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Research Article

Mobile Irrigation System-A Capstone Project

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Abstract

A capstone project was designed to apply principles learned in fluid mechanics and other MET courses. The project was done by a team composed of three MET students who designed a mobile irrigation system through an overhanging irrigation boom. The system pumped water through a single 5.3 gal/min (20 liters/min) pump that was powered by a 12-volts DC battery. Water was fed to eight nozzles through PVC plastic tubing that allowed flexible installation and durability. The water exiting the nozzles fed all the area under the feeding rail over a width of 10 feet (3.34 m). The nozzles were installed at a height of 14 inch (35.5 cm) above the ground. The team installed a long rectangular tube stock. The wing of the spray was designed to fold in and out, providing a more compact unit. The mobile irrigation unit was expected to cover 1 acre (4046 m^3) of land in approximately 1 hour if it was moving at a speed of 1.25 m/s1.25 m/s. Students performance and project outcomes were assessed against ABET learning outcomes such as: (a) applying engineering science, (b) conduct tests, measurements, calibration and improve processes, (c) system design, (d) team work, (e) problem solving: ability to identify, formulate, and solve engineering problems, and (g) effective communication: ability to communicate effectively.

Keywords: *Field Fertilization; Irrigation System; Nozzle Coverage Area; Irrigation Speed; Irrigation Efficiency.*

1. Introduction

Field fertilization and plants' irrigation are vital for good season produce. There are different irrigation systems such as sprinklers, drip systems, or hand watering (Efficient Irrigation, 2018). Irrigation time and volumetric flow of water to be supplied depend on soil texture, organic matter, and rooting depth (Schultheis, 2013). Thus, two lands that are equal in areas can have totally different irrigation needs.

Although drip systems seem to be more efficient over the other two, sprinklers and hand-watering, but it needs either storage tanks to store the water in or tubes to be laid along the irrigated area. For larger areas of land, sprinklers driven by mobile trucks are more viable and efficient (Conserve H_2O, 2019).

A capstone project lead by a group of three senior students in the mechanical engineering technology program at Purdue University, USA, designed, built and tested a mobile and portable irrigation system that can be run by one person only and covers a total area of 1 acre (4064 m^3) in approximately 1 hour. The system was similar to the traveling gun type sprinkler system described in (NEH, 2005). The designed system needed to be self-powered to allow it to move around the irrigated area and, thus, had to be independent of any electric power supply or should have its own power that needed to be embedded with the mobile system. Upon initial stages of the design, financial constraints drove the design and implementation of the final product. On the other hand, the team wanted to build a real life application that could be used at a later time in a farm for water spraying purposes. The main objective of the project was to have a functioning sprayer that was going to be efficient and reliable.

2. Design Process and Progress

2.1 Brainstorming phase

During the brainstorming phase, it was thought to build a system that would compose of a tank to hold the water, a pump, hoses, and sprinklers. Many ideas were examined and discussed. At the preliminary design phase, the team wanted to mount a 2.2 gallons/min (gpm) (8.8 lit/min) pump that was fed by two different five gallon buckets onto a big trailer. Another thought was to drill out nozzles into a 1 inch (2.54 cm) diameter, 10 ft (3.34 m) long PVC pipe and putting it across the back, but this would not be very practical when in field. The team wanted to build something that could be towed behind a lawnmower or even maybe a four wheeler. A lightweight design, large volume tank, high flow pump, and large wingspan with equidistant sprinklers was the final agreed design. A generic 3D model was built and is shown in Figure 1 to check on any challenges and to discuss most details

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before starting the fabrication stage. The thought system was contained within a towed trailer that contains a plastic tank in the back, a pump powered by a 12-volts battery in the center of the trailer to balance the weight of tank on the trailer.

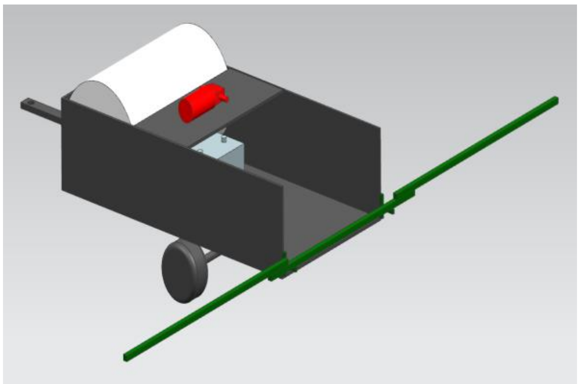

Fig. 1 Preliminary 3D model design during brainstorming phase

2.2 Concept selection

The team decided to select a suitable tank that fit the budget and the need and then the remaining parts were selected based on the tank volume and dimensions. First, research was done investigating companies making larger volume tanks such as those that are used to store food for plants. Based on the collected information, a 35 gallons (0.133 m^3) tank was chosen. The selection of the trailer, shown in Figure 1, was selected based on the dimensions of the tank. A Steel Lawn Cart was selected trailer. A 5.3 gpm (20 lit/min) pump was selected and a ½ inch (12.7 mm) diameter braided hose was recommended to be connected with the pump. Thus, the team purchased reinforced vinyl braided hose. The time needed for a full tank to be drained was calculated based on equation (1) and it was found approximately 6.59 minutes.

$$T_{empty} = \frac{V_{tank}}{Q_{pump}} \quad (1)$$

where T_{empty} in the time needed to empty the tank in minutes, V_{tank} is the tank volume in gallons and Q_{pump} is the water volumetric flow rate delivered by the pump in gpm. Spraying nozzles or sprinklers were then selected which had a spray cone angle of 140°. The trailer floor was approximately at a height of 1.375 ft (0.46 m) from the ground and, thus, it was determined that the circular covered area by each nozzle would be approximately 1.25 ft (0.42 m). With a 10 ft (3.34 m) long arms, that were designed to hold the nozzles, eight nozzles or sprinklers were required based on equation (2).

$$\# \, Sprinklers = \frac{L_{arm}}{A_{sprinkler}} \quad (2)$$

where L_{arm} is the arm length and $A_{sprinkler}$ is the coverage area of each sprinkler.

The pump was selected to run with a DC battery. Thus, a 12-volts battery was resourced.

2.3 Final design and fabrication

The final designed unit was close to what was planned in the brainstorming and conceptual design phases. The 35-gallon tank was laid horizontally on its side. The tank was pushed all the way to the front of the trailer, as shown in Figure 2, and was secured using the weight of the 12-volt battery that was held down by metal brackets, as shown in Figure 3.

Fig. 2 Trailer with the 35-gallon tank, pump, hoses and feeding brackets

Fig. 3 Battery with mounting brackets used to power the pump

The spray brackets were designed so the center piece, which has a width equal to that of the cart, can hold two foldable arms. This gave the unit a more compact size. A fully expanded and partially folded photos are shown in Figures 4 and 5, respectively.

As mentioned earlier, eight sprinklers were equally mounted into the full length of the arms shown in Figure 4. Braided vinyl reinforced tubing was used to connect the pump with the tank from suction side and to sprinklers the outlet side. After securing all the nozzles with zip ties, a pressure regulator was installed at the outlet of the pump as shown in Figure 6 with a return line into the tank. The system was then tested to check for any leaks. All hose clamps were tightened if any leak was observed. The arms were folded couple times to check for durability.

Fig. 4 Fully expanded arms

Fig. 5 Arms being folded

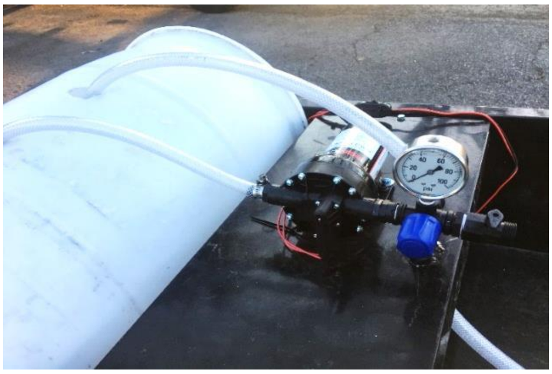

Fig. 6 Installed pump with the pressure regulator

2.4 Cost analysis

Table 1 summarizes the main parts used to fabricate and implement this project. The total cost for the project, excluding labor since it was done in house by the students, was approximately $489.

Table 1 Parts cost

Part	Source	Cost
35 Gallon Tank	Kokomo Garage Sales	$25
5.3 GPM Pump	Rural King	$105
Exide 12V Marine Deep Cycle Battery	Rural King	$70
7 Cubic feet Steel Lawn Cart	Kokomo Garage Sales	$50
20' of 1/2" Clear Vinyl Braided Hose	Lowes	$23
1/2" Valley Industries Pressure Regulator Assembly	Rural King	$20
Valley Industries Glycerin Pressure Gauge	Rural King	$10
Nozzle Assemblies (8 Qty.)	Rural King	$56
Wiring Harness with Switch	Rural King	$10
Bolts, Nuts & Washers	Rural King	$15
Barbed End Connectors	Rural King	$20
4 1/2" Angle Grinder Wheel	Menards	$10
16 Gauge Rectangular Tube Stock	Craigslist	$25
Rust-Oleum Green Paint	Menards	$10
DAP Clear Silicone Caulk	Menards	$5
Caulk Gun	Menards	$8
120 Grit Sand Paper	Menards	$10
Putty Knife	Lowes	$4
Zip Ties	Harbor Freight Tools	$5
1/2" to 5/8" Hose Clamps	Menards	$8
Total Cost		$489

3. Product Testing

The product can be used for many applications. The unit can be used to fertilize or water a personal yard or can even be used to water some small land.

The unit was tested under different weather conditions while standing and while being pulled by a truck. A photo for the unit in operation is shown in Figure 7. With the arms unfolded, a total area of 12.5 ft^2

(10 ft (width) × 1.25 ft (nozzle covered width)) (1.12 m^2) could be instantly covered, as shown in Figure 8. Assuming that the truck and trailer move at a speed of 1.25 m/s (4.5 km/hr), 58 minutes (43560 / 12.5) were required to cover 1 acre (43560 ft^2) of land which is equivalent to a soccer playground area. However, it should be mentioned that the tank needs to be filled every 6-7 minutes which would require 8 refills to cover the assumed area.

Fig. 7 Built unit in operation with all nozzles spraying as intended

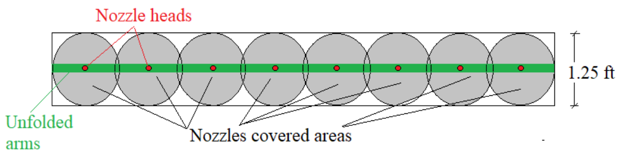

Fig. 8 Instantaneous covered area by the designed arms and sprinkler

4. Project Assessment

Through the implementation of the project, the students got experience in many aspects needed in industry after their graduation such as brainstorming, preliminary and final design, testing and measurements, written and oral communication skills. The outcomes of the project were evaluated against ABET learning outcomes summarized in Table 3. Performance assessment and feedback were done through the evaluation of biweekly submitted reports. There were four main categories toward the final GPA of the students: biweekly and final draft reports (15%), final report (50%), presentation (25%), and team work evaluation (10%). The details of the four categories are as follows:

1) Biweekly reports: constituted 15% of the final GPA. These reports summarized the work of the previous two weeks. Each report was recorded on a log-book that included minutes of meetings, weekly list of achieved and pending goals, notes from outside research, calculations, sketches and drawings, test plans, collected data, and analyses.

Each of the biweekly reports had a general theme as follows:

Report 1 Proposal
Report 2 Conceptual Design
Report 3 Preliminary Design
Report 4 Critical Design
Report 5 Proceed to Test
Report 6 Draft - Final Report

Each report was evaluated based on rubrics given in Table 2.

The purpose of the draft final report was to evaluate the project and to see the percent completion. This was done before the presentation in order to provide the students with enough feedback for their presentations.

2) Presentation (25% of final GPA): The student presented results of the project to interested MET faculty members and guests.
3) Final report (50% of final GPA): submitted by the end of the semester after getting feedback from the project supervisor, guests and other faculty members, who served as external evaluators, and then embedding their comments, suggestions and corrections in the final report.
4) Team evaluation (10% of final GPA): The remaining 10% of the grade were assigned to team evaluation where the team members evaluated each other and submitted, separately, their evaluation for themselves and other team members. This self-evaluation was half the 10% assigned to team evaluation. The other half was obtained through oral testing where the instructor asked each team member some questions and evaluated his knowledge to the design, manufacturing and implementation of the project.

Table 3 shows the relation between the ABET learning outcomes and the category/ies that were used to meet these expectations.

Conclusions

The team successfully designed and built a portable watering system that can water a soccer playground (approximately 4000 m^2 or 43500 ft^2) area in around 1 hour, without taking into consideration the water storage tank refill time, if the trailer was moving at a speed of 1.25 m/s. This covered area would require almost 8 refills to complete the task. Although it seems to be a high frequency of refills, but it should be pointed that the team was targeting towards a personal portable watering unit and it was not the plan to be used for big areas. A few modifications in terms of the water tank size and the pump size could be done to meet more demands which can help in lowering refill frequencies.

The project helped the students meet multiple ABET learning outcomes. The capstone assessment should be redesigned to include the other ABET outcomes such as ethics in working environment and to allow better team.

Table 2 Rubrics used for evaluating biweekly reports

Points	4	3	2	1	0
Weekly notes from supervisor and other parties	Notes exceeded expectations	Notes were appropriately relative to meeting content	Notes qty & quality were missing some meeting contents	Some evidence of notes	No evidence of notes
Legibility	Exceeded expectations	All entries clear & legible	75% or less clear & legible	50% or less clear & legible	25% or less clear & legible
Readability	Exceeded expectations, cross-referenced	Well identified entries	< 75% are identified, erratic flow in places	50% are identified, erratic flow in most places	< 25% identified, erratic flow
Completeness	Well documented, flow and content of entries demonstrated forethought, connections, and results, in and between process phases	75% of flow and content of entries demonstrated forethought, connection, and results	50% of flow and content of entries demonstrated forethought, connection, and results	Flow and content were spotty and unconnected	No evidence of forethought, connections, or results in and between process phases
Lab Notebook Guidelines (items i-viii above)	Followed all criteria	Criteria followed about 75% of the time	Criteria followed about 50% of the time	Criteria followed about 25% of the time	No evidence of following guidelines

Table 3 ABET outcomes and assessment methods

ABET ETAC Rubric/Learning Outcomes		Assessment Method
(1)	Apply knowledge, techniques and skills to engineering technology activities	Final Report and biweekly reports
(2)	Apply knowledge of mathematics, science, engineering, and technology to engineering technology problems	Final report and biweekly reports
(3)	Conduct tests, measurements, calibration and improve processes	Biweekly reports, draft report, and final report
(4)	Problem Solving: ability to identify, formulate, and solve engineering problems	Project proposal and biweekly reports
(5)	Team work	Self-evaluation (described previously)
(6)	Effective Communication: ability to communicate effectively	Presentation and biweekly reports

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