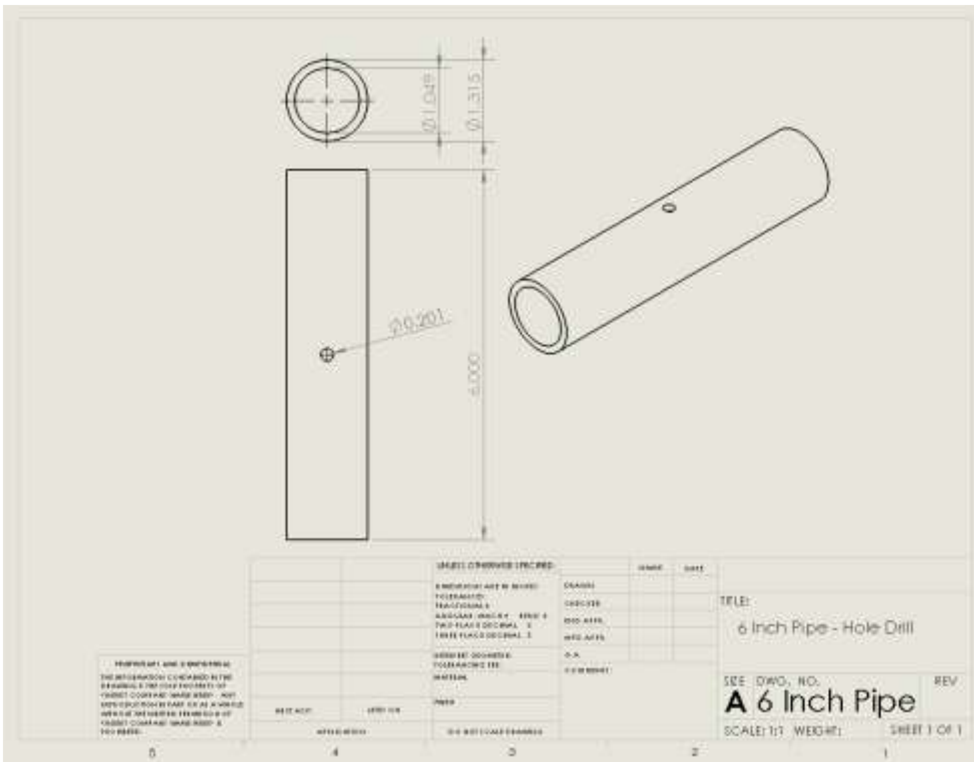



**Figure 82. PVC straight Pipe Drilling engineering drawing (all of the dimensions are manufacture in +/- 0.05 tolerances -not shown in the drawing-)**

**Manufacturing PVC straight Pipe – Cutting**

The machining of the PVC straight Pipe would be performed in the Home Depot Shop as well. The goal of this process is reduce the length of the PVC pipe. The method in cutting the PVC pipe will be explained below:

1. Mark the PVC Pipe with a permanent marker indicating which part the cutting process will be performed.

2. Place the 2’ straight PVC Pipe on a vise. Tighten the clamp with enough force to hold the PVC Pipe in place.

3. The band saw has two speed of medium or high; use the medium speed for cutting and set the parameter.

4. Hold the vise and PVC Pipe firmly, and start the cutting process.

5. After finished with the cutting process, clean the surface of the cut using knife to get a good surface finish.

**Assembly plan**

The assembly plan will be divided into two sections. They are the mechanical assembly and the electrical assembly of the prototype.

**Fluid Simulator Mechanical Assembly**
This section will elaborate the assembly of the mechanical components in the prototype. Figure 83 below shows the 3D Model of the Mechanical sub assembly.

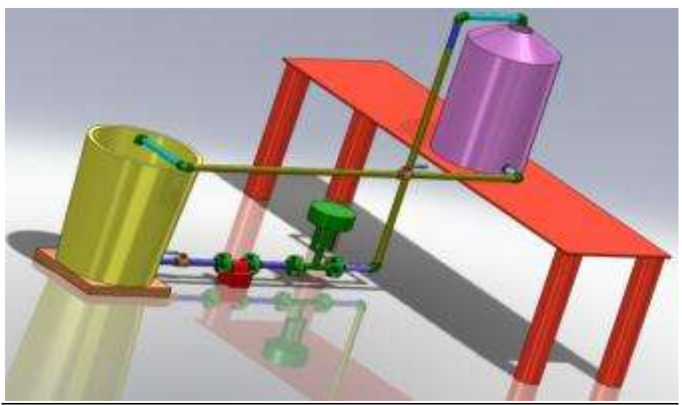


**Figure 83. Final Mechanical Assembly.**

Note: the dimensional value of the piping in the assembling description refers to the length of the piping not of pipe diameter. The diameter for all piping are 1” size.

The sub assembly procedure will be explained below:

**1. Storage Tank and PVC Couplings**
First, place the storage tank on top of a Cement support. Then, attach the 1” hole on the bottom of the storage tank with the PVC tank fittings. First insert the PVC MIPT x Slip connection adapter on the outside hole of the storage tank. Secondly, connect the inserted PVC adapter with a PVC Female adapter HUB x FIPT connection. After connecting both PVC couplings, apply PVC cement on the gap between the couplings and hole. Figure 81 below shows the assembling schematic. Both PVC connections must be twisted (threaded connection) and connected properly. Figure 84 below shows the assembled schematic of the storage tank and the PVC couplings.

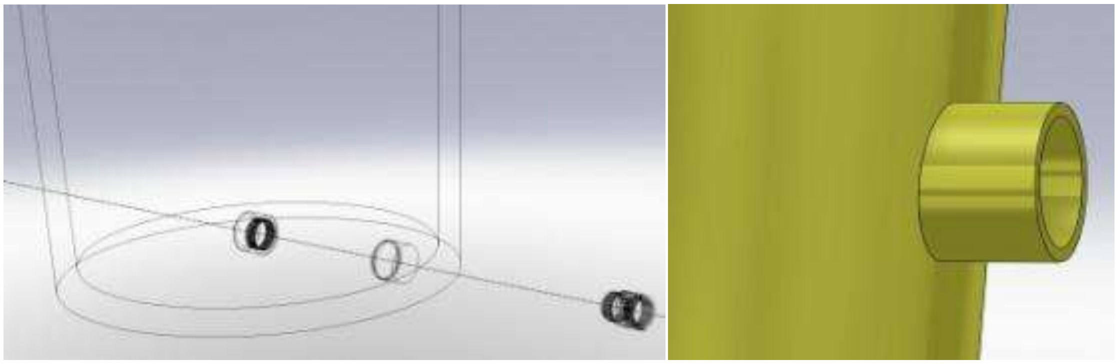


**Figure 84. Attached couplings on the storage tank.**

**2. Ball Valve and PVC pipe connection and to Step 1**

The PVC ball valve and PVC pipe both has Slip x Slip connection. Therefore, the assembly of the ball valve and two 6” length PVC pipe is by simple attachment of slip connections of both components. Then, apply PVC cement on the connection points of the ball valve with the two PVC Pipes. After then, connect the assembled connections to step 1 assembly. The connection to step 1 assembly is a simple Slip connection to the PVC hex coupler. Figure 85 below shows a schematic of the assembly at the end of Step 2.

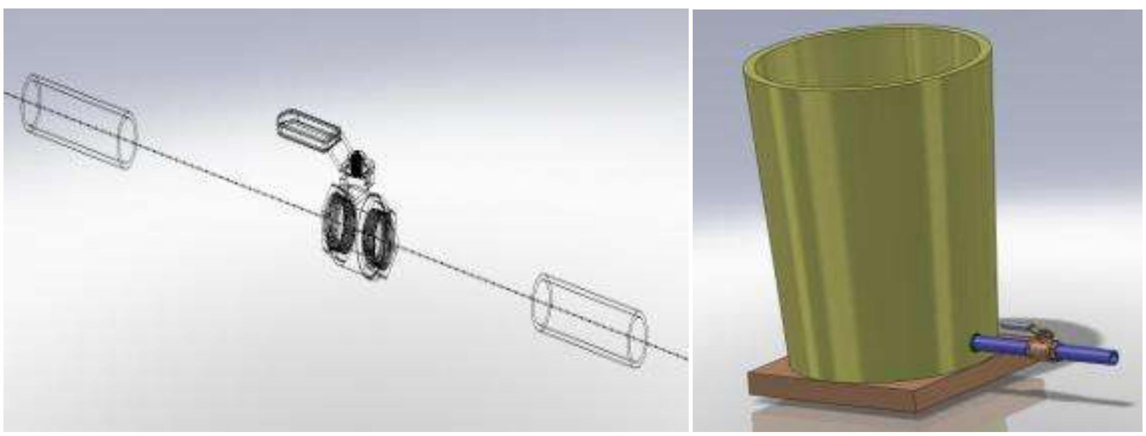


**Figure 85. Ball valve and PVC pipe Assembly.**

**3. Pump and Pump Fitting Flange Connection to Step 2**

Connect both inlet and outlet hole of pump with a threaded flange by using screws and nuts on the four small holes. Next, connect both sides threaded flanges with Slip x NPT threaded hex couplers. A PVC Cement should be added between connection points of the outlet and inlet pump, flange, and couplings. After finishing the assembly, connect them to Step 2 assembly. The connection to step 2 assemblies uses a simple Slip connection. Figure 86 below shows the schematic of the assembly at the end of Step 3.

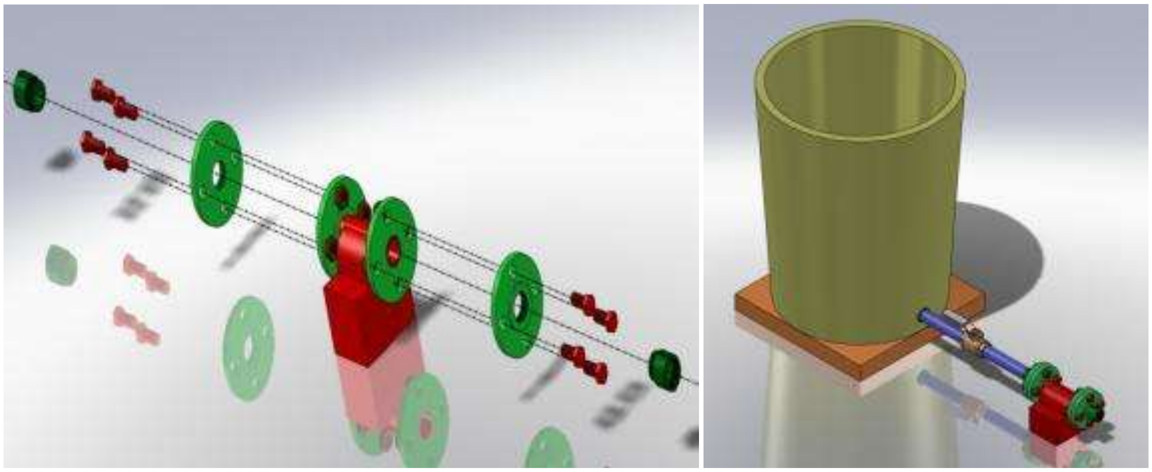


**Figure 86. Pump and Flange Fitting Connection**

**4. Control Valve and Flange Connection to Step 3**

Connect the control valve with a threaded flange using 4 screws and 4 nuts. Then, connect a Slip x NPT threaded Hex Coupling to the threaded flange. This hex coupling will be used for connection to the PVC Pipe connection. Therefore, connect the assembly mentioned above to Step 3 assembly; the connection to step 3 assembly uses a Slip in Figure 87 below shows the schematic of the control valve, flange fittings, and hex coupling assembly.

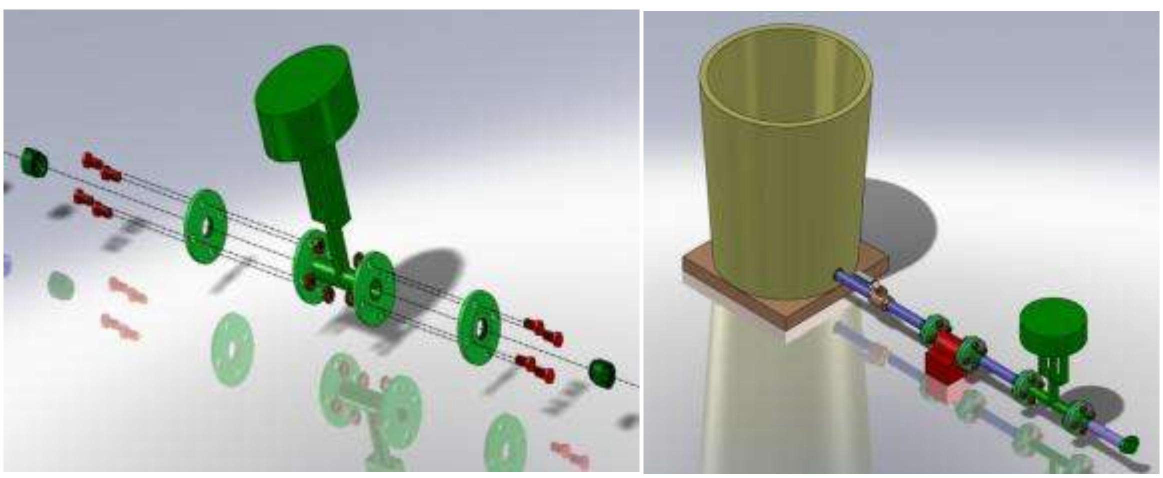


**Figure 87. Control Valve and Flange Fitting Connection.**

5. **Stand Pipe and PVC Couplings.**
   Similar to the storage tank, attach the 1” hole on the bottom of the stand pipe with the PVC tank fittings. First insert the PVC MIPT x Slip connection hex adapter on the outside hole of the storage tank. Secondly, connect the inserted PVC hex adapter with a PVC Female adapter HUB x FIPT connection. Both adapters are connected by threaded connection. After connecting both PVC couplings, apply PVC cement on the gap between the couplings and hole. Figure 88 below shows the assembling schematic.

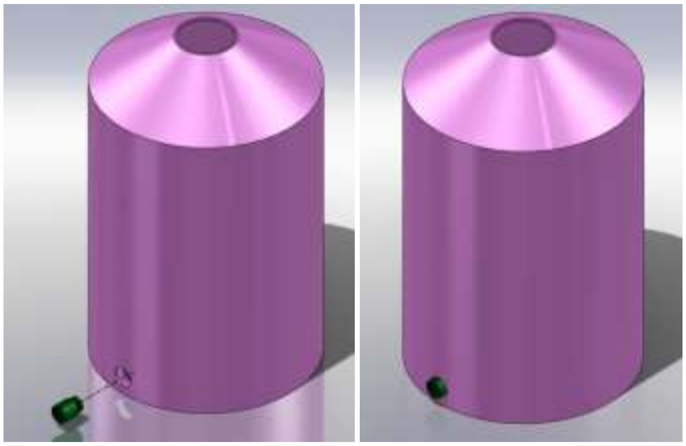


**Figure 88 PVC coupling to Stand Pipe Assembly**

**6. Vertical Pipe Connection to Step 4**

First, attach the elbow pipe to a straight PVC pipe that makes the connection vertical. Then, connect the straight 2' PVC pipe to another 2' PVC pipe with a PVC coupler. Next, attach another coupling to connect it to a 6' straight PVC pipe. After then, attach another elbow pipe that makes the connection back to horizontal. Lastly, connect the elbow pipe to another elbow pipe pointing downwards with a 12" straight PVC pipe. With the assembly done, now connect them to Step 4 assembly using a 6" straight PVC pipe. The PVC pipe connects to a Slip connection for both sides end of the pipe. Figure 89 below shows the final assembly at step 6.

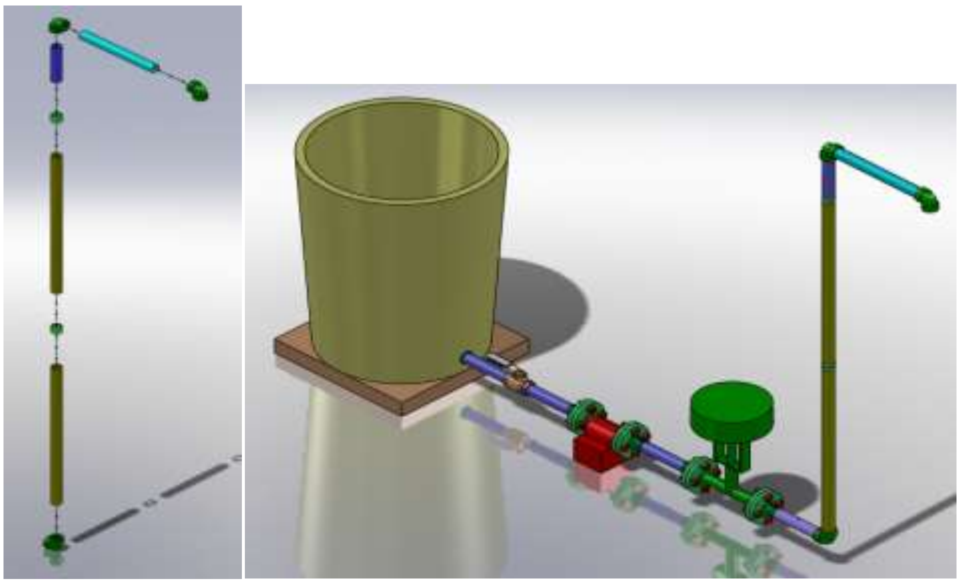


**Figure 89. Vertical Pipe Connection to Step 6 assembly**

**7. Stand Pipe to Storage Tank connection from Step 5.**

Connect Slip vs. NPT thread hex coupler (from Step 5 assembly) to a 3" Straight PVC pipe. Then, attach an elbow pipe to change the direction of connection 90° clockwise and attach the elbow pipe to a 2' straight PVC pipe. Next, using the same method in step 2, connect the 2' straight PVC pipe to a ball valve, then to another 2' straight PVC pipe. After then, connect another 2' straight PVC using a PVC coupler. At the end of the connection, attach another elbow pipe to change the direction facing the storage tank. Then, attach a 6" straight PVC pipe to reach the open hole on top of the storage tank, and attach an elbow pipe to make the connection facing perpendicular to the storage tank hole. Figure 90 below shows the final assembly of step 7.

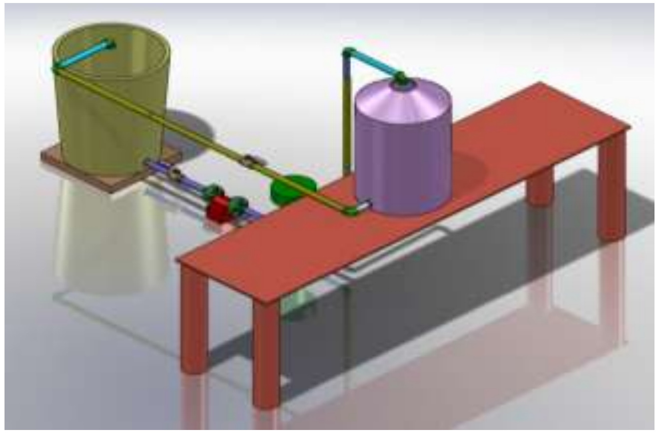


**Figure 90. Stand pipe to storage tank connection from Step 5 schematic**

**8. Pressure Transmitter to Stand pipe**

Connect the NPT threaded connection of the Pressure transmitter (indicated by Hi Port) to the stand pipe 0.5" hole using a stainless steel pipe fittings. The stainless steel pipe fitting has a NPT Pipe x Barbed Tube connection. The low port need no connection since it is required to have it open to the atmospheric pressure. Figure 91 below shows the schematic of pressure transmitter to stand pipe assembly.

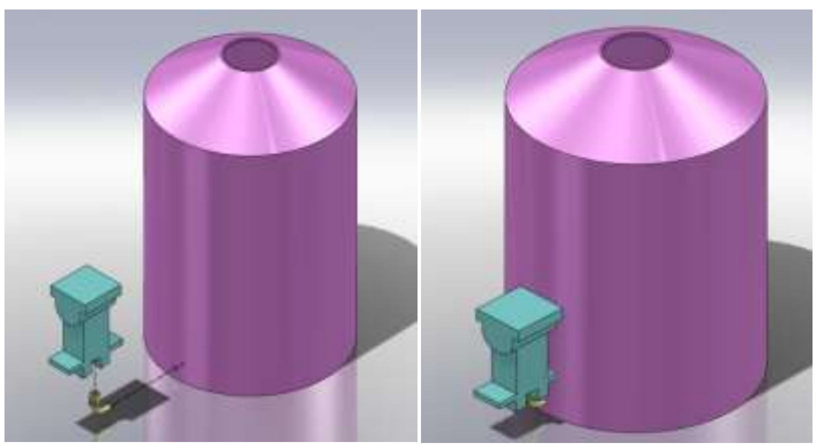


**Figure 91. Pressure Transmitter to Stand Pipe Assembly**

**Fluid Simulator Electrical Component Assembly**

after finished with the mechanical component assembly, we start with the electrical component assembly. The plc sets that are provided by our sponsor consist of a CPU, Hub, Profibus and the module board. The level transmitter needs to be connected to analog input (A/I). The pump and control valve will be connected to analog output (A/O). The diagrams of the connection are shown in figure 92 below. It elaborates how each part is connected according to the port indicated.

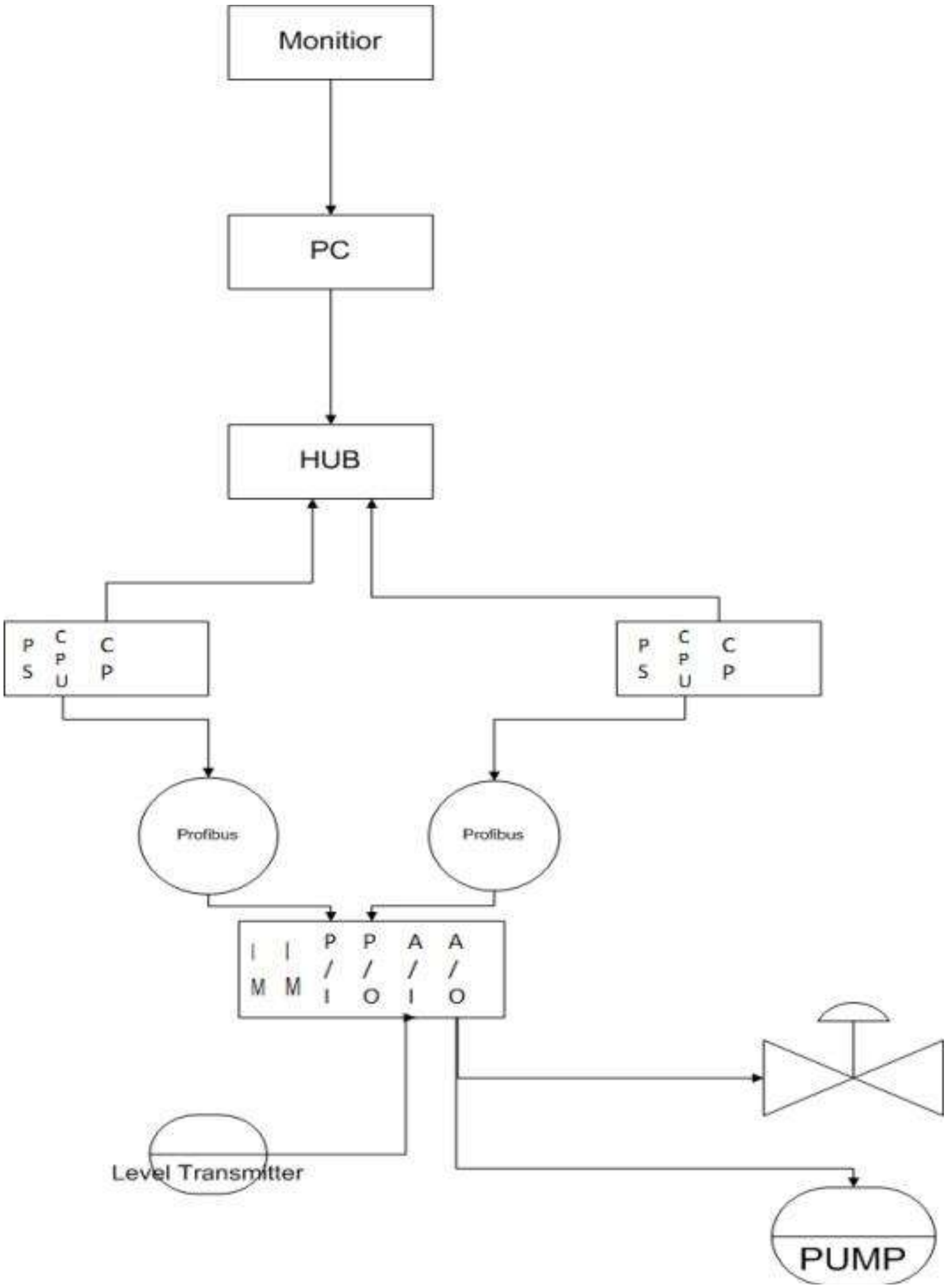



**Figure 92. PLC Connection**

**Location of Assembly and Potential Problems**

To put in all the parts together, we might need a big space. The soldering of electrical components will be carried out in the X50 Laboratory in G.G. Brown building. Assembly of the components will be completed in both the X50 Lab and the Machine Shop.

We are only dealing with hole drilling on the storage tank, stand pipe and PVC pipe. Thus, we need to pay a close attention to the quality of the hole drills to ensure proper fitting on the tank. Furthermore, improper cutting will cause the rough cut edges of the PVC pipe. The quality of gluing the PVC pipe is another important aspect to prevent pipe leakage. We also need to write the code for PLC to control the pump, control valve and pressure transmitter. This must be done correctly ensure the system synchronized and could show the function of level control loop. The other potential problems will be detaching the system and reassembly it once we tested it. Since a lot of materials are glued into the system and the parts will be bulky in size to be transported.

**Validation Plan**

The final design will be tested in the X50 lab. The main goal of this validation project is to ensure the logic of the system works properly and there is not defects on the off-the-shelf products. To validate the system, we will run the system using the pump and water with the actual prototype mechanisms. The following section will go through step by step on validating the prototype.

**Mechanical Testing**

The first thing to do is, fill up water to the storage tank and stand pipe to check if there are any leakages on both reservoirs before turning on the pump. Than let the water flow into pipes to ensure there is no leakage on the joints. No constant source of water will be needed to maintain the storage tank and stand pipe. The initial amount of water required will be transported to the testing place using a bucket or a hose from the nearest sink. An emergency bucket of water will be kept at the side to ensure that the pump remains primed in case of water spillage.

**Parameter Testing**

After going through mechanical testing, we will test if our desired flow rate is achievable. We will need to turn on the pump and tested it to run in three different pump speeds (low, medium, high). Then, we need to have the water flow into the suction inlet of the pump before running it, because it might cause damage for the pump if it is operating dry. In addition to water containment, the electrical outlet used for the circulator pump will be kept at least 5 ft away from the storage tank and stand pipe to ensure that no water splashed onto the cord or onto the outlet. The pressure gauge attach on the pipe after control valve will show the pressure coming from the water and we could convert the pressure to flow rate of the water.

**Logic Testing**

We will write the PLC coding before the testing so it could read the signal send out from the level transmitter. The level transmitter will send the signal of pressure difference in the stand pipe. This test will allow us to determine if the PLC will turn on or off the control valve and pump to let the water flow into the stand pipe once the water in the stand pipe decreases to a certain level. The prototype will have a ball valve connecting the stand pipe to storage tank so the user could drain the water. Moreover, the PLC for the system will be kept in the table separately from the stand pipe. Using these safety precautions will help ensure a safe and successful test of the prototype. The first attempt for the logic might not work during the first trial. Therefore, rewriting the logic might be necessary after validation testing.

The prototype will help validate several aspects of the final design. Validation is essential in proving that our final design will meet the proposed engineering target and specifications. This will be done by building the smaller version of a full scale simulator which could run in smaller flow rate of water and exhibit a water level control logics. However, not all engineering specifications stated can be validated on the prototype due to various constraints. The engineering specifications that will and will not be validated an on the prototype are listed below:

**Table 31: Prototype will validate**

| Prototype will Validate |
|---|
| Instrument testing |
| Logic for Level Control System |
| Stand Pipe Transparency to monitor the level of water |
| Ability to operate at desired flow rate |

In order to validate the ability of the system to run compatibly with an instrument, we will attach an instrument that could read off a parameter from the system. By simply getting a pressure gauge and tap it into the pipe, we will achieve the specifications of testing an instruments.

Both our final simulator design and prototype will incorporate a system logic controlled by PLC. To validate this, we will first write the code for the PLC logic. The PLC logic will read from level transmitter how the pressure in the stand pipe changes and it will be connected to the pump and control valve. This will verify that the PLC could control the water in the stand pipe at the desired level. Moreover, the logic could turn on or off the pump and control valve when desired level of water has been reached.

Validating the stand pipe transparency is trivial task since we only need to get a clear polyethylene tank to fit in the system. Allowing for transparent reservoirs gives the observer a view of the level of water and a sense of interaction. Moreover, the marker on the tank will show level of water flowing into the stand pipe. This will validate the ability of the full size simulator of monitoring the water flowing in and out of the stand pipe.

Volumetric flow rate can be determined from the pump sizing. The volumetric flow rate will determine the ability of the system to deliver water from a reservoir to the stand pipe. Our selected pump has the ability to adjust into three speeds flow rate. The prototype will validate the expected accuracy flow rate for the system in order to create the working full scale simulator. These four specifications are possible to validate through a prototype.

**Table 32: Prototype will not validate**

| Prototype will not validate |
|---|
| ability to calibrate variety of instruments |
| Easy to use of the full size simulator |
| Technician Training |
| Smaller size of full size simulator |
| Robustness and lifetime of the full size simulator |

It will not be possible to test and calibrate variety of instruments in our prototype, as the budget constraint from our project. For the final design, it is critical to ensure that we would not only calibrate one instrument in the simulator but also several instruments in one time since this will save the technician working time. In the full size simulator, the testing slots are usually used to calibrate flow meter, pressure transmitter and pressure regulating valves.

One of the main concerns of the ease of use of the simulator is the accessible path and working area to the testing slots. It will not be able to validate in our prototype since it is a simplify system that only has one instrument attached on the system. We will not be able to test how long it takes to attach the regular instruments and detach it. The prototype will not have a big working space as the full scale simulator required in which each instruments are big in size.

Technician training is part of the customer requirements for the full scale simulator. It is required that the technician running the final design simulator will be able to calibrate an instruments and shutting off the instruments off in case of emergency. This is not possible to be validated in our prototype since our prototype has no testing slots for the instruments calibration and the required instruments to shut off the pump during emergency are not in the prototype.

Smaller size of full size simulator is required in the design of the full design simulator. However it is hard to be validated in our prototype, since it is only parts of the whole full design simulator. Moreover, the prototype is only running a fraction of the full size simulator parameters.

We are not able to test the robustness and life time of full size simulator since the prototype is the smaller version of full scale design which run on smaller parameter and uses a different materials. The prototype is made from different materials than the final design, and because experimental testing is only intended to prove functionality of the simulator, no lifetime testing will be conducted.

## PROJECT PLAN

In the following section the most important goals we must accomplish are highlighted. These goals are divided into two parts, full scale design and prototype. For a complete list of goals and corresponding expected dates for completion refer to the Gantt chart in Appendix G

### Full Design

#### Manual for Station Plan

We are going to have the manual for the station plan done by November 24. This manual is required by our sponsor and is due on November 25th. The manual will include wiring schematics of the system and manual how to calibrate the instruments. The simulator team will start working on this after the DR3 report is due.

### Prototype

#### Materials for Assembly

We would like to have all of the required materials for assembly of the prototype by November 23. These materials include the storage tank, stand pipe, PVC piping, fittings and pump. The manufacture parts of the prototype will be done in Home Depot and have it done by November 21.The assembly parts are off-the-shelf from Home Depot and Stadium Hardware. The stand pipe has been shipped here and estimated time for it to be here is by November 20.

#### PLC Control Logic

To write the code for PLC control might be the biggest challenge for the prototype to work properly. Besides that, we can only tested if the code works or not once we assembly everything. We want to have the PLC logic completed before initial prototype testing November 29th. Demo Team will start working on this after DR3 report is due.

#### Initial Prototype Testing

After finishing assembly and writing the logic for PLC we will run an initial test to approve the fabrication of the complete device by November 30. The initial prototype testing will be completed by filling up water into the storage tank and stand pip and pumping the water from storage tank to stand pipe using the circulatory pump. Furthermore, we will also test the logic that we write in the prototype.

#### Final Prototype Testing

After initial prototype testing, improvement might be made for the prototype. There might be problems on the assembly parts and we might need to buy additional parts for the prototype to work properly. We might also encounter problems with the PLC and need to rewrite the logic. We hope to finalize the testing before DR4 which is December 3rd. if further testing is needed, we could do it after DR4 which is a week before design expo.

**Logistical, Special Challenges and Contingency Plan**

The biggest problem we might encounter is the writing logic code for PLC. All of us have no prior experience to this PLC logic. It might take us some time to understand the program. Moreover, we have thanksgiving break coming and DR4 is actually due after thanksgiving. Thus, we will start writing the logic after DR3 report due. Our sponsor also gave us the number of the Siemens supplier who is Michigan based and he might be able to troubleshoot our logic if we encounter any problems.

We need to establish electrical connection for the instruments and pump for the prototype. This might be time consuming and might not work at the first time. Thus, we will work on this in the X50 lab where we could get the materials needed and get assistant from GSI if necessary.

**Contingency Plan**

There are unexpected things could happen in the validation testing and in the expo for the prototype. The following will list the possible potential problems that might occur in the testing and the possible back up plan to solve the problems.

**Table 33: Potential problems in the prototype**

| Potential Problems Occur in the Prototype |
| --- |
| Crack in the water reservoir |
| Leakage in the piping connection |
| Pump is not working |

Crack in the water reservoir might happen during testing. Inappropriate handling of the material and production defect might lead to this problem. If by any chance this happen in the expo, we will rearrange the pipe connection so the water will flow back into one tank instead of using two tanks.

We will prepare some spare piping during the testing and design expo. We will have the glued pipe and regular pipe prepared for the incidental needs. The PVC cement glued in the pipe takes time to dry up that is why we need to have spared glued piping.

In the worst case scenario, the pump might not be pumping water from the storage tank to the stand pipe. We will just put in water in the storage tank and rearrange the piping so water could flow from the storage tank to stand pipe by gravity pull.

**Design Critique of Full Scale Simulator**

- Existing Simulator
    - Layout
    - Cost
- Equipments/Instruments/Components
    - Type
    - Cost

One of the engineering specifications that we were unable to fulfill was the designed floor space of the simulator. Since the start of the project, we were unable to full grasp the actual layout of the whole system. Our sponsor was only able to provide us with pictures of the current simulator; so we were only able to use the bricks on the wall as a measuring tool to estimate the floor size of the current simulator. Through this primary problem, we were unable to evaluate the down size of 25% accurately and led to the inability to fulfill that engineering speciation. Another reason we were over our expected floor size was the extra space in the center of our re-designed simulator, we had constructed a small floor area for the installation of the PLC system which our existing simulator had outside their floor plan. We believe that with a clearer quantifiable start, we would be able to design a better layout to fulfill that specification. Another problem we had were the instruments and devices used and also the cost of the existing simulator. As we were unable to visit and obtain data on the current simulator, we had to look for the equipments based on the pictures that were given to us. We would be able to calculate the cost of the re-designed simulator and provide an analysis of the cut-cost. In conclusion, we believe we would be able to provide a clearer analysis and designed a better simulator.

**Recommendations for Full Scale Simulator**

Firstly, we believe a clearer communication to the actual simulator site would have allowed us to work on the project more efficiently. A scheduled visit to the power plant simulator would also allow us to get a better understanding and a direct view of what the simulator looked like. We would then be able to obtain information from the technicians that are currently maintaining that simulator and learn what additional specifications are required to make it better.

**Prototype Validation Results**

Fabrication and testing of the prototype was successful and confirmed the functionality of the prototype in representing partial functions of the full scale simulator.

The validation of the stand pipe transparency and attaching instruments was possible through the fabrication of the prototype. In prototype fabrication plans, it was ensured that all these specifications were met and thus were validated. The instrument was attached in between pump and control valve and is able to read off the pressure of the water. The volumetric flow rate was validated through the three speed of the pump. It is observed in the stand pipe, how fast could the water in the stand pipe filling up to the desired set point.

After calibrating the level transmitter, we connected the level transmitter to the PLC. The PLC is programmed so it could proportionally adjust the control valve according to the level transmitter input. The control valve travelling range is 0% for fully closed and 100% for fully opened. For testing purpose, we use the 25 gallons of water at our set point. The logic was tested by filling up the storage tank and let the pump filled up the stand pipe. It is observed that the pump and control valve was shut off right after it reaches 25 gallons of water. When the water was drained out from the stand pipe, the control valve and pump was turned on to maintain the level of water we had previously set. The corresponding value in the validation for of the level transmitter input with the gallons of water in the standpipe is summarized in the table 34 below.

**Table 34. Calibration of logic and stand pipe**

| Level Transmitter Input (%) | Gallons of Water | Control Valve Travelling (%) |
|---|---|---|
| 100 | 25 | 0 |
| 90 | 22.5 | 10 |
| 80 | 20 | 20 |
| 70 | 17.5 | 30 |
| 60 | 15 | 40 |
| 50 | 12.5 | 50 |
| 40 | 10 | 60 |
| 30 | 7.5 | 70 |
| 20 | 5 | 80 |
| 10 | 2.5 | 90 |
| 0 | 0 | 100 |

The viability of the final design was confirmed through the ties between the prototype and the final design. The PLC, level transmitter and control valves are part of the final design instruments. Being able to operate and integrate the instruments to our prototype shows the validity of our final design.

**Design Critique of Prototype Simulator**

Our prototype was able to validate the strength of the final design. The prototype demonstrates the logic controlling instruments of the full scale simulator. It is able to demonstrate the simple level maintaining logic. Once the water drained out from the stand pipe, the logic could sense the level difference and fill up to maintain the level of the water. The logic could also control the valve proportionally to the level of the water in the stand pipe. The transparent stand pipe gave the user ability to observe the level of water flowing out and observe the set point for level of water maintain in the stand pipe. The prototype could also show ability to attach instruments in the system. In which validate the ability of integrating testing slots in our full scale simulator.

Although our prototype could show the proper water circulation from the storage tank to the stand pipe, there are aspects that could be further improved. The joint for the pipe and fittings are vulnerable to leakage. The connection between the pipe and the pump is prone to leak because it is different materials. In the storage tank, the fittings attached are prone to leakage due to improper drilling of the storage tank.

Secondly, The PLC is a powerful automation controlling tools that we could further explore if we have enough time. We could have integrated a more complex logic to control the system as in the full scale simulator. The PLC could be programmed such that giving an alarm warning when the water fall below and or go above a certain range. It might also be possible for the PLC to control the speed of the pump instead of just turning it on or off.

Thirdly, The prototype does not have the ability to attach testing slots for instruments calibration. This is due to budget constraint and size constrain for our prototype. If the budget allowed, we will be able to validate the amount of time needed to attach instruments into the testing slot. We could have also validated allowable working space needed to attach and detach instruments.

**Conclusions**

We conclude that the full scale simulator we have design has met the required requirement and specification in terms of ease of use, able to calibrate instruments, cost, weight, and technician training. The reason we are unable to fulfill the requirement of size is due to the additional size designed within the simulator to include the size of the PLC system. When we initially estimated the floor size of the current simulator, we did not take the PLC system into our calculations, thus ending up with a bigger floor size then predicted. The physical layout of the actual simulator was approximated from visual images to generate the components size for the analysis. Then, brainstormed ideas and engineering analysis are performed in parallel to generate different selections for the new full scale simulator.

A scaled prototype is manufactured to validate the functions of the full scale simulator physically. Overall, we have successfully designed and prototyped a power plant fluid simulator that validates the level control, size, and cost of the full scale simulator. Our system literature focuses mainly on its ability to control water level inside the standpipe using the logic controls and instruments. Several functions of the real simulator such as: instrument calibration and the availability of testing slots are not imbedded in the system due to budget constraints. Furthermore, the prototype components are 90% purchased off the shelf or loaned; selection of parts are assisted by third party plumbing expert; this is done to ensure safety in the prototype design assembly and fabrication processes. Upon completion, validation tests are completed with the Section professor and GSI.

With our research and results, the prototype in the future could be improved. Some of our recommendations include adding testing slots for instrument calibration and flow meters to further validate the real simulator yet in far smaller size and cost.

**References**

[1] United States Department of Energy. Net Generation By Energy Source [Data File]. Retrieved from http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html

[2] Greg, Gerald. Training Simulator for a Nuclear Power Plant. U.S. Patent 4,997,529 filed Feb 23, 1973, and issued December 11, 1990

[3] Desalu, Adewunmi. Engineered Safeguard systems and method in nuclear power plant simulator. U.S. Patent 4064,392 filed Oct 31, 1974, and issued December 20, 1977

[4] Chung, Jibum. "Onboard testing of the Control System in the LNG Carrier Using a Dynamic Simulator" http://sim.sagepub.com/cgi/content/abstract/78/2/113

[5]Watson McDaniel Company. Retrieved from <http://www.jiajievalve.com/PDFfiles/Regulator-Pressure_Regulating_Valves-B.pdf>

[6]Brooks Inc. Retrieved from <www.temflow.se/pdf/temflow_brooks_GT1000.pdf>

[7]Emerson Process. Retrieved from <www.emersonprocess.com/Rosemount/document/pds/1151.pdf>

[8] Ashcroft Inc. Retrieved from <www.ashcroft-gauges.com/pdf/1279.pdf>

[9]Signet Co. Retrieved from <http://www.panner.com/assets/pdf/Signet2551spec.pdf>

[10]Masoneilan. Retrieved from <http://www.masoneilan.com/internet/businessunits/measurement/subunits/masoneilan/products/reciprocating/21000.cfm>

[11] Masoneilan. Retrieved from http://www.masoneilan.com/internet/businessunits/measurement/subunits/masoneilan/products/pneumatic/cr3000.pdf

[12]Fristam Pumps USA. http://www.fristam.com/MenuNav/Whoweare/tabid/54/language/en-US/Default.aspx

[13]Stan Samuelsen, Pump Director. Corrossion Fluid Products Corporation.

[14] Sargent & Lundy.

*[15]Wikipedia. Retrieved from <http://en.wikipedia.org/wiki/Human_height*>

*[16]* Eyeway. Retrieved from <*http://www.eyeway.org/informs/eye-care/ideal-reading-distances*>

*[17]Ace Hardware. Retrieved from <http://www.acehardware.com/product/index.jsp?productId=2242683&cp=2568443.2568451.2626212.1260276>*

[18] "Types of Valves - Ball Valve", Retrieved 12 October 2009, http://profmaster.blogspot.com/2008/10/type-of-valves-ball-valve.html

[19] "Knowledge Publications", Retrieved 12 October 2009, <http://knowledgepublications.com/doe/doe_mechanical_science_web_educational_textbook_solar_hydrogen_fuel_cells.htm>

[20] Answers.com, Retrieved 12 October 2009, <http://www.answers.com/topic/globe-valve>

[21] Wikipedia.org, Retrieved 20 October 2009, < http://en.wikipedia.org/wiki/Globe_valve>

[22] Crane. "Flow of Fluids Through Valves, Fittings and Pipe". Crane Co. Shenandoah: 1988

[23]Engineering Toolbox. Retrieved from <http://www.engineeringtoolbox.com/pumps-parallel-serial-d_636.html>

[24] Expo Inc. Retrieved from <http://www.expo21xx.com/automation77/news/2095_control_mitsubushi/robotics_control_plc.jpg>

[25] http://www.wastechengineering.com/images/vfd.gif

[26] http://www.keil.com/support/man/docs/mcb2300/mcb2368-2387_board.jpg

[27] McMaster-Carr. http://www.mcmaster.com/#pipe-supports/=45awvx.

[28] http://www.miroind.com/images/prod_images/PH/Large/ph25_SB_H.jpg

**[29] Mcmaster. Retrieved from <** http://www.mcmaster.com/#centrifugal-pumps/=46ja3j>

[30] "Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-coated, Welded and Seamless", ASTM A53, Accessed on November 1, 2009.

[31] R.C. Hibbeler, "Static and Mechanics of Material", 2nd edition, New Jersey: Pearson, 2004.

[32] Kurniawan, Sutrisno. PERSONAL INTERVIEW. 5 November 2009.

[33] Engineering Tool Box. "ANSI rating". Accessed on 5 November 2009. <http://www.engineeringtoolbox.com/steel-flanges-pressure-rating-d_49.html>

**Appendix A: Bill of Materials**

| Item | Quantity | Source | Catalog Number | Cost/Piece | Cost | Contact |
|---|---|---|---|---|---|---|
| Pump | 1 | Stadium Hardware | n/a | 150.48 | 150.48 | 19132273400 |
| Stand Pipe | 1 | CSI Industry | n/a | 102 | 102 | (262)-375-8570 |
| Small Purple Primer | 1 | Carpenter Brothers | 212 | 3.79 | 4.018048 | (734) 663-2111 |
| 8" Cable tie | 1 | Carpenter Brothers | 440868 | 5.29 | 5.608304 | (734) 663-2111 |
| 1/2" Teflon Tape A | 1 | Carpenter Brothers | X520 | 1.79 | 1.897706 | (734) 663-2111 |
| 1/2" Teflon Tape B | 1 | Carpenter Brothers | X260 | 1.49 | 1.579655 | (734) 663-2111 |
| Marine Seal | 1 | Home Depot | 51135052037 | 6.86 | 6.86 | (734) 975-1029 |
| Electrical Connection | 1 | Stadium Hardware | 125728 | 7.5 | 7.951282 | 19132273400 |
| 2' PVC Pipe | 9 | Home Depot | 6119421 | 1.6 | 15.26646 | (734) 975-1029 |
| 1" PVC Ball Valve | 2 | Home Depot | 8794200 | 4.92 | 10.43208 | (734) 975-1029 |
| 1" PVC Elbow 90 Pipe | 5 | Home Depot | 12871623356 | 0.44 | 2.332376 | (734) 975-1029 |
| 1" M Adapter | 2 | Home Depot | 12871626050 | 0.53 | 1.123781 | (734) 975-1029 |
| 1" PVC Coupling | 2 | Home Depot | 78864430103 | 0.38 | 0.80573 | (734) 975-1029 |
| 1" PVC Bushing | 2 | Home Depot | 12871626630 | 1.02 | 2.162749 | (734) 975-1029 |
| 1" PVC Fitting | 2 | Home Depot | 12871559273 | 0.88 | 1.865901 | (734) 975-1029 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2x4-96 Stud | 2 | Home Depot | 7.61542E+11 | 1.95 | 4.134667 | (734) 975-1029 |
| 1" M Adapter | 2 | Home Depot | 1.28717E+11 | 0.53 | 1.123781 | (734) 975-1029 |
| 2' PVC Pipe | 2 | Home Depot | 6.11942E+11 | 1.6 | 3.392547 | (734) 975-1029 |
| 1" PVC Coupling | 1 | Home Depot | 12871625015 | 0.38 | 0.402865 | (734) 975-1029 |
| 1" PVC Elbow 90 Pipe | 1 | Home Depot | 12871623356 | 0.44 | 0.466475 | (734) 975-1029 |
| Terminal | 1 | Home Depot | 81203000059 | 0.35 | 0.37106 | (734) 975-1029 |
| 3/4" Female Adapter | 1 | Home Depot | 34481000082 | 0.35 | 0.37106 | (734) 975-1029 |
| Cord | 2 | Carpenter Brothers | 506722 | 8.99 | 19.06187 | (734) 663-2111 |
| Steel Struts | 1 | Stadium Hardware | - | 20.96 | 22.22 | (734) 663-8704 |
| Steeld Rod | 1 | Stadium Hardware | 313261 | 11.07 | 11.73 | (734) 663-8704 |
| 1.5x5 CI Comp Flange | 1 | Wolverine Supply | 50820 | 12.6 | 13.35815 | 7346659771 |
| 0.5x1.75 bolts | 8 | Wolverine Supply | 510029 | 0.22 | 1.865901 | 7346659771 |
| 0.5 Nuts flex | 8 | Wolverine Supply | 51002 | 0.06 | 0.508882 | 7346659771 |
| 1.5 PVC 40 m Adapter | 2 | Wolverine Supply | 1090210 | 0.66 | 1.399426 | 7346659771 |
| Galvanized Bushing | 1 | Home Depot | 32888309333 | 1.58 | 1.67507 | (734) 975-1029 |
| #17 O Ring | 1 | Home Depot | 0.371559673 | 1.97 | 2.088537 | (734) 975-1029 |
| Trash Can | 1 | Home Depot | 86876131567 | 29.97 | 31.77332 | (734) 975-1029 |
| Conduit lckn | 1 | Home Depot | 51411261979 | 0.91 | 0.964756 | (734) 975-1029 |

| | | | | | | |
|---|---|---|---|---|---|---|
| PVC Bushing | 1 | Home Depot | 12871627293 | 0.6 | 0.636103 | (734) 975-1029 |
| 3/4 M Adapter | 1 | Home Depot | 012871626036 | 0.32 | 0.339255 | (734) 975-1029 |
| CMT Handypack | 1 | Home Depot | 038753302485 | 6.96 | 7.37879 | (734) 975-1029 |
| Refund | 1 | Stadium Hardware | n/a | -8.33 | -8.33 | (734) 975-1029 |
| **GRAND TOTAL** | | | | | **$431.3166** | |

**Appendix B: Description of Engineering Changes since Design Review #3**

**Appendix C: Design Analysis**

1. **Material Selection – Functional Performance**

The two components to be investigated for material selection are the pipes for full-scale simulator and the pipes for demo prototype. The full-scale simulator pipe must withstand extremely large tensile load, shear stress, and bending moment due to the weight of itself and the weight of water contained in it. It must also have a good corrosion resistant property. The demo prototype pipe must withstand shear stress and bending moment as well as minimizing the cost for each objective.

The material indices were plotted on log-log axes. In general, the numerator and denominator of the material index were separated allowing each to be potted on separate axes. Then, a coupling line is formed to allow easier method of picking the materials. Materials that fell on the same coupling line would perform equally well when used on the same component. Because more than one index were compared for each piping, the optimum material could be the best combination between the indices. Thus pugh chart is utilized to select the best material.

**Full-scale Simulator Piping**
**Function:** Pipe containing high speed and high pressure water (Pipe in tension, shear, and bending moment)
**Objective:** Contain the pressurized water; minimize mass of the pipe by minimizing density (to minimize forces), corrosion resistant
**Constraints:** L is fixed, $D_i$ is fixed, no yield, deflection cannot exceed 0.15”

The specific material selection criteria for the full-scale simulator piping are presented above. Two performance indices were used for the material selection: stiffness limited, and strength limited. These were chosen to avoid failure by yield, and failure at the joints of the pipes due to deflection. The resulting plot of strength limited index is presented in figure C.1. In addition, a plot of materials with stiffness limited was also made, but it is not included since it is of the same style as figure C.1. Instead, the results are presented in Table C.1.

The top five material choices and their selection are shown in Table C.1. These were chosen as the best overall performing materials considering the combination of performance indices. The best performance was determined by looking at the performance indices for each of the five material and utilize pugh chart system to choose the best material.

**Table C.1: Material choices for the full-scale simulator piping. Materials are ranked from 1 to 5 for each performance attribute (1 being the worst, 5 being the best)**

| Material index | Stiffness limited $E/\rho$ | Strength limited $\sigma_y/\rho$ | Total |
|---|---|---|---|
| Carbon steel, AISI 1141, tempered at 650 C and oil quenched | 3 | 4 | 7 |
| Epoxy SMC (carbon fiber) | 5 | 1 | 6 |
| PA (type 612, 10% PTFE/30% PAN carbon fiber, lubricated) | 4 | 1 | 5 |
| Tungsten carbide-cobalt (74.8) | 1 | 4 | 5 |
| Cobalt base superallot, MAR-M 509 cast | 3 | 3 | 6 |

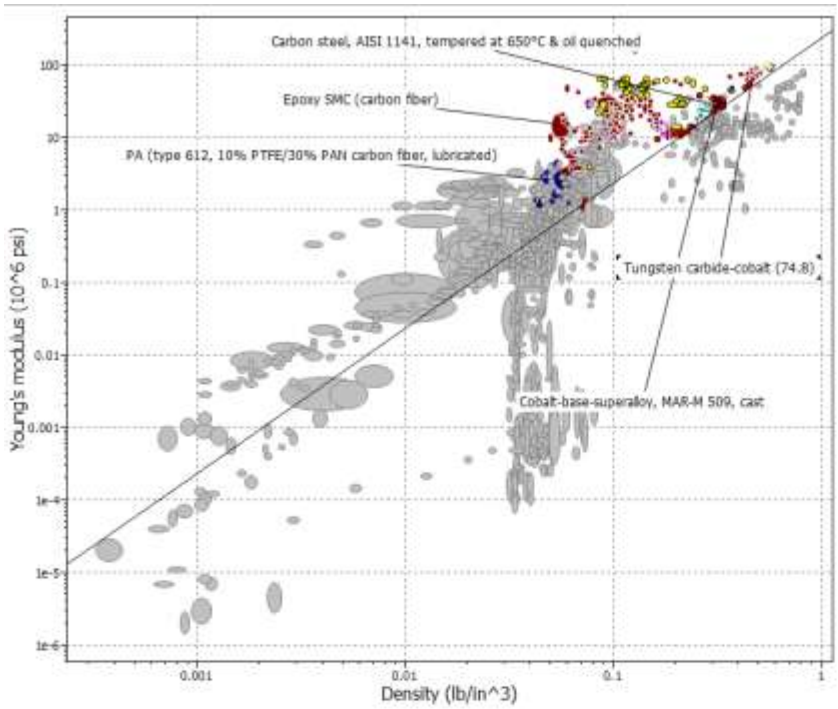



**Figure C.1: Log-log plot of performance index for full-scale simulator piping**

The top material selected was AISI 1141 carbon steel tempered at 650$^{o}$C and oil quenched. This material was chosen due to its excellent strength and stiffness. It has an acceptable rate for water exposure which is crucial since the piping will contain water inside. It is also 30 to 100 times cheaper compared with the other materials. Furthermore, actual power plant also uses steel in its piping system, by using the same material for our simulator, we can get similar pipe friction effect to ensure even greater accuracy in our simulator.

**Prototype Piping**
**Function:** Pipe containing pressurized flowing water (Pipe in tension, shear, and bending moment)
**Objective:** Contain the pressurized water; minimize mass of the pipe by minimizing density (to minimize forces), corrosion resistant
**Constraints:** L is fixed, no yield, deflection cannot exceed 0.05"

The specific material selection criteria for the prototype piping are presented above. Three performance indices were used for the material selection: stiffness limited, strength limited, and price. These were chosen to avoid failure by yield, failure at the joints of the pipes due to deflection, and to minimize the total cost of the piping.  The resulting plot of strength limited index is presented in figure C.2. In addition, a plot of materials with stiffness limited was also made, but it is not included since it is of the same style as figure C.2. Instead, the results are presented in Table C.2.

The top five material choices and their selection are shown in Table C.2. These were chosen as the best overall performing materials considering the combination of performance indices. The best performance was determined by looking at the performance indices for each of the five material and utilize pugh chart system to choose the best material.

**Table C.2: Material choices for the prototype piping. Materials are ranked from 1 to 5 for each performance attribute (1 being the worst, 5 being the best)**

| Material index | Stiffness limited $E/\rho$ | Strength limited $\sigma_y/\rho$ | Price | Total |
|---|---|---|---|---|
| Palm (0.35) | 3 | 5 | 5 | 13 |
| Aluminum-SiC foam (0.27) | 3 | 4 | 3 | 10 |
| Graphite foam (0.12) | 1 | 2 | 1 | 4 |
| Cork (low density) | 1 | 1 | 4 | 6 |
| PVC foam: rigid closed cell (0.046) | 5 | 3 | 3 | 11 |

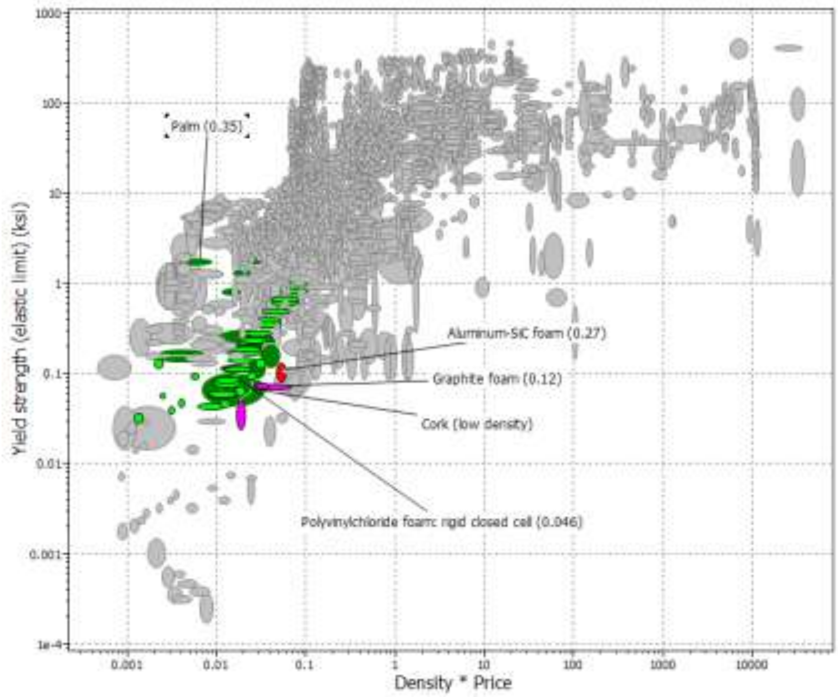



**Figure C.2: Log-log plot of performance index for demo prototype piping**

The top material selected was Palm due to its superior strength and price. However, it is virtually impossible to find pipe that was made out of palm, thus we decided to use the second best option that was PVC. PVC pipe is easy to find, has excellent stiffness, good strength and also excellent durability against fresh or salt water.

### 2. Environmental Performance

The existing full-scale simulator uses a combination of Steel and PVC pipe, while our final design utilized full steel pipe due to customer requirement. In this section, we shall analyze the environmental performance of our full-scale simulator if it were to use all steel piping or all PVC piping.

In our design, we used 3” schedule 40 pipe with total length of 3468”. This translates to 987 kg of mass for all steel piping, and 185 kg for all PVC piping. An environmental performance analysis was ran using SimaPro 7. Results from the run are shown on the following figures.

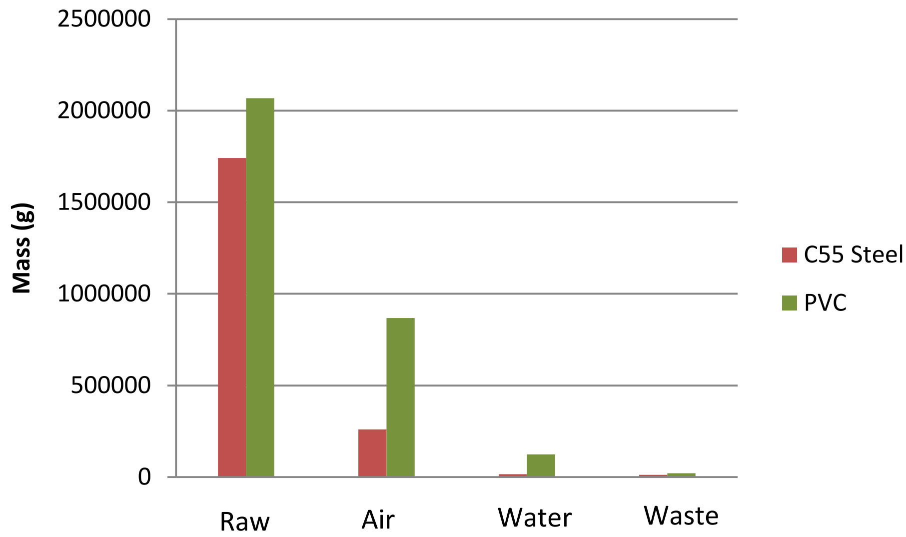



**Figure C.3: Emission comparison between C55 Steel and PVC showed us that PVC consumes more mass of resource (raw, air, water) compared with C55 Steel, PVC also produces more waste**

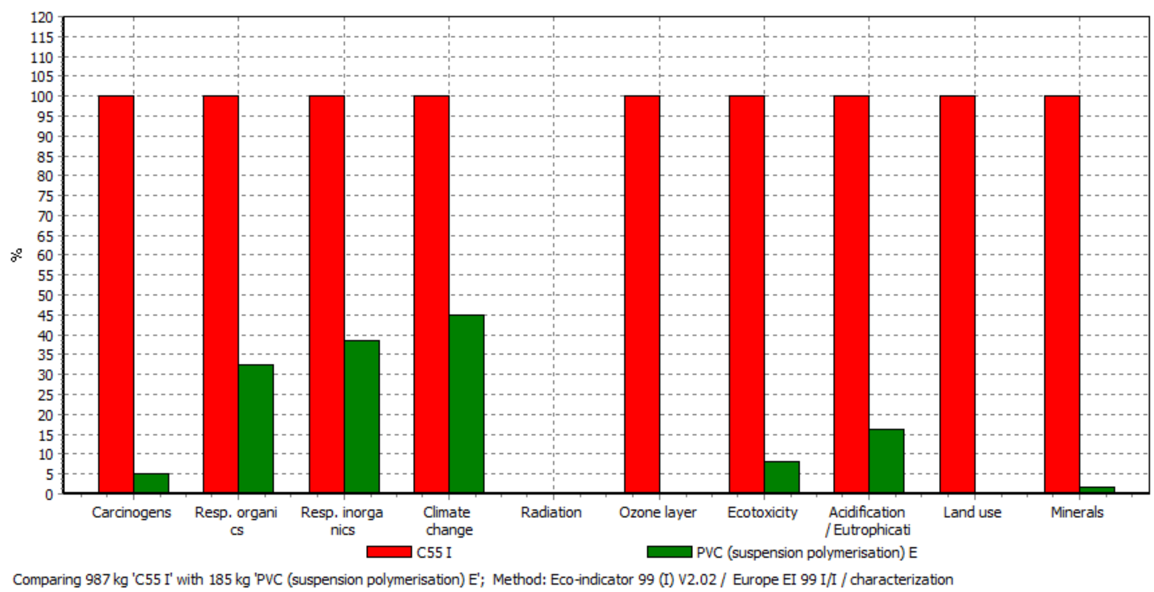



**Figure C.4: Relative Impacts in Disaggregated Damage Categories, C55 Steel has much worse impact to the environment (higher points means worse)**

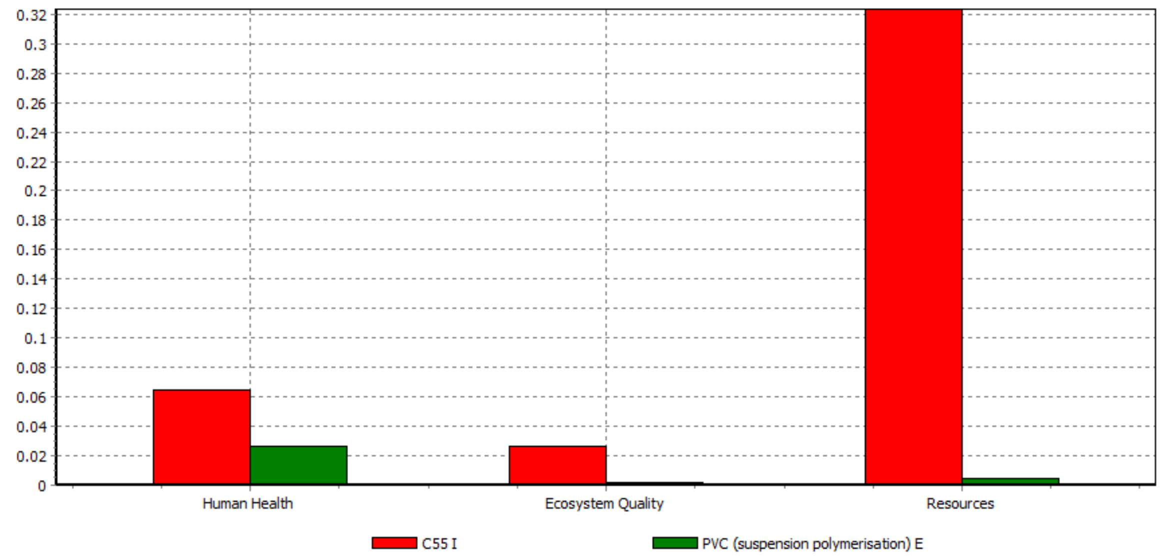



**Figure C.5: Normalized Score in Human Health, Eco-Toxicity, and Resource Categories (higher points means worse for the environment)**

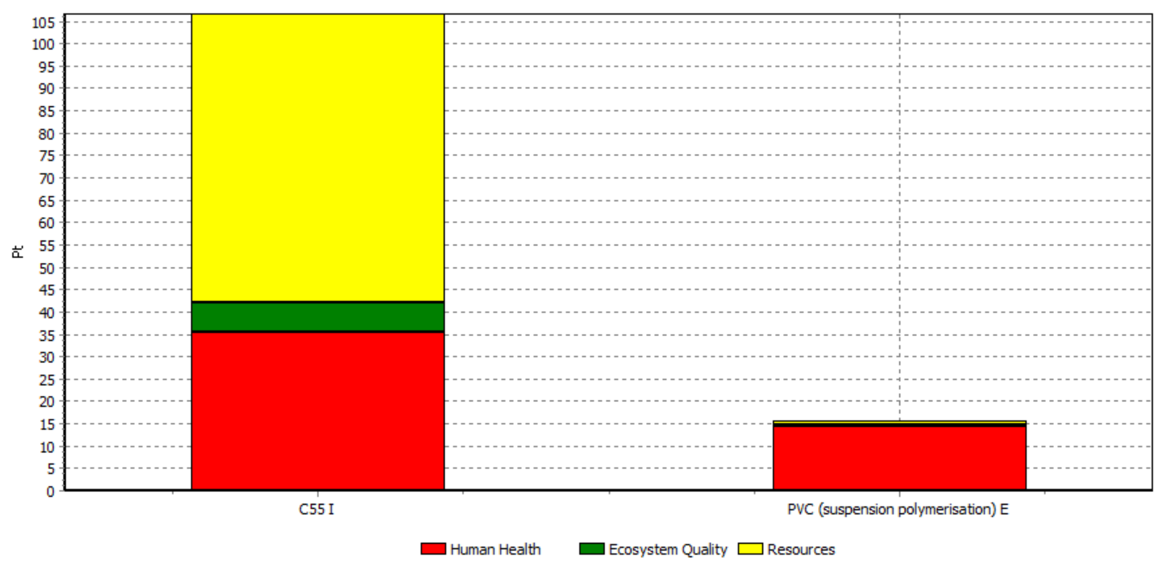



**Figure C.6: Single Score Comparison in "Points", steel has bigger negative impact to the environment compared with PVC (higher points means worse for the environment)**

For our design, C55 steel is much worse for the environment compared with PVC (Figure C.6). Overall, more resources are needed to use C55 steel for our design (Figure C.5). The meta-category of "Resource" has the highest score in our analysis, so the damage caused by resources to the environment plays the most significant factor in the total damage. Steel requires complicated process, large amount of minerals and other resources to produce, while PVC uses much less resource demand in comparison.

Second most important meta-category for this comparison is the "human health". C55 steel is again worse in human-health impact compared with PVC (Fig C.5). Figure C.4 shows us, steel has high impact on carcinogens and respiratory organics and inorganic. Overall, producing steel has a much larger negative impact to human health than producing PVC. The last meta-category is "Ecosystem quality". Again, steel is worse compared with PVC. The score for this category however is much lower compared with the previous two categories. Thus it does not have as big of an impact as the others, however it is still an important factor to consider.

When considering the entire lifetime of the design, the environmental changes slightly. The existing simulator is going through its 30$^{th}$ year in service now, thus our simulator is expected to have the same life cycle. Steel pipe will contain water, thus exposing itself to highly corrosive environment. Throughout the later part of its lifetime, it will be subject to breaking down due to corrosion. PVC will not have corrosion problem. However, given its lower strength, it may be more prone to failure due to fatigue. Without the data of steel pipe and PVC pipe lifetime, it is impossible to determine which material is worse for the environment when the life cycle of the design is considered, especially when the lifetime of the product is this long. PVC might have a slight advantage due to its much lower one-time manufacturing impact, but more research needs to be conducted on how often will the two material breaks down.

In the future, when the supporting data has been gathered, it may shows that PVC has lower negative impact to the environment even after considering the lifetime of the product. In environmental perspective, we will choose PVC over steel. However, we may still to choose steel material in the end due to its higher strength. It should be noted that the main reason why we choose steel is because actual power plant also uses steel piping. Thus by using similar material, which is our customer requirement, we can provide a more accurate flow in our simulator.

### 3. Manufacturing Process Selection

Since our simulator and the existing simulator are meant to test and calibrate the instruments of nuclear power plant, the maximum number of simulator that is beneficial should be the total number of nuclear power plant around the world. Currently there are around 436 nuclear power plants in the world, with US alone operates 104 of them [1].

**Full Scale Simulator-Pipe**

Several selection criteria were used to determine which manufacturing process is best to produce our pipes. First, the pipes are assumed to be a circular prismatic, hollow 3-D shape which would first be manufactured by a primary shaping processes. Next, the mass of the total pipe used in this design was used to eliminate manufacturing processes that would not be compatible with this design.

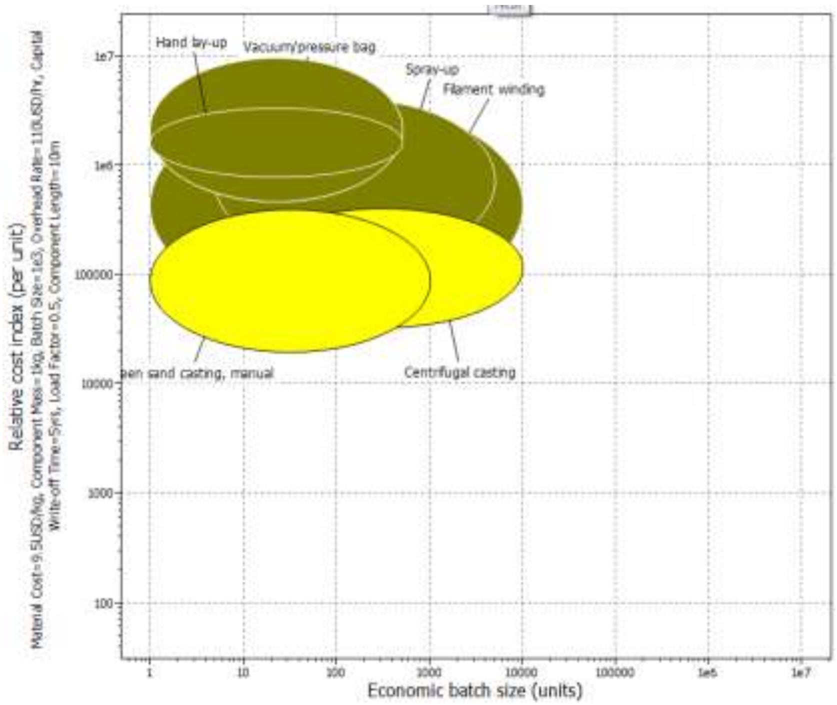



Figure C.7: Centrifugal casting was selected as the primary manufacturing process for the full-scale pipe

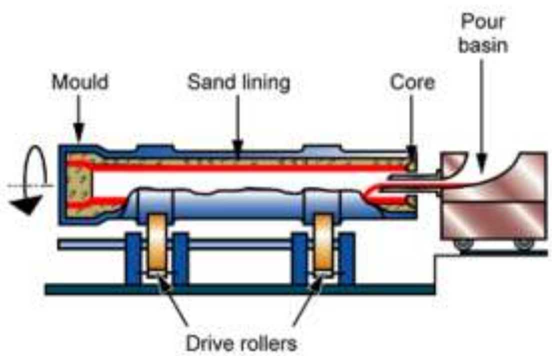



Figure C.8: Centrifugal casting

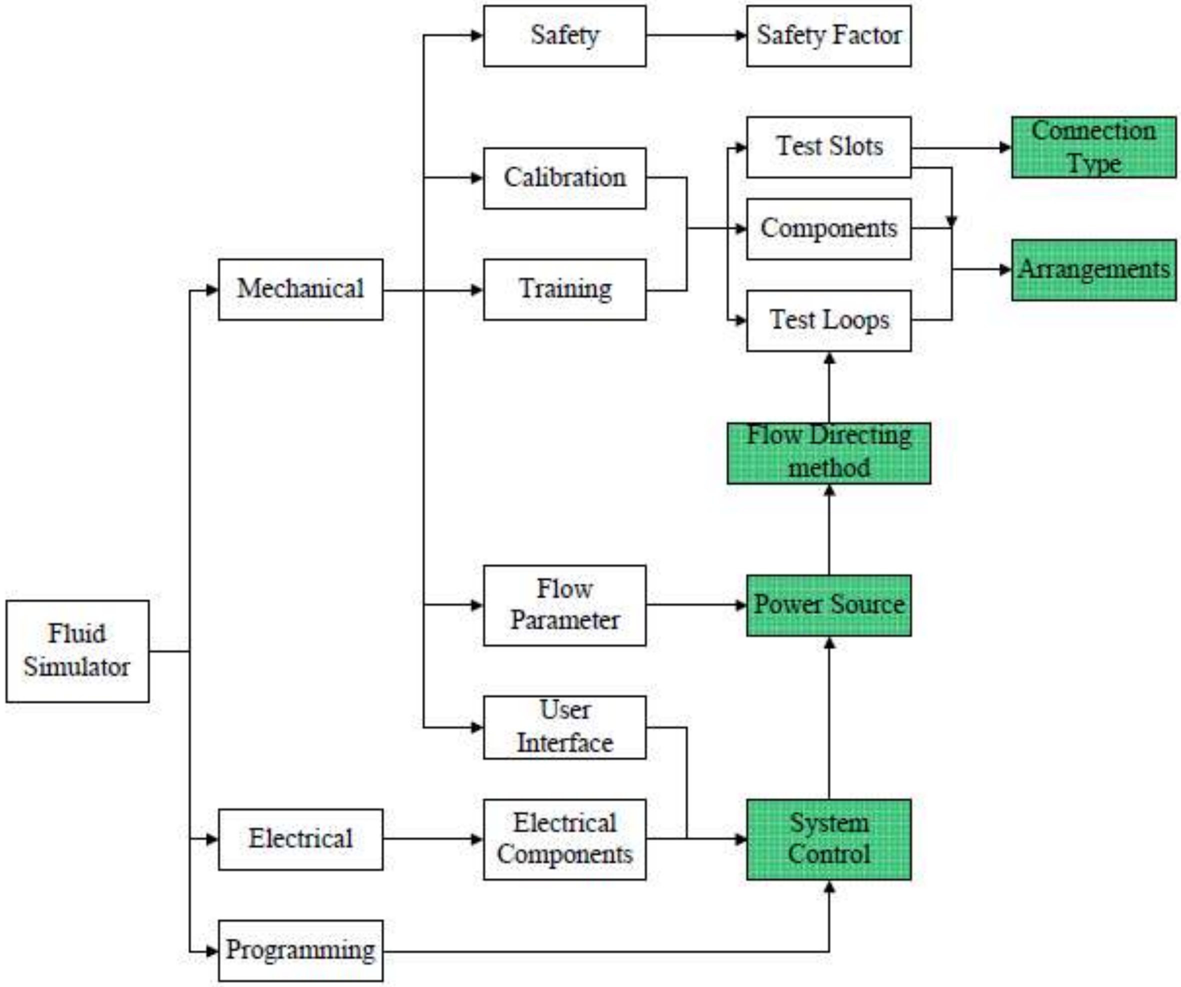
Centrifugal casting was chosen as the manufacturing process for the full-scale simulator pipes. This process provides the lowest cost, suitable for steel manufacturing, and it is typically used for pipe manufacturing. The low cost is attributed from the mold that can be used over and over again.

**Prototype Piping**

Since the prototype pipe has similar shape to full-scale pipe, similar method was used to determine the best manufacturing process for the prototype pipe. However, since the material for prototype piping are made out of PVC, not all manufacturing process that works on steel can work on the PVC and vice versa. The simplest and best method to produce PVC pipe was determined to be extrusion to pipe shape straight from PVC melt. PVC needs to melted before they can be shaped to any products, from there on the easiest method to manufacture tube shape is to directly extrude them to pipe shape.

[1] euronuclear. Feb 2009. Accessed on 12/11/2009.
http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm

**Appendix D: Element Decomposition**




**Appendix X : Concept Generation – Test slot arrangement**

This section will provide description of the test slot arrangement concepts that were deemed infeasible and also on why they were deemed infeasible

*Parallel O loops*

The concept illustrates a ring shaped testing loop with two testing slots on each. Thus, there are three O-loop in total, having a parallel configuration. The testing slots are connected using tee pipe and straight pipe that give the O-shape structure. The disadvantage of the design is that it is theoretically only one loop, which contradicts the customer requirement of having two loops for testing. From the team discussion, this design is therefore considered unfeasible. Figure 88 below shows the schematic of the Parallel O loops.

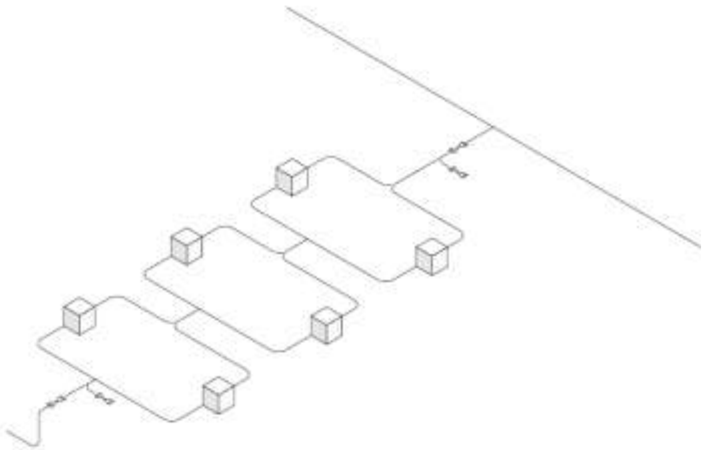


**Figure 88. Parallel Loops Schematic**

*Stacked U loops*

Based on the parallel U loop idea, this concept is having the U-loop stacked on another U-loop. The testing slots are connected using 90° and straight pipes that shape the U-shape of testing loops. Each testing loop contains three testing slots available. The advantage of a stacked structure is reduced floor space. The disadvantage if the concept includes height constraint that is too high for the technician to work on the testing loop. Thus, it is unfeasible. Below is Figure 89 that illustrates a stacked U loops.

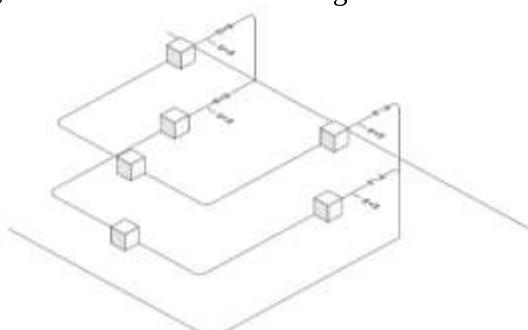


**Figure 89. Stacked U Loops Schematic**

*Stacked I loops*

The stacked I loops is developed based on the parallel I loop idea. However, the configuration is now stacked by having one testing loop on top of the other. Also, the testing slots are connected by straight pipe. The advantage of this concept includes reduced floor space as the testing loops are stacked. The disadvantage includes difficulties in operating the testing slots that are on the second level, which is too high for the users to be able to reach. This concept is considered to be unfeasible as well. Figure 90 below shows stacked I loops illustration.

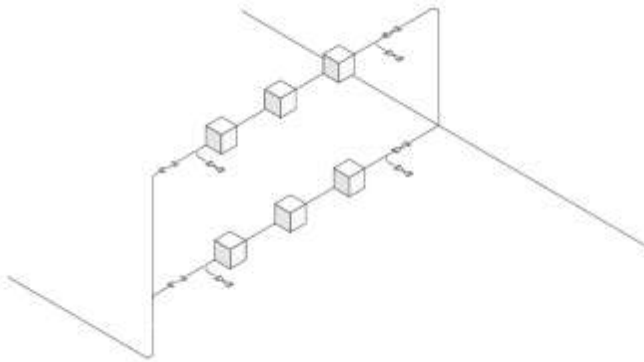


**Figure 90. Stacked I Loops Schematic**

Stacked E loops

The stacked E loops have the similar testing loop structure (E shape) with the parallel E loops. However, this design configuration is now stacked on top of the other. The advantage of this idea includes reduced floor space. The disadvantage of it includes making the testing loop to high, which would make technician more difficult to operate the testing loops. For example, switching a heavy instrument on the second level would be hard to lift and dangerous. Therefore, a stacked E loop is not feasible. Figure 91 below shows the stacked E loops schematic.

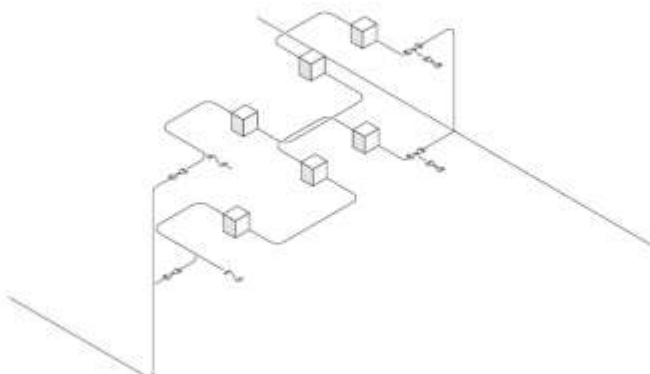


**Figure 91. Stacked E Loops Schematic**

*Vertical E loops*

This unique idea involves and E-shape testing loops that rises vertically. Therefore, flow will be flowing upwards with elbow and straight pipes connecting each testing slots. The advantage of the design is it meets the customer requirement in reducing physical size. The disadvantage is that the design would be unfeasible as the height of the vertical loop is too high for technician to operate. Because of height constraint, this concept is not feasible. Figure 92 below shows the schematic of a Vertical E loops.

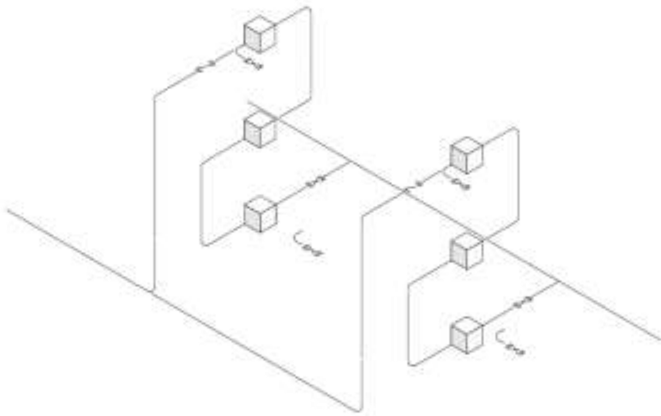


**Figure 92. Vertical E Loops Schematic**

**Table 34. Pugh Chart for Feasible and Unfeasible Testing Slots**

| | | | Concept 1 | | Concept 2 | | Concept 3 | | Concept 4 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Selection Criteria** | | **Weight** | **Parallel U** | | **Stacked U** | | **Nested U** | | **Parallel I** | |
| *Customer Requirement* | *Engineering Specification* | | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| Technicians training | Height of the testing slot | 0.04 | 4.00 | 0.17 | 2.00 | 0.08 | 4.00 | 0.17 | 4.00 | 0.17 |
| | Working space area | 0.04 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 |
| | Operating Pressure | 0.04 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 |
| | Operating Flow Rate | 0.04 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 |
| Accurate | Steel Material for all the piping "Customer specification" | 0.08 | 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 |
| | Able to extract free air from testing flow loop | 0.08 | 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 |
| Robust | Safety factor for maximum pressure in the pipe | 0.17 | 4.00 | 0.67 | 4.00 | 0.67 | 4.00 | 0.67 | 4.00 | 0.67 |
| Easy to use | Able to drain instruments | 0.03 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 |
| | Accessible path to the testing slots | 0.03 | 4.00 | 0.13 | 2.00 | 0.07 | 4.00 | 0.13 | 4.00 | 0.13 |
| | Minimum turning radius in the path | 0.03 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 |
| | Minimum width of the path | 0.03 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 |
| Small Size | Floor Size | 0.04 | 3.00 | 0.13 | 3.00 | 0.13 | 1.00 | 0.04 | 4.00 | 0.18 |
| | Number of Testing Flow Loop "Customer specification" | 0.04 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| | Number of Level control Loop "Customer specification" | 0.04 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| Able to test variety of instruments | Total Number of testing slot per flow loop | 0.04 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| | Types of instruments that can be tested | 0.04 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| | Testing slot size | 0.04 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| Cost | Cannot be quantified | 0.10 | 3.00 | 0.30 | 3.00 | 0.30 | 3.00 | 0.30 | 3.00 | 0.30 |
| Total Score | | | | **3.86** | | **3.71** | | **3.77** | | **3.90** |

| Concept 5 | | Concept 6 | | Concept 7 | | Concept 8 | | Concept 9 | |
|---|---|---|---|---|---|---|---|---|---|
| **Stacked I** | | **Parallel O** | | **Parallel E** | | **Stacked E** | | **Vertical E** | |
| Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted | Rating | Weighted |
| 2.00 | 0.08 | 4.00 | 0.17 | 4.00 | 0.17 | 2.00 | 0.08 | 1.00 | 0.04 |
| 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 |
| 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 |
| 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 | 4.00 | 0.17 |
| 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 |
| 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 | 4.00 | 0.33 |
| 4.00 | 0.67 | 4.00 | 0.67 | 4.00 | 0.67 | 4.00 | 0.67 | 4.00 | 0.67 |
| 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 |
| 2.00 | 0.07 | 4.00 | 0.13 | 4.00 | 0.13 | 2.00 | 0.07 | 2.00 | 0.07 |
| 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 |
| 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 | 4.00 | 0.13 |
| 3.00 | 0.13 | 3.00 | 0.13 | 3.00 | 0.13 | 3.00 | 0.13 | 3.00 | 0.13 |
| 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 | 4.00 | 0.18 |
| 3.00 | 0.30 | 3.00 | 0.30 | 3.00 | 0.30 | 3.00 | 0.30 | 3.00 | 0.30 |

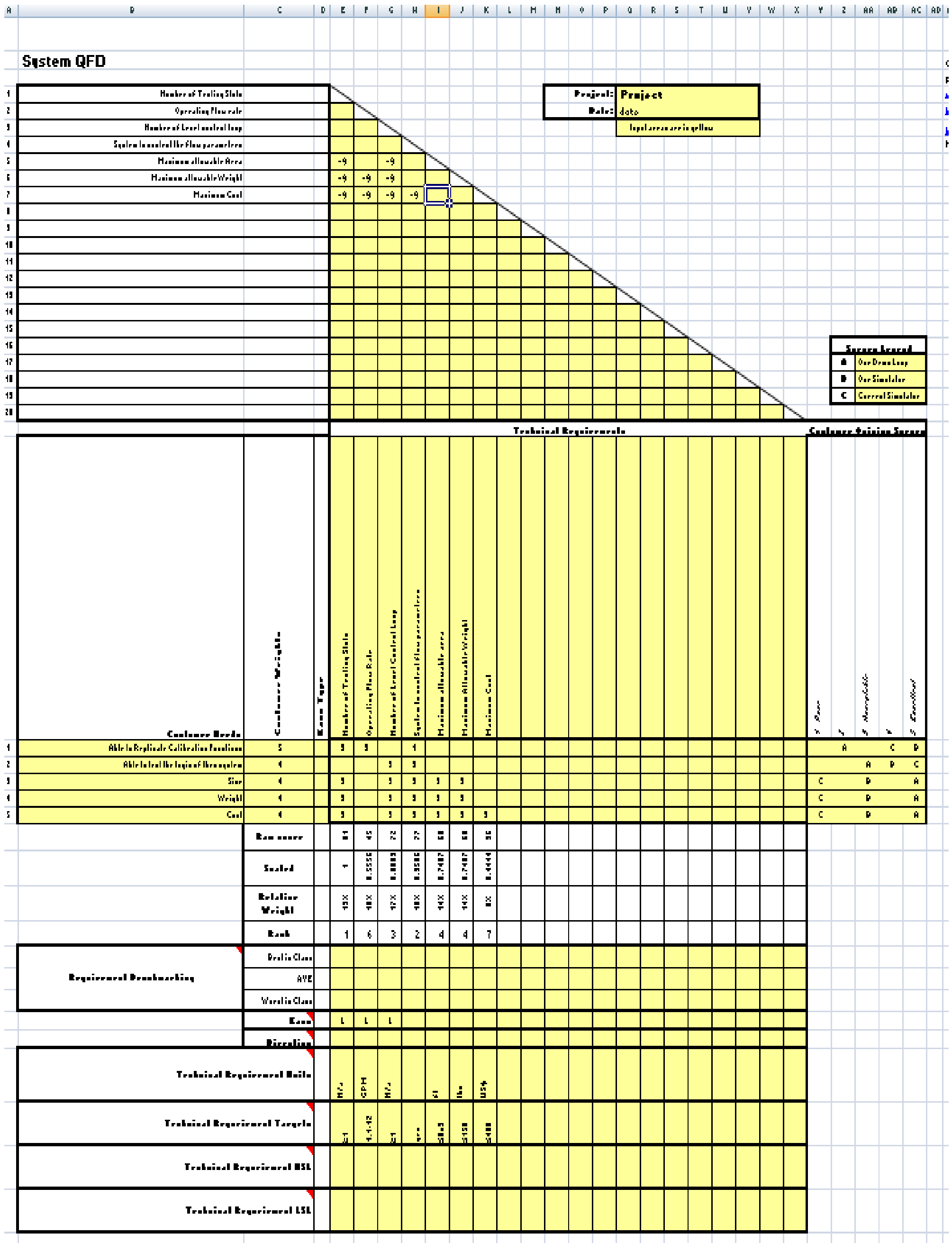
## Appendix E: Cost analysis on single and dual pump

| Pricing in US$ | **Single Pump** | **Dual Pump** |
|---|---|---|
| Pump Price | 150,000 | 100,000 |
| Quantity | 1 | 1 |
| Pump Cost | 150000 | 100000 |
| Check Valve Price | 136.94 | 136.94 |
| Quantity | 1 | 2 |
| Check Valve Cost | 136.94 | 273.88 |
| Orifice Price | 1,500 | 1,500 |
| Quantity | 1 | 1 |
| Orifice Cost | 1500 | 1500 |
| Gate Valve Price | 998.74 | 998.74 |
| Quantity | 4 | 7 |
| Gate Valve Cost | 3994.96 | 6991.18 |
| Straight Pipe Length | 42" | 137" |
| Straight Pipe Cost | 154.23 | 256.45 |
| Tee Pipe Price | 140.96 | 140.96 |
| Quantity | 5 | 8 |
| Tee Pipe Cost | 704.8 | 1127.68 |
| Elbow Pipe Price | 102.17 | 102.17 |
| Quantity | 9 | 10 |
| Elbow Pipe Cost | 919.53 | 1021.7 |
| **Grand Total Cost ($)** | **157410.46** | **111170.89** |

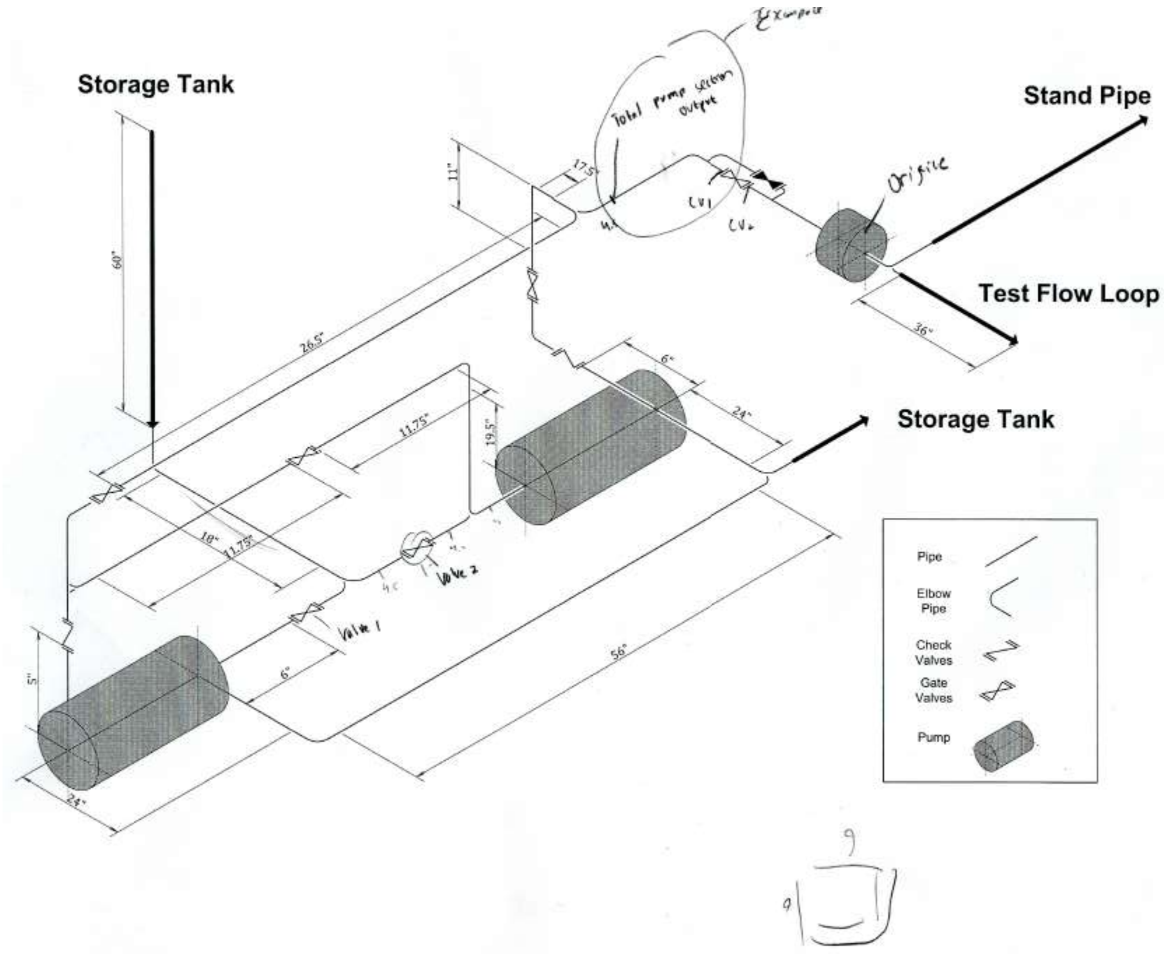
**Appendix F – Complete Concept Generations Summary**

| Concept | Area (m^2) | Area (ft^s) | Description |
|---|---|---|---|
| 1 | 40.8 | 439.1712 | Parallel I – Standard – Ball valve – Dual Pump – PLC+Valve – Clamp |
| 2 | 53.1 | 571.5684 | Parallel I – Spread Out – Ball valve – Dual Pump – PLC+Valve – Bolt on |
| 3 | 85.79 | 923.4436 | Nested U – Spread Out – Ball valve – Dual Pump – PLC+Valve – Bolt on |
| 4 | 55.4 | 596.3256 | Parallel U – Standard – Ball Valve – Dual Pump – PLC+Valve – Clamp |
| 5 | 49.6 | 533.8944 | Parallel E – Standard – Ball Valve – Dual Pump – PLC+Valve – Clamp |
| 6 | 40.8 | 439.1712 | Parallel I – Standard – Ball valve – Dual Pump – PLC+Valve – Bolt on |
| 7 | 53.1 | 571.5684 | Parallel I – Spread Out – Ball valve – Dual Pump – PLC+Valve – Clamp |
| 8 | 55.4 | 596.3256 | Parallel U – Standard – Ball Valve – Dual Pump – PLC+Valve – Bolt on |
| 9 | 88 | 947.232 | Parallel U – Spread Out – Ball Valve – Dual Pump – PLC+Valve – Bolt on |
| 10 | 88 | 947.232 | Parallel U – Spread Out – Ball Valve – Dual Pump – PLC+Valve – Clamp |
| 11 | 70.3 | 756.7092 | Nested U – Standard – Ball valve – Dual Pump – PLC+Valve – Bolt on |
| 12 | 70.3 | 756.7092 | Nested U – Standard – Ball valve – Dual Pump – PLC+Valve – Clamp |
| 13 | 85.79 | 923.4436 | Nested U – Spread Out – Ball valve – Dual Pump – PLC+Valve – Clamp |
| 14 | 49.6 | 533.8944 | Parallel E – Standard – Ball Valve – Dual Pump – PLC+Valve – Bolt on |
| 15 | 60.4 | 650.1456 | Parallel E – Spread out – Ball Valve – Dual Pump – PLC+Valve – Bolt on |

**Appendix G – Demo Model QFD**


System QFD
Project:
Project
Date:
date
Number of Trailing Slots
Operating Flow rate
Maximum allowable Area
Maximum allowable Weight
Maximum Cost
Technical Requirements
Customer Opinion Survey
Survey Legend
Customer Needs
Customer Weights
Kano Type
Size
Weight
Cost
Raw score
Scaled
Relative Weight
Rank
Requirement Benchmarking
Direction
Technical Requirement Units
Technical Requirement Targets
Technical Requirement USL
Technical Requirement LSL

**Appendix H – Sample Hydraulic Analysis for the Simulator**



~~Sec~~

Back analysis from CV 1 to Total pump section output (TPSO)

CV 1 → $V_1 = 25$ ft/s

$P_1 = 1037.637$ psi

$z = 3$ ft

Pipe inner d $D = 0.25$ ft

$Re_d = 2.09 \times 10^7$

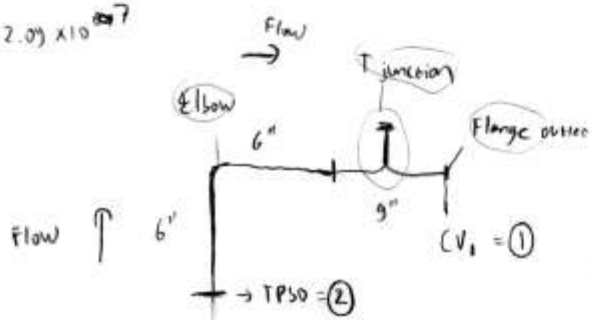
TPSO → $V_2 = 25$ ft/s

$P_2 = ?$

$Z_2 = 3$ ft

$D_2 = 0.25$ ft

$Re_d = 2.09 \times 10^7$




$$h_L + \cancel{z_1} + \frac{144 P_1}{\rho} + \cancel{\frac{V_1^2}{2g}} = \cancel{z_2} + \frac{144 P_2}{\rho_2} + \cancel{\frac{V_2^2}{2g}}$$

$$\frac{h_L \rho}{144} + P_1 = P_2 \quad ①$$

$$h_L = k \frac{V_2^2}{2g}$$

$$K_{\text{due to length}} = \frac{f L}{D} = \frac{(0.0175)\left(\frac{9'' + 6'' + 6''}{12''}\right)}{0.25 \text{ ft}} = 0.137$$

(0.0175: from curve; $9''+6''+6''$: total length)

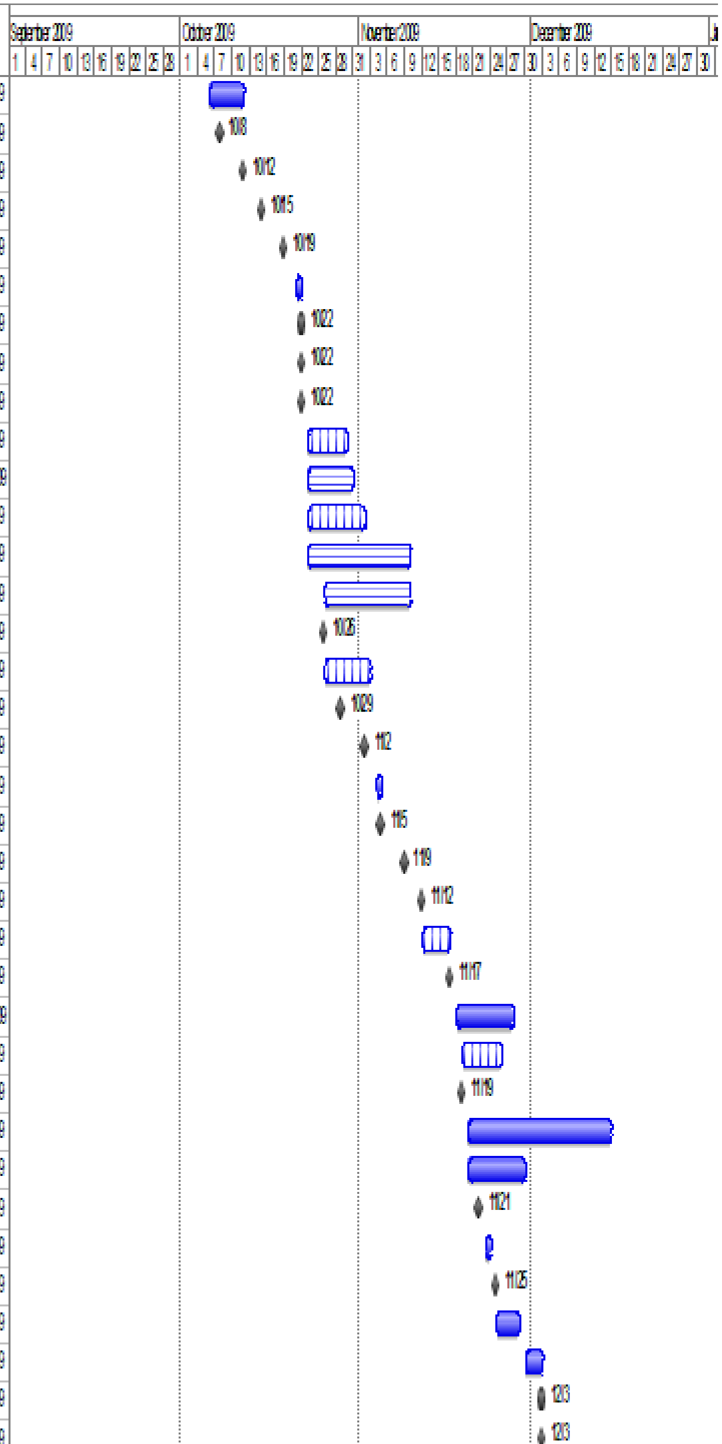
$$K_{\text{due to T junction}} = 20 f_t = (20)(0.018) = 0.36$$

$$K_{\text{due to bend (elbow)}} = 30 f_t = (30)(0.018) = 0.54$$

$$K_{\text{due to flange outlet}} = \qquad = 1 \qquad +$$

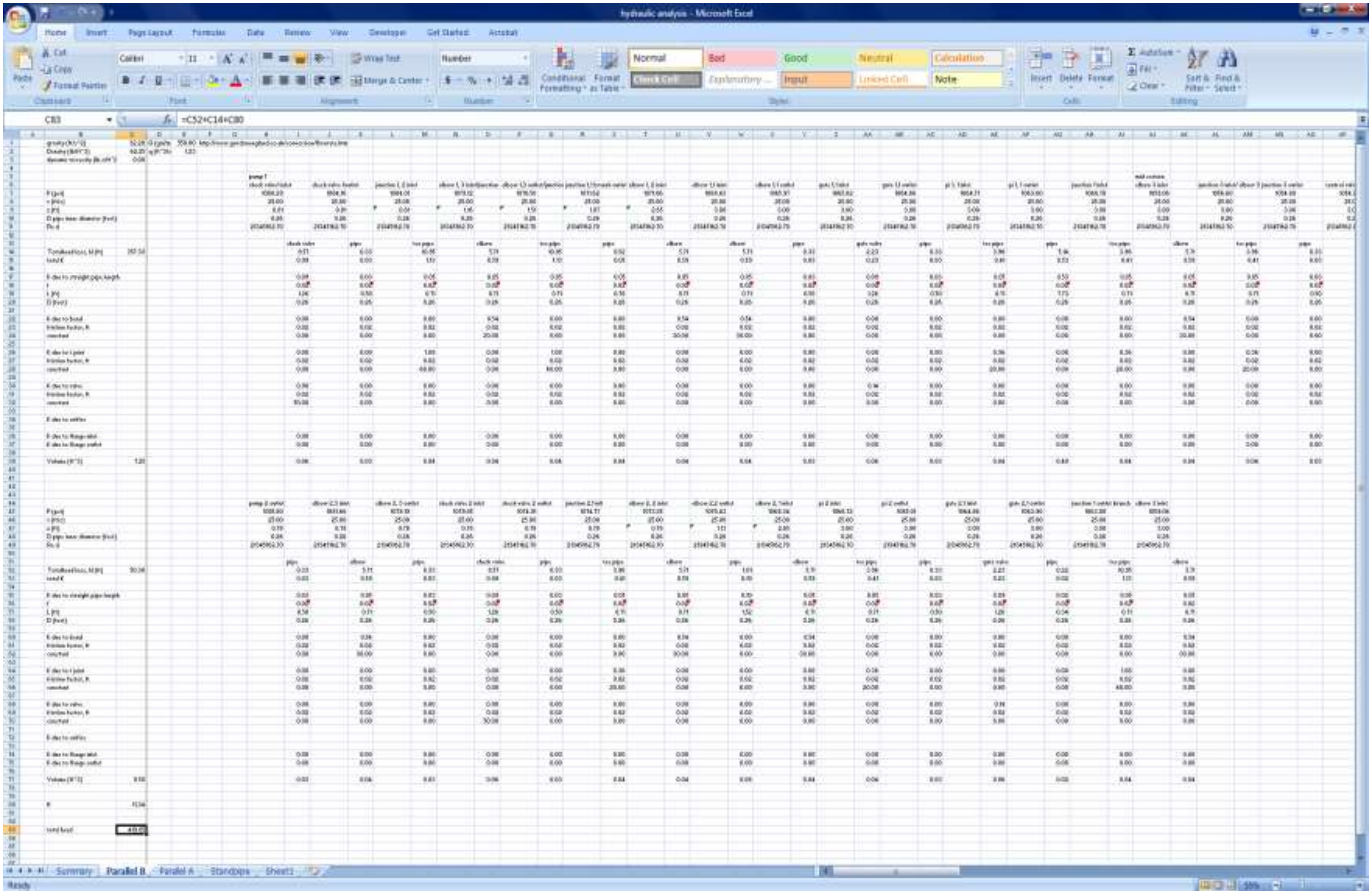
**Appendix I –Gantt Chart**

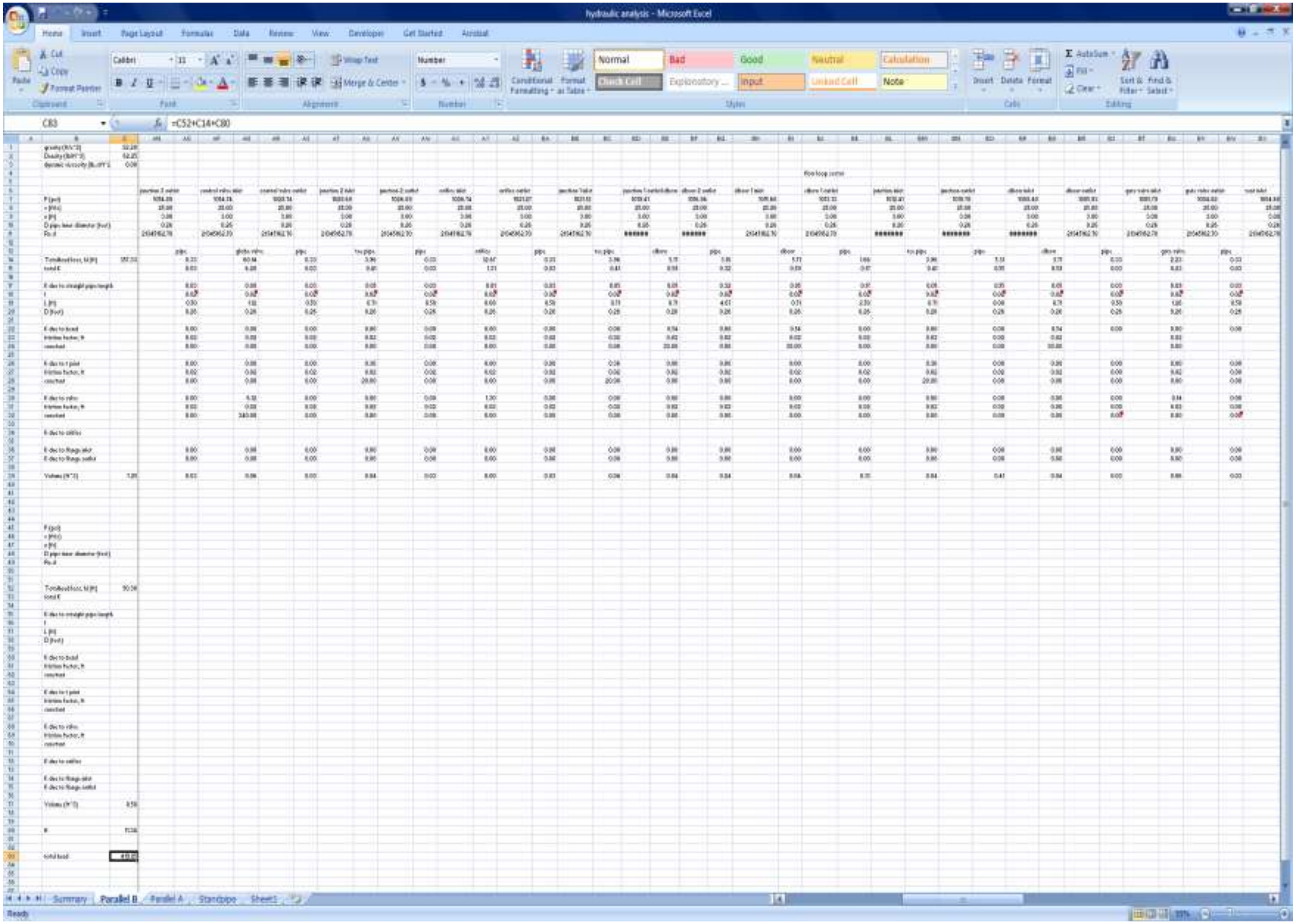
| ID | | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|
| 39 | | Drawing piping isometrics and Preliminary analysis | 4 days? | Tue 10/6/09 | Sun 10/11/09 |
| 46 | | Conference Call With Sargent Lundy | 0 days | Thu 10/8/09 | Thu 10/8/09 |
| 27 | | Submit Piping Isometric Drawings & Preliminary Piping Analysis | 0 days | Mon 10/12/09 | Mon 10/12/09 |
| 47 | | Conference Call With Sargent Lundy | 0 days | Thu 10/15/09 | Thu 10/15/09 |
| 28 | | Component Data Sheets, Final Piping Analysis, Demo Units Components | 0 days | Mon 10/19/09 | Mon 10/19/09 |
| 40 | | Group Meeting to Compile and Prepare for Presentation for DDR2 | 1 day? | Wed 10/21/09 | Wed 10/21/09 |
| 12 | | Design Review 2 = Alpha Design | 0 days | Thu 10/22/09 | Thu 10/22/09 |
| 29 | | Design Review Meeting , Design Option Decision Made | 0 days | Thu 10/22/09 | Thu 10/22/09 |
| 48 | | Conference Call With Sargent Lundy | 0 days | Thu 10/22/09 | Thu 10/22/09 |
| 13 | | Prototype Development | 5 days? | Fri 10/23/09 | Thu 10/29/09 |
| 14 | | Engineering Analysis for Simulator in the Station | 6 days? | Fri 10/23/09 | Fri 10/30/09 |
| 17 | | Completed and Verified PLC Program for Demo | 6 days? | Fri 10/23/09 | Sun 11/1/09 |
| 41 | | Improvised final design simulator and Prepare Wiring Schematics | 12 days? | Fri 10/23/09 | Mon 11/9/09 |
| 16 | | Bill of Materials for what would be built in the station | 11 days? | Mon 10/26/09 | Mon 11/9/09 |
| 30 | | Commit to Finalized Design | 0 days | Mon 10/26/09 | Mon 10/26/09 |
| 43 | | Finishing Schematic and Power Supply for Demo | 6 days? | Mon 10/26/09 | Mon 11/2/09 |
| 49 | | Conference Call With Sargent Lundy | 0 days | Thu 10/29/09 | Thu 10/29/09 |
| 31 | | PLC Software Control Submission | 0 days | Mon 11/2/09 | Mon 11/2/09 |
| 44 | | Visit from Sargent Lundy Regarding Demo Model | 1 day? | Wed 11/4/09 | Wed 11/4/09 |
| 50 | | Conference Call With Sargent Lundy | 0 days | Thu 11/5/09 | Thu 11/5/09 |
| 32 | | Bill of Materials , Control Wiring Schematics | 0 days | Mon 11/9/09 | Mon 11/9/09 |
| 51 | | Conference Call With Sargent Lundy | 0 days | Thu 11/12/09 | Thu 11/12/09 |
| 55 | | Preparing Safety report for DDR3 | 3 days? | Thu 11/12/09 | Mon 11/16/09 |
| 18 | | Design Review 3 = Final Design | 0 days | Tue 11/17/09 | Tue 11/17/09 |
| 19 | | Final Design Analysis | 9 days? | Wed 11/18/09 | Fri 11/27/09 |
| 42 | | Preparing Manual for Station Plan | 6 days? | Thu 11/19/09 | Wed 11/25/09 |
| 52 | | Conference Call With Sargent Lundy | 0 days | Thu 11/19/09 | Thu 11/19/09 |
| 45 | | Start Writing Final Report | 20 days? | Fri 11/20/09 | Mon 12/14/09 |
| 57 | | Writing PLC Software | 8 days? | Fri 11/20/09 | Sun 11/29/09 |
| 15 | | Prototype Manufacturing | 0 days | Sat 11/21/09 | Sat 11/21/09 |
| 56 | | Assembly Prototype | 1 day? | Mon 11/23/09 | Mon 11/23/09 |
| 33 | | Manual, Power Supply Spec and Schematic for Test Instruments (Simulator) | 0 days | Wed 11/25/09 | Wed 11/25/09 |
| 54 | | Thanksgiving Break | 3 days? | Wed 11/25/09 | Sat 11/28/09 |
| 20 | | Initial and Final Prototype Testings | 3 days? | Mon 11/30/09 | Wed 12/2/09 |
| 21 | | Design Review 4 = Alpha Prototype | 0 days | Thu 12/3/09 | Thu 12/3/09 |
| 53 | | Conference Call With Sargent Lundy | 0 days | Thu 12/3/09 | Thu 12/3/09 |

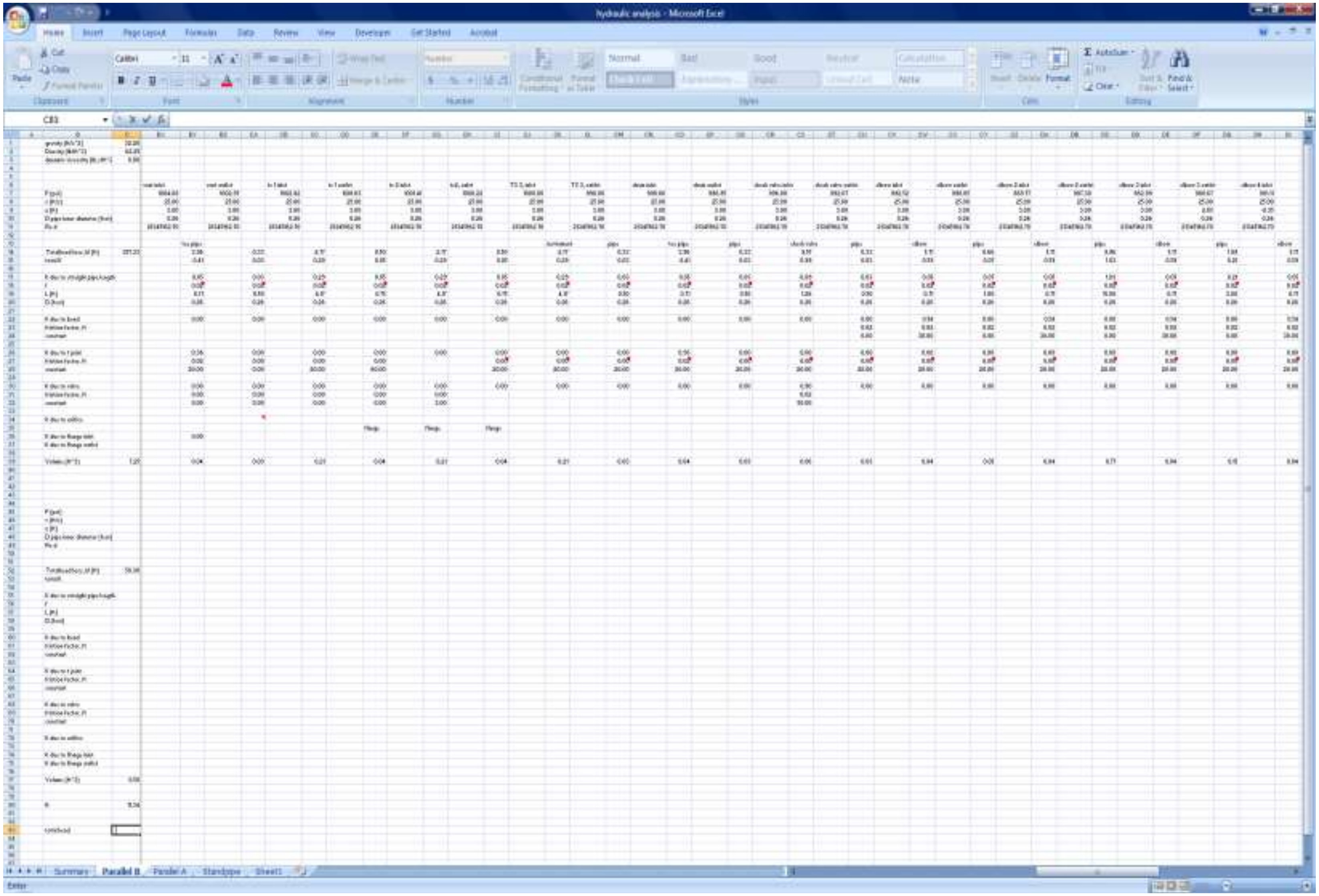


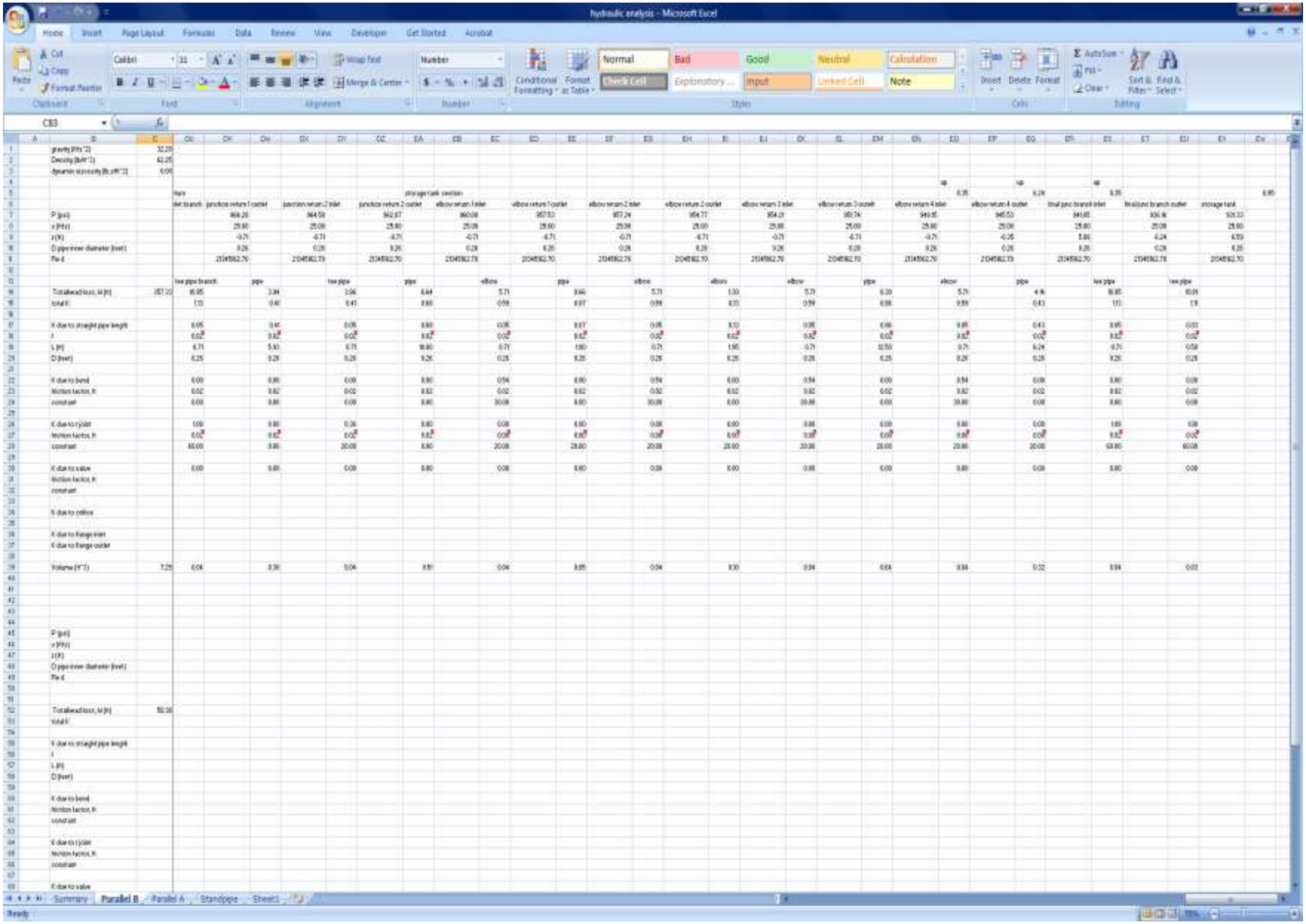
| | | |
|---|---|---|
| Project: ME450 Gantt chart.mpp<br>Date: Fri 10/23/09 | Task by Owen & Elwin | Summary |
| | Task by Anthony & Yudie | Project Summary |
| | Task | External Tasks |
| | Split | External Milestone |
| | Progress | Deadline |
| | Deliverable for Sargent Lundy | Deliverable for ME450 |

## Appendix J: Hydraulic Analysis


hydraulic analysis - Microsoft Excel
Summary
Parallel B
Parallel A
Standpipe
Sheet1


hydraulic analysis - Microsoft Excel
Home
Insert
Page Layout
Formulas
Data
Review
View
Developer
Get Started
Acrobat
Normal
Bad
Good
Neutral
Calculation
Check Cell
Explanatory ...
Input
Linked Cell
Note
C83
=C52+C14+C80
Summary
Parallel B
Parallel A
Standpipe
Sheet1
Ready


Hydraulic analysis - Microsoft Excel
Summary
Parallel B
Parallel A
Standpipe
Sheet1


hydraulic analysis - Microsoft Excel
Summary
Parallel B
Parallel A
Standpipe
Sheet1

**Appendix K: Pipe Failure Analysis and Pipe Support Analysis**

Due to the size and shape of our project, since the analysis for such a complex geometry is statically indeterminate we utilized RISA software to calculate the bending moment, shear stress, and deflection. Due to the complex geometry of our simulator, we decided to divide the support placement calculation into 4 different sectors. At each sectors, we used the following step by step approach:

1. We started by fixing both extreme end of the section with a fixed support
2. Run the solution
3. Add one additional support to the place where it has the maximum shear stress
4. Re-run the solution
5. Repeat step 3

We did these iterations and only add one support at a time to ensure that the amount of pipe support that we use is minimal.

**Testing flow loop sector:** Table 1 showed the maximum shear force, bending moment and deflection of the flow loop section.

**Table 1: Maximum Shear force, bending moment and deflection of Flow loop sector**

| Max y shear (lb) | Max z shear (lb) | Max yy moment (lb-ft) | Max zz moment (lb-ft) | x deflection (in) | y deflection (in) | z deflection (in) |
|---|---|---|---|---|---|---|
| 1346.055 | 0 | 0 | 2456.329 | 0 | -0.094 | 0 |

The maximum value in table 1 is computed from the RISA recorded value as shown in table 2

**Table 2: Shear force, bending moment and deflection of Flow loop section from RISA**

| Member/Pipe Name | Sec (based on the length of the pipe, 1 means 0-20% pipe length) | y shear (lb) | z shear (lb) | yy moment | zz moment (lb-ft) |
|---|---|---|---|---|---|
| yes | 1 | 0 | 0 | 0 | |
| | 2 | -21.752 | 0 | 0 | 0.963 |
| | 3 | -43.504 | 0 | 0 | 3.852 |
| | 4 | -65.257 | 0 | 0 | 8.667 |
| | 5 | -87.009 | 0 | 0 | 15.408 |
| tpipe | 1 | -1157.093 | 0 | 0 | -0.457 |
| | 2 | -1178.845 | 0 | 0 | 102.957 |
| | 3 | -1200.598 | 0 | 0 | 208.297 |
| | 4 | -1222.35 | 0 | 0 | 315.563 |
| | 5 | -1244.102 | 0 | 0 | 424.755 |
| pipe | 1 | 477.279 | 0 | 0 | 301.658 |
| | 2 | 446.57 | 0 | 0 | 243.918 |
| | 3 | 415.861 | 0 | 0 | 190.016 |
| | 4 | 385.152 | 0 | 0 | 139.953 |
| | 5 | 354.443 | 0 | 0 | 93.728 |
| valve | 1 | 354.443 | 0 | 0 | 93.728 |

| | | | | | |
|---|---|---|---|---|---|
| | 2 | 277.056 | 0 | 0 | -5.733 |
| | 3 | 199.669 | 0 | 0 | -80.817 |
| | 4 | 122.283 | 0 | 0 | -131.525 |
| | 5 | 44.896 | 0 | 0 | -157.855 |
| M1M | 1 | 44.896 | 0 | 0 | -157.855 |
| | 2 | 14.187 | 0 | 0 | -161.548 |
| | 3 | -16.522 | 0 | 0 | -161.402 |
| | 4 | -47.231 | 0 | 0 | -157.417 |
| | 5 | -77.94 | 0 | 0 | -149.594 |
| M1L | 1 | -77.94 | 0 | 0 | -149.594 |
| | 2 | -121.445 | 0 | 0 | -131.94 |
| | 3 | -164.949 | 0 | 0 | -106.583 |
| | 4 | -208.453 | 0 | 0 | -73.521 |
| | 5 | -251.958 | 0 | 0 | -32.755 |
| M1K | 1 | -251.958 | 0 | 0 | -32.755 |
| | 2 | -282.667 | 0 | 0 | 0.659 |
| | 3 | -313.376 | 0 | 0 | 37.911 |
| | 4 | -344.085 | 0 | 0 | 79.003 |
| | 5 | -374.794 | 0 | 0 | 123.933 |
| instrua1 | 1 | -374.794 | 0 | 0 | 123.933 |
| | 2 | -630.702 | 0 | 0 | 647.632 |
| | 3 | -10.922 | 0 | 0 | -843.387 |
| | 4 | 798.159 | 0 | 0 | 662.497 |
| | 5 | 542.25 | 0 | 0 | -35.636 |
| M1I | 1 | 542.25 | 0 | 0 | -35.636 |
| | 2 | 496.187 | 0 | 0 | -132.989 |
| | 3 | 450.123 | 0 | 0 | -221.706 |
| | 4 | -493.126 | 0 | 0 | -133.563 |
| | 5 | -539.19 | 0 | 0 | -36.783 |
| instrua2 | 1 | -539.19 | 0 | 0 | -36.783 |
| | 2 | -795.098 | 0 | 0 | 658.162 |
| | 3 | 0 | 0 | 0 | -836.929 |
| | 4 | 795.098 | 0 | 0 | 658.162 |
| | 5 | 539.19 | 0 | 0 | -36.783 |
| M1G | 1 | 539.19 | 0 | 0 | -36.783 |
| | 2 | 493.126 | 0 | 0 | -133.563 |
| | 3 | -450.123 | 0 | 0 | -221.706 |
| | 4 | -496.187 | 0 | 0 | -132.989 |
| | 5 | -542.25 | 0 | 0 | -35.636 |
| instrua3 | 1 | -542.25 | 0 | 0 | -35.636 |
| | 2 | -798.159 | 0 | 0 | 662.497 |

| | | | | | |
|---|---|---|---|---|---|
| | 3 | 10.922 | 0 | 0 | -843.387 |
| | 4 | 630.702 | 0 | 0 | 647.632 |
| | 5 | 374.794 | 0 | 0 | 123.933 |
| M1E | 1 | 374.794 | 0 | 0 | 123.933 |
| | 2 | 344.085 | 0 | 0 | 79.003 |
| | 3 | 313.376 | 0 | 0 | 37.911 |
| | 4 | 282.667 | 0 | 0 | 0.659 |
| | 5 | 251.958 | 0 | 0 | -32.755 |
| M1D | 1 | 251.958 | 0 | 0 | -32.755 |
| | 2 | 208.453 | 0 | 0 | -73.521 |
| | 3 | 164.949 | 0 | 0 | -106.583 |
| | 4 | 121.445 | 0 | 0 | -131.94 |
| | 5 | 77.94 | 0 | 0 | -149.594 |
| M1C | 1 | 77.94 | 0 | 0 | -149.594 |
| | 2 | 47.231 | 0 | 0 | -157.417 |
| | 3 | 16.522 | 0 | 0 | -161.402 |
| | 4 | -14.187 | 0 | 0 | -161.548 |
| | 5 | -44.896 | 0 | 0 | -157.855 |
| M1B | 1 | -44.896 | 0 | 0 | -157.855 |
| | 2 | -122.283 | 0 | 0 | -131.525 |
| | 3 | -199.669 | 0 | 0 | -80.817 |
| | 4 | -277.056 | 0 | 0 | -5.733 |
| | 5 | -354.443 | 0 | 0 | 93.728 |
| M1A | 1 | -354.443 | 0 | 0 | 93.728 |
| | 2 | -385.152 | 0 | 0 | 139.953 |
| | 3 | -415.861 | 0 | 0 | 190.016 |
| | 4 | -446.57 | 0 | 0 | 243.918 |
| | 5 | -477.279 | 0 | 0 | 301.658 |
| M1 | 1 | 296.854 | 0 | 0 | 89.728 |
| | 2 | 275.101 | 0 | 0 | 64.407 |
| | 3 | 253.349 | 0 | 0 | 41.012 |
| | 4 | 231.597 | 0 | 0 | 19.543 |
| | 5 | 209.845 | 0 | 0 | 0 |
| M18 | 1 | 209.845 | 0 | 0 | 38.798 |
| | 2 | 188.093 | 0 | 0 | 21.181 |
| | 3 | 166.34 | 0 | 0 | 5.49 |
| | 4 | 144.588 | 0 | 0 | -8.275 |
| | 5 | 122.836 | 0 | 0 | -20.114 |
| M19 | 1 | 122.836 | 0 | 0 | -20.114 |
| | 2 | 61.418 | 0 | 0 | -43.146 |
| | 3 | 0 | 0 | 0 | -50.823 |

| | | | | | |
|---|---|---|---|---|---|
| | 4 | -61.418 | 0 | 0 | -43.146 |
| | 5 | -122.836 | 0 | 0 | -20.114 |
| M20 | 1 | -122.836 | 0 | 0 | -20.114 |
| | 2 | -144.588 | 0 | 0 | -8.275 |
| | 3 | -166.34 | 0 | 0 | 5.49 |
| | 4 | -188.093 | 0 | 0 | 21.181 |
| | 5 | -209.845 | 0 | 0 | 38.798 |
| M21 | 1 | -209.845 | 0 | 0 | 0 |
| | 2 | -231.597 | 0 | 0 | 19.543 |
| | 3 | -253.349 | 0 | 0 | 41.012 |
| | 4 | -275.101 | 0 | 0 | 64.407 |
| | 5 | -296.854 | 0 | 0 | 89.728 |
| M22 | 1 | 1228.36 | 0 | 0 | 2047.267 |
| | 2 | 0 | 0 | 0 | -1023.633 |
| | 3 | -1228.36 | 0 | 0 | 2047.267 |
| | 4 | 0 | 0 | 0 | -1023.633 |
| | 5 | -1228.36 | 0 | 0 | 2047.267 |
| M24 | 1 | 1070.084 | 0 | 0 | 1406.268 |
| | 2 | 1048.332 | 0 | 0 | 1312.484 |
| | 3 | 1026.58 | 0 | 0 | 1220.626 |
| | 4 | 1004.828 | 0 | 0 | 1130.694 |
| | 5 | 983.076 | 0 | 0 | 1042.687 |
| M25 | 1 | 983.076 | 0 | 0 | 1042.687 |
| | 2 | 491.732 | 0 | 0 | -432.12 |
| | 3 | 0.388 | 0 | 0 | -924.239 |
| | 4 | -490.956 | 0 | 0 | -433.67 |
| | 5 | -982.3 | 0 | 0 | 1039.587 |
| M26 | 1 | -982.3 | 0 | 0 | 1039.587 |
| | 2 | -1004.053 | 0 | 0 | 1127.525 |
| | 3 | -1025.805 | 0 | 0 | 1217.388 |
| | 4 | -1047.557 | 0 | 0 | 1309.178 |
| | 5 | -1069.309 | 0 | 0 | 1402.893 |
| M27 | 1 | -1069.309 | 0 | 0 | 0.457 |
| | 2 | -1091.062 | 0 | 0 | 96.098 |
| | 3 | -1112.814 | 0 | 0 | 193.666 |
| | 4 | -1134.566 | 0 | 0 | 293.159 |
| | 5 | -1156.318 | 0 | 0 | 394.578 |
| M28 | 1 | 477.279 | 0 | 0 | 301.658 |
| | 2 | 446.57 | 0 | 0 | 243.918 |
| | 3 | 415.861 | 0 | 0 | 190.016 |
| | 4 | 385.152 | 0 | 0 | 139.953 |

| | | | | | |
|---|---|---|---|---|---|
| | 5 | 354.443 | 0 | 0 | 93.728 |
| M29 | 1 | 354.443 | 0 | 0 | 93.728 |
| | 2 | 277.056 | 0 | 0 | -5.733 |
| | 3 | 199.669 | 0 | 0 | -80.817 |
| | 4 | 122.283 | 0 | 0 | -131.525 |
| | 5 | 44.896 | 0 | 0 | -157.855 |
| M30 | 1 | 44.896 | 0 | 0 | -157.855 |
| | 2 | 14.187 | 0 | 0 | -161.548 |
| | 3 | -16.522 | 0 | 0 | -161.402 |
| | 4 | -47.231 | 0 | 0 | -157.417 |
| | 5 | -77.94 | 0 | 0 | -149.594 |
| M31 | 1 | -77.94 | 0 | 0 | -149.594 |
| | 2 | -121.445 | 0 | 0 | -131.94 |
| | 3 | -164.949 | 0 | 0 | -106.583 |
| | 4 | -208.453 | 0 | 0 | -73.521 |
| | 5 | -251.958 | 0 | 0 | -32.755 |
| M32 | 1 | -251.958 | 0 | 0 | -32.755 |
| | 2 | -282.667 | 0 | 0 | 0.659 |
| | 3 | -313.376 | 0 | 0 | 37.911 |
| | 4 | -344.085 | 0 | 0 | 79.003 |
| | 5 | -374.794 | 0 | 0 | 123.933 |
| instrub1 | 1 | -374.794 | 0 | 0 | 123.933 |
| | 2 | -630.702 | 0 | 0 | 647.632 |
| | 3 | -10.922 | 0 | 0 | -843.387 |
| | 4 | 798.159 | 0 | 0 | 662.497 |
| | 5 | 542.25 | 0 | 0 | -35.636 |
| M34 | 1 | 542.25 | 0 | 0 | -35.636 |
| | 2 | 496.187 | 0 | 0 | -132.989 |
| | 3 | 450.123 | 0 | 0 | -221.706 |
| | 4 | -493.126 | 0 | 0 | -133.563 |
| | 5 | -539.19 | 0 | 0 | -36.783 |
| instrub2 | 1 | -539.19 | 0 | 0 | -36.783 |
| | 2 | -795.098 | 0 | 0 | 658.162 |
| | 3 | 0 | 0 | 0 | -836.929 |
| | 4 | 795.098 | 0 | 0 | 658.162 |
| | 5 | 539.19 | 0 | 0 | -36.783 |
| M36 | 1 | 539.19 | 0 | 0 | -36.783 |
| | 2 | 493.126 | 0 | 0 | -133.563 |
| | 3 | -450.123 | 0 | 0 | -221.706 |
| | 4 | -496.187 | 0 | 0 | -132.989 |
| | 5 | -542.25 | 0 | 0 | -35.636 |

| | | | | | |
|---|---|---|---|---|---|
| instrub3 | 1 | -542.25 | 0 | 0 | -35.636 |
| | 2 | -798.159 | 0 | 0 | 662.497 |
| | 3 | 10.922 | 0 | 0 | -843.387 |
| | 4 | 630.702 | 0 | 0 | 647.632 |
| | 5 | 374.794 | 0 | 0 | 123.933 |
| M38 | 1 | 374.794 | 0 | 0 | 123.933 |
| | 2 | 344.085 | 0 | 0 | 79.003 |
| | 3 | 313.376 | 0 | 0 | 37.911 |
| | 4 | 282.667 | 0 | 0 | 0.659 |
| | 5 | 251.958 | 0 | 0 | -32.755 |
| M39 | 1 | 251.958 | 0 | 0 | -32.755 |
| | 2 | 208.453 | 0 | 0 | -73.521 |
| | 3 | 164.949 | 0 | 0 | -106.583 |
| | 4 | 121.445 | 0 | 0 | -131.94 |
| | 5 | 77.94 | 0 | 0 | -149.594 |
| M40 | 1 | 77.94 | 0 | 0 | -149.594 |
| | 2 | 47.231 | 0 | 0 | -157.417 |
| | 3 | 16.522 | 0 | 0 | -161.402 |
| | 4 | -14.187 | 0 | 0 | -161.548 |
| | 5 | -44.896 | 0 | 0 | -157.855 |
| M41 | 1 | -44.896 | 0 | 0 | -157.855 |
| | 2 | -122.283 | 0 | 0 | -131.525 |
| | 3 | -199.669 | 0 | 0 | -80.817 |
| | 4 | -277.056 | 0 | 0 | -5.733 |
| | 5 | -354.443 | 0 | 0 | 93.728 |
| M42 | 1 | -354.443 | 0 | 0 | 93.728 |
| | 2 | -385.152 | 0 | 0 | 139.953 |
| | 3 | -415.861 | 0 | 0 | 190.016 |
| | 4 | -446.57 | 0 | 0 | 243.918 |
| | 5 | -477.279 | 0 | 0 | 301.658 |
| M43 | 1 | 296.854 | 0 | 0 | 89.728 |
| | 2 | 275.101 | 0 | 0 | 64.407 |
| | 3 | 253.349 | 0 | 0 | 41.012 |
| | 4 | 231.597 | 0 | 0 | 19.543 |
| | 5 | 209.845 | 0 | 0 | 0 |
| M44 | 1 | 209.845 | 0 | 0 | 38.798 |
| | 2 | 188.093 | 0 | 0 | 21.181 |
| | 3 | 166.34 | 0 | 0 | 5.49 |
| | 4 | 144.588 | 0 | 0 | -8.275 |
| | 5 | 122.836 | 0 | 0 | -20.114 |
| M45 | 1 | 122.836 | 0 | 0 | -20.114 |

| | | | | | |
|---|---|---|---|---|---|
| | 2 | 61.418 | 0 | 0 | -43.146 |
| | 3 | 0 | 0 | 0 | -50.823 |
| | 4 | -61.418 | 0 | 0 | -43.146 |
| | 5 | -122.836 | 0 | 0 | -20.114 |
| M46 | 1 | -122.836 | 0 | 0 | -20.114 |
| | 2 | -144.588 | 0 | 0 | -8.275 |
| | 3 | -166.34 | 0 | 0 | 5.49 |
| | 4 | -188.093 | 0 | 0 | 21.181 |
| | 5 | -209.845 | 0 | 0 | 38.798 |
| M47 | 1 | -209.845 | 0 | 0 | 0 |
| | 2 | -231.597 | 0 | 0 | 19.543 |
| | 3 | -253.349 | 0 | 0 | 41.012 |
| | 4 | -275.101 | 0 | 0 | 64.407 |
| | 5 | -296.854 | 0 | 0 | 89.728 |
| M48 | 1 | 1346.055 | 0 | 0 | 2456.329 |
| | 2 | 117.695 | 0 | 0 | -1203.048 |
| | 3 | -1110.665 | 0 | 0 | 1279.375 |
| | 4 | 128.586 | 0 | 0 | -789.099 |
| | 5 | -1099.774 | 0 | 0 | 1638.585 |

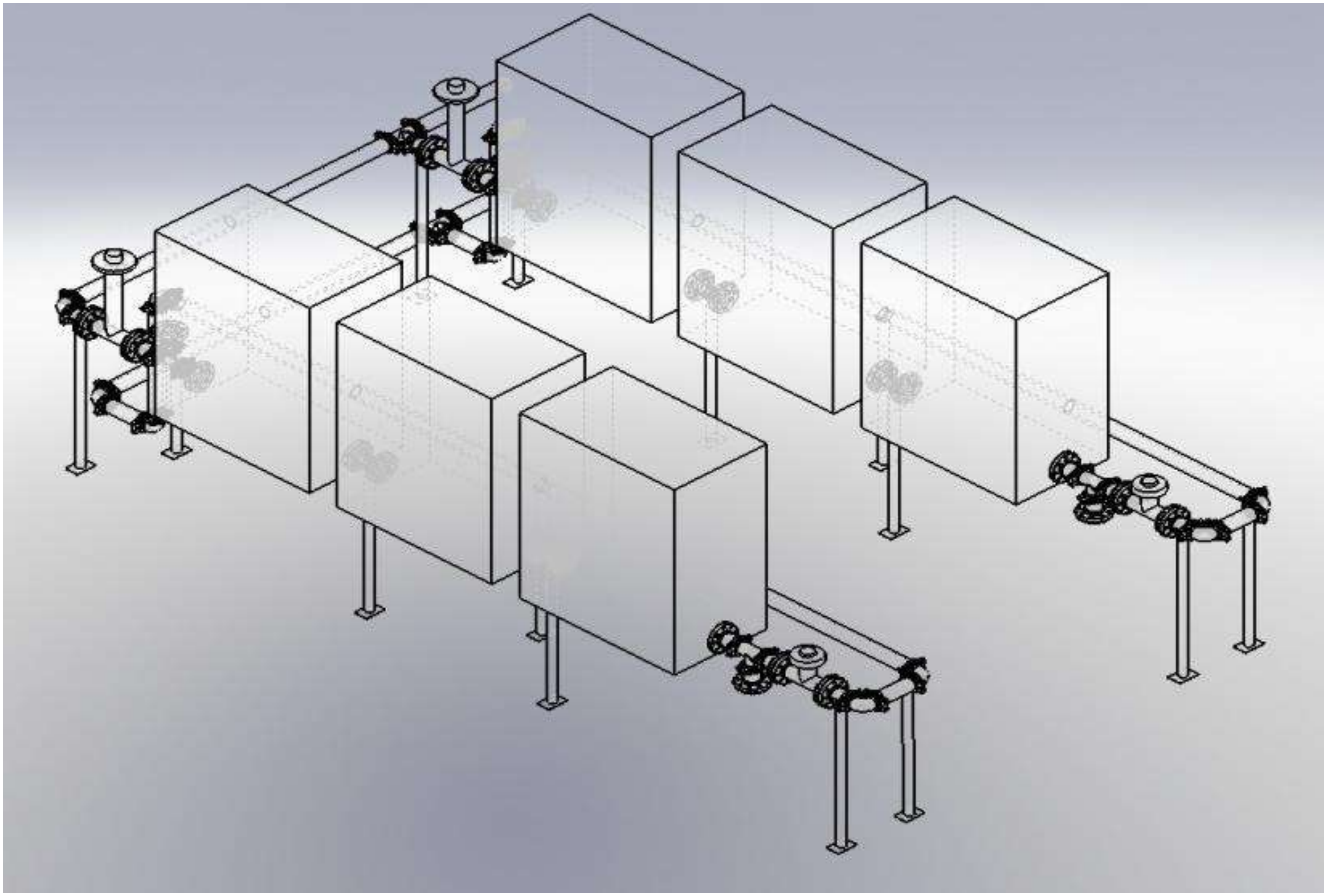


**Figure 93: Testing Flow loop sector**

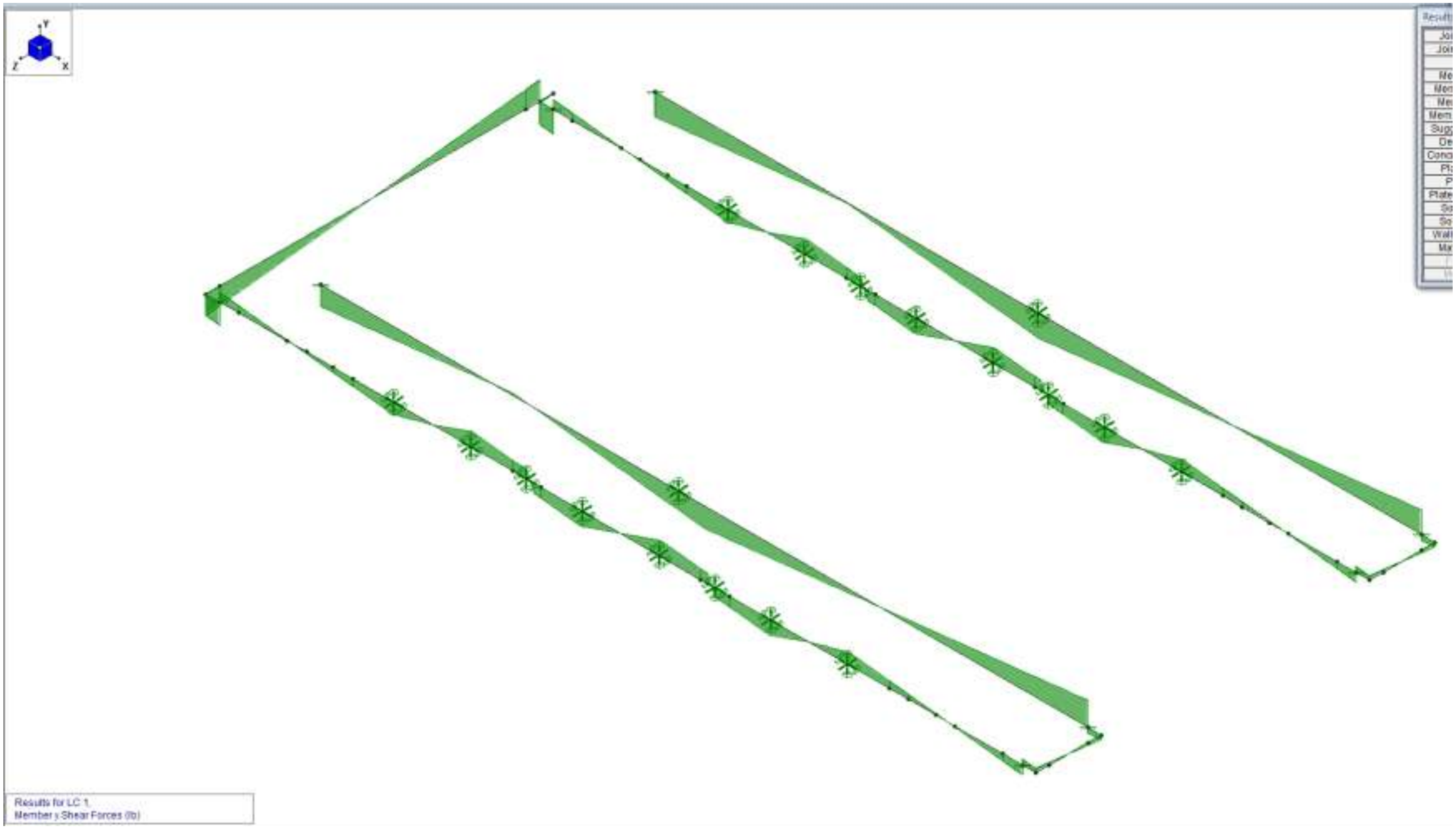



**Figure 94: Shear force distribution in the flow loop sector**

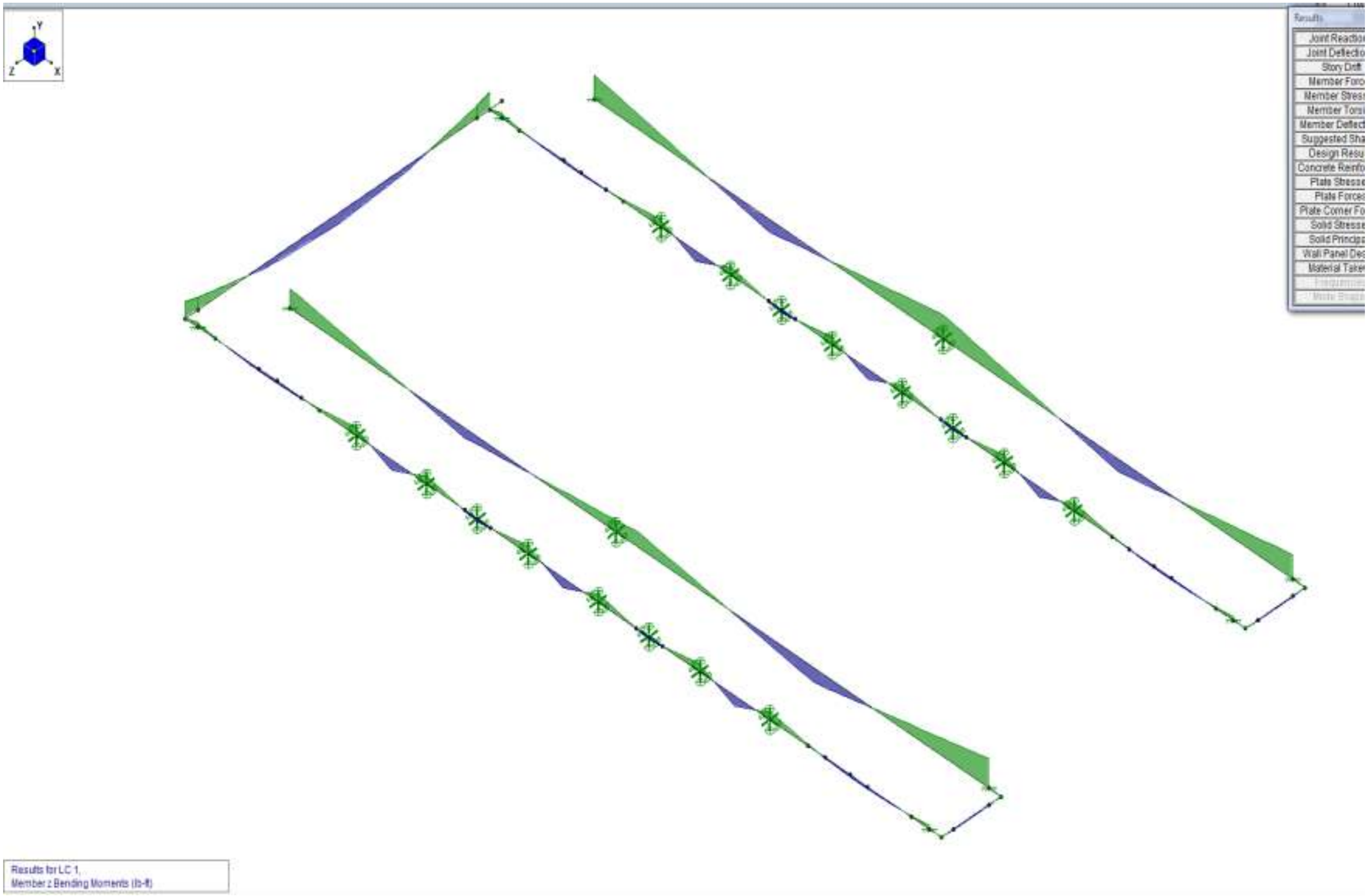



Figure 95: Bending moment distribution in the flow loop sector

**Dual Pump Sector:** Table 3 showed the maximum shear force, bending moment and deflection of the dual pump sector.

**Table 3: Maximum Shear force, bending moment and deflection of dual pump section**

| Max y shear (lb) | Max z shear (lb) | Max yy moment (lb-ft) | Max zz moment (lb-ft) | x deflection (in) | y deflection (in) | z deflection (in) |
|---|---|---|---|---|---|---|
| 3533.187 | 785.804 | 2339.863 | 2110.444 | 0.014 | 0.08 | 0.006571 |

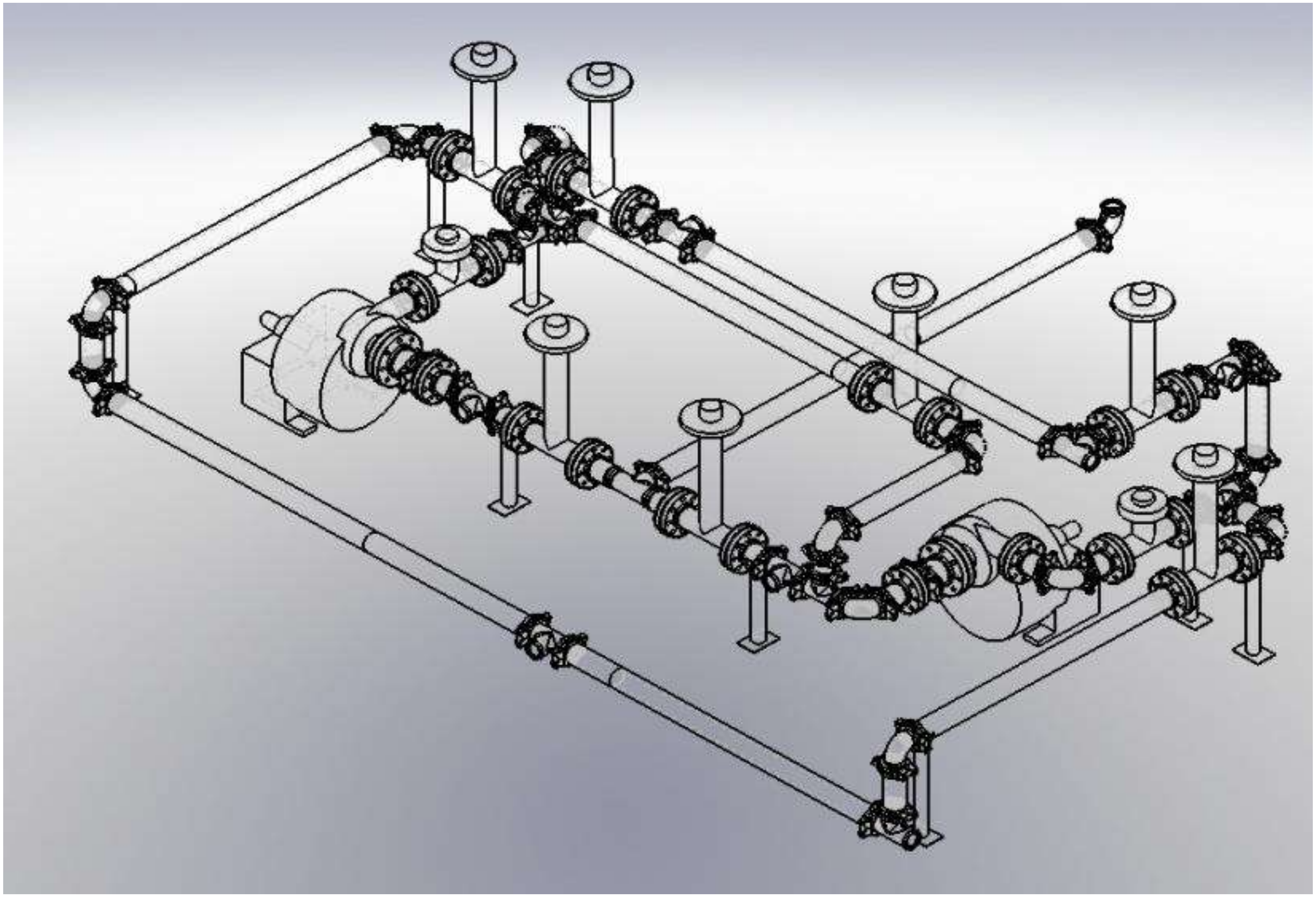


**Figure 96: Dual pump sector**

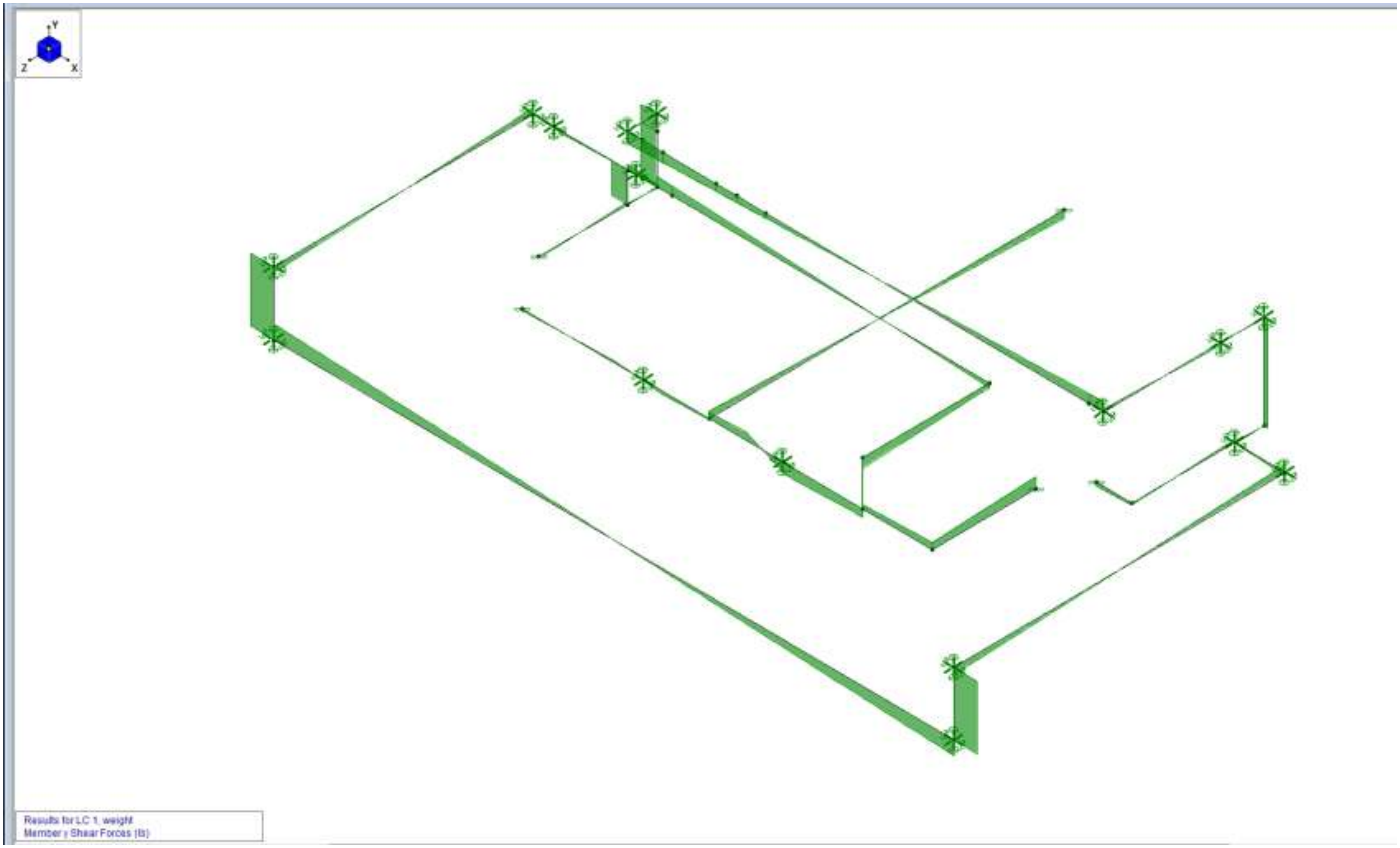



**Figure 97: y Shear force distribution in the dual pump sector**

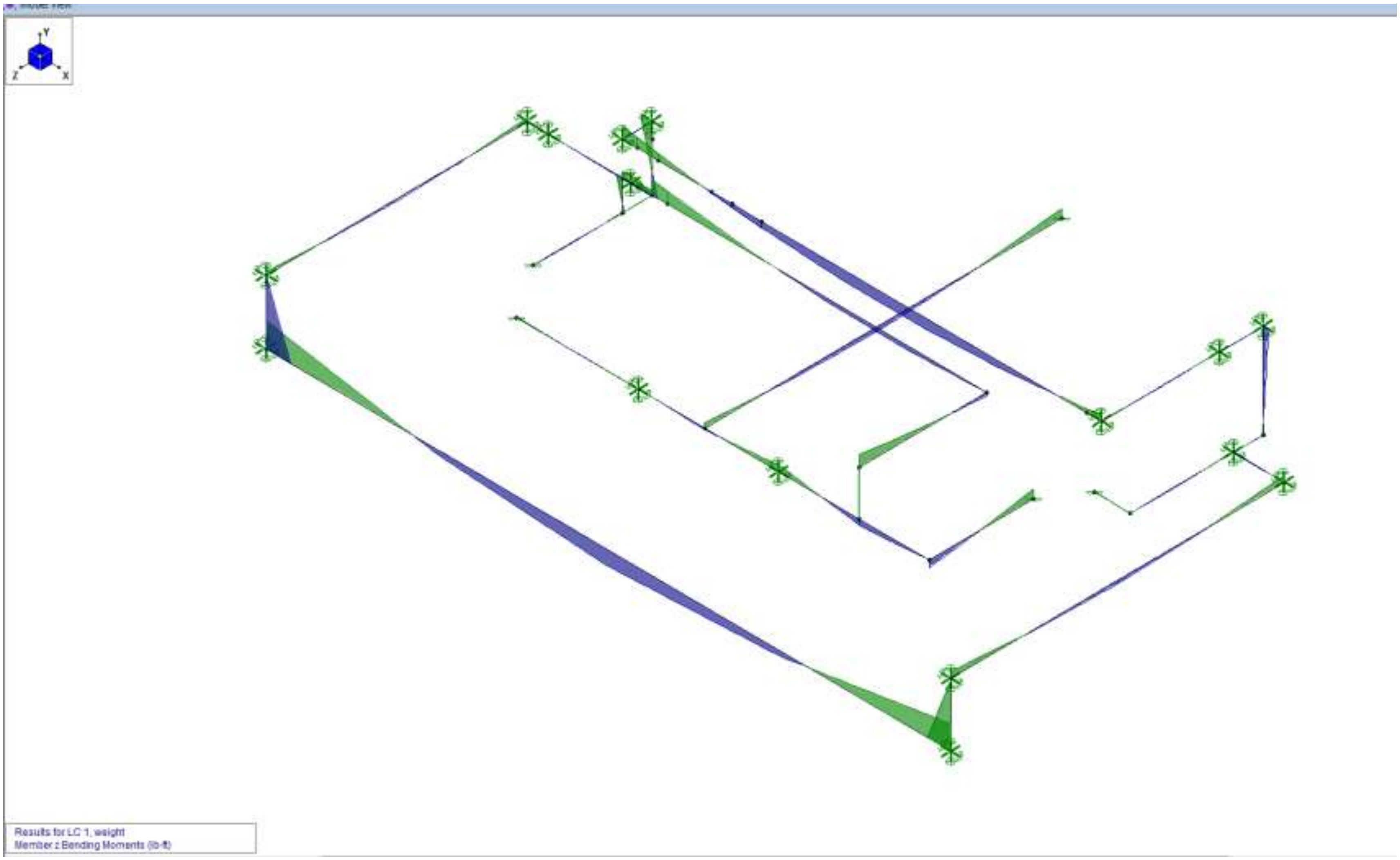


Figure 98: zz Bending moment distribution in the dual pump sector

**Stand pipe Sector:** Table 4 showed the maximum shear force, bending moment and deflection of the stand pipe sector.

**Table 4: Maximum Shear force, bending moment and deflection of stand pipe sector**

| Max y shear (lb) | Max z shear (lb) | Max yy moment (lb-ft) | Max zz moment (lb-ft) | x deflection (in) | y deflection (in) | z deflection (in) |
|---|---|---|---|---|---|---|
| -2133.34 | 0 | 0 | 2016.581 | 0 | -0.129 | 0 |

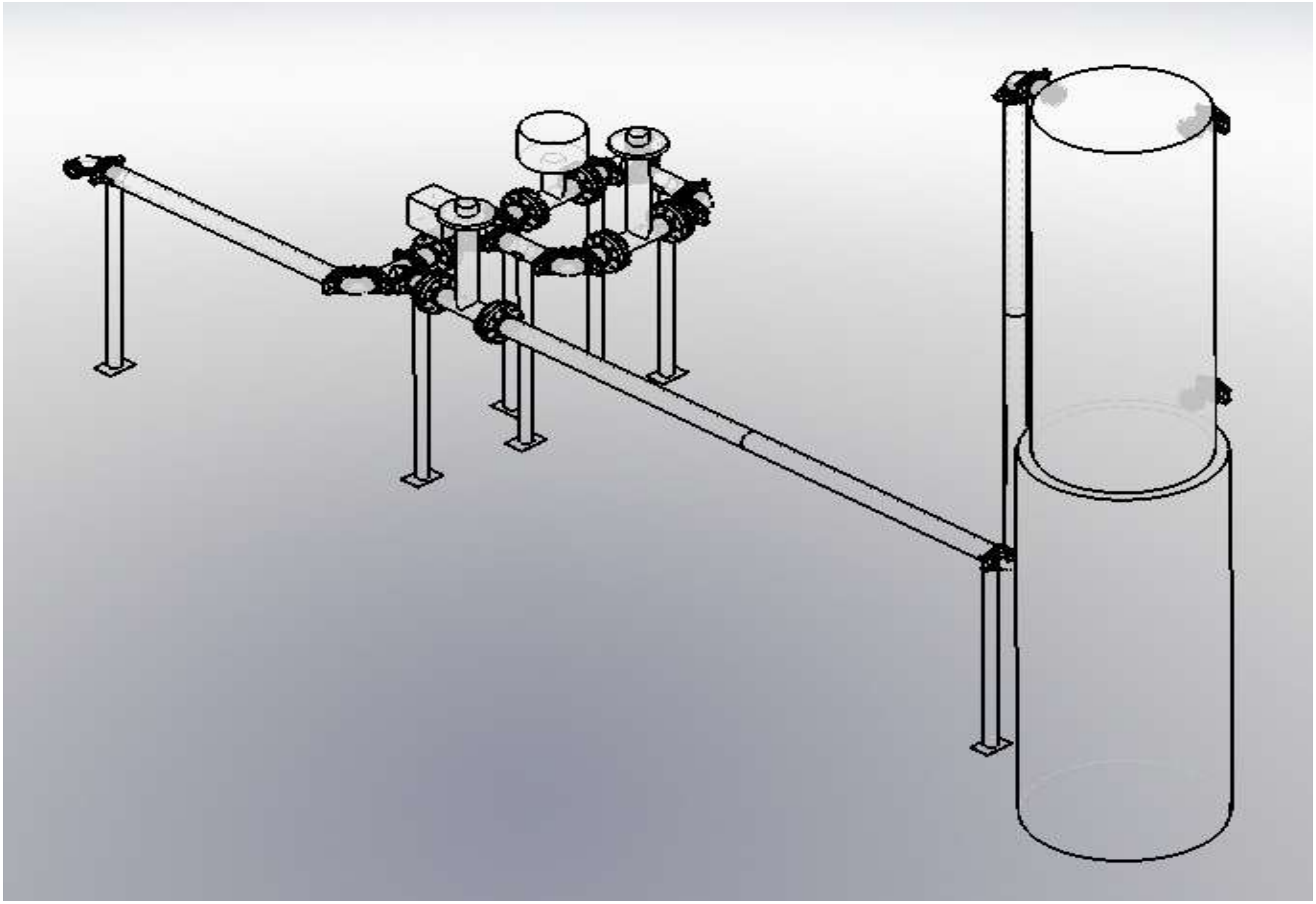


**Figure 99: Stand pipe sector**

**Figure 100: y Shear force distribution in the stand pipe sector**

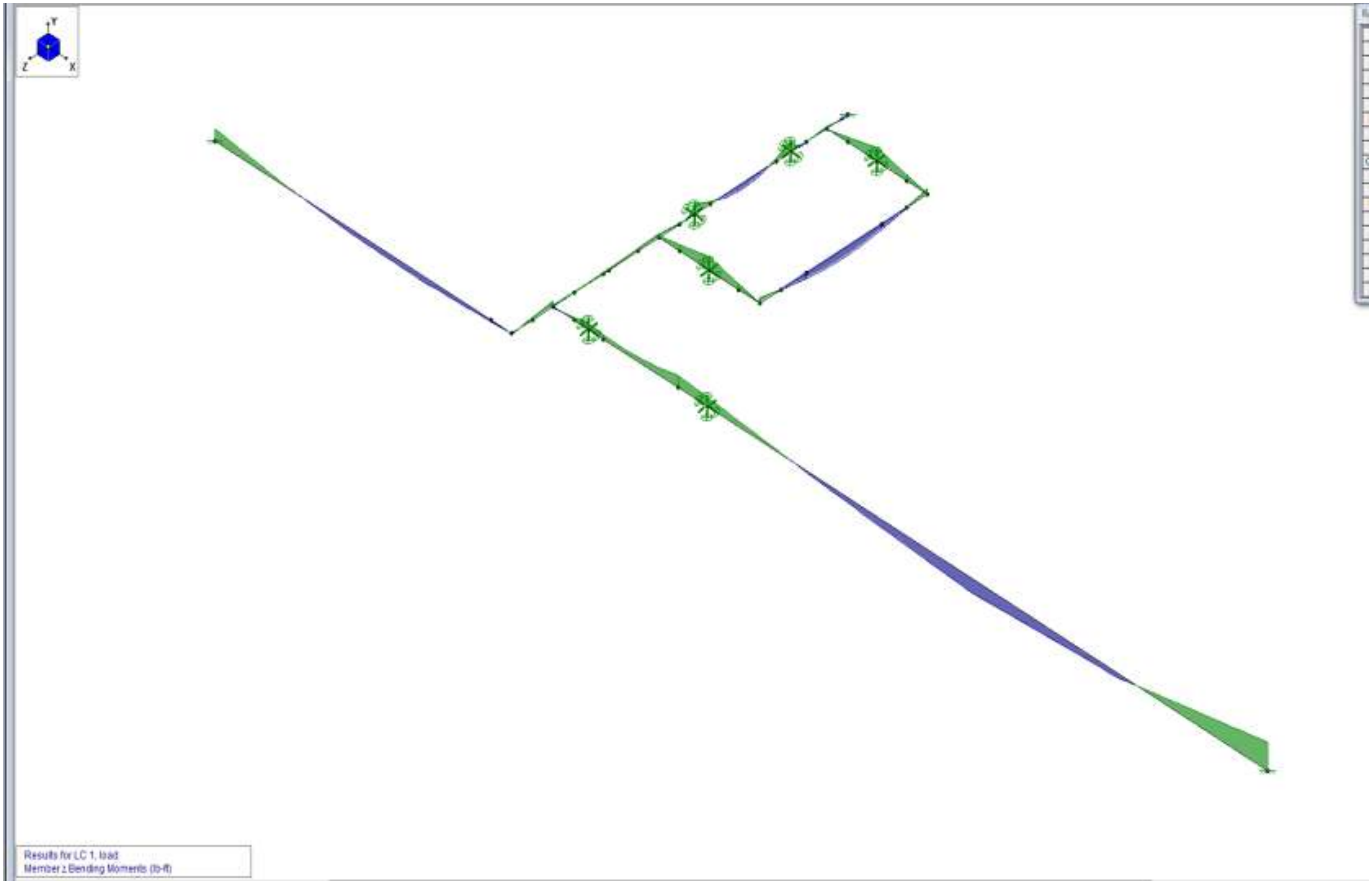



**Figure 101: zz Bending moment distribution in the stand pipe sector**

**Storage tank Sector:** Table 5 showed the maximum shear force, bending moment and deflection of the storage tank sector.

**Table 5: Maximum Shear force, bending moment and deflection of storage tank sector**

| Max y shear (lb) | Max z shear (lb) | Max yy moment (lb-ft) | Max zz moment (lb-ft) | x deflection (in) | y deflection (in) | z deflection (in) |
|---|---|---|---|---|---|---|
| 1193.864 | 769.928 | 666.901 | 1933.893 | -0.134 | -0.134 | 0.01 |

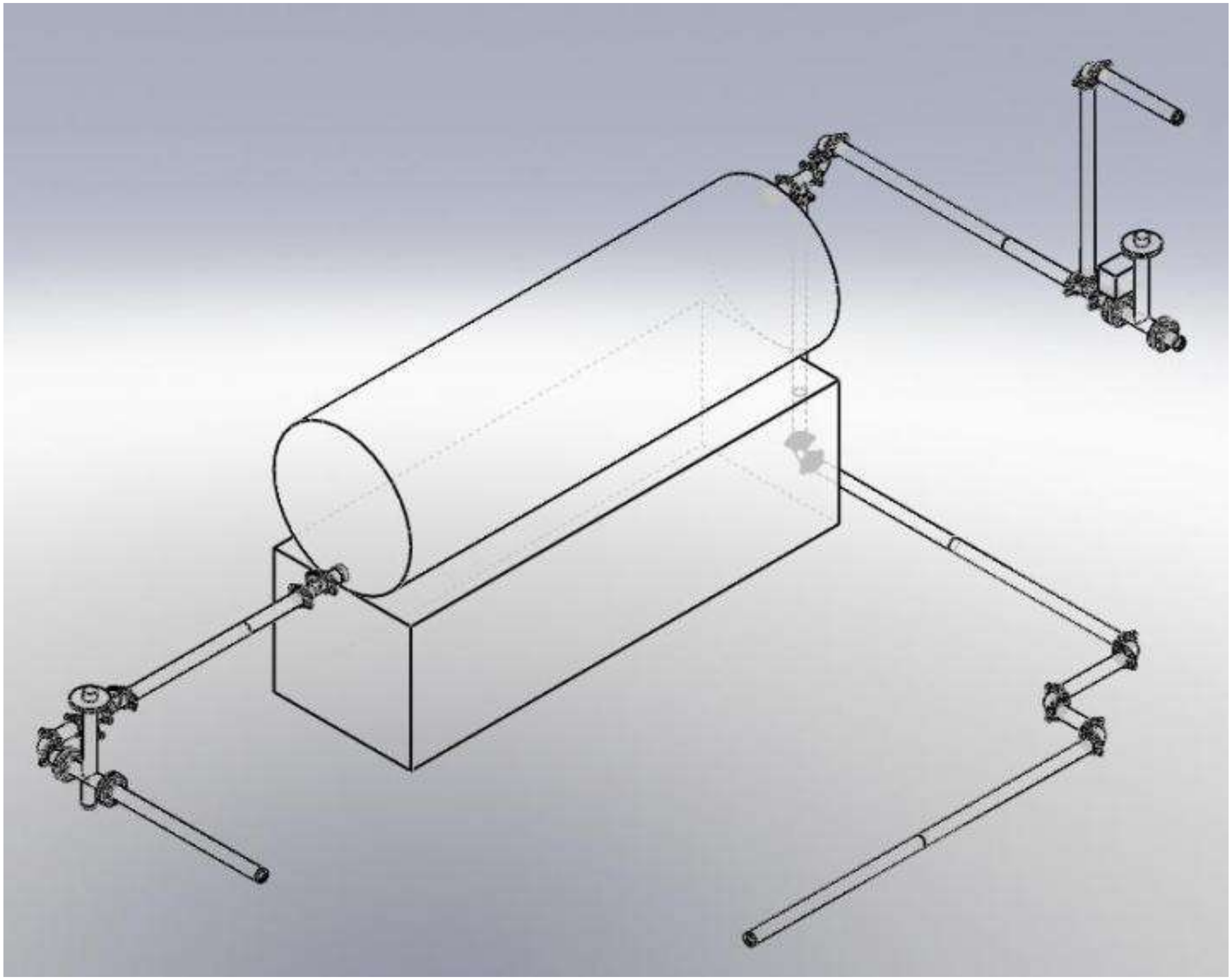


**Figure 102: Storage tank sector**

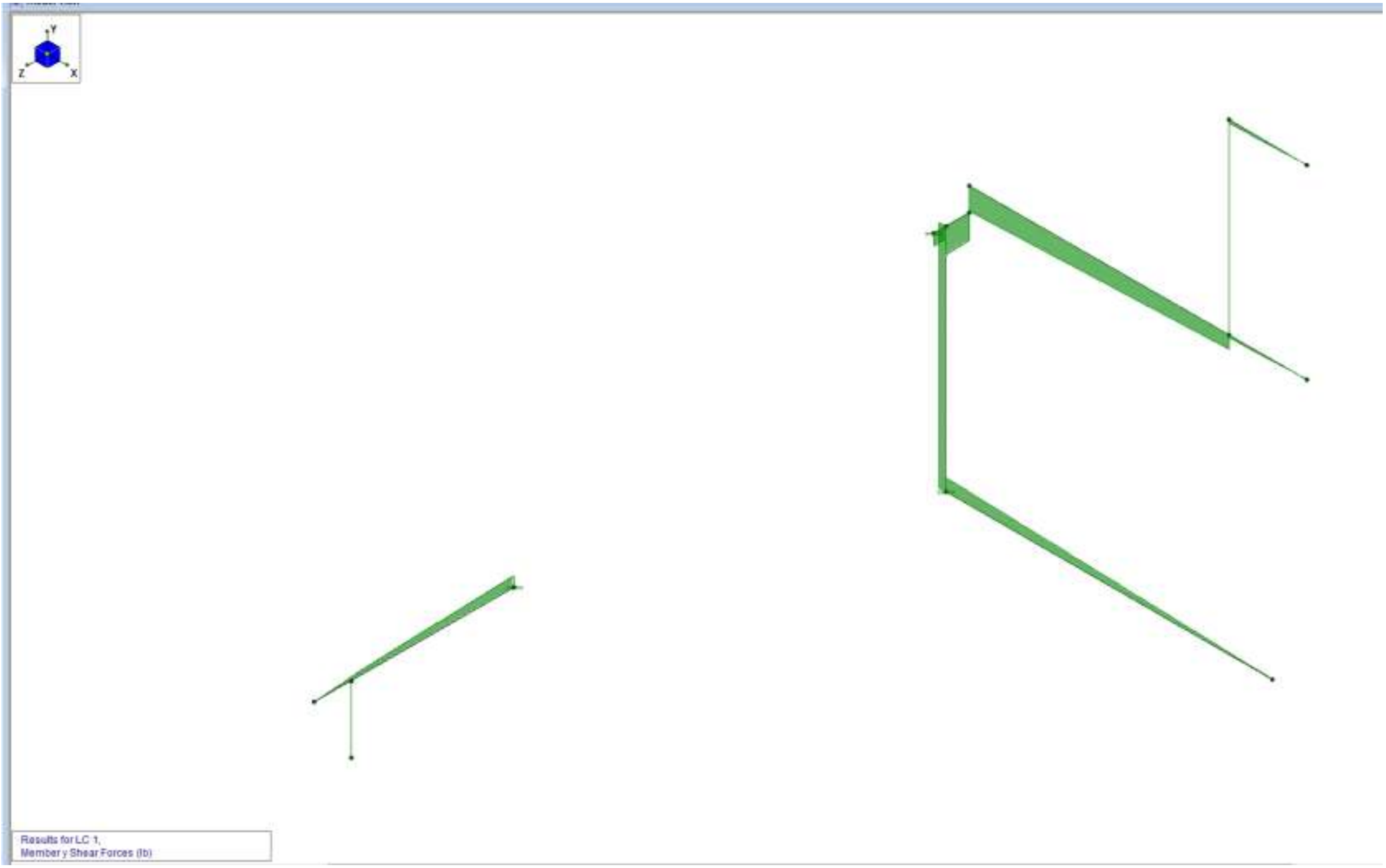



**Figure 103: y Shear force distribution in the storage tank sector**

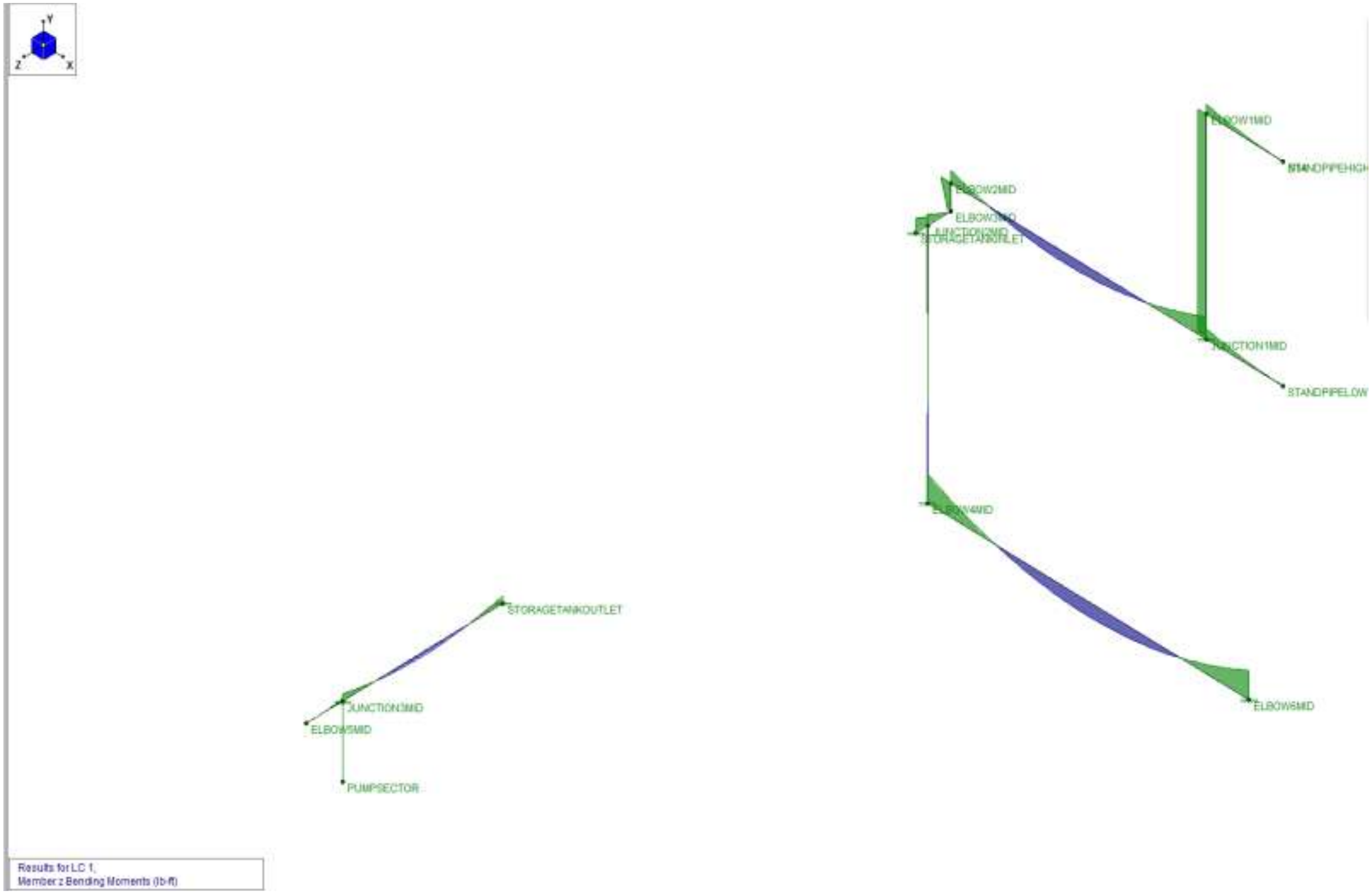



**Figure 104: zz Bending moment distribution in the storage tank sector**

**Appendix L. Last: Validity of RISA analysis**

To ensure that we use the RISA software correctly, we did a simple sample calculation by hand and compare the results with the RISA results. Their results were the same thus ensuring the accuracy of our analysis

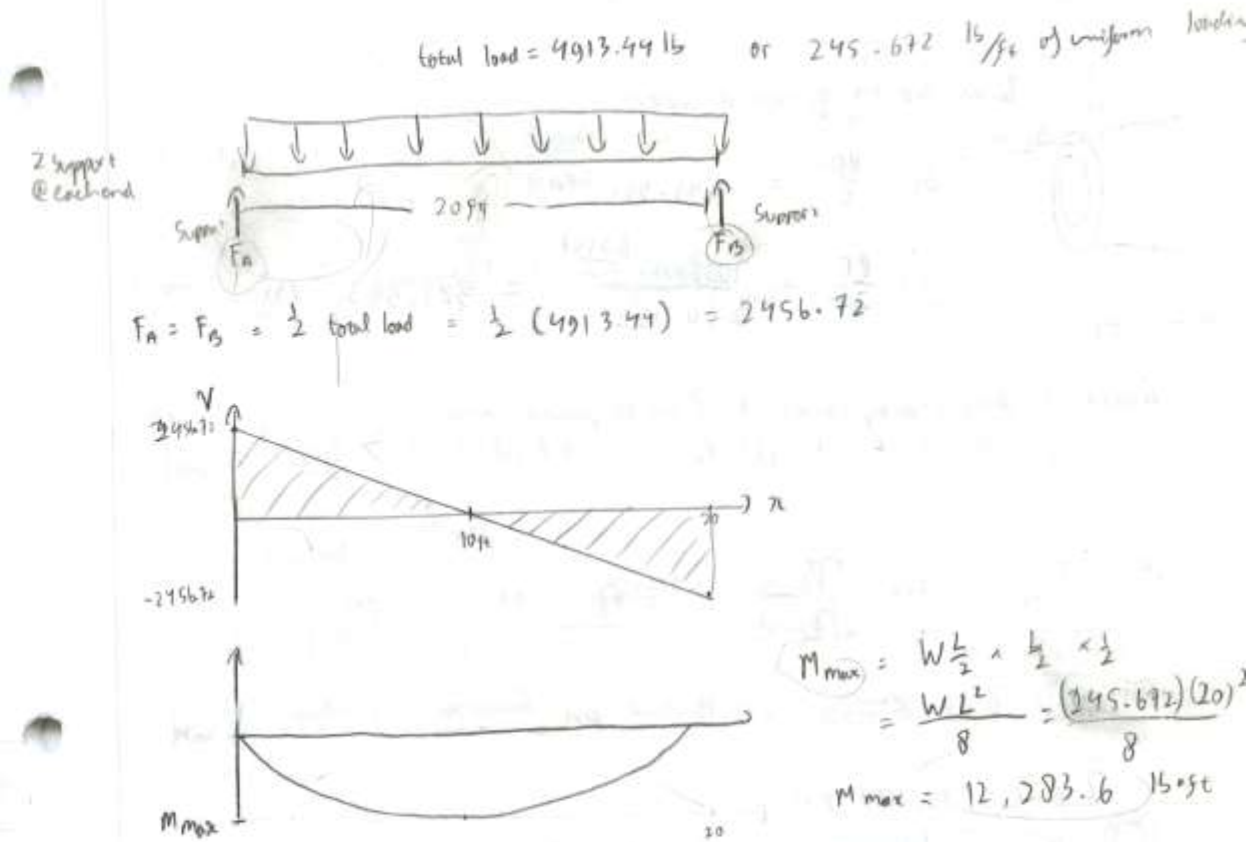



**Figure 104: Our hand calculation showed us that the maximum shear force should be 2456.72 lb and maximum bending moment to be 12283.6 lb-ft**

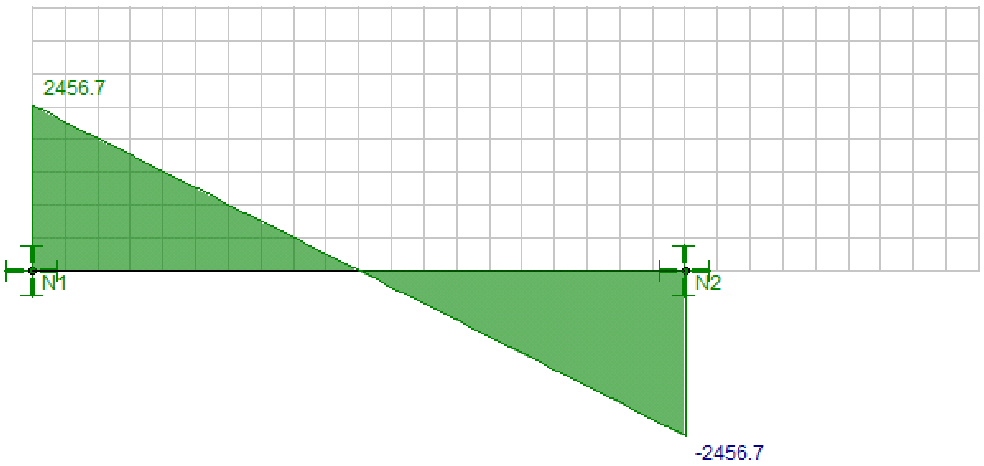



**Figure 105: RISA plot showed that the maximum shear force of the same problem should be 2456.7 lb**

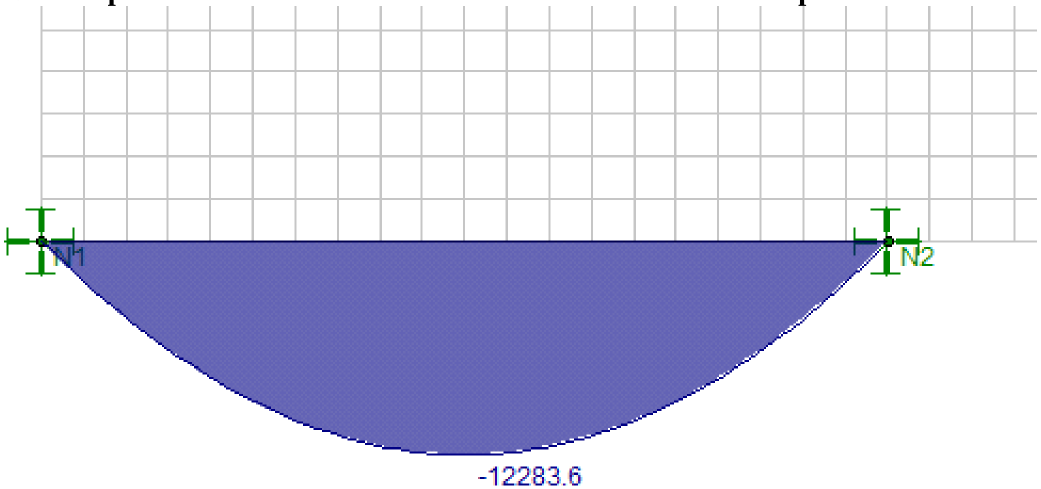



**Figure 106: RISA plot showed that the maximum bending moment of the same problem should be 12,283 lb-ft**

## Appendix M: DesignSafe for Simulator

### designsafe Report

| | | | |
|---|---|---|---|
| Application: | Power Plant Fluid Simulator | Analyst Name(s): | Elwin Lingga Ho |
| Description: | DesignSafe analysis regarding operation hazard for the actual Power Plant Fluid Simulator | Company: | |
| Product Identifier: | | Facility Location: | |
| Assessment Type: | Detailed | | |
| Limits: | | | |
| Sources: | | | |

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | mechanical : unexpected start<br>Operator turned on the pump before setting up the control valve and loop gate valves. This will cause early water flow to the flow loop, which may leads to leakage or instrument failure | Catastrophic<br>Frequent<br>Possible | High | Training for the operator to ensure they understand how the simulator mechanically work | Catastrophic<br>Frequent<br>Negligible | Moderate | On-going [Daily] |
| All Users<br>All Tasks | mechanical : impact<br>Instruments might bump into the pipes when they are being installed or taken off | Serious<br>Frequent<br>Unlikely | High | Ensure the operator have proper equipment to lift and adjust heavy instruments when trying to install or take off instruments to slots | Slight<br>Frequent<br>Negligible | Low | |
| All Users<br>All Tasks | electrical / electronic : water / wet locations<br>Water leaks from the fittings of the pipe may interact with the electrical power supply | Catastrophic<br>Frequent<br>Unlikely | High | Ensure that each fitting is properly sealed with sealing materials to prevent leakage | Catastrophic<br>Remote<br>Negligible | Moderate | |
| All Users<br>All Tasks | electrical / electronic : software errors<br>Software error may causes control valve to not work properly | Catastrophic<br>Frequent<br>Probable | High | Ensuring the software work properly before installing it to the system; safety button to shut down all the power of the simulator | Serious<br>Remote<br>Unlikely | Moderate | |
| All Users<br>All Tasks | slips / trips / falls : slip<br>Water leakage may cause slippery floor surface | Serious<br>Occasional<br>Unlikely | Moderate | Ensure proper sealing; ensure proper containment for the drain | Serious<br>Remote<br>Negligible | Low | |
| All Users<br>All Tasks | slips / trips / falls : trip<br>Operator trip over low pipes at the pumps sector | Serious<br>Remote<br>Unlikely | Moderate | Ensure the operator is fully aware of the surroundings | Slight<br>Remote<br>Unlikely | Low | |

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | fluid / pressure : fluid leakage / ejection<br>Leakage in the fittings of pipes | Serious<br>Remote<br>Possible | Moderate | Ensure each fittings is properly sealed and visually check them by running the simulator on low speed | Slight<br>Remote<br>Unlikely | Low | |

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | slips / trips / falls : object falling onto<br>Instruments fell from the slots | Serious<br>Remote<br>Unlikely | Moderate | Ensure it is securely attached after every replacement | Slight<br>Remote<br>Unlikely | Low | |
| All Users<br>All Tasks | ergonomics / human factors : lifting / bending / twisting<br>Bending: Operator needs to bend down to reach valves at the pump sectors. However the time required to adjust them are minimal | Serious<br>Remote<br>Possible | Moderate | Ensure operator stretch up after adjusting one valve that requires them to bend down | Slight<br>Remote<br>Negligible | Low | |
| All Users<br>All Tasks | noise / vibration : loss of awareness<br>technician loss their awareness due to fatigue | Serious<br>Remote<br>Possible | Moderate | ensure the operator is fully fit and responsive before giving them the cleareance to work on the simulator | Slight<br>Remote<br>Unlikely | Low | |
| All Users<br>All Tasks | noise / vibration : personnel fatigue<br>Fatigue of the technicians that is having training in the test flow loop | Serious<br>Remote<br>Possible | Moderate | Ensure there is an operator watching over in the control room and ready to take action if technicians start to show signs of fatigue | Slight<br>Remote<br>Unlikely | Low | |
| All Users<br>All Tasks | environmental / industrial hygiene : corrosion<br>Corrosion due to the fact that the pipe is made of steel | Serious<br>Occasional<br>Possible | High | The pipe and fitting selected for the simulator is designed for water usage, thus they have corrosion resitant coating on the inner diameter; Change the pipes whenever they show signs of corrosion | Serious<br>Remote<br>Probable | High | |
| All Users<br>All Tasks | fluid / pressure : hydraulics rupture<br>Hydraulic rupture | Catastrophic<br>Occasional<br>Probable | High | Safety factor of minimum 1.5 was put into requirement when designing the simulator. This ensure there will be no hydraulic rupture | Slight<br>Remote<br>Negligible | Low | |
| All Users<br>All Tasks | fluid / pressure : surges / sloshing<br>Water overflows from the storage tank and flood the room | Catastrophic<br>Occasional<br>Possible | High | Built a safety drain line on top of the storage tank. The drain line returns the excess water to the storage tank | Slight<br>Occasional<br>Negligible | Low | |

**Appendix N: FMEA for simulator**

**Failure Mode and Effects Analysis Worksheet (Adapted from Cincinnati Machine PFMEA)**

| | | |
|---|---|---|
| Description of system and mode of operation: Power Plant Fluid Simulator, main function is to replicate the flow of water in the power plant. This flow is achieved by driving the water using 2 pumps and control valve with programmed logic control to throttle the flow into the desired parameter | Key Contact / Phone: Elwin Ho/734-272-9263 | Date of Initial FMEA: November 20, 2009 |
| | Core Team: ME 450 team 25 | Date of Initial System Demonstration: TBD |
| | | Review Board Approval / Date |
| | Location: TBD | |

**Potential Failure Modes and Hazard Identification Discussion**: Identify all potential failures and safety hazards for this system in the applicable mode of operation. Complete a FMEA rating form for each significant item.

Simulator contains energy stored in the form of pressurized and high velocity water. Main hazard is water leakage . Rapid release of water can cause injury and damage to surrounding people and object. Furthermore, water may cause damage to the electircal components in the simulator. Individual component failure may occur. Again this will result in fluid leakage at varyind rates. Instruments are relatively massive, therefore injury to person handling the equipement could occur if objects are lifted incorectly or if they fall

**FMEA rating form for a single Failure / Hazard**

| Categorize: | | | | | | | | | | Person | Action Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identify susbsystem and mode of operation | Potential Failure Mode and 5 Whys [1] | Potential Effect of Failure [2] | SEV | Probability of Occurrence of Failure [3] | OCC | Current Controls for Detection / Prevention [4] | DET | RPN | Recommended Action [5] | Responsible & Completion Date | Action Taken [6] | SEV | OCC | DET | RPN |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pump | Bad seal/ incorrect connection | fluid leak | 9 | highly improbab le | 1 | inspection of connection after small flow | 2 | 18 | | | | | | | | |
| | | Breakage | explosion/ device stop running | 10 | higly improbab le | 1 | inspection and monitoring before and during pump usage | 1 | 10 | | | | | | | | |

1. Discuss root cause of the failure mode (based on the 5 whys): cause of bad seal can be improper installation of the pump to the simulator. The likelihood can be reduced if care is taken to ensure proper connectinon and seal.
Breakege of the pump is highly unlikely because the pump can work at even higher load that our simulator requires

2. Discuss/justify the severity rating (SEV): SEV is very low and is not a concern for either failure mode

| |
|---|
| 3. Discuss/justify the rating for probability of occurrence (OCC) Probability of occurrence is low. They are unlikely due to manual inspection that will be conducted everytime the simulator is being used |
| 4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET): Visual inspection wil be sufficient to prevent pump bad seal and breakage. Since the inspection must be conducted whenever the operator wants to turn on the pump |
| 5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. |

**FMEA rating form for a single**
**Failure / Hazard**

| Categorize: | | | | | | | | | | Person | Action Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identify susbsystem and mode of operation | Potential Failure Mode and 5 Whys [1] | Potential Effect of Failure [2] | S E V | Probability of Occurrence of Failure [3] | C C C | Current Controls for Detection / Prevention [4] | D E T | R P N | Recommended Action [5] | Responsible & Completion Date | Action Taken [6] | S E V | C C C | D E T | R P N |
| Storage tank | Leakage | fluid leak | 9 | highly improbable | 1 | inspection of connection after small flow | 2 | 18 | | | | | | | |
| | Overflow | flood | 10 | higly improbable | 1 | ensure not using the maximum capacity of the storage tank | 1 | 10 | Ensure the water storage tank is never filled to the maximum at the beginning | | | | | | |

| |
|---|
| 1. Discuss root cause of the failure mode (based on the 5 whys): cause of leakage can be improper installation of the fittings that carry the water out from the storage tank. The likelihood can be reduced if care is taken to ensure proper connectinon and seal.<br>Overflow of the storage tank is highly unlikely because the simulator only requires less than half of the total capacity of the storage tank. Thus the storage tank only needed to be filled till half leavind safety margin to prevent overflow of storage tank |
| 2. Discuss/justify the severity rating (SEV): SEV ishigh and  a major concern for either failure mode |
| 3. Discuss/justify the rating for probability of occurrence (OCC) Probability of occurrence is low. They are unlikely due to manual inspection that will be conducted everytime the simulator is being used. Storage tank will never overflow since we will only fill it until half of its total capacity |

| |
|---|
| |
| 4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET): Visual inspection wil be sufficient to prevent storage tank leakage and overflow |
| 5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. |

**FMEA rating form for a single Failure / Hazard**

| Categorize: | | | | | | | | | | Person | Action Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identify susbsystem and mode of operation | Potential Failure Mode and 5 Whys [1] | Potential Effect of Failure [2] | SEV | Probability of Occurrence of Failure [3] | OCC | Current Controls for Detection / Prevention [4] | DET | RPN | Recommended Action [5] | Responsible & Completion Date | Action Taken [6] | SEV | OCC | DET | RPN |
| Stand pipe | Leakage | fluid leak | 9 | highly improbable | 1 | inspection of connection after small flow | 2 | 18 | | | | | | | |
| | Overflow | flood | 10 | higly improbable | 1 | safety return line | 1 | 10 | | | | | | | |

1. Discuss root cause of the failure mode (based on the 5 whys): cause of leakage can be improper installation of the fittings that carry the water to/ from the stand pipe. The likelihood can be reduced if care is taken to ensure proper connectinon and seal.
Overflow of the stand pipe is highly unlikely because the simulator has a safety return line on top of the stand pipe that will channel the excessive water from standpipe to the storage tank

2. Discuss/justify the severity rating (SEV): SEV ishigh and  a major concern for either failure mode

| |
|---|
| |
| 3. Discuss/justify the rating for probability of occurrence (OCC) Probability of occurrence is low. They are unlikely due to manual inspection that will be conducted everytime the simulator is being used. Stand pipe wil never overflow due to its safety return line |
| 4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET): Visual inspection wil be sufficient to prevent standpipe leakage and ensure there is no leakage in the stand pipe return line |
| 5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. |

**FMEA rating form for a single Failure / Hazard**

| Categorize: Identify susbsystem and mode of operation | Potential Failure Mode and 5 Whys [1] | Potential Effect of Failure [2] | SEV | Probability of Occurrence of Failure [3] | OCC | Current Controls for Detection / Prevention [4] | DET | RPN | Recommended Action [5] | Person Responsible & Completion Date | Action Results: Action Taken [6] | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Manual Valves, gate to open or close the channel, check valve | Losse Fittings | fluid leak | 8 | highly improbable | 1 | inspection of connection after small flow | 2 | 16 | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | to prevent backflow | | | | | | | | | | | | | | | |
| | | Breakage | flood | 10 | higly improbable | 1 | safety return line | 1 | 10 | | | | | | | |

1. Discuss root cause of the failure mode (based on the 5 whys): cause of leakage can be improper installation of the fittings . The likelihood can be reduced if care is taken to ensure proper connectinon and seal. Breakage is highly unlikely due to working pressure range is way below the rated pressure for these valves

2. Discuss/justify the severity rating (SEV): SEV ishigh and a major concern for either failure mode

3. Discuss/justify the rating for probability of occurrence (OCC) Probability of occurrence is low. They are unlikely due to manual inspection that

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| will be conducted everytime the simulator is being used. Stand pipe wil never overflow due to its safety return line |
| 4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET): Visual inspection will be sufficient to prevent fittings leakage |
| 5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. |

**FMEA rating form for a single Failure / Hazard**

| Categorize: Identify susbsystem and mode of operation | Potential Failure Mode and 5 Whys [1] | Potential Effect of Failure [2] | SEV | Probability of Occurrence of Failure [3] | OCC | Current Controls for Detection / Prevention [4] | DET | RPN | Recommended Action [5] | Person Responsible & Completion Date | Action Results: Action Taken [6] | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control valve, adjust the flow of water by automatically throttling it up or down based on the input of PLC | Wear | Motion Failure | 8 | low | 2 | periodical inspection | 1 | 16 | periodical thorough inspection | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Electric Short | Fire | 8 | low | 2 | Visual inspection | 2 | 32 | Proper installation of electric connection. Double check the connection port. | | | | | | |
| | Loose Fittings | Fluid Leak | 2 | low | 2 | visual inspection of the control valve and match the specification with operated flow parameters. | 3 | 12 | Follow Standard of procedure when installing the conection and ensure control valve is suitable for 22 psi of working pressure. | | | | | | |

1. Discuss root cause of the failure mode (based on the 5 whys): cause of leakage can be improper installation of the fittings . The likelihood can be reduced if care is taken to ensure proper connectinon and seal. Wear of the control valve is due to long time usage. Cause of electric short is leakage and exposed electric cable

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| 2. Discuss/justify the severity rating (SEV): SEV ishigh and  a major concern for either failure mode |
| 3. Discuss/justify the rating for probability of occurrence (OCC) Probability of occurrence is low. They are unlikely due to manual inspection that will be conducted everytime the simulator is being used. |
| 4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET): Visual inspection wil be sufficient to prevent fittings leakage and electric short, periodical inspection will ensure the condition of control valve. |

5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered.

**FMEA rating form for a single Failure / Hazard**

| Categorize: | | | | | | | | | | Person | Action Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identify susbsystem and | Potential Failure Mode and | Potential Effect of Failure [2] | SE | Probability of Occurrence of | OC | Current Controls for Detection / Prevention [4] | DE | RP | Recommended Action [5] | Responsible & Completion | Action Taken [6] | SE | OC | DE | RP |

| mode of operation | 5 Whys [1] | | V | Failure [3] | C | | T | N | | Date | | V | C | T | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLC system | Electric Short | Fire | 10 | low | 2 | Visual inspection | 2 | 40 | Proper installation of electric connection. Double check the connection port. Place the plc in other room | | | | | | |

1. Discuss root cause of the failure mode (based on the 5 whys): Cause of electric short is leakage and exposed electric cable

2. Discuss/justify the severity rating (SEV): SEV is high and a major concern for failure mode

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| 3. Discuss/justify the rating for probability of occurrence (OCC) Probability of occurrence is low. They are unlikely due to manual inspection that will be conducted everytime the simulator is being used. |
| 4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET): Visual inspection wil be sufficient to prevent fittings leakage and electric short, placement of plc unit in a water proof cabinet or even at differnet room will also make the probability low |
| 5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. |

**FMEA rating form for a single Failure / Hazard**

| Categorize: | | | | | | | | | | Person | Action Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identify susbsystem and mode of operation | Potential Failure Mode and 5 Whys [1] | Potential Effect of Failure [2] | SEV | Probability of Occurrence of Failure [3] | OCC | Current Controls for Detection / Prevention [4] | DET | RPN | Recommended Action [5] | Responsible & Completion Date | Action Taken [6] | SEV | OCC | DET | RPN |
| Steel pipe and pipe fittings | Breakage | Leakage | 8 | low | 2 | Visual inspection/ ensure proper rated pipe and fittings | 2 | 32 | | | | | | | |
| | corrosion | Leakage/fa | 9 | low | 2 | Visual | 2 | 3 | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ilure | | | | inspection | | 6 | | | | | | | |
| | Loose fittings | Leakage | 8 | low | 2 | Visual inspection/ ensure proper rated pipe and fittings | 2 | 3<br>2 | | | | | | | |

1. Discuss root cause of the failure mode (based on the 5 whys): Cause of breakage is higher working pressure compared with the rated pressure, cause of loose fittings is improper set connction between pipes. For the corrosion it is because of the nature of steel and water and also due to age

2. Discuss/justify the severity rating (SEV): SEV is high and a major concern for all failure mode

3. Discuss/justify the rating for probability of occurrence (OCC) Probability of occurrence is low. They are unlikely due to applied sealing material to ensure there is no leakage between fittings, furhtermore we chose the pipe and fittings to ensure they are rated much higher than the working

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| pressure. Corrosion is also unlikely since all of the pipes and fittings that we choose are designed for water usage, thus they are coated with corrosion resistance coating on the inner diameter |
| 4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET): Visual inspection wil be sufficient to prevent fittings leakage and breakage. Safety measurement to cut off the power from the pump also help |
| 5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered. |

**FMEA rating form for a single Failure / Hazard**

| Categorize: Identify susbsystem and mode of operation | Potential Failure Mode and 5 Whys [1] | Potential Effect of Failure [2] | SEV | Probability of Occurrence of Failure [3] | OCC | Current Controls for Detection / Prevention [4] | DET | RPN | Recommended Action [5] | Person Responsible & Completion Date | Action Results: Action Taken [6] | SEV | OCC | DET | RPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipe support | Breakage | Pipe and instruments drop | 10 | low | 1 | Ensure engineering analysis is done correctly with safety margin | 2 | 20 | | | | | | | |
| | Wear | unreilable support | 8 | low | 2 | Visual inspection | 2 | 32 | Prepare spare pipe support just in case | | | | | | |

1. Discuss root cause of the failure mode (based on the 5 whys): Cause of breakage is higher load than the rated load for the pipe support, cause of wear is aging

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| 2. Discuss/justify the severity rating (SEV): SEV is high and a major concern for failure mode, since it will cause simulator failure |
| 3. Discuss/justify the rating for probability of occurrence (OCC) Probability of occurrence is low. Breakage is unlikely since the load that we apply to each support is relatively low compared with the rated load. Aging is also rated low since it will take a considerably amount of time before they became structurally weak |
| 4. Discuss/justify the rating for the probability of detecting a "failure imminent" condition and avoiding the failure (DET): Visual inspection wil be |

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| sufficient to notice bad support, and also safety margin when doing the engineering anlysis of the pipe support |
| 5. Recommended actions: Make specific recommendations for action and include some discussion of the alternatives that were considered.: prepare spare pipe support, so that in case a bad pipe support is found, it can be replaced quickly to prevent further damage. |

**APPENDIX O :**
**Prototype**

Project # 25

Project Title Power Plant Fluid Simulator

Team Members Anthony Bingei, Elwin Ho, Owen Ali, Yudie Soenjoto

| Part Number, Name, and Functions | Potential Failure Mode and 5 Whys [1] | Potential Effect of Failure [2] | SEV | Probability of Occurrence of Failure [3] | OCC | Current Controls for Detection / Prevention [4] | DET | RPN = SEV X OCC X DET | Recommended Action | Responsible & Completion Date |
|---|---|---|---|---|---|---|---|---|---|---|
| Part #1: Pump | Vibration | Noise | 2 | Manufacturing Defects, improper clamping system, and overuse of pump. | 4 | Using pressure gauge to check pressure difference and whether control valve is in normal operation. | 2 | **16** | Proper Design Analysis | Anthony |
| | Wear | Flying debris | 8 | Pressure build up between control valve and pump. | 2 | Connecting pump to PLC control to automatically turn off or on the device. | 2 | **32** | Proper control logic installation for the pump. | Anthony |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #2: Pump Fitting, The connection between pump and straight Pipe. | Loose Fittings | Fluid Leak | 2 | Improper assembly and manufacturing defects. | 4 | Inspection of connection after small pressurization. | 3 | **24** | Follow Standard of procedure when installing the conection. | Yudie |
| | Breakage | Flying debris and cause injury to surrounding people. | 7 | Manufacturing Defects | 2 | Visual inspection of fittings for cracks and dimensions | 2 | **28** | Ensure the engineering specification of the tank fittings meet the required flow paramaters. | Yudie |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #3: Electric Cable. Connection cable used to connect the pump to PLC and power source. | Burning | Fire | 8 | Manufacturer defect | 2 | Visual inspection and product speficication check | 2 | **32** | Ensure the selected cable is not defective and suitable to wishstand 20 mA of electric current. | Yudie |
| | Stripping | Electric surge | 8 | Manufacturer Defect | 2 | Visual inspection | 1 | **16** | Check the insulation of electric cable for any defects. | Yudie |
| Part #4: Storage Tank. Tank the contains water supply. | Unbalanced | Storage tank topple of the ground and cause floods. | 3 | Manufacturer Defects | 2 | Visual inspection | 3 | **18** | Visually inspect the bottom part of the tank and see any defects. Before assembly, test the tank by filling water and check the balance. | Yudie |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Leaking | Fluid Leak | 2 | Manufacturer Defects | 2 | Visual inspection and match the component specification. | 2 | **8** | Check in detail on tank surface for any cracks and trade new stocks on the vendor if any are found. | Yudie |
| Part #5:Tank Fitting. Fittings to connect tank to the straight PVC pipe. | Loose Fittings | Fluid Leak | 2 | Improper assembly and manufacturing defects. | 4 | Inspection of connection after small pressurization. | 3 | **24** | Follow Standard of procedure when installing the conection. | Yudie |
| | Breakage | Flying debris and cause injury to surrounding people. | 7 | Manufacturing Defects | 2 | Visual inspection of fittings for cracks and dimensions | 2 | **28** | Ensure the engineering specification of the tank fittings meet the required flow paramaters. | Yudie |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #6: Stand Pipe. A supply tank that receive water from storage tank. | Unbalanced | Storage tank topple of the ground and cause floods. | 3 | Manufacturer Defects | 2 | Visual inspection | 3 | **18** | Visually inspect the bottom part of the stand pipe and see any defects. Before assembly, test the tank by filling water and check the balance. | Yudie |
| | Leaking | Fluid Leak | 2 | Manufacturer Defects | 2 | Visual inspection and match the component specification. | 2 | **8** | Check in detail on tank surface for any cracks and trade new stocks on the vendor if any are found. | Yudie |
| Part #7: PVC Cement. Chemical sealant that protects connection point. | Bonding Failure | Fluid Leakage | 2 | Material Defect | 2 | Ensure PVC cement matches the specification that works with PVC connection. | 2 | **8** | Visual inspection and read MSDS of the product. | Yudie |

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|---|---|---|---|---|---|---|---|---|---|---|
| | Erosion | Fluid Leakage | 2 | Material Defect | 2 | Ensure PVC cement could handle the specified 22 kPA pressure. | 2 | **8** | Visual inspection and read MSDS of the product. | Yudie |
| Part #8: Ball Valves. Manual ball valve that restrict and discharge flow of water. | Losse Fittings | Fluid leakage | 2 | Improper installation or manufacturer defects. | 3 | Visual inpection on the connection and ensure usage of PVC cement. | 2 | **12** | Proper installation with standard of procedure and check with pressure level | Yudie |
| | Breakage | Explosion or high pressure fluid leak | 5 | Manufacturer defect | 1 | Part selection that withstand an operating pressure of 22 kPa | 1 | **5** | Double check the spefication for ball valve to withstand much higher pressure then the flowing parameter pressure | Yudie |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #9: PLC. Programmed logic control that connect the software and hardware. | Overshooting | Failure in controlling the pump, control valve, and pressure transmitter that lead leakage. | 8 | Invalid algorithm used in the PLC software program. | 2 | Siemens assistance in creating the correct alogrithm for the prototype. | 1 | **16** | Troubleshoot the code and perform tests before final stage. | Anthony |
| | Electrical Short | Burn the PLC internal components and system failure. | 7 | Improper electrical onnection to electric hub. | 2 | Visual inspection and expert aid to ensure proper connection. | 1 | **14** | Inspect each cable that connects to either ground, positve or negative hub. | Anthony |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #10: Control Valve. Automated valve that controls the flow of water. | Wear | Motion Failure | 8 | Simulation Failure | 4 | | 1 | **32** | Proper Design Analysis | Anthony |
| | Electric Short | Fire | 8 | Improper electrical connection that causes short electric circuit. | 2 | Visual inspection and assistance of GSI recheck before operation. | 2 | **32** | Proper installation of electric connection. Double check the connection port. | Anthony |
| | Loose Fittings | Fluid Leak | 2 | Improper assembly and manufacturing defects. | 4 | visual inspection of the control valve and match the specification with operated flow parameters. | 3 | **24** | Follow Standard of procedure when installing the conection and ensure control valve is suitable for 22 psi of working pressure. | Anthony |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #11: Pressure Transmitter. An instrument that measures the level of water level in stand pipe. | Overshooting | Fluid Leak | 3 | Invalid coding that inhibit the functions of pressure transmitter. | 3 | Ensure the software and controls are properly build to perform the right function. | 3 | **27** | Ask for assistance from siemens expert for installation and technical issues. | Yudie |
| | Electric Short | Electric surge on the water inside the stand pipe. | 8 | Improper assembly of electrical connection to the pressure transmitter. | 2 | Visual inspection of electrical connection to the pressure transmitter. | 2 | **32** | Ask for siemens expert and GSI assistance for connection checks. | Yudie |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Part #12: PC Set. A set of CPU, monitor, and keyboard that controls the input of PLC. | Electric Short | Control failure that leads to system failure. | 8 | Manufacturer decfs or improper electrical connection. | 3 | PC set must be tested for perforamance before including them in the assembly | 2 | **48** | Ask for siemens expert for clarification about the installation and usage of the PC set. | Anthony |
| Part #13: Pipe Fittings Connection. Connecting one straight PVC pipe to another Straight PVC pipe. | Loose Fittings | Fluid Leak | 2 | Improper assembly and manufacturing defects. | 4 | Inspection of connection after small pressurization. | 3 | **24** | Follow Standard of procedure when installing the conection. | Yudie |
| | Breakage | Flying debris and cause injury to surrounding people. | 7 | Manufacturing Defects | 2 | Visual inspection of fittings for cracks and dimensions | 2 | **28** | Ensure the engineering specification of the tank fittings meet the required flow paramaters. | Yudie |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #14: Straight PVC Pipe. PVC pipe that connects prototype components for water flows. | Loose Fittings | Fluid Leak | 2 | Improper assembly and manufacturing defects. | 4 | Inspection of connection after small pressurization. | 3 | **24** | Follow Standard of procedure when installing the conection. | Yudie |
| | Breakage | Flying debris and cause injury to surrounding people. | 7 | Manufacturing Defects | 2 | Visual inspection of fittings for cracks and dimensions | 2 | **28** | Ensure the engineering specification of the tank fittings meet the required flow paramaters. | Yudie |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #15: Elbow PVC Pipe.PVC pipe that connects prototype components for water flows while changing direction. | Loose Fittings | Fluid Leak | 2 | Improper assembly and manufacturing defects. | 4 | Inspection of connection after small pressurization. | 3 | **24** | Follow Standard of procedure when installing the conection. | Yudie |
| | Breakage | Flying debris and cause injury to surrounding people. | 7 | Manufacturing Defects | 2 | Visual inspection of fittings for cracks and dimensions | 2 | **28** | Ensure the engineering specification of the tank fittings meet the required flow paramaters. | Yudie |

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|---|---|---|---|---|---|---|---|---|---|---|
| Part #16: Air Compressor. A device used to power the actuator in the control valve. | Vibration | Noise | 2 | Manufacturing Defects, improper clamping system, and overuse of pump. | 4 | Using pressure gauge to check pressure difference and whether control valve is in normal operation. | 2 | **16** | Proper Design Analysis | Anthony |
| | Wear | Flying debris | 8 | Pressure build up between control valve and pump. | 2 | Connecting pump to PLC control to automatically turn off or on the device. | 2 | **32** | Proper control logic installation for the pump. | Anthony |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Electric Short | Fire | 8 | Improper electrical connection that causes short electric circuit. | 2 | Visual inspection and assistance of GSI recheck before operation. | 2 | **32** | Proper installation of electric connection. Double check the connection port. | Anthony |
| Part #17: Pressure Gauge. Device used to show pressure difference between control valve and stand pipe. | Wear | Fluid Leak and unable to read pressure difference later on. | 3 | Manufacturing defects or mismatch of component specification with operating parameters. | 2 | Visual inspection | 3 | **18** | Test the pressure gauge at low pump speed before final testing and search for abnormalities on the component. | Yudie |
| | Fracture | Flying Debris unable to read pressure difference later on. | 7 | Manufacturing defects or mismatch of component specification with operating parameters. | 2 | Visual inspection and make sure pressure gauge is to withstand much more than 22 kPa | 2 | 28 | Test the pressure gauge before final testing for any initial fracture on the part. | Yudie |

**Appendix P.**
**PVC Cement MSDS**

**CPVC HEAVY DUTY SOLVENT CEMENT**
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**SECTION 1 IDENTITY OF MATERIAL**
Trade Name: OATEY HEAVY DUTY CPVC SOLVENT CEMENT
Product Numbers: 31080, 31081, 31082, 31083, 31084, 31566, 31567, 31568, 31569, 31962, 31963, 31964, 31965
Formula: CPVC Resin in Solvent Solution
Synonyms: CPVC Plastic Pipe Cement
Firm Name & OATEY CO. 4700 West 160th Street P.O. Box 35906 Cleveland,
Mailing Address: Ohio 44135, U.S.A. http://www.oatey.com
Oatey Phone Number: (216) 267-7100
Emergency Phone For Emergency First Aid call 1-303-623-5716 COLLECT. For
Numbers: chemical transportation emergencies ONLY, call Chemtrec at
1-800-424-9300

**SECTION 2 COMPOSITION**
INGREDIENTS: %: CAS NUMBER: ACGIH TLV TWA: OSHA PEL TWA: OTHER:
Cyclohexanone 7 - 15% 108-94-1 20 ppm(skin) 25 ppm
Tetrahydrofuran 55 - 65% 109-99-9 200 ppm 200 ppm 25 ppm (Mfg)
750 ppm STEL
Methyl Ethyl Ketone 10 - 20% 78-93-3 200 ppm 200 ppm
CPVC Resin 12 - 16% 68648-82-8 10 mg/m3 None
(Non-hazardous) Established
Orange Colorant 0 - 2% N/A None None
(Non-hazardous) Established Established
Amorphous Fumed Silica 1 - 3% 112945-52-5 10 mg/m3 None
(Non-hazardous) Established

**SECTION 3 EMERGENCY OVERVIEW**
Orange liquid with an ether-like odor. Extremely flammable liquid and vapor. Vapors may cause flash fire. May cause eye and skin irritation. Inhalation of vapors or mist may cause respiratory irritation and central nervous system effects. Swallowing may cause irritation, nausea, vomiting, diarrhea and kidney or liver disorders. Aspiration hazard. May be fatal if swallowed. Symptoms may be delayed.
NFPA Hazard Signal: Health: 2 Stability: 1 Flammability: 3 Special: None
HMIS Hazard Signal: Health: 3 Stability: 1 Flammability: 3 Special: None
OSHA Hazard Classification: Flammable, irritant, organ effects
Canadian WHIMS Classification: Class B, Division 2; Class D, Division 2, Subdivision B

**SECTION 4 EMERGENCY AND FIRST AID PROCEDURES - CALL 1-303-623-5716 COLLECT**
Skin: Remove contaminated clothing immediately. Wash all exposed areas with soap and water. Get medical attention if irritation develops. Remove dried cement with Oatey Plumber's Hand Cleaner or baby oil.
Eyes: If material gets into eyes or if fumes cause irritation, immediately flush eyes with water for 15 minutes. If irritation persists, seek medical attention.

Inhalation: If symptoms of exposure develop, remove to fresh air. If breathing becomes difficult, administer oxygen. Administer artificial respiration if breathing has stopped. Seek immediate medical attention.
Ingestion: **DO NOT INDUCE VOMITING.** Rinse mouth with water. Never give anything by mouth to a person who is unconscious or drowsy. Get immediate medical attention by calling a Poison Control Center, or hospital emergency room. If medical advice cannot be obtained, then take the person and product to the nearest medical emergency treatment center or hospital.

**CPVC HEAVY DUTY SOLVENT CEMENT**
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**SECTION 5 FIRE FIGHTING MEASURES**
Flashpoint / Method: 0 - 5 Degrees F. / PMCC
Flammability: LEL = 1.8 % Volume, UEL = 11.8 % Volume
Extinguishing Use dry chemical, CO2, or foam to extinguish fire. Cool fire
Media: exposed container with water. Water may be ineffective as an extinguishing agent.
Special Fire Firefighters should wear positive pressure self-contained
Fighting breathing apparatus and full protective clothing for fires in
Procedure: areas where chemicals are used or stored
Unusual Fire and Extremely flammable liquid. Keep away from heat and all
Explosion sources of ignition including sparks, flames, lighted
Hazards: cigarettes and pilot lights. Containers may rupture or explode in the heat of a fire. Vapors are heavier than air and may travel to a remote ignition source and flash back. This product contains tetrahydrofuran that may form explosive organic peroxide when exposed to air or light or with age.
Hazardous Combustion will produce toxic and irritating vapors including
Decomposition carbon monoxide, carbon dioxide and hydrogen chloride.
Products:

**SECTION 6 ACCIDENTAL RELEASE MEASURES**
Spill or Remove all sources of ignition and ventilate area. Stop leak if it
Leak can be done without risk. Personnel cleaning up the spill should
Procedures: wear appropriate personal protective equipment, including respirators if vapor concentrations are high. Soak up spill with an inert absorbent such as sand, earth or other non-combusting material. Put absorbent material in covered, labeled metal containers. Prevent liquid from entering watercourses, sewers and natural waterways. Report releases to authorities as required. See Section 12 for disposal information.

**SECTION 7 HANDLING AND STORAGE**
Handling: Avoid contact with eyes, skin and clothing. Avoid breathing vapors or mists. Use with adequate ventilation (equivalent to outdoors). Wash thoroughly after handling. Do not eat, drink or smoke in the work area. Keep product away from heat, sparks, flames and all other sources of ignition. No smoking in storage or use areas. Keep containers closed when not in use.

Storage: Store in a cool, dry, well-ventilated area away from incompatible materials. Keep containers closed when not in use.
Other: "Empty" containers retain product residue and can be hazardous. Follow all MSDS precautions in handling empty containers. Do not cut or weld on or near empty or full containers.

**SECTION 8 ECOLOGICAL INFORMATION**
This product is not expected to be toxic to aquatic organisms.
Cyclohexanone: 96 hour LC50 values for fish is over 100 mg/l.
Tetrahydrofuran: 96 hour LC50 fathead minnow: 2160 mg/L.
Methyl Ethyl Ketone: 96 hour LC50 for fish is greater than 100 mg/L.
VOC This product emits VOC's (volatile organic compounds) in its use.
Information: Make sure that use of this product complies with local VOC emission regulations, where they exist.
VOC Level: 550 g/l per SCAQMD Test Method 316A.

**CPVC HEAVY DUTY SOLVENT CEMENT**
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**SECTION 9 EXPOSURE CONTROLS/PERSONAL PROTECTION**
Ventilation: Open doors & windows. Provide ventilation capable of maintaining emissions at the point of use below recommended exposure limits. If used in enclosed area, use exhaust fans. Exhaust fans should be explosion-proof or set up in a way that flammable concentrations of solvent vapors are not exposed to electrical fixtures or hot surfaces.
Respiratory For operations where the exposure limit may be exceeded, a NIOSH
Protection: approved organic vapor respirator or supplied air respirator is recommended. Equipment selection depends on contaminant type and concentration, select in accordance with 29 CFR 1910.134 and good industrial hygiene practice. For firefighting, use self-contained breathing apparatus.
Skin Rubber gloves are suitable for normal use of the product. For long
Protection: exposures chemical resistant gloves may be required such as 4H(tm) or Silver Shield(tm) to avoid prolonged skin contact.
Eye Safety glasses with side shields or safety goggles.
Protection:
Other: Eye wash and safety shower should be available.

**SECTION 10 PHYSICAL AND CHEMICAL PROPERTIES**
Boiling Point: 151 Degrees F / 66 C
Melting Point: N/A
Vapor Pressure: 145 mmHg @ 20 Degrees C
Vapor Density: (Air = 1) 2.5
Volatile Components: 86-88%
Solubility In Water: Negligible
pH: N/A
Specific Gravity: 0.95 +/- 0.02
Evaporation Rate: (BUAC = 1) = 5.5 - 8.0
Appearance: Orange Liquid
Odor: Ether-Like

Will Dissolve In: Tetrahydrofuran
Material Is: Liquid

**SECTION 11 STABILITY AND REACTIVITY**
Stability: Stable.
Conditions To Avoid: Avoid heat, sparks, flames and other sources of ignition.
Hazardous Combustion will produce toxic and irritating vapors
Decomposition including carbon monoxide, carbon dioxide and hydrogen
Products: chloride.
Incompatibility/ Oxidizing agents, alkalies, amines, ammonia, acids, chlorine
Materials To Avoid: compounds, chlorinated inorganics (potassium, calcium and sodium hypochlorite) and hydrogen peroxides. May attack
plastic, resins and rubber.
Hazardous Will not occur.
Polymerization:

**SECTION 12 DISPOSAL INFORMATION**
Waste Disposal: Dispose in accordance with current local, state and federal regulations.

**CPVC HEAVY DUTY SOLVENT CEMENT**
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**SECTION 13 TOXICOLOGICAL INFORMATION**
Inhalation: Vapors or mists may cause mucous membrane and respiratory irritation, coughing, headache, dizziness, dullness, nausea,
shortness of breath and vomiting. High concentrations may cause
central nervous system depression, narcosis and unconsciousness.
May cause kidney, liver and lung damage.
Skin: May cause irritation with redness, itching and pain. Methyl
ethyl ketone and cyclohexanone may be absorbed through the skin
causing effects similar to those listed under inhalation.
Eye: Vapors may cause irritation. Direct contact may cause irritation
with redness, stinging and tearing of the eyes. May cause eye
damage.
Ingestion: Swallowing may cause abdominal pain, nausea, vomiting and
diarrhea. Aspiration during swallowing or vomiting can cause
chemical pneumonia and lung damage. May cause kidney and liver
damage.
Chronic Prolonged or repeated overexposure cause dermatitis and damage
Toxicity: to the kidney, liver, lungs and central nervous system.
Toxicity Data: Cyclohexanone: Oral rat LD50: 1,620 mg/kg
Inhalation rat LC50: 8,000 ppm/4 hours
Skin rabbit LD50: 1 mL/kg
Tetrahydrofuran: Oral rat LD50: 1,650 mg/kg
Inhalation rat LC50: 21,000 ppm/3 hours
Methyl Ethyl Ketone: Oral rat LD50: 2,737 mg/kg
Inhalation rat LC50: 23,500 mg/m3/8 hours
Skin rabbit LD50: 6,480 mg/kg
Sensitization: None of the components are known to cause sensitization.
Carcinogenicity: None of the components are listed as a carcinogen or suspect

carcinogen by NTP, IARC or OSHA. The National Toxicology Program
has reported that exposure of mice and rats to Tetrahydrofuran
(THF) vapor levels up to 1800 ppm 6 hr/day, 5 days/week for
their lifetime caused an increased incidence of kidney tumors in
male rats and liver tumors in female mice. The significance of
these findings for human health are unclear at this time, and
may be related to "species specific" effects. Elevated
incidences of tumors in humans have not been reported for THF.
Mutagenicity: Cyclohexanone has been positive in bacterial and
mammalian assays. Tetrahydrofuran was positive in a bacterial
assay. Methyl ethyl ketone is not considered genotoxic based on
laboratory studies.
Reproductive Methyl ethyl ketone and cyclohexanone have been shown to cause
Toxicity: embryofetal toxicity and birth defects in laboratory animals.
Tetrahydrofuran has been found to cause adverse
developmental effects only when exposure levels cause other
toxic effects to the mother.
Medical Persons with pre-existing skin, lung, kidney or liver disorders
Conditions may be at increased risk from exposure to this product.
Aggravated By
Exposure:

**CPVC HEAVY DUTY SOLVENT CEMENT**
Latest Revision: 05/20/04 Last Reviewed: 05/20/04 Page 5 of 5

**SECTION 14 TRANSPORTATION INFORMATION**
DOT Less than 1 Liter (0.3 gal) Greater than 1 Liter (0.3 gal)
Proper Shipping Name: Consumer Commodity Adhesives
Hazard Class/Packing Group: ORM-D 3, PGII
UN/NA Number: None UN1133
Hazard Labels: None Flammable Liquid
IMDG
Proper Shipping Name: Adhesives Adhesives
Hazard Class/Packing Group: 3, II 3, II
UN Number: UN1133 UN1133
Label: None (Limited Quantities Class 3 (Flammable
are excepted Liquid)
from labeling)
RCRA Hazardous Waste Number: U057, U159, U213
EPA Hazardous Waste ID Number: D001, D035, F003, F005
EPA Hazard Waste Class: Ignitable Waste. Toxic Waste (Methyl Ethyl Ketone content)
2000 North American Emergency Response Guidebook Number: 127 or 128

**SECTION 15 REGULATIONS**
Hazard Category for Section Acute Health, Chronic Health, Flammable
311/312:
Section 302 Extremely This product does not contain chemicals regulated
Hazardous Substances (TPQ): under SARA Section 302.
Section 313 Toxic Chemicals: This product contains the following chemicals
subject to SARA Title III Section 313 Reporting
requirements:

Chemical CAS # %
Methyl Ethyl Ketone 78-93-3 10-20%
CERCLA 103 Reportable Spills of this product over the RQ (reportable Quantity: quantity) must be reported to the National Response Center. The RQ for the product, based on the RQ for Tetrahydrofuran (65% maximum) of 1,000 lbs, is 1,538 lbs. Many states have more stringent release reporting requirements. Report spills required under federal, state and local regulations.
California Proposition 65: This product does not contain any chemicals subject To California Proposition 65 regulation.
TSCA Inventory: All of the components of this product are listed on the TSCA inventory.

**SECTION 16 DISCLAIMER**
The information herein has been compiled from sources believed to be reliable, upto-date, and is accurate to the best of our knowledge. However, Oatey cannot give any guarantees regarding information from other sources, and expressly does not make warranties, nor assumes any liability for its use.

## Appendix Q – DesignSafe Full Assembly



**designsafe Report**

| | | | |
|---|---|---|---|
| Application: | ME 450 Team 25 (Demo Model) | Analyst Name(s): | Anthony Bingei |
| Description: | This assessment is to assess the hazards in assembling the whole components for the prototype. | Company: | |
| Product Identifier: | | Facility Location: | |
| Assessment Type: | Detailed | | |
| Limits: | | | |
| Sources: | | | |

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | mechanical : head bump on overhead objects<br>The stand pipe is located on top of a 30" table, which is tall enough to cause head bump | Minimal<br>Occasional<br>Unlikely | Low | Write a warning sign on the stand pipe. | Minimal<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | mechanical : break up during operation<br>if the pipe we attach to the fitting lose it will cause leakage of working fluid (water). | Serious<br>Remote<br>Unlikely | Moderate | Usage of PVC cement reduce break up and loose fittings that reduces the chance of fluid leakage. | Slight<br>Occasional<br>Possible | Moderate | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | mechanical : machine instability<br>The Pump Instability will cause the control valve not working on the minimum requirement flow | Serious<br>Occasional<br>Possible | High | As the pump has three level of operation, start the pump at low level to test the system. | Slight<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | electrical / electronic : energized equipment / live parts<br>If there is an error in the computer program to shut off the valve, it will blow the pump. | Serious<br>Occasional<br>Unlikely | Moderate | delayed start and visually inspect all system before final testing. | Slight<br>Occasional<br>Possible | Moderate | On-going [Daily]<br>Anthony |
| All Users<br>All Tasks | electrical / electronic : improper wiring<br>if there is improper wiring,the PLC,Air Compressor and Pump will fail | Serious<br>Occasional<br>Possible | High | Visual inspection on connection before proceeding with the operation. Also, check for the insulation of the electonic wiring. | Slight<br>Remote<br>Possible | Moderate | TBD<br>Anthony |

| User / Task | Hazard / Failure Mode | Initial Assessment<br>Severity<br>Exposure<br>Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment<br>Severity<br>Exposure<br>Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | electrical / electronic : water / wet locations<br>If any the water from storage tank and stand pipe overflow it will cause the water to fall over the ground | Catastrophic<br>Occasional<br>Possible | High | Engineering analysis must be done rigorously and operation testing should be done before turning the pump on (pouring water for circulation). | Slight<br>Remote<br>Possible | Moderate | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | electrical / electronic : unexpected start up / motion<br>If the pump start up suddenly | Catastrophic<br>Occasional<br>Possible | High | Start the pump at low mode before proceeding for higher flow rate and power from the pump. | Minimal<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | electrical / electronic : software errors<br>If there is an error in the computer program to shut off the valve, it will blow the pump | Serious<br>Occasional<br>Unlikely | Moderate | Make sure the software program is working correctly with the mechanical component. Ask for help from the expert in Siemens. | Slight<br>Remote<br>Possible | Moderate | In-process<br>Anthony |
| All Users<br>All Tasks | electrical / electronic : power supply interruption<br>The PLC and the pump will not function properly | Serious<br>Occasional<br>Possible | High | other devices | Serious<br>Occasional<br>Possible | High | In-process<br>Anthony |
| All Users<br>All Tasks | slips / trips / falls : slip<br>If the water from storage tank flows out the ground, it will be slippery | Serious<br>Occasional<br>Possible | High | Apply PVC Cement to any cracks and connection points to prevent leakage. In addition, visual inspection every time operation is running. | Slight<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | slips / trips / falls : trip<br>The majority of connections are connected at low height. It might trip people that walks around it. | Serious<br>Remote<br>Unlikely | Moderate | Put a warning sign for people to be able to see components that are installed at the bottom of the ground. | Slight<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | slips / trips / falls : fall hazard from elevated work<br>The stand pipe, pressure transmitter, and most electronic devices are mounted on top of the table, which might fall due to instabilituy | Serious<br>Remote<br>Unlikely | Moderate | Make sure the tables are strong enough to hold the components. | Slight<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | ergonomics / human factors : lifting / bending / twisting<br>The weight of components are heavy. Therefore,If it is not handle properly it will cause unnecessary injury to the back. For example, threaded connection needs twisting steps. | Serious<br>Remote<br>Unlikely | Moderate | Ask for assistance when lifting heavy material, especially during installation process. | Minimal<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | fire and explosions : hot surfaces<br>The PC set or pump are both operating frequently during testing, which might cause hot surface. | Slight<br>Occasional<br>Possible | Moderate | Turn off the process when the components are getting too hot. | Minimal<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | noise / vibration : noise / sound levels > 80 dBA<br>When the pump works on high limit, it will cause a noise | Serious<br>Occasional<br>Probable | High | fixed enclosures / barriers. in addition, the pump purchased is actually a very quiet pump that does not pose noise pollution. | Minimal<br>None<br>Negligible | Low | Complete [11/19/2009]<br>Yudie |
| All Users<br>All Tasks | material handling : excessive weight<br>The weight of the whole tank with water will be around 240 lb. In addition, control valve and pump are heavy as well. If it is not handle properly it will cause unnecessary injury to the back | Slight<br>Occasional<br>Possible | Moderate | Two people or mroe should be lifting together for any heavy components. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | fluid / pressure : fluid leakage / ejection<br>If any connection on the pump has holes it could cause fluid ejection that affects surrounded people | Slight<br>Occasional<br>Probable | High | Visual inspection and and PVC Cement application on connection points. | Minimal<br>Remote<br>Unlikely | Low | Complete [11/19/2009]<br>Yudie |

# Appendix R – DesignSafe Storage Tank Machining



**designsafe Report**

| | | | |
|---|---|---|---|
| Application: | Team 25 Prototype Storage Tank | Analyst Name(s): | Yudie Soenjoto |
| Description: | This assessment is to assess the hazards in fabricating the hole on the stand pipe | Company: | |
| Product Identifier: | | Facility Location: | |
| Assessment Type: | Detailed | | |
| Limits: | | | |
| Sources: | | | |

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | mechanical : crushing<br>Clamping the storage tank on the vise with too much force might crush the storage tank. | Slight<br>Occasional<br>Possible | Moderate | Clamp the storage tank on the vise with enough force to hold it in place. Ask for machine shop assistance for clamping procedure. | Slight<br>None<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | mechanical : cutting / severing<br>Improper technique of drilling | Catastrophic<br>Occasional<br>Unlikely | High | Ask for assistance and give the action to competent individual. | Slight<br>Remote<br>Unlikely | Low | In-process<br>Yudie |
| All Users<br>All Tasks | mechanical : unexpected start<br>Unexpected start of drilling would damage the storage tank or cause unsafe events. | Serious<br>Remote<br>Unlikely | Moderate | Start the motor drill at low speed before raising to the specified speed for drilling. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | mechanical : break up during operation<br>Excessive drilling or material defects lead to break up | Serious<br>Remote<br>Possible | Moderate | Visual inspection on raw material before proceeding with drilling. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | slips / trips / falls : debris<br>Drilling the storage tank might cause debris around it. | Slight<br>Occasional<br>Possible | Moderate | Wear safety glasses to protect users eyes. | Minimal<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | ergonomics / human factors : excessive force / exertion<br>Excessive drilling might cause bad surface finish | Serious<br>Occasional<br>Possible | High | Ask the machine shop expert for drilling guidance. | Slight<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | ergonomics / human factors : deviations from safe work practices<br>Unsafe techniques in drilling would cause improper finish. | Slight<br>Occasional<br>Unlikely | Moderate | Understand the safety manual for drilling in the machine shop ethics. | Minimal<br>None<br>Unlikely | Low | On-going [Daily]<br>Yudie |

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | noise / vibration : equipment damage<br>Improper technique in clamping and drilling would damage the storage tank. | Serious<br>Remote<br>Unlikely | Moderate | Handle machining and fabrication safely and mindfully. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | material handling : instability<br>Inexperience individuals or bad working area. | Serious<br>Occasional<br>Possible | High | Ensure knowledge of material and give action to competent person. | Minimal<br>Remote<br>Unlikely | Low | In-process<br>Yudie |

## Appendix T – DesignSafe for Stand Pipe Machining



**designsafe Report**

| | | | |
|---|---|---|---|
| Application: | Team 25 Prototype Stand Pipe | Analyst Name(s): | Yudie Soenjoto |
| Description: | This assessment is to assess the hazards of machining the stand pipe hole. | Company: | |
| Product Identifier: | | Facility Location: | |
| Assessment Type: | Detailed | | |
| Limits: | | | |
| Sources: | | | |

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | mechanical : crushing<br>Clamping the storage tank on the vise with too much force might crush the storage tank. | Slight<br>Occasional<br>Possible | Moderate | Clamp the storage tank on the vise with enough force to hold it in place. Ask for machine shop assistance for clamping procedure. | Slight<br>None<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | mechanical : cutting / severing<br>Improper technique of drilling | Catastrophic<br>Occasional<br>Unlikely | High | Ask for assistance and give the action to competent individual. | Slight<br>Remote<br>Unlikely | Low | In-process<br>Yudie |
| All Users<br>All Tasks | mechanical : unexpected start<br>Unexpected start of drilling would damage the storage tank or cause unsafe events. | Serious<br>Remote<br>Unlikely | Moderate | Start the motor drill at low speed before raising to the specified speed for drilling. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | mechanical : break up during operation<br>Excessive drilling or material defects lead to break up | Serious<br>Remote<br>Possible | Moderate | Visual inspection on raw material before proceeding with drilling. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | slips / trips / falls : debris<br>Drilling the storage tank might cause debris around it. | Slight<br>Occasional<br>Possible | Moderate | Wear safety glasses to protect users eyes. | Minimal<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | ergonomics / human factors : excessive force / exertion<br>Excessive drilling might cause bad surface finish | Serious<br>Occasional<br>Possible | High | Ask the machine shop expert for drilling guidance. | Slight<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | ergonomics / human factors : deviations from safe work practices<br>Unsafe techniques in drilling would cause improper finish. | Slight<br>Occasional<br>Unlikely | Moderate | Understand the safety manual for drilling in the machine shop ethics. | Minimal<br>None<br>Unlikely | Low | On-going [Daily]<br>Yudie |

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | noise / vibration : equipment damage<br>Improper technique in clamping and drilling would damage the storage tank. | Serious<br>Remote<br>Unlikely | Moderate | Handle machining and fabrication safely and mindfully. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | material handling : instability<br>Inexperience individuals or bad working area. | Serious<br>Occasional<br>Possible | High | Ensure knowledge of material and give action to competent person. | Minimal<br>Remote<br>Unlikely | Low | In-process<br>Yudie |

**Appendix S– DesignSafe PVC Sraight Pipe Machining**



**designsafe Report**

| | | | |
|---|---|---|---|
| Application: | Team 25 Prototype PVC Pipe | Analyst Name(s): | Yudie Soenjoto |
| Description: | This assessment is to asess the hazards in cutting the PVC Pipe to manufacture for the prototype connection components. | Company: | |
| Product Identifier: | | Facility Location: | |
| Assessment Type: | Detailed | | |
| Limits: | | | |
| Sources: | | | |

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users All Tasks | mechanical : crushing Clamping the PVC pipe with excessive force would crack the pipe. | Serious Occasional Possible | High | Exert enough force just to hold the pvc pipe in place. | Serious Remote Negligible | Low | On-going [Daily] Yudie |
| All Users All Tasks | mechanical : cutting / severing Improper cutting technique that causes users injury. | Catastrophic Remote Unlikely | Moderate | Follow the procedure in cutting process. | Serious Remote Unlikely | Moderate | In-process Yudie |
| All Users All Tasks | mechanical : stabbing / puncture Improper cutting technique that causes injury. | Catastrophic Remote Unlikely | Moderate | Follow standar of procedure in machine shop for cutting. | Serious Remote Unlikely | Moderate | In-process Yudie |
| All Users All Tasks | mechanical : machine instability Machine technical problem | Slight Occasional Possible | Moderate | Consult with machine shop expert. | Slight Remote Unlikely | Low | On-going [Daily] Yudie |
| All Users All Tasks | slips / trips / falls : debris Burrs flying out during cutting process. | Slight Occasional Possible | Moderate | Wear safety glasses. | Slight Occasional Unlikely | Moderate | On-going [Daily] Yudie |
| All Users All Tasks | ergonomics / human factors : excessive force / exertion Excessive force when cutting the pipe. | Serious Remote Possible | Moderate | understand material hanling | Slight Remote Unlikely | Low | On-going [Daily] Yudie |
| All Users All Tasks | heat / temperature : radiant heat Cutting process cause heat due to friction. | Minimal Remote Unlikely | Low | Use cutting fluid wisely. | Minimal None Negligible | Low | Complete [11/19/2009] Yudie |
| All Users All Tasks | noise / vibration : equipment damage Improper technique during cutting. | Serious Occasional Unlikely | Moderate | Follow standarad of procedure for cutting. | Slight Remote Unlikely | Low | On-going [Daily] Yudie |

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | material handling : instability<br>Inexperience individual | Slight<br>Remote<br>Unlikely | Low | Ask for competent individual to help. | Slight<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudi |

## Appendix U – DesignSafe PVC Hole Machining



**designsafe Report**

| | | | |
|---|---|---|---|
| Application: | Team 25 Prototype PVC Pipe Hole | Analyst Name(s): | Yudie Soenjoto |
| Description: | This assessment is to assess the hazards of machining the PVC Pipe hole for pressure gauge connection. | Company: | |
| Product Identifier: | | Facility Location: | |
| Assessment Type: | Detailed | | |
| Limits: | | | |
| Sources: | | | |

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | mechanical : crushing<br>Clamping the storage tank on the vise with too much force might crush the storage tank. | Slight<br>Occasional<br>Possible | Moderate | Clamp the storage tank on the vise with enough force to hold it in place. Ask for machine shop assistance for clamping procedure. | Slight<br>None<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | mechanical : cutting / severing<br>Improper technique of drilling | Catastrophic<br>Occasional<br>Unlikely | High | Ask for assistance and give the action to competent individual. | Slight<br>Remote<br>Unlikely | Low | In-process<br>Yudie |
| All Users<br>All Tasks | mechanical : unexpected start<br>Unexpected start of drilling would damage the storage tank or cause unsafe events. | Serious<br>Remote<br>Unlikely | Moderate | Start the motor drill at low speed before raising to the specified speed for drilling. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | mechanical : break up during operation<br>Excessive drilling or material defects lead to break up | Serious<br>Remote<br>Possible | Moderate | Visual inspection on raw material before proceeding with drilling. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | slips / trips / falls : debris<br>Drilling the storage tank might cause debris around it. | Slight<br>Occasional<br>Possible | Moderate | Wear safety glasses to protect users eyes. | Minimal<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | ergonomics / human factors : excessive force / exertion<br>Excessive drilling might cause bad surface finish | Serious<br>Occasional<br>Possible | High | Ask the machine shop expert for drilling guidance. | Slight<br>Remote<br>Negligible | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | ergonomics / human factors : deviations from safe work practices<br>Unsafe techniques in drilling would cause improper finish. | Slight<br>Occasional<br>Unlikely | Moderate | Understand the safety manual for drilling in the machine shop ethics. | Minimal<br>None<br>Unlikely | Low | On-going [Daily]<br>Yudie |

| User / Task | Hazard / Failure Mode | Initial Assessment Severity Exposure Probability | Risk Level | Risk Reduction Methods /Comments | Final Assessment Severity Exposure Probability | Risk Level | Status / Responsible /Reference |
|---|---|---|---|---|---|---|---|
| All Users<br>All Tasks | noise / vibration : equipment damage<br>Improper technique in clamping and drilling would damage the storage tank. | Serious<br>Remote<br>Unlikely | Moderate | Handle machining and fabrication safely and mindfully. | Slight<br>Remote<br>Unlikely | Low | On-going [Daily]<br>Yudie |
| All Users<br>All Tasks | material handling : instability<br>Inexperience individuals or bad working area. | Serious<br>Occasional<br>Possible | High | Ensure knowledge of material and give action to competent person. | Minimal<br>Remote<br>Unlikely | Low | In-process<br>Yudie |