Cummins: Water Spray System

Final Design Report

Group 17
Justin Collins
Scott McMurry
Shane Boland

FAMU-FSU College of Engineering
Department of Mechanical Engineering

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I Executive Summary

The Water Spray System project sponsored by Cummins involves knowledge of many aspects of the Mechanical Engineering field. This provides many challenges and limitations throughout the design process in and of itself. The design of the chosen piping system must take into account the design of the spray structure. Additionally, the arrangement of the piping system will go a long way into determining how any automated controls will interact with the system. All of these had to be taken into consideration along with any requirements or constraints specified by Cummins.

Though it brings along its own challenges, this project demanded creativity and innovation on the part of our design team as the client had few requirements and constraints for the desired product. The main requirement of a 6 ft x 3 ft simultaneous spray area provided the most difficulty in addressing. Additional constraints of 1 gallon per minute for each nozzle and the automation of the spray duration and frequency provided challenges as well.

The initial stages of concept generation and selection involved quite a few problems. Taking what our team understood to be all of the product specifications into consideration, three initial design concepts were developed some of which featured automated motion as well. However, after further discussion with our sponsor, additional design concepts needed to be conceived. This led to the design that was ultimately decided upon that features an array of six nozzles on each side.

The square spray pattern of the nozzles and manner in which they are arranged, adequately and uniformly covers the required spray area. In order to spray as desired, analysis on the piping system and the losses within the system had to be done. With the nozzle specifications given by its distributor, an inlet pressure of 14.9 psi needed to be maintained by our chosen pump. This would yield the appropriate pressure behind the nozzle ensuring that the spray coverage functions as desired. Also, the total flow rate out of the system forced our team, under the guidance of our faculty advisor Dr. Kareem Ahmed, to include a reservoir in the system.

Upon assembly of our product, we will look to test the system experimentally to ensure that calculations regarding spray coverage and flow rate were accurate.

II Problem

Problem Statement

Cummins employs a water spray system at their facilities to conduct various tests on engines. One specific test is meant to simulate water splashing onto the engine, for instance from a truck driving over a puddle. The system currently in use, while it does meet design requirements, is inefficient and not as robust as they would like. A schematic drawing of this inefficient system can be seen in Figure 1. Our task is to design a new water spray system that is more efficient and stable.

Objective

The objective of this project is to design and manufacture a stable, efficient water spray system that allows for adjustable spray settings to be used in engine splash testing by Cummins, a diesel engine manufacturer for applications ranging from automotive to industrial construction equipment and power supplies. The design will feature pipes and nozzles in an array such that every area on the engine can be sprayed simultaneously. It will also have an automation feature that allows for spray duration and frequency to be adjusted. The motivation behind this project is to reduce the need for human-system interaction resulting in more efficient testing with increased repeatability.

III Product Specifications

The nature of this project involved much discretionary decisions on the part of the design team which was only furthered by the sponsor's few requirements and constraints. However few they may be though, they must be addressed and under consideration throughout the entire design process.

As mentioned previously, one of the chief requirements of the resulting product is that it must be capable of spraying a 6 ft by 3 ft area. The misunderstanding of whether this spray area had to be sprayed simultaneously or not was the source of many difficulties through this process. The structure had to be height adjustable from 3 ft to 6 ft as well. Also, in order to increase the efficiency of the engine endurance testing, the client required that the spray settings, both the duration of the spray and the frequency with which it will spray, be automated. The final specification given to us by the sponsor was for there to be a volumetric flow rate of 1 gallon per minute for each nozzle. The remaining variability in the system was up to the discretion of our design team. Among the choices to be made by our team were the number of nozzles and the pump selection. The figure below tabulates these specifications.

Table 1: Summarizes the required product specifications

Specification	**Requirement**
Spray Coverage	3 feet x 6 feet
Flow Rate	1 gpm
Automation	Spray Settings only

IV Original Design Concepts

Concepts Generation

Our original design is based on the precept that the tests in which Cummins is going to run are on a single electrical circuit at a time and that they are only planning on running these tests for around a day. Taking this into account our group decided on going with a single nozzle spray system that could be moved anywhere on the 3 ft by 6 ft spray area. The automation would be controlled by a GUI interface.

Concept 1

This design institutes a flex hose attached to a stationary base. The base will be two reverse steel t-junctions with a horizontal crossbar for increased stability. The flex hose will be 5 ft long so that it will be able to reach anywhere on the test section. There will be a nozzle attached to the end of the flex hose. The pipe hose will be rubber and run along the inside of the t-junction and flex hose connecting to the valve. It will utilize a pump that will be controlled by a controller so that there is no need for a valve. The design will be replicated on the opposite side and have a different pump. This design will use a hardware interface to input the duration of the spray and the frequency of the spray.

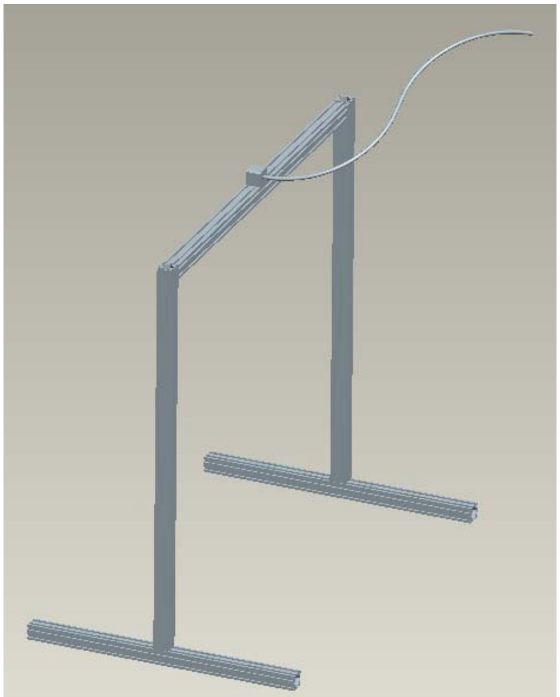

Figure 1: Concept #1

Concept 2

This design uses multiple set screws along tracks powered by multiple motors (X-Y table). This design will implement a rectangular base to not only help support the X-Y table but also to have the X-Y table stand 3 ft off the ground so that it can move through the test section. Another hand cranked set screw will be used to move the platform, which will have the nozzle attached to it, in the 3rd dimension. This design will again be replicated on the other side. It will use a pump for each side of the spray system and about 9 ft of rubber hosing connecting each pump to the nozzle. This design will involve a Graphical User Interface (GUI). This will allow the user to type in a time and frequency of the spray as well as input coordinates and the order in which they will execute the points. The most likely program that will be used is Lab View but other programs are also being considered.

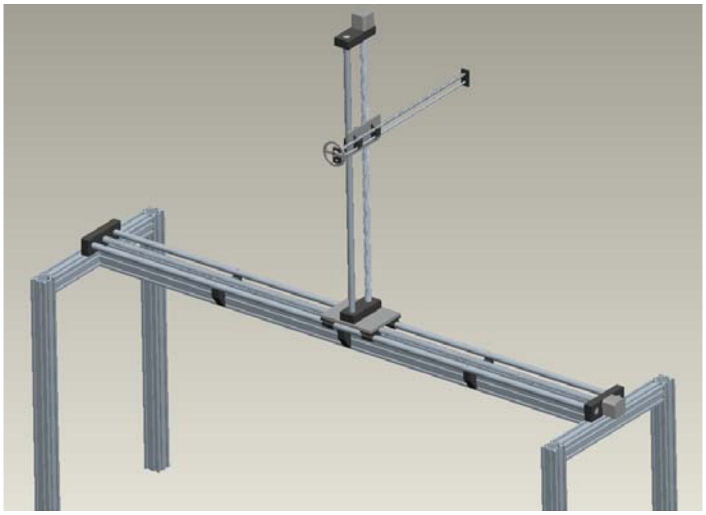

Figure 2: Concept #2

Concept 3

This design will be similar to the concept 2, however instead of designing and building an X-Y table it will be purchased from Nook Industries. This system can be modified to accept an automated 3rd-axis to maximize system precision and accuracy. Essentially, it will go to the same location every time rather than having the potential for human error outside programming the system motion prior to test execution. The pump, hose, nozzle and water supply will not change from concept two to this concept.

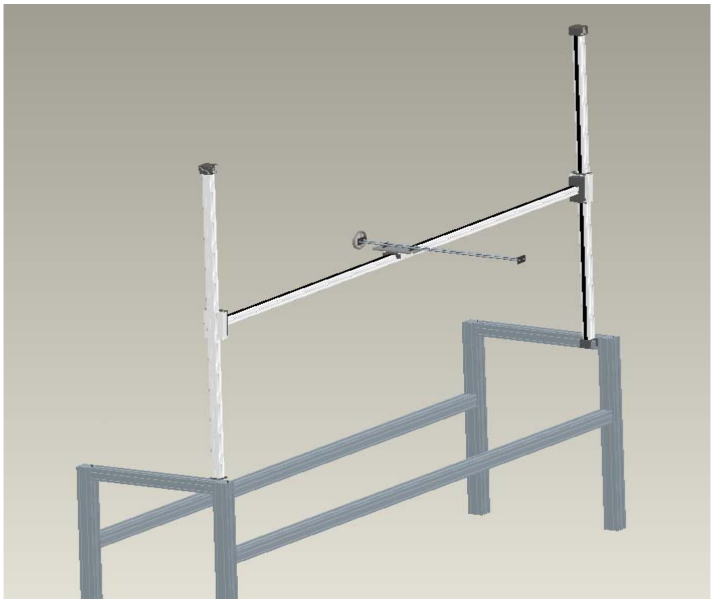

Figure 3: Concept #3

Initial Concept Selection

Cost Analysis

Concept 1

Table 2: Cost analysis for initial Concept #1

Components	**Cost (dollars)**
Flex Hose	150
Pump	50
Infrastructure	100
Water Hose	40
Controller	50
Analog to Digital Converter	40
Nozzle	25
Total	**455**

Concept 2

Table 3: Cost analysis for initial Concept #2

Components	**Cost (dollars)**
Power Screw Components	200
Tracks	100
Bearings	90
Pump	50
Infrastructure	100
Water Hose	40
Motors + Controllers	450
Software	0
Analog to Digital Converter	40
Nozzle	25
Total	**1095**

Concept 3

Table 4: Cost analysis for initial Concept #3

Components	Cost
X-Y table (Nook industries)	1600
Pump	50
Infrastructure	100
Water Hose	40
Motors + Controllers	450
Nozzle	25
Software	0
Analog to Digital Converter	25
Total	**2290**

Decision Matrix

Table 5: Decision Matrix for initial design concepts

		Concept #1 Flex Hose		**Concept #2 2D Automation**		**Concept #3 2D Automation (Nook Industries)**	
Characteristic	**Weight**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Automation	40%	2	0 .8	6	2.4	8	2.8
Cost	30%	8	2.4	5	1.5	0	0
Repeatability	10%	2	0.2	6	0.6	10	1.0
Stability	20%	6	1.2	6	1.2	4	0.8
		Total:	4.6	Total:	**5.7**	Total:	4.6

Decision Matrix Specifications

Table 6: Criterion for decision matrix for initial design concepts

	Cost	**Automation**	**Stability**	**Repeatability**
0	2000+	No Automation	Not Stable	Unrepeatable
2	1600-1800	Spray Automated		Low P Low A
4	1200-1400	Spray and 1 axis		
6	800-1000	Spray and 2 axis	Stable	High P Low A
8	400-600	Spray and 3 axis		
10	0-200	Spray and 5 axis	Fully Rigid	High P High A

Each of the weights given was chosen by how the group deemed the importance of each of the design characteristics were from our communications with our sponsor. Automation is by far the most important design characteristic since it is what their current design lacks. Cost was weighted slightly less since it is only considered because of our budget constraint and is this design in not for commercial use. Stability was given a significant weight since Cummins said that the system that is to be developed needs to be able to last and not break down. Since the reason for this system is to do a water spray test then our group felt that it would be good to factor in how repeatable the test would be from our design concepts.

V Final Design Concept

Considerations

Once the initial concept selection had been completed, we showed our results to the sponsor for approval to move forward with the design process. Our group was unaware that these endurance tests can range anywhere from 1000 hours to 4000 hours. With this new knowledge, it became apparent that fatigue would become a factor due to the high number of moving parts associated with an automated motion device. Also, our previous designs featured only one nozzle and therefore were unable to cover the 6 foot by 3 foot required spray coverage area simultaneously. Thus, we were forced to forego the initial designs realizing that automated motion was not necessary and also not desired by the client.

While the difficulty of dealing with automated motion was no longer an issue, the focus of the project shifted to that of optimization of the piping system to obtain the specified flow rate and spray coverage.

Design

This design utilizes two arrays of six nozzles. Each array has two rows of three nozzles each. It is possible to go with fewer nozzles in our array design which would allow for the use of a less powerful pump and therefore save on money. However, one of the design requirements is to have an evenly distributed spray and the fewer nozzles used in the array the more spray overlap. Therefore we deemed it better to have the increased cost of more nozzles and a stronger pump to better suit the clients design requirements. After extensive searching, an appropriate nozzle was chosen. Our team decided to use Quick FullJet full-cone, square spray nozzles, more specifically the QHA-SQ model. From the information given by the distributor, these specific nozzles are very useful in applications requiring a uniform coverage of a rectangular area. Another added benefit from the use of these nozzles is their ease of replacement. The body of the nozzle remains in place while only the nozzle tip need be replaced.

Each of the nozzles is directly threaded into a hollow aluminum pipe. The nozzle array is constructed out of extruded aluminum so that the entire structure is lightweight and strong. There is a semicircular bracket with ¼ in. holes extruded out of it at 10 degree increments over a range of 120 degrees with its maximum being 60 degrees. The semicircular bracket has an additional piece of aluminum that has a 1 in hole that helps support the CPVC piping structure. This arrangement can be seen below in Figure 5.

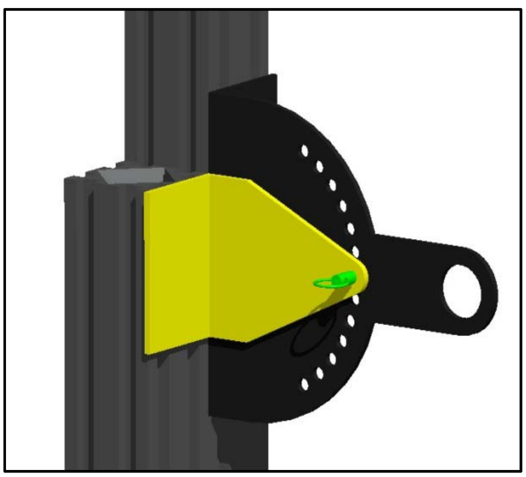

Figure 4 shows the tilt bracket

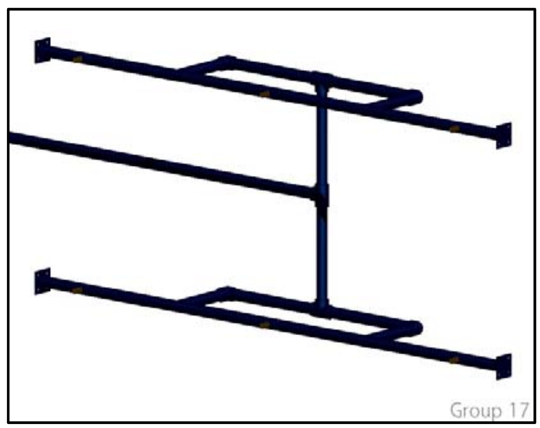

Figure 5 shows the H style pipe configuration

In order to connect to the nozzle array we decided to use an H- shaped pipe system. This configuration was chosen so that there is a more even pressure distribution as opposed to inputting the water from one end of the pipe. Another reason for this type is to minimize the time is takes for all nozzles to reach a steady flow. There is a one way valve at the beginning of each h shaped part of the piping system to minimize the prime time for the system. This entire configuration has been modeled and shown in Figure 6.

A hose is provided at the testing facilities but does not likely have the required mass flow rate required of our system therefore a reservoir will be required to be attached to the pump. There is a system of valves that cuts the pump off from the system to help maintain water in the piping system as well as allowing the pump to prime itself while circulating the water back into the reservoir.

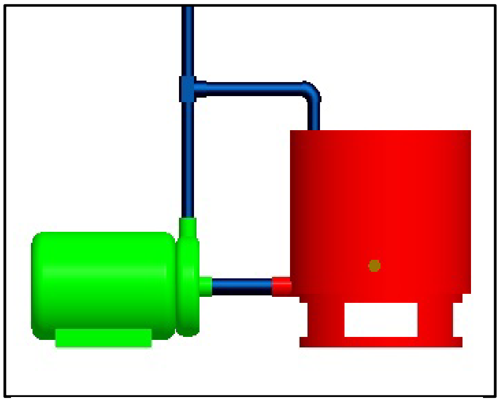

Figure 6 shows the pump (left) and the reservoir (right) connected in a loop

The last of the requirements yet to be addressed is the manner in which this system will be controlled. Much thought was put into using a control board to operate the pump so as to make the spray duration and frequency adjustable. However, after discussion with various advisors, it would be better to employ some Graphical User Interface (GUI) to control the pump, valves, or both. The GUI to be used by our team is LabView. LabView was chosen principally because of its universal nature, more specifically because our sponsor mentioned it as a program they would be compatible with. LabView is also user friendly once the executable program has been designed. The adjustability of spray duration and frequency are well within the ability of a LabView program.

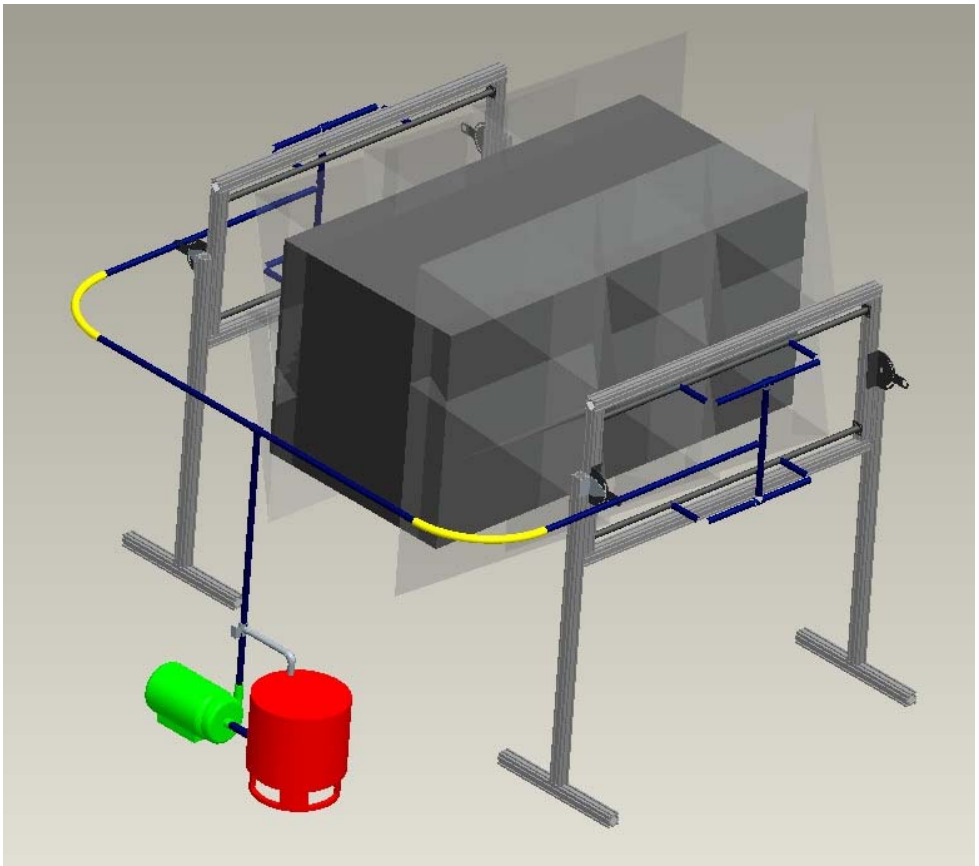

Figure 7- Overview of the entire water spray system.

Cost Analysis

Table 7: Cost analysis of our final design concept shows that our product is within budget

Part	Unit Price	Quantity	Price	Vendor	Part Number
"1-48" CPVC	8.29	8	66.32	Plumbing Supply	N/A
1" Clear Braided Vinyl Tubing	2.83	8	22.64	Plumbing Supply	CTB100
1"x1"x1" Tee Sharkbite Fitting	25.57	3	76.71	Cash Acme	U374
1"x1" Check Valve Sharkbite	44.00	1	44.00	Cash Acme	U2020-0000A
48" Framing Extrusion	18.24	10	182.40	Faztek	15EX1515UL-48
L-Bracket	4.00	16	64.00	Faztek	15CB4804
X-Vane 2-piece Square Nozzle	14.30	12	171.60	TecPro	3170
Misc Electrical Components	150.00	1	150.00	N/A	N/A
Extended-Life Centrifugal Pump	737.84	1	737.84	McMaster-Carr	4320K47
		TOTAL	**1515.51**		

VI Conclusion

When first discussing the problem statement and design requirements, we decided to go with a one nozzle system that could spray anywhere on the engine. After doing a decision matrix we decided on going with an x-y table that could be manually moved in the third dimension. This system would be move using multiple set screws and motors that is controlled by a GUI interface. This system had high accuracy and repeatability and minimized human interaction.

After discussing our design concept further with our representatives at Cummins, we discovered that there was miscommunication and that our selected design would not be able to meet the design requirements. Since that meeting, we have eliminated the automated motion from our design is now capable of spraying the entirety of the engine simultaneously.

Our new finalized design features an array of six nozzles on both sides of the structure. These nozzles will have a square spray pattern and have been arranged such that all parts of the engine can be sprayed. Though the motion will not be automated, we have added certain features that allow for some adjustability to account for different shape engines. One feature is that the spray structure can be tilted to account for different shaped engines.

This design process has indeed presented many challenges to our team. It was a new experience for our team members to not be able to meet face-to-face with the people we were working with. The communication barrier resulted in some problems that needed to be overcome by our team. One problem that became a frustrating one at first was the delay in communication. Initially, our team was under the impression that all of the product specifications put forth by our sponsor had been addressed and accounted for. From there, our team focused on increasing the efficiency and repeatability of the testing by Cummins by use of an automated motion table. However, after taking these design ideas back to our sponsor, we discovered that automated motion was not a feature that was necessary or even desired. This forced our team to abandon those design concepts for the most part and begin the redesigning of our product. Though this challenge proved rather frustrating in its timing, it did change the driving force of our project. We were no longer as concerned with the controlling of an XY automated motion table. We were now faced with the challenge of optimizing the piping system and all of its components such as the pump, nozzles, and any valves that might be needed. Again, this was all a new experience for this team but the experience itself has benefited our team members. The fact that the design process is not always going to be a smooth one was never more apparent. Also, the importance of staying in contact with your client was a lesson learned by our entire team.

VII References

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Janna, William S. *Design of Fluid Thermal Systems.* Stamford, CT: Cengage Learning, 2011. Print.

McMaster-Carr. <http://www.mcmaster.com/#>

Faztek T-Slotted Aluminum Solutions. <http://www.faztek.net>

Spraying Systems Co. <http://spray.com/cat70/index.html>

Plumbing Supply <http://www.plumbingsupply.com/cpvc.html>

VIII Appendix

Calculations

Calculation of Needed initial pressure to result in P_2= 12 psi (with an included 20% factor of safety)

$$\boldsymbol{P_1 = P_2 + \left(\frac{\rho}{2g_c}\right)(v_2{}^2 - v_1{}^2) + \left(\frac{\rho g}{g_c}\right)(z_2 - z_1) + \left(\frac{fL_P}{D_h}\right)\left(\frac{\rho v_1{}^2}{2g_c}\right) + \sum K\left(\frac{\rho v_1{}^2}{2g_c}\right)}$$

Where

$$\sum K = K_{nozzle} + 2 * K_{90} + 3 * K_{Tee} + K_c = 5.265$$

$$K_{nozzle} = 0.1\left(1 - \frac{d_2}{d_1}\right) = 0.075$$

Additional Figures

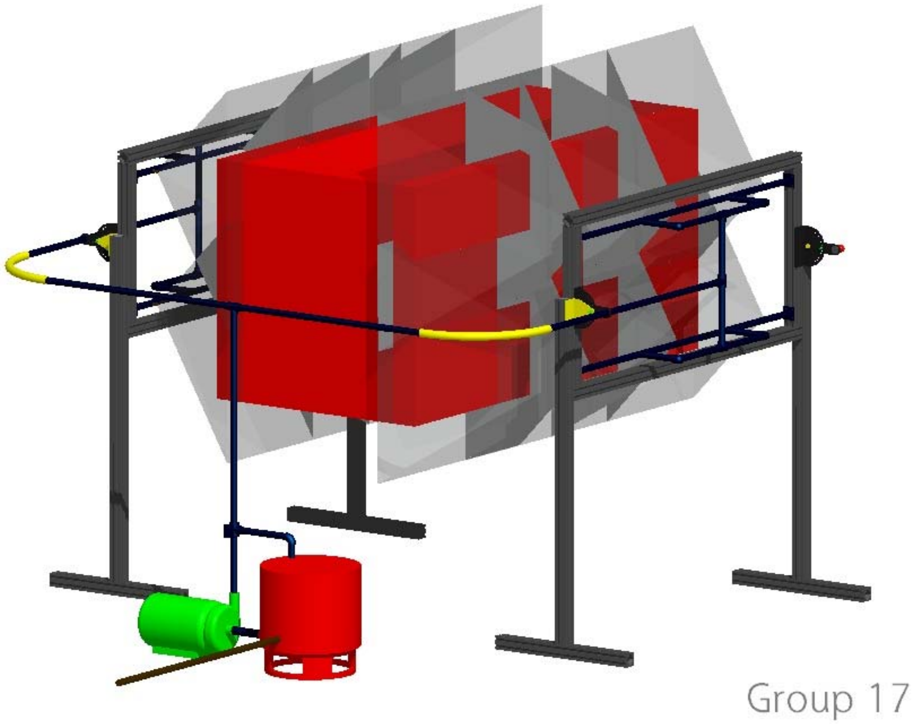

Figure 8: The entire system assembled

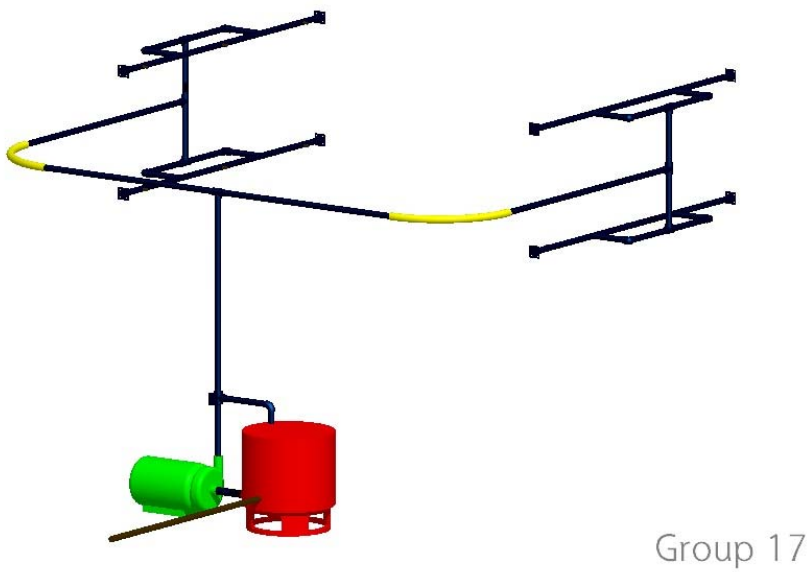

Figure 9: The piping system isolated