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A Robust Environmental Chamber for Testing the Durability of Outdoor Pumps and Coatings

Kyle Kirkpatrick [1], Ryan Ashley [2], Mason Hoffer [3], Tarek Mohammed [4,*]
[1, 2, 3, 4] Purdue University, Fort Wayne, IN, USA
Email: [4] mohammat@purdue.edu
*Corresponding Author

***Abstract*—This work presents an improved and robust six-nozzle water spray chamber used for testing the outer wear-resistance of outdoor pumps. The existing water spray chambers have multiple design flaws such as its two-piece construction and unstable connections creating an unreliable and inefficient system. The proposed six-nozzle water spray chamber prototype would simulate rain and other environmental factors at an accelerated pace to observe the product's ability to withstand those environmental effects over long periods of time. Along with an increase in reliability and compatibility with the existing heating unit, a digital control of the system was implemented. This paper outlines the conceptual and detailed design process used to analyze each concept created for the subsystems. Three subsystems of the chamber were utilized: the floor of the chamber, the opening mechanism for the chamber, and the controller programming. Using the sub-system designs, a conceptual design parameter matrix was created. The FEA were conducted to confirm the structural rigidity of the system.**

To test susceptibility to liquid ingress at the component level, room level, and field-level, 3 tests were carried out using the chamber prototype: Wet – Dry Cycle Test, Hydrogen Embrittlement Test, and the Water Ingress Test. The Wet – Dry Cycle Test examined for bleeding or leaching of colors or cracking, peeling, and failure of the paints. This test included a 3-hour period of spraying water followed by a 1.5-hour 'dry off' period in which air at 90 psi will be blown onto the products. This cycle was then repeated up to 42 times. The Hydrogen Embrittlement utilized the same Wet – Dry Cycle however, this test left the products uncoated and examined for any hydrogen build up or rusting within the fasteners. The Water Ingress Test exposed products to thermal and rain/weather effects. The pumps were placed within the chamber and, using an external heating unit, the products will be heated to 60 degrees Celsius. Once that temperature was reached, water was sprayed onto the pumps for 1 hour and the cycle was then repeated until corrosion occurs.

Keywords—Robust; Environment; Durability; Outdoor Pumps ; Chamber.

I. INTRODUCTION

Water spray test chamber is a versatile testing apparatus designed to evaluate the anti-rain and waterproof performance of pumps [1], [2], [3], [4]. This paper represents the design and development of an environmental chamber to test the durability of pumps and their coatings designed and manufactured by Fill-Rite™. The desired test chamber would simulate rain and other environmental factors at an accelerated pace to observe the product's ability to withstand those environmental effects over long periods of time [4] [5]. To do so, the chamber utilizes 3 tests: Wet – Dry Cycle Test, Hydrogen Embrittlement Test, and the Water Ingress Test. The Wet – Dry Cycle Test looks for bleeding or leaching of colors or cracking, peeling, and failure of the paints [6], [7]. This test includes a 3-hour period of spraying water followed by a 1.5-hour 'dry off' period in which air at 90 psi will be blown onto the products [8]. This cycle then repeats up to 42 times. The Hydrogen Embrittlement utilizes the same Wet – Dry Cycle however, this test leaves the products uncoated and looks for any hydrogen build up or rusting within the fasteners [9], [10]. The Water Ingress Test exposes products to thermal and rain/weather effects. The pumps will be placed within the chamber and, using an external heating unit, the products will be heated to 60 degrees Celsius. Once that temperature is reached, water will be sprayed onto the pumps for 1 hour and the cycle is then repeated until corrosion occurs.

The previous chamber was inefficient and did not meet the desired criteria for a versatile testing apparatus. With testing becoming more frequent, and being made of two large wash tubs, loose wires, poorly routed hosing, and makeshift electrical work, a more stable and efficient chamber was sought after. The design ideas began with brainstorming and communicating with the intended operators. From there, iterations of the subsystems were created and rated. Choosing the best of each subsystem design, this new design would allow the company to run tests on more pumps at once while trusting that there would not be failure during testing.

Using the design created, construction and assembly of the chamber began. In the assembly process, it was realized that a large amount of hardware and other components were still required for completion. Later on, the complete prototype was implemented, assembled, and tested. The testing confirmed that the given parameters were met and displayed the true strength of the design.

II. DESIGN CONFIGURATION

After considering all options within the conceptual design phase, the primary design choice is further developed and converted into a detailed design. The concept design matrix showed that the grate system and the hinged door were the best options for the chamber floor and chamber door subsystems. However, after conversing with Fill-Rite, their preferred options were the T-slot system for the chamber

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floor, and a combination of the sliding door and full top door. While the T-slot system was rated second within the matrix, Fill-Rite felt the ease of implementation, cost efficiency, and the ability to integrate with other systems was superior to the grate system. An idea to incorporate two concepts for the door subsystem was also introduced. By separating the upper and front faces of the full top door, and having the front face mimic the vertical sliding door, the ability to easily place the pumps within the chamber is maintained. This also allows for a superior seal on the openings and a system to direct the water flow away from the seal can be implemented. The completed assembly of the water spray chamber can be seen below in Fig. 1. The assembly of the device can be broken down into the following components and analysis performed where applicable.

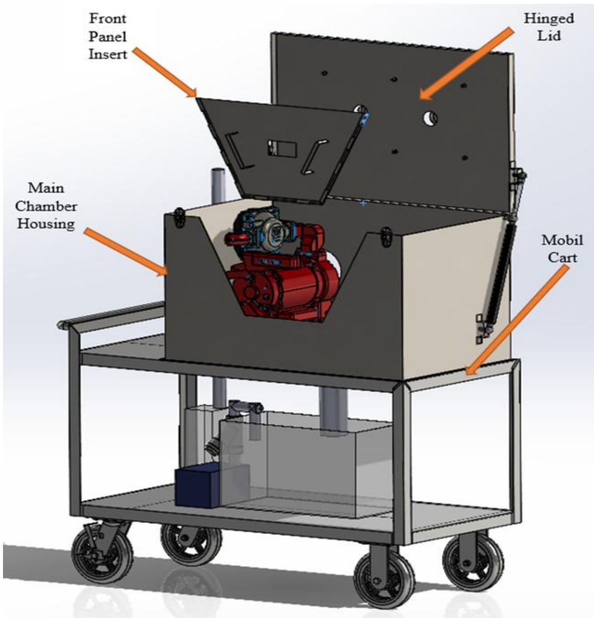

Fig. 1. SolidWorks Model Depicting the Final Assembly

A. *Cart Stand*

To give the chamber mobility, a mobile stand was required for the chamber to rest on. Many options were explored, however, for a cart to withstand the required load of 800 pounds, the cost was exceedingly high. When talking about cost savings with Fill-Rite, it was noted that they had a cart with sufficient load bearing capacity on hand already. That model was found online and implemented into the SolidWorks assembly to display its function. To allow for the water circulation system to maintain a clean, minimal design, and be more cost efficient, the manufacturing of two holes on the top surface will be required. The bigger hole at 3 inches in diameter is for the draining of the system to the reservoir and the smaller hole is for the hose to reach back up to the nozzles. Fill-Rite's in house cart with the necessary holes is shown below in Fig. 2.

One of the main areas of concern for this project is the ability of the cart to hold the combined chamber weight and the pumps inserted. A model of the cart provided by Fill-Rite was created and used in a SolidWorks simulation as shown in Figures 2 and 3.

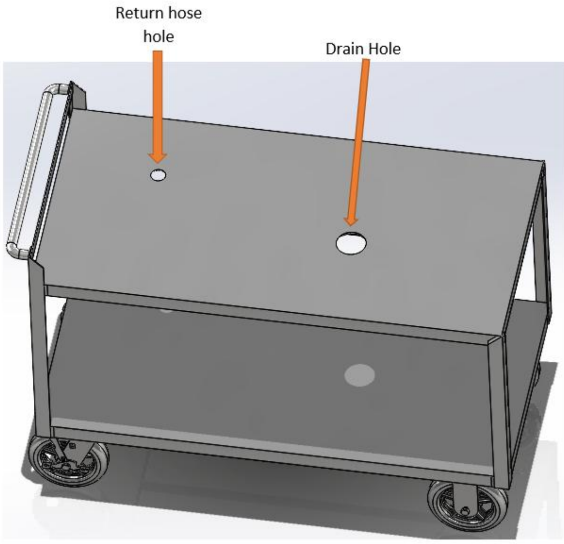

Fig. 2. SolidWorks Model of the Mobile Cart Provided by Fill-Rite

In the simulation, the structural integrity of the cart was analyzed by applying a maximum load of 850 pounds to the top surface of the cart. The cart is made of 304 stainless steel and has a modulus of elasticity of 27,577,170 psi with the top plate being supported by vertical channels. In this study, the wheels were fixed to the ground with a roller condition and the load was applied over the entirety of the top plate. This allowed for the cart to move if needed when the load is applied. As seen by figure 10 below, the SolidWorks analysis returned a maximum displacement of 0.275 inches in the center of the cart with a very little displacement of the vertical channels.

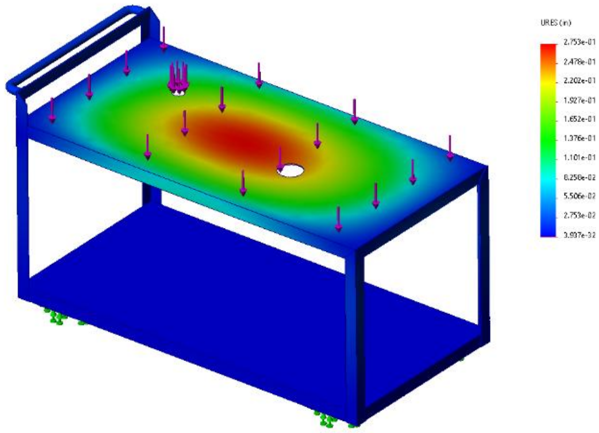

Fig. 3. SolidWorks FEA Simulation on Mobile Cart

After the simulation was run within SolidWorks, hand calculations were performed to ensure that the simulation results were accurate. The following equation 1 was used describing the displacement of a simply supported plate.

$$y_m = \frac{0.0284 P b^4}{E t^3 \left[1.056\left(\frac{b}{a}\right)^5 + 1\right]} \quad (1)$$

where:

$$P = Uniform\ Pressure\ [psi]$$

$$E = Modulus\ of\ Elasticity\ [psi]$$
$$b = Width\ of\ plate\ [in]$$
$$a = Length\ of\ Plate\ [in]$$
$$t = Plate\ Thickness\ [in]$$
$$P = \frac{Force}{Area} = \frac{850lb}{47.8 * 23.79\ in^2} = 0.74747$$
$$b = 23.79\ [in]$$
$$E = 27{,}577{,}170\ [psi]\ (From\ SolidWorks\ Material\ Properties)$$
$$a = 47.8\ [in]$$
$$t = 0.1\ [in]$$
$$y_m = \frac{0.0284(0.7474)(23.79)^4}{27{,}577{,}170(0.1)^3[1.056\left(\frac{23.79}{47.8}\right)^5 + 1]} = 0.2388in$$

The resulting maximum displacement at the center of the cart was found to be 0.238 inches. When compared to the values obtained from SolidWorks, a percent error of about 13% was found. Due to the inability to factor in the holes within the top plate of the cart stand, the percentage error is slightly higher than expected, however, it is still reasonable. This equation was found from the sources listed in the references section and deemed usable for this case.

B. Main Chamber Housing

The chamber will be made up of 16-gauge 304 stainless steel sheet metal and will be the main housing for the pumps during testing. For the water drainage, there is a 3-inch diameter hole in the bottom of the chamber that will flow through the cart into a reservoir below. On the backside of the chamber, two connection ports will be implemented, allowing for connection to a separate environmental chamber that heats the air inside the chamber. Within the chamber, along the bottom corner of the front and back walls, will be a 1/8th inch strip of steel for the T-slots that will be holding the pumps to rest on. This allows for water to flow underneath the gap created between the floor of the chamber and the T-slots. The top edge will then be covered with a strip of high temperature gasket material to provide a seal between the chamber and the door system. Shown below in figure 4 is a picture of the chamber.

With the concern for heating the chamber and the materials in it, the chamber material is made of 304 stainless steel which has a melting point of 1400 °C and would not deform up to 870 °C. This means that the chamber would be able to withstand elongated times under the flow of the 60°C air during testing. Since air will be flowing through the chamber at a maximum of 60 °C, there was no need to account for thermal heat transfer of the chamber's exterior. The operator will not need to be present when the temperature reaches its maximum during the tests and can wait for the metal to cool off when the testing is done. There will be, however, extra precautions for the operator as the chamber exterior can reach 60 °C temperatures.

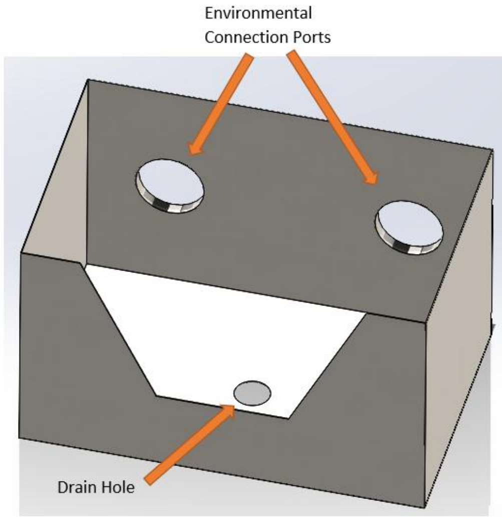

Fig. 4. SolidWorks Design for the Main Chamber Housing

C. Chamber Door System

The front panel insert is a trapezoidal slab of 16-gauge 304 stainless steel that slides vertically out of the chamber box. The ability of the front face to come out allows for ease of use when inserting the pumps. To provide a better seal and direct water away from the gasket, a small strip of steel will be welded onto the back edge with a slight overhang covering the edge of the chamber. To keep the panel in place, tabs of the same thickness and material will be welded onto the front surface to overhang the same amount. This will create a slot in which the edge of the chamber can slide into. The insert will also have a small viewing window with a heat resistant material in it to allow the operator to see inside the chamber while the tests are being performed. Also attached to the panel will be two handles to allow for easy lifting of the panel. A picture of the panel being inserted into the chamber is shown in figure 5 as well as a close-up view of the connection point to the chamber in Fig. 6.

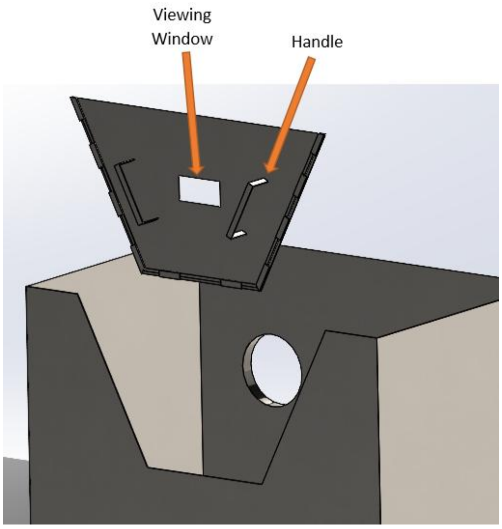

Fig. 5.SolidWorks Model of the Front Panel While Inserted

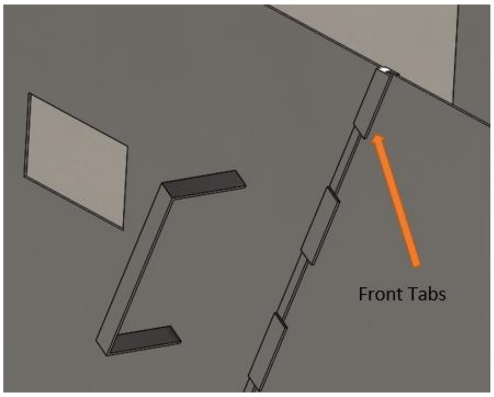

Fig. 6. Close-up view of the front panel's connection to the chamber

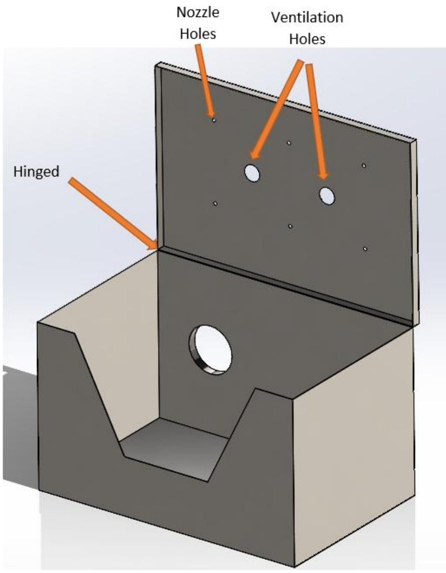

Fig. 7. SolidWorks Model of the Lid of the Chamber While Attached

Topping off the chamber is a hinged lid of 16-gauge 304 stainless steel with multiple holes cut out. The two large holes centered on the medial axis are vent holes that will allow for unwanted moisture to be wicked away during testing. The six smaller holes placed around the vent holes are the nozzle inserts where the nozzles will be embedded. A hinge on the back side connecting the lid and the chamber will be paired with two gas spring shocks on either side that will allow for the lid to be easily opened and locked into the upwards position. The lid connected to the chamber is shown below in Figure 7.

D. *Chamber Accessories*

Attached to the chamber are two gas spring shocks mounted to the side of the chamber using U-brackets. Two draw latches will be mounted to the front face of the chamber box and the front face of the lid to ensure the gasket is sealed when closed. Within the chamber are four T-Slots that will be resting on the 1/8th inch strips of steel that line the length of the chamber. The horizontal adjustability of the slots allows pumps of any size to rest with minimal contact area. The T-slots also open the possibility for Fill-Rite to manufacture a mounting system for the pumps so that the only contact points are on the mounting surface that, in practice, would be covered. Lastly, a ventilation cap will be used to cover the ventilation holes when needed. A diagram of all the accessories attached to the chamber is shown below in Fi. 8.

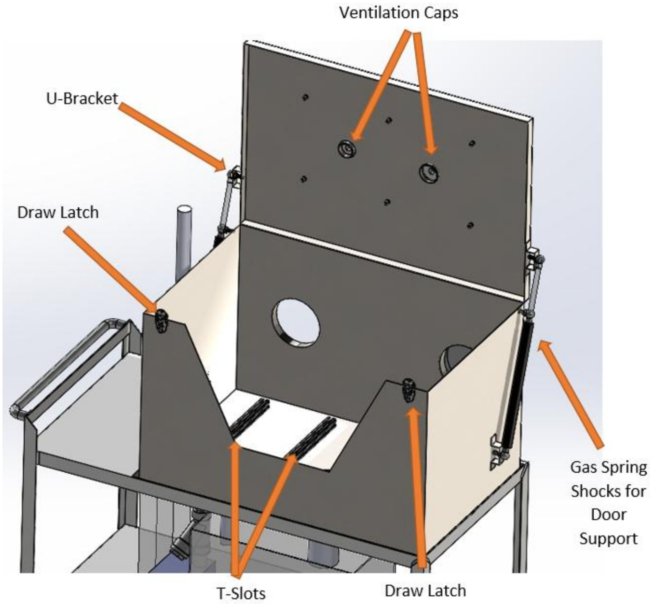

Fig. 8. Labelled Diagram of all Chamber Attachments Within SolidWorks

E. *Water Recirculation System*

To ensure the chamber has proper water flow and water does not build up, a 3-inch drain will be cut from the chamber box and a rubber hose will be attached to allow for water to run through the cart and into a glass reservoir below. From the reservoir, a pump will suck the water through a hose that's connected to a Y strainer to catch any remaining sediment before entering the pump. That pump will then send water through a filter to rid the water of any chemicals that were transferred, and then into hoses that lead the water up into the nozzles that spray the water into the chamber. A visual of the plumbing can be seen in Fig. 9 below.

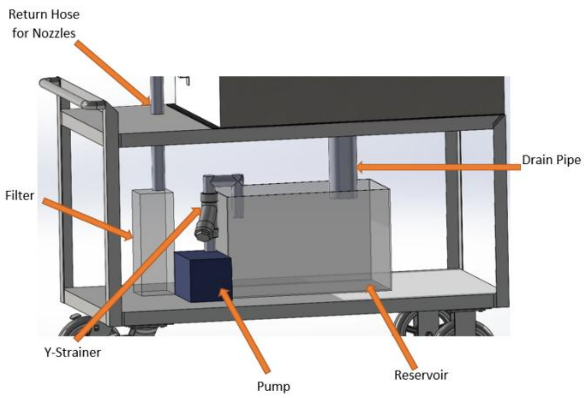

Fig. 9. Labelled diagram of the components in the water circulation system

F. *Digital Control Implementation*

As stated previously in the preliminary designs, a PLC was required to be implemented into the system to automatically run the tests. There were no different choices to choose from in the preliminary designs due to all PLC having the same outcome. After meeting with Fill-Rite, an Arduino was mentioned to be purchased to run the tests. With this, there were some added costs, first for the Arduino itself, and second for the connections that come with it such as wiring and electrical connections. These extra costs, however, were necessary due to the automatic control of the system. This specific PLC was used due to a member at Fill-Rite knowing how it works and can update the programs was years go on if needed. This PLC will be located near the electrical components on the apparatus to ensure minimal wiring is needed. The specific location will be determined when the system is assembled to make sure no water leaking occurs near it since it is an electrical component.

III. Prototype Build Process

The first step in bringing the project from design to prototype was to outsource the design to a company that could fabricate the four stainless steel components required. The items being the chamber itself, the lid, the environmental chamber attachments, and the front insert. From the original design, a few items changed to increase manufacturability. The insert was changed from a stainless-steel panel with a plexiglass insert to a panel comprised entirely of clear plexiglass. With this change, the only things needed to be fabricated were the chamber, the lid, and the attachments. The sheet metal thickness was mainly decided by the cost per gauge of the material while keeping the potential strength of the material in consideration as well. Thus, the resulting decision was for it to be made at 16 gauge, or 0.0625 inches, thick. Maintaining rigidity and sturdiness while still being cost effective. The chamber, lid, and attachments were welded according to the CAD models sent and were delivered to the Fill-Rite facility.

For the assembly process to begin effectively, a check for all the required components was done. A list of the products that were still required was then made and subsequently ordered. The first required step was to cut a rubber mat to fit the top of the movable cart. This would increase friction and prevent the chamber from moving while on top of the cart, allowing work to be done to the chamber more effectively. The necessary cuts and adjustments were then made to the cart to allow for the eventual drainage of the chamber.

With the chamber being completely assembled, the water and air systems were the next focus. A digital mapping of the required components for the chamber was created. Any missing components were ordered, and the layout of the chamber was planned. The diagram used to organize the order of the components within each system is shown on the next page in Fig. 14.

With the two inlets of the T joint being the conjoined water and air systems, the outlet could then lead up to the nozzles at the top of the chamber. The nozzles were required to be 60-degree conical nozzles to ensure the products being tested had water coverage of at least 80%. With the two inlets of the T joint being the conjoined water and air systems, the outlet could then lead up to the nozzles at the top of the chamber. With the two inlets of the T joint being the conjoined water and air systems, the outlet could then lead up to the nozzles at the top of the chamber.

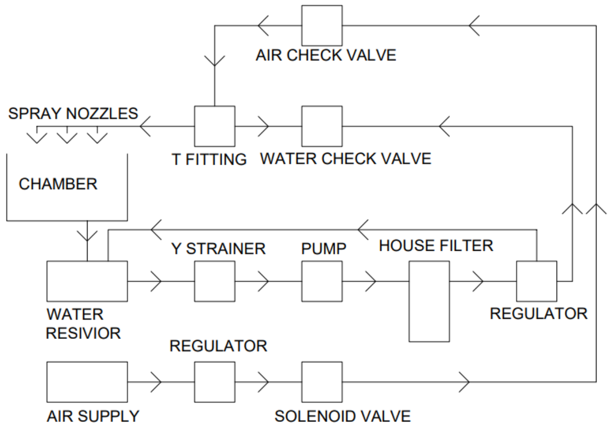

Fig. 14. Block diagram showing the layout of each device for water and air cycles

With the two inlets of the T joint being the conjoined water and air systems, the outlet could then lead up to the nozzles at the top of the chamber. The nozzles were required to be 60-degree conical nozzles to ensure the products being tested had water coverage of at least 80%. Once the desired nozzles were obtained, they were installed into the predrilled holes within the lid of the chamber. Hoses were then connected to the 6 nozzles in a parallel fashion, as shown below in Fig. 15. A pressure gauge was then placed at the end of the series of nozzles to obtain the true pressure at which the nozzles sprayed.

Fig. 15. Hosing layout for dispersing water evenly to each of the 6 nozzles

The final addition to the chamber was the inclusion of a thermocouple port. By drilling a hole into the lid, a thermocouple could be inserted to ensure the chamber is resting at the desired temperature as laid out by the Water Ingress Test. A picture of the port can be seen below in Fig. 16.

Figure 16: Installed thermocouple port (Black button in corner)

IV. Testing and Evaluation

A. The Overall Chamber Function Testing

The proper function of the chamber should firstly include proper power supply to the water pump and air solenoid valve. Ensuring all electronic devices were connected, the system was turned on, powering the pump and sending water throughout the devices. The desired functionality of the chamber includes running the 4.5-hour cycle upwards of 40 times. Therefore, proper connections and no leakage must then be ensured. With all fittings and gaskets being watertight and no leaks occurring, 100% of the 12 gallons of water was sent back into the chamber through the nozzles and returned to the reservoir, completing the cycle. Then, using the in-house air supply, the air system was tested to ensure all fittings and devices could withstand the high pressure. Confirming the air cycle's success, the automation of these cycles was then tested using the Arduino program connected to the power supply. This program is a timer-based program that allows for the user to input a desired amount of time in which both the air and water cycles will run.

B. Water Flow Rate Test

The rate of which water runs through the system is important in testing to maintain consistent water coverage from test to test. If one specimen were to be exposed to more water than another, test results may be skewed. The given parameter for flow rate out of one nozzle was required to be at least 0.29 GPM at a pressure of 20 psi.

List of Needed Materials

- A 5000 mL test beaker to collect the water in
- A stand for the beaker to rest on
- A stopwatch to record time

Set Up

To begin with the water rate test, the water flow system was turned on, and using the water regulator, the water pressure was altered until 20 psi was reached. A beaker was then positioned atop a stand to encapsulate the nozzle. This ensures two things; 100% of the water from the nozzle would be captured, and that water from the other nozzles would not be. The lid of the chamber was then sealed. Fig. 17 shows the setup of the beaker in the chamber on the stand.

Fig. 17. Beaker placed within chamber before testing.

Test Procedure

Ensuring the reservoir had a sufficient amount of water, the water cycle was powered on and allowed to flow through the system. The moment water began to spray from the nozzles, a stopwatch timer was then started to record how long it took to fill the beaker. Once the beaker filled to 2000 mL of water, the timer was stopped, and the time was recorded. This test was done for each nozzle to ensure consistency throughout the chamber. After each nozzle's time had been recorded, the values were put into an excel sheet and the flow rate in gallons per minute was calculated. The data can be seen in Table 1 below.

Table 1. Water Flow Rate Test Results

Nozzle	Approximate Water (mL)	Volume (Gallon)	Time (minutes)	Flow Rate (GPM)
1	2100	0.55	01:36.5	0.3871
2	2000	0.528	01:34.8	0.3864
3	2000	0.528	01:35.7	0.3862
4	2100	0.55	01:37.2	0.3848
5	2200	0.58	01:37.8	0.3850
6	2000	0.528	01:33.4	0.3869

The flow rate for each nozzle measured substantially above the required 0.29 GPM. While the system had a minimum allowable flow rate, it did not have a maximum capable flow rate. Meaning the 0.38 GPM value obtained was satisfactory and the system operates as desired

C. Pressure Drop Test

Along with the water flow rate test, the pressure drop across the system also needed to be verified. The given parameter for pressure drop was stated to be no greater than 15 psi. This meant that the pressure reading before nozzle 1 and after nozzle 6 must not have a difference larger than 15 psi.

List of Material Needed

- 3x Water pressure gage
- Extra hosing/fittings (if necessary)
-

Set Up

The water flow system already contains two installed pressure gauges; one attached to the pressure regulator directly after the pump, and another after nozzles 5 and 6. By reading these two calibrated gauges, it was noted that the difference in pressure from the pump to the end of the system was only 5 psi. Meaning the system already conformed to the given parameters.

However, the pressure drop across the nozzles was still independently tested. For testing the pressure drop across the nozzles alone, a third gauge was implemented into the system. This was done by implementing a tee-fitting directly before nozzles 1 and 2. That allowed for the water to flow across the gauge and then into the nozzles. A picture of the installed tee-fitting with pressure gauge is shown below in Fig. 18.

Fig. 18. Pressure Gage 2 Temporarily Installed, Reading the Pressure Before the Nozzles

Test Procedure

With the 3rd gauge installed, the water cycle was turned on. The regulator was set to an arbitrary pressure and the attached gauge (gauge 1) was recorded. As the water ran through the system, the values from the gauge before and after the nozzles (gauge 2 and 3 respectively) was also recorded. The system was turned off and air was blown through the system to reset it. The pump was turned on once again and the values were recorded again. This test was done a total of three times to ensure consistency. The results can be seen below in Table 2.

Due to the pressure readings oscillating, an estimated value was given for the tenths place. However, the pressure drops across the board remained consistent throughout each test.

Table 2: Pressure Drop Test Results

	Gauge 1 (psi)	Gauge 2 (psi)	Gauge 3 (psi)
Test 1	27.3	22.4	22.1
Test 2	26.5	21.6	21.4
Test 3	27.0	22.3	22.1

With the pressures being about the same, this ensures that the nozzles are getting supplied with water at the same pressure throughout the system. Also, with the multiple tests, it displays that the pressure should remain constant for each test that gets performed going forward.

D. Weight Test

Although this test was not one of the measurable parameters, the strength on the chamber on the cart was tested. For the weight test, there was not a full procedure due to the cart being rated for a high load. The weight was a concern due to the requirement of withstanding their largest pumps. Each large pump weighs around 100 pounds and Fill-Rite requested a larger chamber to fit 2 of these pumps. At the time of testing, there were no pumps available to insert into the chamber. However, a known weight of 200 pounds was placed onto the cart. Visually, there was no movement in the cart and the chamber strength was deemed acceptable by the Fill-Rite team. Additionally, with a factor of safety of 2, the cart would need to withstand a load of 400 pounds during testing. With the cart being rated for 800 plus pounds, the chamber apparatus was deemed acceptable to hold the necessary weight of two 100-pound pumps during testing.

E. Heating Unit Compatibility

Due to the cost of running the external heating chamber, it was advised to not test the chamber's ability to withstand heat until a test actually needed to be done. However, the connection vents were test fitted to the connection ports at the back of the chamber. The material that the chamber is constructed of has a melting point of 1,375 degrees Celsius and 100% tensile strength until 870 degrees Celsius. With the chamber only being exposed to 60 degrees Celsius, the structural integrity of the chamber will not be of concern.

V. CONCLUSION

Overall, the water chamber met all the requirements and constraints and performed the desired tests successfully. The building process came with some struggles at first with not having all the components to build the chamber, but in the end, it came together and worked well. During the design and while troubleshooting there were times where the experience of those at Fill-Rite provided insights that helped progress the team and introduce ideas that hadn't been thought of.

Once the building was complete, the testing portion displayed the hard work that the team spent putting into this project. With everything assembled, the measurable parameters were put to the test to see how well the chamber held up to its expectations. With the minimum gpm of each nozzle being 0.29 at 20 psi, the chamber was able to output a greater amount of 0.38 gpm. This amount well exceeds the requirement while also being low enough to not damage anything inside the chamber. Along with the flow rate, the pressure for each nozzle must stay within a 15 psi difference. After testing, the nozzles all displayed a great pressure of 22 psi all around. Since the distance in nozzles are small, this number makes sense. Finally, the cost of the chamber was not allowed to exceed the threshold of $5,000.

ACKNOWLEDGMENT

Our group would like to acknowledge our sponsor and individuals who have helped make this project come to life. A special thanks to Fill-Rite of Fort Wayne for sponsoring this project. Fill-Rite provided the funds, space, tools, and knowledge necessary to build the prototype and make this project possible. A special thanks to AH and SS for being the main points of contact at Fill-Rite and for providing insights to the team to work through conceptual ideas and making them into a reality. These two helped accomplish the outlined milestones in a timely manner and took interest in helping find better solutions to problems that arose. They also aided the group with their knowledge in creating a more optimal system.

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