Design of a Mobile Water Sprayer for Car-Washing and Agricultural Businesses

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Abstract

Mechanical water sprayers remove loose paint, mold, grime, dust, mud, and dirt from surfaces and objects such as buildings, vehicles and surfaces under high pressure. This study is aimed at designing a mobile water sprayer to be fabricated with locally-sourced materials for watering of plants, and removal of dirt from cars and other dirty surfaces, in order to eliminate the drudgery associated with manual handling of tools and other repetitive tasks. Past literature of water sprayer were reviewed, after which a target water volume of 1600cm^3 was selected. Also, Scrap batteries will be connected in series to make a 12V power supply that will be connected to the DC 12V diaphragm water pump with the average working pressure of 100psi, which will automatically turns off at 160psi. The design of the nozzle yielded a velocity of 31.794m/s, and water pressure of 1.00MPa. The minimum pump power was designed to be 62 Watts. With a total battery power of 80.25 Watts, the required battery efficiency of 85%, the battery capacity with standard battery rating of 672 Watts-hour was designed to be 661.176Watts-hour. After the design of the trolley, as well as the prototyping and programming of the microcontroller, the research succeeded in designing an efficient and effective mobile water sprayer for agricultural and car washing businesses.

Keywords: mobile water sprayer, agriculture, car washing, nozzle, pump, design

1. Introduction

Drudgery in car washing and house cleaning may be as a result of different causes which can range from manual handling of tools to repetitive tasks and can be successfully eliminated or greatly improved through mechanization of washing tools (Naik et al., 2015). Exposure of vehicles to high-level dust, mud, grime and dirt without better cleaning can create drag, damage paintings, reduce as well as visibility.

The pain and stress associated with car washing can be relegated to the equipment used, cleaning agent and water. The essence of the chemical cleaning agent being for one end of the molecule to be attracted to water and the other end attracted to dirt, helping water to get hold of grease, break it up and wash it away (Woodford, 2019). Water as a universal solvent now greatly depends on the velocity and pressure flow with which it is driven or supplied (Naik et al., 2015). Water supply for such purposes can come from buckets, hosts and sprayers. This means that the major burden of washing significantly falls on the equipment with which water functioning with the cleaning agent is delivered (ASABE, 2007).

A mechanical means of delivering water at a high pressure designed with a mechanical pump is known as water sprayer. Sprayers in all forms are available to general users, some are used in the farms (fertilizer sprayers) for protection (Pranavamoorthi et al., 2017) and others such as the wheel driven sprayer, mechanical pest sprayer, boom sprayer (NASDA, 2014), multipurpose sprayer serving various functions of liquid delivery and the very essential aspect of the cleaning, where a water sprayer is used to remove loose paint, mold, grime, dust, mud and dirt from surfaces and objects such as buildings and vehicles. Most importantly, the water sprayer pressure which is expressed in pounds per square inch (psi), Pascal, or bar, is designed into the pump and can be varied by adjusting the unloaded valve (Naik et al., 2015; Nuyttenset et al., 2009).

The need for the design and fabrication of a cost-effective Mobile Water Sprayer (MWS) cannot be over-emphasized, as it will lead to the elimination of musculoskeletal disorders which arise when people are involved in strenuous activities like manual washing of cars and other job conditions that increasingly lead to the disease. According to Godwin and Okpala (2013), musculoskeletal disorders “apart from leading to human sufferings, musculoskeletal disorders also have negative economic impacts as a result of decrease in working capacity and production output."

A mechanical sprayer that is capable of being moved, which can be used to deliver water at different points of washing or cleaning is known as Mobile Water Sprayer (MSW). The MSW is a reliable and better means for removing dirt from surfaces and objects where they have been embedded in. The spraying of water can be varied using different nozzles or by varying the pressure under which it is being forced out (Kiran et al., 2018).

To easily assess the functional and physiological implications of manual handling of tools and task repetitiveness in car washing and house cleaning, it is provident to replace or enhance human labor with machines (Sanjay et al., 2015; Wolf et al., 2009).

2. Literature Review

The Mobile Water Sprayer is a high-pressure mechanical sprayer that is used to remove loose paint, mold, grime, dust, mud, and dirt from surfaces and objects such as buildings, vehicles and surfaces. The MWS delivers formulation in droplet forms which may either be tiny or large depending on the size of the nozzles or by varying the pressure under which it's been forced out (Kiran et al., 2018). The MWS is employed by businesses and home owners to reduce allergies, minimize hazards, and improve aesthetics, depending on the surface to be cleaned, as higher or lower pressure should be used, alongside an appropriate nozzle (Pranavamoorthi et al., 2017).

The pressure washing industry where water sprayers have its applications can trace its roots back to 1926 and the glory days of prohibition. Frank W. Ofeldt II, an employee of a Pennsylvanian producer of gas-fired water heaters and boilers and a maker of whisky stills, is credited as the inventor of water sprayers. It was quite by accident, while working on a whisky still, that he discovered that steam forced at high pressure through a small hose provided an effective method of cleaning grease off his garage floor (Perrin, 2014).

He began a crusade to create a cleaning contraption that would mix this new-fangled wet steam with chemicals. Today, pressure washing is a worldwide, multi-billion-dollar industry that employs hundreds of thousands of people with water sprayer as its number one tool. For the men and women in the industry more than 90 years later, pressure washing is a career, not just a job (Perrin, 2014).

The car washing industry necessitated a better water sprayer as the constant use of the model was faced with incessant flow stoppages, changing from hot to cold water or moving from clean water to detergents and waxes. As water sprayers were developed, its efficiency, ease of operation and running costs became a very much needed advantage.

The Mobile Water Sprayer uses the principle of air compression passing through the air atomizing orifice as the velocity of air is gradually increased to a higher value. This is to say that water under pressure passes through this orifice to give an increased velocity of flow. The flow pressure of the water sprayer can be gauged using the nozzle (Gangwar and Dixit,2017).

The pump is a major component of the water sprayer whose function is to collect water up from a level of low pressure to that of high pressure. This mechanical device provides the driving strength required for liquid flow. Pumps are of different types, sizes and shapes. These can range from the small-scale industrial pumps to the large-scale industrial pumps. In terms of techniques of displacement, impulse, velocity, gravity and steam, pumps can be classified into two types; centrifugal pumps (Gangwar and Dixit,2017; Zhu and Chow, 2004) and positive displacement pumps.

Water Sprayer Injury Assessment

Any device that produces over 100psi has the potential for serious injury. Immediate acknowledgement and treatment of a water sprayer injury is crucial.

The following steps should be taken if an injury occurs while using a mobile water sprayer:

a) Access injuries including wounds, muscle function and blood flow
b) Remove any object in the way of caring for any visible wound
c) Wash hands thoroughly with soap and clean water
d) Put pressure on the wound with a clean towel or cloth to stop bleeding
e) Apply a clean adhesive bandage or dry clean cloth to cover the wound

Persons who have been injured by high pressure spray are urged to seek professional medical treatment as soon as possible. Not all water sprayer injuries are immediately obvious or even visible. Internal injuries may occur even if no external wound is apparent. Medical professionals can access injuries more appropriately and provide appropriate medical treatment such as a tetanus shot or antibiotics.

Advantages of Using Mobile Water Sprayer over the Conventional Stationary Types

The Mobile Water Sprayer has numerous advantages over the conventional stationary types of the water sprayers. Using the mobile water sprayer, car washing or house cleaning can be done irrespective of the location or region. Surfaces or objects with mobility issues can easily be cleaned using the mobile water sprayer. More so, the reduction in size and its mobility makes the device more affordable and reduces its power consumption rate.

Improved efficiency and effective of operations are obtained using the mobile type as they are easily set at varying velocities and volumes. Lastly, there is virtually little or no complexity in the operation of the mobile water sprayer as the only things required are knowledge of operation and a steady source of water/pump.

3. Methods and Materials

The design of the mobile water sprayer was carried out using the materials presented in Table 1. The choice of the materials was based on functionality, affordability and the design specifications.

Table 1: List of components used in the design of the water sprayer

S/No	Components Description	Quantity	Considerations
1	Battery Pack	1	Strength, stiffness and corrosion resistance
2	Diaphragm Water Pump	1	Efficiency, flow rate and discharge pressure
3	Galvanized Metal Sheet	1	Durability, cost and corrosion resistance
4	Spray Gun	1	Purchased
5	Hose	2	Flexibility and light weight
6	Battery Monitoring System (BMS)	1	Efficiency and cost

7	Trolley	1	Strength and hardness
8	Relief Valve	1	Pressure
9	Pressure Regulator	1	Pressure
10	Trolley Tyres	4	Strength, hardness and surface roughness
11	Charger Indicator	1	Purchased
12	Pressure Gauge	1	Purchased
13	Water Sensors	2	Purchased
14	Arduino	1	Purchased
15	Battery	20	Voltage Capacity, energy density Battery life, recharge ability

The methods applied for the design of the mobile water sprayer were discussed in the sub-units:

Process flow of the designed mobile water sprayer

The design of the water sprayer was done using Solid Works to follow the operation principle whereby the diaphragm pump at 12V generates the required pressure of 100-160 per square inch (psi), pumps water through the hose, gauged and directed through the spray gun as depicted in Figure 1

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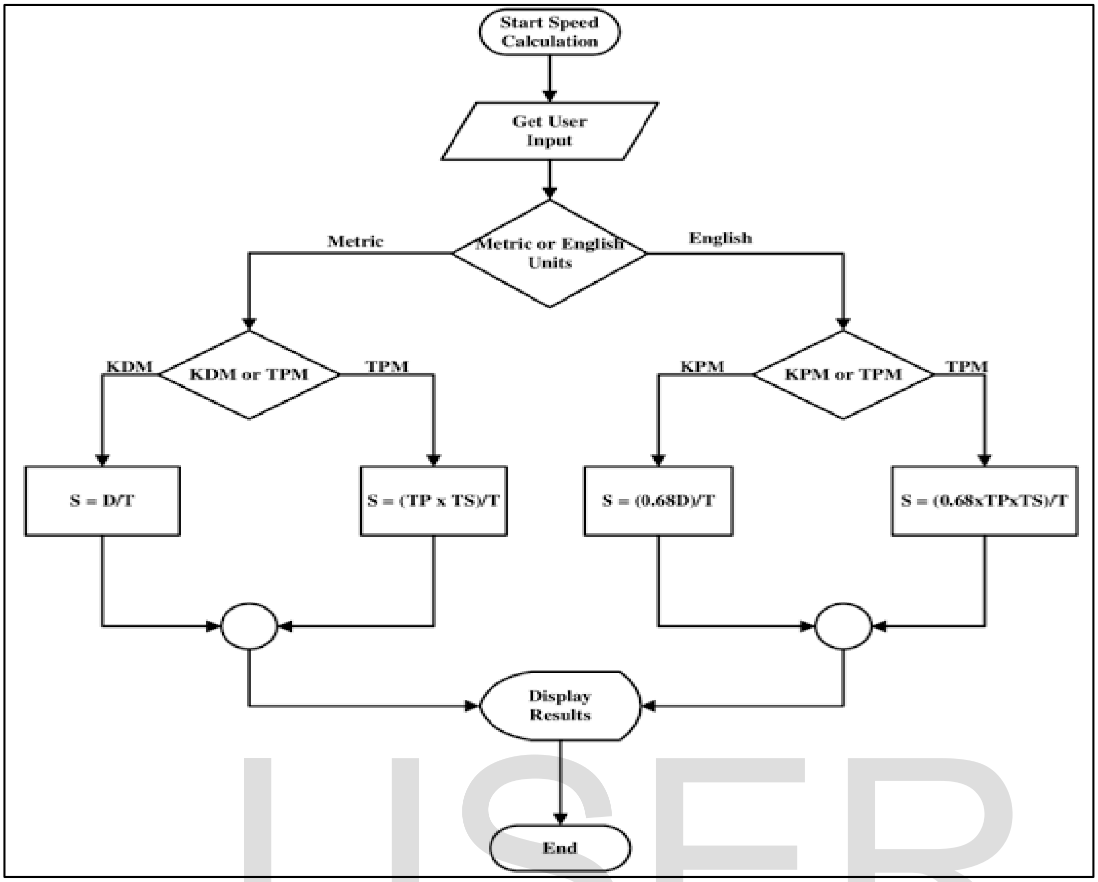

Figure 1: Pictorial representation of process flow for spray speed calculation for device

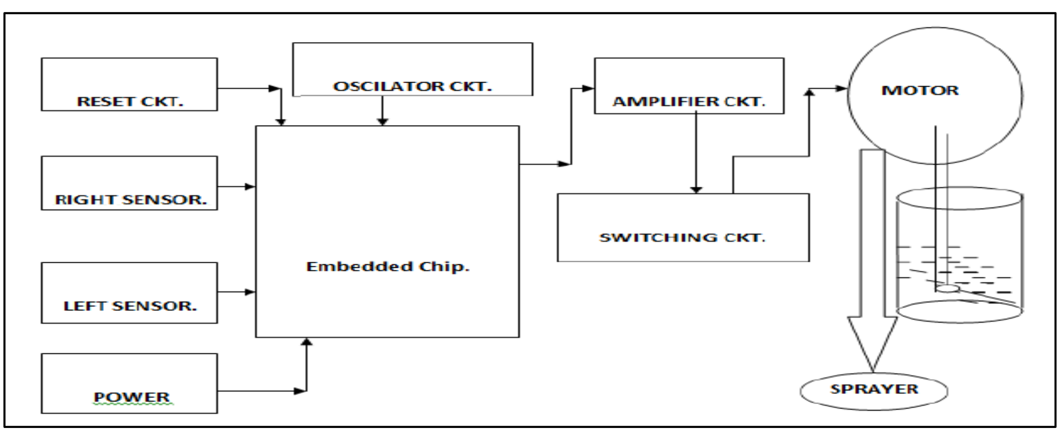

Figure 2: Block flow diagram of the Mobile Water Sprayer

Power Supply Unit

The power supply involves a 12.6V, 5A battery pack, rectifier and some other discrete components that made the conversion possible. The battery pack is made up of scrap laptop/power bank battery (Lithium-ion battery). Each lithium cell is connected in series.

DC 12V Diaphragm Water Pump

The battery pack will be connected to the 12V diaphragm water pump and ejects the water from the tank at 6litres/min. The tank for water storage will be constructed using galvanized metal sheet of 3mm thickness and takes about 150 liters of water. The water will move from the tank through the nozzle to an outlet hole drilled to the tank to which a tank nipple is placed. The pipe will be connected to the tank nipple which then again forms the inlet to the pump, while a fully filled tank of 150 litres will exert a weight of 8kg on the trolley.

The Water Regulation Unit

The Water regulation unit contains the water tank, nozzle parts, hose, over-flow pipe, relief valve and parts which provide channel for the water movement as required pressure is generated by the device. The system uses a matrix to regulate the volume of water to be channeled to the output points of the spray gun. The hose is a flexible, cylindrical hollow tube which carries the water and is designed on a combination of application and performance. The factors taken into consideration are size, pressure, rating, weight, length, straight hose or coil hose and chemical compatibility. The hose has a diameter of 4mm; a length of 3.5m sustains the pressure produced inside it by the action of the pump and nozzle. The nozzle has a diameter of 0.039 inches and is connected to the outlet of the tank and its other end to the trigger gun.

Processing/Control unit

This section processes and controls the rate at which the mobile water sprayer operates. It is the heart of the entire system behavior, as it decides when the water sprayer should start and when to stop. It monitors the entire system and communicates to the output for easy interpretation. The major component of this unit is the diaphragm water pump and the pressure regulator.

Output/Discharge Unit

The discharge unit comprises of the spray gun, hose and spray boom whose function is to visualize the system behavior for proper communication. The diaphragm pump communicates to the hose and spray gun at every point in time to enable the operator/reader to understand the pressure and volume of water to be discharged by the system. The trolley which conveys the entire system measures 50cm in length, 37cm width and 90cm in height. The frames of the trolley are made of mild steel using angle channels.

Complete Circuit Diagram of the System

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The complete circuit diagram of the designed pure tone water sprayer showing all the units is shown in figure 3.

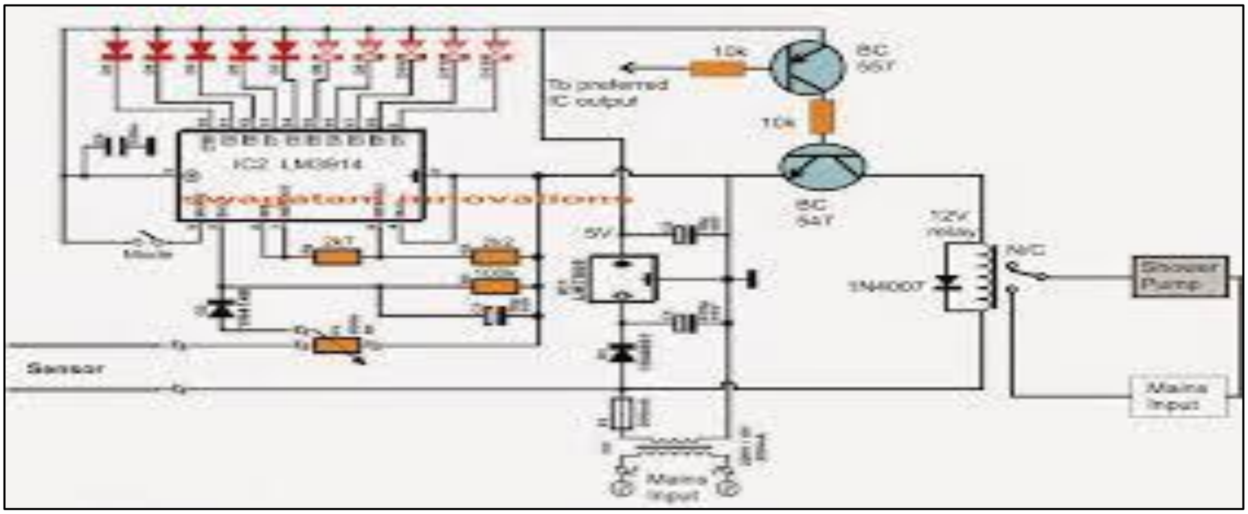

Figure 3: Complete Circuit Diagram of the System (Drawn using Proteus)

Physical structure of the designed mobile water sprayer

In designing the physical structure of the system, the specifications taken were largely targeted at obtaining a mobile device which would still carry out efficiently and effectively water spraying for agricultural use and cleaning. A target volume of 1600cm^3 was set up.

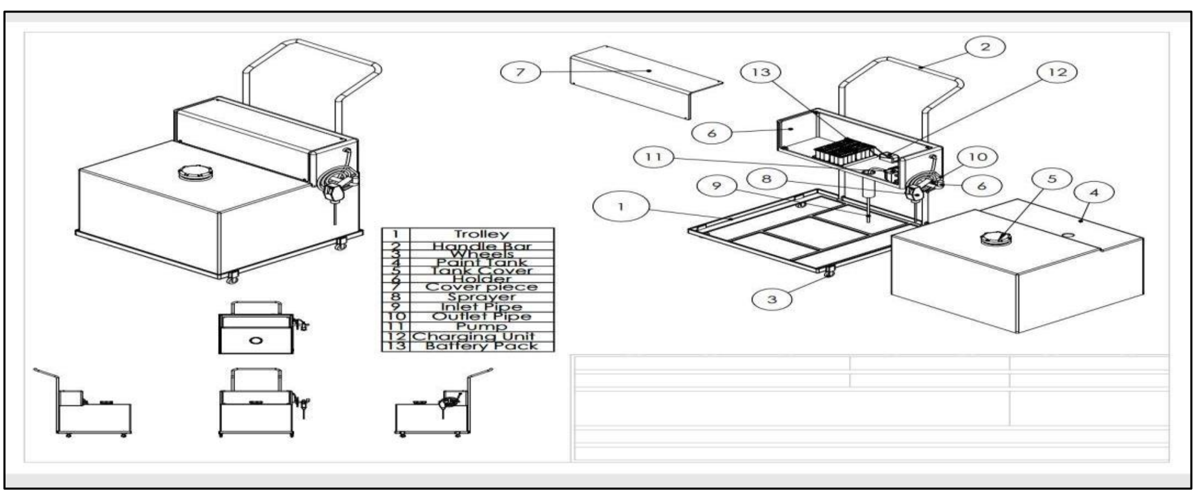

Figure 4: Physical structure of the mobile water sprayer

Power supply

The study is geared towards recycling wastes into wealth. Scrap batteries will be connected in series to make a 12V power supply that is connected to the DC 12V diaphragm water pump with the average working pressure of 100psi, which automatically turns off at 160psi. The battery is connected to an ON and OFF switch for regulation. The diaphragm motor comes on as the switch is turned on and the hose drops in to eject water, while the adjustable spray gun at the outlet hose regulates the water pressure.

The battery requires a Battery Monitoring System for monitoring the cells. Each Lithium cell will be charged to 4.2V and does not exceed the limit.

Volume of Water in the tank

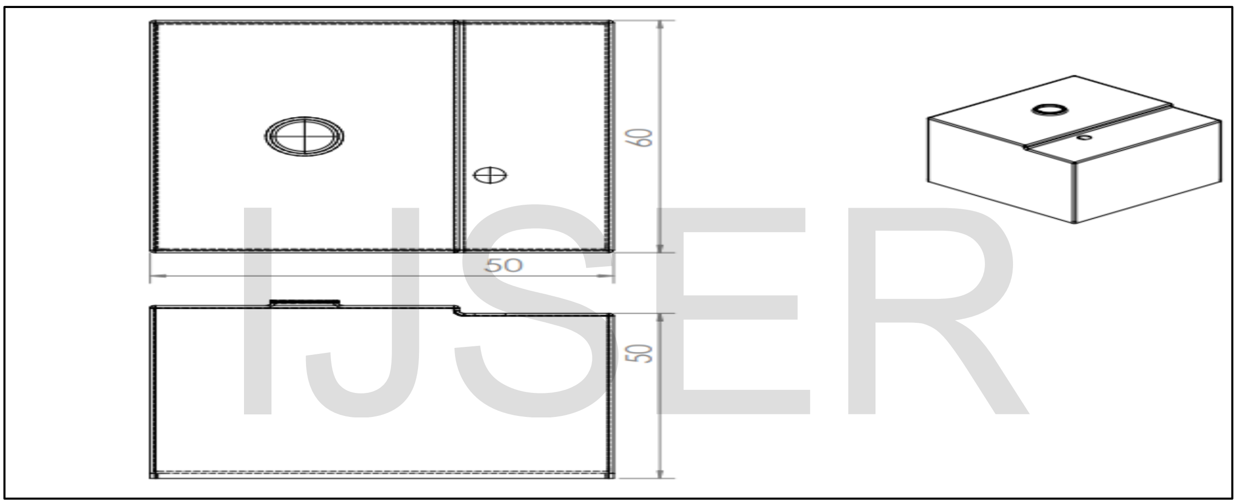

Figure 5: Water tank volume

The total volume of water to be stored in the tank is given thus;

$V = L \times W \times H$ 1

(Length x width x height)

$$= 60cm \times 50cm \times 50cm$$

$$= 150\,000cm^3$$

Where

$$1cm^3 \ = \ 1ml^3$$

$$1000ml^3 \ = 1L$$

Therefore

$$V = 150L$$

4. Design and Prototyping

Design of Nozzle

The actual performance of a nozzle is related to the ideal performance by means of empirical coefficients. Each performance characteristics such as flow rate has its own empirical performance coefficients (Zhu and Chow et al., 2004).

The three empirical coefficients commonly used to describe nozzle performance are:

Coefficient of Discharge, C_D–Flow rate

Nozzle Efficiency, ^nN–Velocity

Coefficient of Thrust, C_F–Thrust

Flow through Nozzle at the end of a Pipe or hose

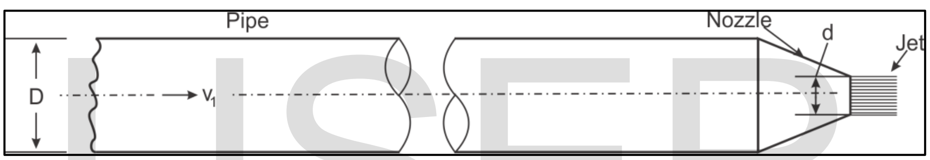

Figure: 6: Flow through a pipe

Let D=Diameter of pipe or hose

L=Length of the hose

d=Diameter of the nozzle

v=Velocity of flow at nozzle outlet

f=Co-efficient of friction for the pipe

H=Height of water level in the reservoir above the center line of the nozzle.

Head lost due to friction in pipe, $hf = \frac{4fLV^2}{D\times 2g}$

Head available at the base of the nozzle=H–h $_f$= H–$\frac{4fLV^2}{D\times 2g}$

Total head at the nozzle outlet= $\frac{V^2}{2g}$

Power transmitted through the nozzle, H = $h_f + \frac{V^2}{2g} = \frac{4fLV^2}{D\times 2g} + \frac{V^2}{2g}$

Mass of liquid flowing per second at the outlet of the nozzle, m=pav

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The K.E. of the jet at outlet of the nozzle

$=\frac{1}{2}mv^2=\frac{1}{2}xpavxv^2 = \frac{1}{2}pav^3$

Power available at the outlet of nozzle = $\frac{1}{2}pav^3$watt

Also, power available at the inlet of pipe = Wqh

Efficiency of power transmission through the nozzle

$$= \frac{power\ available\ at\ the\ outlet\ of\ the\ nozzle}{power\ available\ at\ the\ inlet\ of\ the\ pipe} = \frac{\frac{1}{2}\rho\alpha V^3}{\omega\varphi H}$$

From the low rate the nozzle velocity and pressure is given as

Nozzle velocity

Velocity = flow rate / area

$$V = \frac{Q}{A} \quad 2$$

Where

Q =6L /min

$$= 0.0006m^3/s$$

$$A = \frac{0.002^2 \times \pi}{4}$$

*A = 0.00000314159*m^2

$$V = \frac{0.0006}{0.00000314159}$$

*V = 31.794*m/s

Water pressure

$$P = \rho V^2 \quad 3$$

P = 997×31.8^2

P = 1 008 206.28 Pa

= 1.00MPa

Total Head Demand Analysis

In this section, the total head demand analysis for the MWS is the sum of the head needed at the spray gun, the head needed to lift the water to the necessary application range starting from the earliest stage and ultimately, the head needed to overcome losses produced from the water pipe.

The Head losses in the pipes are given by;

$$h_p = \frac{0.825 f {Q_p}^2 L_t}{10^6 \times {d_p}^5} \qquad 4$$

Given that;

L_t =The total length of pipe

Total head of the system given by;

$$H_t = h_n + h_p + h_i \qquad 5$$

Where

h_i = tank height which must be overcome before spraying of surfaces

Design of Pump

Pump power needed for the MWS is calculated thus;

$P = \frac{Q_p H_t}{76 \eta_t} =$ 6

Pump efficiencyη_t;

$\frac{GPM\ x\ total\ head\ x100}{Input\ HP\ X\ 3960}$ = 0.7

$$P = \frac{0.021 \times 208}{76 \times 0.7}$$

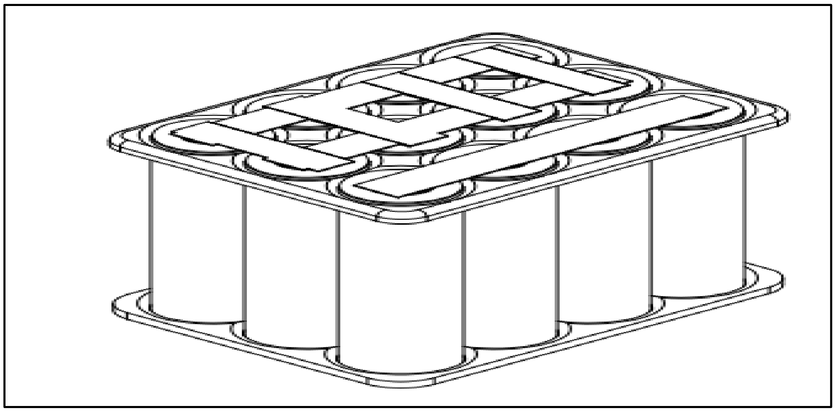
$$P = 0.082hp$$

This is equivalent to

$$P = 0.082hp \times 746$$

$P = 62Watts$ (Minimum Pump Power)

Design of Battery



Fire 7: Battery Arrangement

Pump power = 80 watts

Estimated power of the Arduino = 50mA x 5V

= 0.25watts

Total power = 80 + 0.25

= 80.25watts

Battery capacity = Total power x estimated number of hours to be used

= 80.25 x 7

= 562 watts-hour

Efficiency required = 85%

Battery capacity = 562/0.85 = 661.176watt-hour

Standard battery rating = 672 watts-hour

Design of Trolley

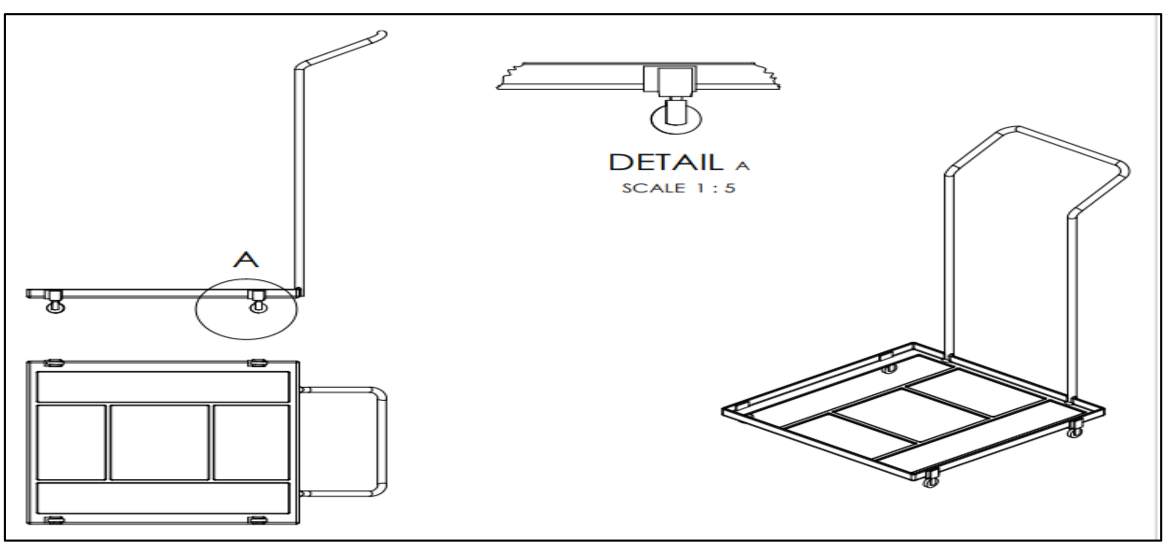


Figure 8: Different views of the designed trolley

Load on the Trolley

Estimated load on the trolley

Weight of the tank as obtained from the CAD (Computer Aided Design) model (Galvanized steel7850kg/m^3) $= 8kg$

Max water load for a volume of 150L

$$= 150kg$$

Weight of Pump Housing as obtained from the CAD model

$$= 5kg$$

Battery cells, 20 cells of 18650 lithium-ion cells (0.045kg per cell)

=0.9kg

Pump and Electronics

=0.6kg

Total estimated load 164.5kg

Factor of Safety 1.5

Design Load 246.75kg

Prototyping and programming of the equipment

The selection of prototype and programming of the system were the next methods employed in the design of the mobile water sprayer

Prototyping

The study was aimed at having an improved model of the water sprayer and so required a suitable prototype. The MWS – 20 was selected and re-designed to accommodate the improved features such as mobility, battery conversion and aesthetic features. Following the design of a working system using Proteus, the micro-controller was placed without the oscillating circuitry on the arduino board to serve as the processing unit, and then the components were connected following the schematic design generated from Solid Works on a bread board using jumper wires to complete the circuitry. This set up would enable the team to program the micro-controller and run real time simulations, tests and calibrations.

Programming of the micro-controller

The code for the programming followed the pin mappings of the micro-controller.

At this point, the target was simply set to optimize the already designed process. The programming code was written to which:

a. The interfacing unit signals through a command which sends pressure for generation of water flow.
b. Gives visible feedback through the LCD
c. Gives visual feedback through the LED on power
d. Reviews system for fluctuation of pressure
e. Adds enhanced aesthetics to the overall functionality

5. Conclusion

An efficient and effective water sprayer was designed and was aimed at eliminating the drudgery in car washing; it can also be employed in the cleaning of house walls, as well as for watering of plants in the farmyards.

The design of the MWS is of great importance as it gives a lead into the development of relatively convenient, portable, affordable and readily available mobile water sprayer for the washing of vehicles in Nigeria. Manual procedures such as the use of buckets, and hand washing, have made musculoskeletal disorders become unavoidable even with the use of pipes. The fabrication of the designed MWS will significantly reduce the effects of such tasks, and also improve convenience and efficiency of operation.

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