# SprAid: Automatic Multi-Solution Dispenser For Superficial Wound Treatment

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***Abstract—*** *The SprAid prototype is the installment of a medical device to include both a pressure and electrical system to theoretically accept different medicinal solutions including: wound dressings, antiseptic and hemostatic agents to hypothetically treat superficial wounds by the use of a pressure spray system. The designed prototype was implemented to ascertain whether or not medicinal solutions of the same viscosity could be added by an electrical system during a pressure differential change. The construction of such a system in its entirety in previous recorded studies has never been attempted due to the problem of viscosity levels and formulation of an electrical system to coordinate the release of fluid into a pressure differential chamber. The solution to the problem was to utilize medicinal solutions, of the same kinematic viscosity incorporated into to the t-fitting of the pressure system driven by a custom motorized palate. The motorized palate would rotate the solution and the pressure system, utilizing a unique valve stem, incorporating an O-ring, would fill the chamber with pressure only when the system is activated by the user, thereby overcoming the pressure differential problem. The overall goal of the design, is to include the working parameters of both pressure and electrical system that can later be used in the process of human trials to determine whether or not the effect of the system improves the healing nature of superficial wounds. The results of the pressure system indicated in regards to spray diameter and pressure that, as the spray diameter decreased, it was proportional to the area of wound coverage provided by the particular pressure. The results in regards to spray diameter and distance illustrated an optimal use within the range of 8-14 inches in which a standard spray diameter was viewed. The electrical system configuration dealing with 2-4, produced the optimal results of degree rotation such as 90°, in which to move from one solution to the next. The measured output pressure results, utilizing Darcy's equation derived from Bernoulli's, ascertained in regards to measured and theoretical output values that, output values matched closely to the theoretical. But, an observed pressure loss was exhibited within the system thereby influencing the percent error. In terms of pressure safety results, the ASME B31 constituted the advantage of determining the measure of maximum pressure allowed within the pressure system, thereby instituting the validity that the pressure system was safe, when operated below a certain parameter. Rotational timing results, exhibited that independent solutions can be rotated within a full 360° rotation within 19.5 seconds, providing ample time for the user to add and replace the solutions on the go when faced with a certain situation. Portability results indicated, that natural convenience and handling can be supported by the device due to the overall weight of 10 lbs., disassembly features and the dimensions of the device being no longer than a foot. The guidance of these results, highlighted that the system could maintain a differential pressure change in the system, along with rotate from one solution to the next. The impact of the design could one day be translated, in the application of wound care in both a hospital and military basis to treat extensive superficial wounds to multiple patients when using the SprAid device.*

***Keywords—Electrical Spraying System, Mechanical Spray System, Spraying Apparatus, Superficial Wound Treatment***

## I. INTRODUCTION

In the field of health care, the aspect of wound care is an undeniable action induced or caused by unavoidable events that leads to resulting wounds to all individuals who come into contact with such events. The author (Fidler, 2002), states in reference to statistical matters concerning wound endeavors in the state of the U.S. that 37.6 million individuals are taken to the emergency room yearly due to injuries. The commonality of such results stated (Fidler, 2002), reveals that 4 out of 10 patients suffer wound related incidents and 22 percent are open ended wounds inflicted to the patients in which 7 out of 10 patient's required medicinal medications. Findings reported (Fidler, 2002) from the National Center for Health Statistics, state in the case of wound care, 29.6 percent required therapeutic treatment. For example, (Fidler, 2002) provides an account of 1997 in which children under the age of 5 and elderly residents showed that accidental falls were the leading cause of wound injuries. The notion of such a field that promises no span of pre-preventable protection can only be followed by the development of a self-sustaining system to treat wound injuries at a safe distance for both the user and patient.

In the literature, relevant devices have not been employed which include both a pressure and electrical system to theoretically spray medicinal solutions onto the aperture of the wound. Reasons highlighting this common core issue include, the problematic nature of designing an electrical system that can coordinate the release of medicinal fluid into an active pressure differential chamber. However, if the nature of such a system were to be developed, the promise of portability, convenience and safety to both user and patient would be highly applicable to any situation. For example, if a patient had a pre-existing infection that is transmittable through the blood and the active user treating the patient did not know, then a potential threat for such as transmission could dominate the situation. In order to counter the situation in this particular incident, when the user has no foreknowledge of the patient's medical history, a device could be employed to spray at a safe distance certain agents. Agents, that would both treat, heal and seal the aperture of the wound without causing potential transmission of biological disorders to the potential user or other users that may come in contact with the patient. Therefore, the projected solution to the problem is to design a self-sustaining system such as SprAid in which it will theoretically accept and apply medicinal solutions to superficial wounds. The SprAid device, would employ two systems: a mechanical and an electrical system. The mechanical system would be designed to accept differential changes in pressure which would allocate the movement of the medicinal fluid from the holding reservoir out through the spray nozzle. The electrical system, indicative to the nature of control, would be influenced by 555 timers, JK flip flops, XOR gates, passive components and transistors to control the movement of a stepper motor in rotational turns within a certain degree. The degree of rotation would have to be configured properly in order to allow the medicinal solutions to feed into the holding reservoir of the pressure system. Therefore, the SprAid device could be used to theoretically apply, treat and prevent certain biological transmissions to both patient and user if the device were employed in certain situations such as recreational, military fields, and hospital settings.

The application of solutions such as antiseptic, hemostatic and thermoregulators when used in a spray applicator device independently [1,5,6], have exhibited optimal results in enhancing wound recovery when dealing with superficial wounds. In theory the solutions can be used with the SprAid device to treat superficial wounds since, each of the solutions possess the same kinematic viscosity as that of water, which is 1.0034 $mm^2/s$. However, the future outlook of the product will include the design and process of a working spray applicator prototype and not in the testing of the device in the effectiveness of enhancing or treating superficial wounds. The mechanical system regarding the pressure system will be powered by a pressurized source, such as a 20 oz. $CO_2$ tank, in which a CO2 regulator purchased by Jac Pac will used to regulate it. The regulator will control the amount of $CO_2$ flowing into the pressure system by rotating the knob clockwise or counterclockwise. The horizontal portion of the L-shape pressure system will include the activator switch connected to the 3D casing, and the placement of the cartridges in the solution holder of the spray head. By pulling back on the spray nozzle, the compression spring will cause the valve stem to move back, thus allowing air to flow into the openings of the valve stem. Once the air rushes into the opening of the valve stem, the pressurized air will move down the tubing of the spray head and exit through the spray nozzle. However, once the spray nozzle is released causing the compression spring to recoil back to its original position, the $CO_2$ pressure will remain confided at a constant pressure. The electrical system of the device includes, the stepper motor and electric circuit boards placed in the storage holder of the device. The circuit boards constructed in such a matter to rotate in 90° intervals will send the necessary command to the stepper motor which will then cause the cartridges to rotate in the solution holder. Each time the activator switch is pressed by the user, the command in-printed in the boards will output the stepper motor to rotate the solutions in the holding case. Once the cartridges are above the holding reservoir, the solutions are gravity fed into the reservoir and will remain until the user activates the spray nozzle. The final setup of the device as shown in Figure 1, will then allow for the following tests to be conducted: spread diameter, spray range, output pressure, pressure safety range, rotational time and portability.

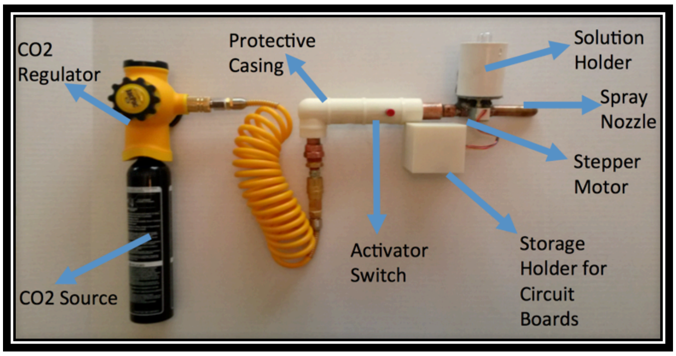


*Figure 1:* An outline of the schematics and spraying system for SprAid. The device contains a CO2 pressure source, a CO2 regulator, a protective casing that houses the pressure valve and the electronic circuitry, a solution holder where the cartridges are placed in, a stepper motor used to differentiate between solutions through a rotating sequence, and a spray nozzle from which the solutions are sprayed out. The cartridges are fed through the t-fitting found bellow the solution holder and can be stored a chamber before exposure to the pressure differential. The pressure differential propagates through the lining of the t-fitting chamber of where the fluid is stored and consequently the fluid is then ejected out of the nozzle head.

The methods section will explain in detail, the setup of the pressure system and electrical system. In regards to the pressure system, the section will explain, how the pressure propagates through the system and remains constant when inactive. The section will provide details of the nozzle construction, along with the mechanism by which the fluid enters into the t-fitting of the spray system. Explanations will be provided regarding the testing procedure of the spray system including the spread diameter, spray range, output pressure and pressure safety range. Following this, the electrical system within the section, will explain what devices were employed within the circuit board to allow the vertical rotation of the solutions from the stepper motor in the solution holder of the spray system. Portability, will be emphasized implicating the measure of the device through scalability and dimensions. Results, regarding the pressure system will include results from four tests such as: spray diameter with variable pressure changes, spray diameter with variations in distances from target, output pressure from spray nozzle observing both theoretical and observed values utilizing Darcy's equation and pressure safety test using ASME B31 equation for mechanical engineers code for pressure piping. The electrical system results will include rotational time, angular velocity, and the rate of turn in RPM based on the appropriate configuration. Last, the portability of the device will include the raw weight of both the device as a whole and the device itself along with the dimensions.

## II. Methods

### A. Pressure System

In order to propel fluid, out of a spray nozzle, pressure must build up in the system and then be actuated by a user mechanically. As a source of pressure, a pressurized $CO_2$ tank was used to deliver 3000-4500 psi. In order to lower pressure, the system was regulated to 20-80 psi, which fits within the specifications determined by the Mechanical Engineers code for pressure piping. Once the pressure was reduced to an appropriate level, it was contained within the elbow joint. A unique valve was created to mechanically actuate the release of the gas. With a release valve at the end of the system, it allowed the pressure to be sustained until the user actuated it as shown in Figure 2.

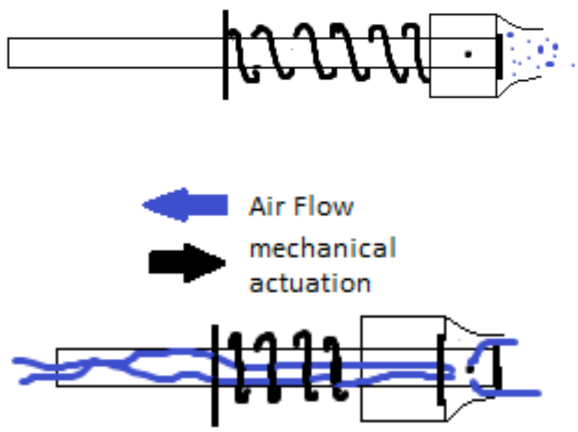


*Figure 2:* Top: in this state the valve maintains a pressurized system. The valve needs to be actuated by the user to initiate pressure differential. An O-ring seals off the $CO_2$ gas from the escaping. Bottom: When the valve is opened, gas flows to the rest of the system through three 1.6mm holes, which have been exposed to pressurized air. The valve facilitates the flow of pressure from one end of the pipe to the other.

By sliding the valve back, into the pressurized side of the copper tubing, $CO_2$ flows into the valve and out through the spray nozzle of the device. Theoretically, medicinal fluids can be delivered to the patient for treatment of superficial wounds through this system. When the user releases the valve spring, it causes a decompression to occur. The decompression factor blocks the flow of gas into the valve, thereby maintaining the pressure at a constant rate. Once this occurs, the pressure remains constant within the lower half of the system until the sliding of the valve stem occurs again.

### B. Spray Nozzle:

The nozzle of the SprAid system was developed by drilling a 1.6 mm hole into a cap on the end of the pressurized system. In doing so, this allowed the gas to be perpetuated by the pressure differential created by the $CO_2$ source. In order for a gentle spray to be delivered, a regulator was used to reduce the input pressure from the tank source. The fluid that is delivered to the system is introduced utilizing 2 different cartridges. Each cartridge contains different fluids that are located on the top of the spray system and are electrically actuated by the user. The fluid is gravity fed into the t-fitting of the barrel based on gravitational forces. Upon this point, the fluid is stored in a chamber until the pressure differential is introduced into the system. Thus allowing the fluid to be ejected from the nozzle head.

### C. Electrical system

In order to insert and differentiate between solutions added to the t-fitting of the spray gun, a motorized palate was developed to rotate the correct solution into place. In order to accomplish this, a full driven controller was created using two, 555 timing ICs for function generation, JK flip flops and XOR logic gates. By utilizing these features, it would allow the driving action of the motor, to control which fluid is selected.
The stepper motor was driven using four 1n4002 diodes, four 1Kohm resistors, and four NPN high voltage NMOS transistors. The electrical system was verified using an oscilloscope and visual observations of the stepper motor function. Eight different configurations were measured in this system and a variance of the correct measurement for optimal rotation was found to be 1.8° as shown in Figure 3.

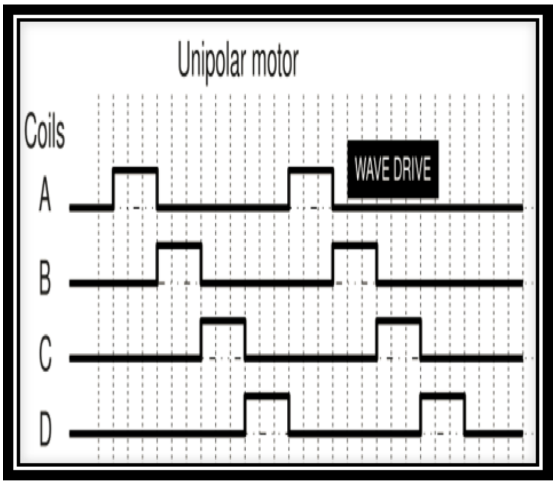


*Figure 3:* In the figure above, shows the wave driven controller for a stepper motor. Each coil represents a coil within the stepper motor. In order for it to move 1.8° it has to have this sequence of propagation from the controller circuit.

Furthermore, a series of configuration were developed in order to create a circuit with a proper 90-degree rotation. The configurations are noted below and can be found in Figure 4.

Configuration 1-4 Normal XOR logic gates

- Configuration 1-Original circuit design
- Configuration 2-Monostable capacitance was doubled
- Configuration 3-Monostable capacitor was switched out
- Configuration 4-Monostable capacitor was switched out

Configuration 5-8 Modified XOR logic Driver

- Configuration 5-Modified XOR driven logic, eliminated feedback
- Configuration 6-Tripled monostable capacitance
- Configuration 7- Doubled monostable capacitance
- Configuration 8- Changed the capacitance from configuration 5

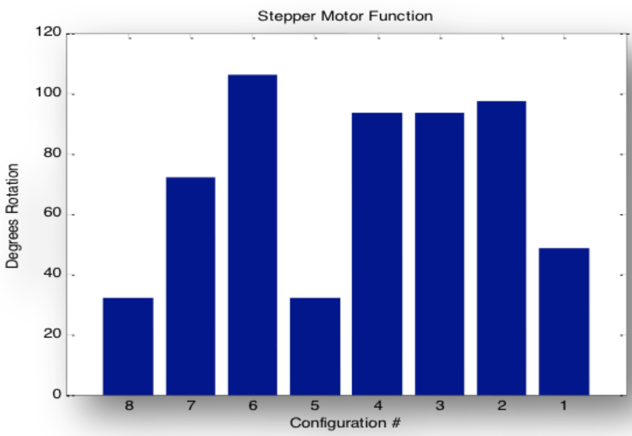


*Figure 4:* In the figure above, configurations 4-2 allowed for the proper rotation to be achieved by the system of 90°. The recorded variance was 1.8°, which was dependent on the tolerance levels of the capacitors used within that pulse generation. There was a large variance in the modified feedback loops for configurations 5-8, which was dependent on the starting position of the control circuit.

In regards to configuration 2-4, theoretically, the 90° rotation provides the optimal vertical rotation in order to lock the fluid cartridges, one by one, into the t-fitting of the pressure system. By locking into place, the fluid is gravity fed into the pressure system. Thereby, awaiting a pressure differential to occur to eject the fluid from the spray nozzle. Therefore, each 90° rotation of the stepper motor will switch from one solution then to a close position and then to he next solution until it reaches a 360 degree revolution.

*D. The Output Pressure Test*

An integral part of the SprAid system was regulating the output pressure so that the solutions are sprayed at pressures below 80psi. In order to accomplish this the input pressure that emits from the $CO_2$ tank source is adjusted down from 4500psi to 20-60 psi as needed. When the trigger pushes back on the pressure valve it releases a certain adjusted pressure from the $CO_2$ tank/regulator system. As the gas flows through the pipe it pushes the solution out through the spray nozzle shown in Figure1. Bernoulli's equation for the flow of a fluid in a streamline was applied to calculate the theoretical pressure at which the fluids were being emitted from the SprAid device.
Bernoulli's equation can be expressed as follows:

Eq. 1

$$Z_1 - \frac{P_1}{p_1 g} + \frac{v_1^2}{2g} += Z_2 + \frac{P_2}{p_2 g} + \frac{v_2^2}{2g}$$

where,
$Z_{1,2}$ = elevation above reference level
$P_1$ = absolute input pressure
$P_2$ = absolute output pressure
$p_{1,2}$ = density of water ( 1.0034 $mm^2/s$)
g = gravity ($9.8 m/s^2$)
$V_1$ = initial velocity (rest velocity = 0 m/s)
$V_2$ = output flow velocity

Bernoulli's equation can be applied for this study because the two points the streamline in the fluid flow are straight at a 180 degree angle, the pipe diameter remains constant and the fluid density also remains constant. Since the device is sprayed at a straight angle, the elevation reference level is the same for both Z terms thus becoming negligible.

It became apparent from the construction of the of the SprAid device that the spray system lost pressure throughout the spraying cycle because a 100% seal could not be maintained through the pressure valve and the cartridge holder. In addition, the copper material also created friction with the fluid, which had to be taken into consideration for a small loss of energy. Darcy's formula, derived from Bernoulli's equation has an additional term to account for a

static pressure drop and this was used to calculate the pressure drop due to friction in the copper pipe.
Darcy's formula can be expressed as follows:

Eq. 2

$$Z_1 - \frac{P_1}{\rho_1 g} + \frac{v_1^2}{2g} + H_p = Z_2 - \frac{P_2}{\rho_2 g} + \frac{v_2^2}{2g} - h_L + H_T$$

where,
$H_T$= turbine head
$H_P$= pump head
$h_L$= head loss due to friction in the pipe

Since there is no pump or turbine head in the pipe the $H_T$ and $H_P$ terms can also be dropped out of the equation for our purposes. First, we begin by measuring the flow velocity of solution using the following equation

Eq. 3

$$v = \frac{q}{A} = \frac{4q}{\pi D^2}$$

where,
q= volumetric flow rate
A= pipe's cross sectional area ($1.43 \times 10^{-4}$)
D= internal pipe diameter (13.5mm)

The volumetric flow rate (q) can be calculated from the mass flux relationship as follows:

Eq. 4

$$q = \frac{j_m A}{\rho}$$

where,
$j_m$= mass flux (rate of mass flow per unit area)
p= density of water (1.0034 $mm^2/s$)
A= pipe's cross sectional area ($1.43 \times 10^{-4}$)

The mass flux can be used to calculate the volumetric flow rate considering that the pipe is straight with a constant cross section and the solution is flowing at a constant rate. The mass flux can thus be calculated as follows:

Eq. 5

$$j_m = \frac{\rho V}{\pi r^2 t}$$

where,
p= density of water (1.0034 $mm^2/s$)
V = volume of solution (4ml)
r= inner radius of the pipe (6.75mm)
t= time for solution to pass through the pipe (0.2sec)

The time for the solution to flow through the pipe is measured once the CO2 gas is ejected until the solution flows out of the nozzle head. The time was measured by video recording the spraying process and using a video editing software we located the precise moment and measured the time to be 0.2 seconds. The amount of solution sprayed from a single cartridge was 4mL. The mass flux was therefore calculated to be $j_m$= 34.93 kg $s^{-1}m^{-2}$. Now, inputting this information into equation 4 the volumetric flow rate was calculated to be q= $2 \times 10^{-5}$ m/s. Then, using equation 3, the velocity was determined to be 0.14 m/s.

In continuation with Darcy's equation (eq. 2), the expression for the head loss due to friction was calculated as follows:

Eq. 6

$$h_L = \frac{f L v^2}{2Dg}$$

where,

f= friction factor

$$f = \frac{64}{Re}$$

Re= Reynolds number

$$Re = \frac{vD}{\nu} = \frac{\rho v D}{\mu}$$

v= flow velocity (0.14m/s)
D= internal pipe diameter (13.5mm)
$\nu$= kinematic viscosity constant for water ($1.004 \times 10^{-6}$ $m^2/s$)
$\mu$= dynamic viscosity constant for water (0.01004 Pa)
p= density of water (1.0034 $mm^2/s$)
L= length of the pipe (130mm)
g= gravity (9.8$m/s^2$)

Then using the above values the Reynolds number was calculated to be Re=187.88. The Reynolds number is used to asses the type of flow laminar or turbulent in the system Using this information, the friction factor was also calculated to be f=0.34. The friction factor is solely based on the material properties of the copper pipe and the type of solution used. The head loss due to friction was then calculated to be $h_L$= $3.26 \times 10^{-3}$ psi.

Meanwhile, the output pressure was also measured experimentally using a pressure gage with a tight seal around the nozzle head. The output pressure was quantified by measuring the output pressure of the system for input pressures going from 20 to 60 psi in 10-psi intervals. The pressure drop was calculated by subtracting the input pressure from the original output pressure. The experimental readings were then compared to the theoretical outputs derived from Darcy's equation (eq. 2).

*E. Pressure Safety Test*

The SprAid device operates within a pressure range of 20 and 100 psi. However, the pressurized CO2 tank used as the input pressure source can deliver pressures up to 3000-4500 psi. Therefore, it is important to confirm that the copper piping can sustain the operational ranges of the device as well as resist a high pressure input from the tank source in case the regulator fails to reduce the pressure to an appropriate level. The maximum pressure allowed by the copper pipe before bursting can be determine using the ASME B31 equation by the Mechanical Engineers code for pressure piping, the equation can be expressed as follows:

Eq.7

$$P = \frac{2S(T_{min} - C)}{D_{max} - 0.8(T_{min} - C)}$$

Where:
P=Pressure allowed, psi.
S=Maximum allowable stress in tension (31908.29 psi)
$T_{min}$=Wall thickness (1.6mm)
$D_{max}$=Outside diameter (15.88 mm)
C=Constant (Due to copper's corrosion the resistance factor is set to 0).

*F. Rotational Test*

The rotational time test was used to assert that the cartridges rotate at 90-degree intervals within a short span of time to differentiate between solutions. The electrical system is initiated with the press of button, the cartridge holder rotates 90 degrees to an open position and stops; consequently, with another press the cartridge holder rotates another 90 degrees to a closed position. In order to insert and differentiate between solutions added to the cartridge holder of the spray system, a motorized palate was developed to rotate the correct solution into place as shown in Figure 5.


*Figure 5:* In the figure above, the rotation of the cartridges is initiated when the red button is pressed which activates the stepper motor below the solution holder. The motor rotates the cartridges 90 degrees clockwise.

In order to accomplish this, a full driven controller was created using two, 555 timing ICs for function generation, JK flip flops and XOR logic gates. By utilizing these features, it would allow the driving action of the motor, to control which fluid is selected. The stepper motor was driven using four 1n4002 diodes, four 1Kohm resistors and four NPN high voltage NMOS transistors. The electronic system was initially measured using an oscilloscope and translating the pulses into Matlab to verify that each of the channels was firing in the proper sequence. After verifying the movement of the stepper motor, the motor was connected to the SprAid device and a 360 range of motion was recorded on video. A video of two revolutions was used along with imageJ, a video editing software, to measure the velocity and time of rotation of the cartridges.

*G. Spread Diameter Test*

The pressure system was tested for the spray diameter that it was able to cover from a fixed position by varying the input pressure. The SprAid device was tested outdoors using a vice clamp, in order to hold the spray gun at a fixed position keeping the pipe at a 180-degree angle with the ground as shown in Figure 6.

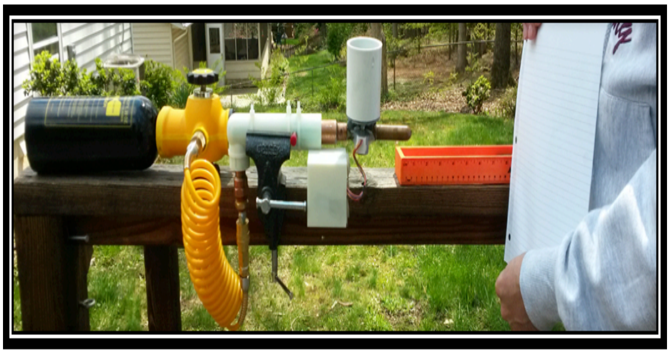

*Figure 6:* The SrpAid device is fixed parallel to the ground with a target located 8 inches away from the nozzle head.

The pressure system was tested for the spray diameter that it was able to cover from a fixed position by varying the input pressure. The SprAid device was tested outdoors using a vice clamp, in order to hold the spray gun at a fixed position keeping the pipe at a 180-degree angle with the ground as shown in Figure 6. A 4ml solution made out of dark food coloring mixed with water was sprayed onto 8in x 11in white paper sheet. By placing the spray gun at a fixed position of 8 inches away from the target, the user was able to spray the solution at 20, 30, 40, and 50 psi. The target was then measured for the diameter that was covered to include at least 95% of the stain. The diameter measured was focused on the central spread area. The test was conducted by running 5 trials per input pressure tested. The variance in the spread diameter was calculated to analyze the consistency in the coverage. The test will demonstrate if the SprAid system is able to cover a spread diameter from 1 to 5 inches by regulating the input pressure.

*H. Spray Range Test*

Similarly to the previous test, the pressure system was tested for the spraying distance range that it was able to cover from a fixed position by varying the input pressure and the distance. The SprAid device was tested outdoors using a vice clamp, in order to hold the spray gun at a fixed position keeping the pipe at a 180-degree angle with the ground as shown in Figure 6. A 4ml solution made out of dark food coloring mixed with water was sprayed onto 8in x 11in white paper sheet. By placing the spray gun at an initial position of 8 inches away from the target and then proceeding to move the target to up to 20 inches apart in 2 inch intervals. Consequently, the user was able to spray the solution at 20, 30, 40, and 50 psi for each interval distance. The target was then measured for the diameter that was covered at a given distance. The diameter measured was focused on the central spread area to include at least 95% of the stain. The spray range was measured in comparison to the coverage diameter that the system was able to produce. The test will validate if the SprAid system is able to cover a distance of up to 1 foot in length. In addition, it will be used to determine the optimum spray range for the system.

*I. Portability Test*

The portability of the SprAid device was determined by measuring quantitatively key properties such as the weight and length of the apparatus. Qualitatively, the portability was determine using a live demonstration of the product to evaluate its ability to be operated by a single user, be portable and suitable for use while traveling as shown in Figure 7.


*Figure 7:* The above image shows the user holding the SprAid device. The CO2 tank is buckled the belt. The user can operate the device by holding on to the elbow joint handle and pushing back on the pipe with the other hand. The device is battery powered and can be operated indoors or outdoors.

In addition, the portability was assessed by its capacity to function indoors and outdoors without the need for an external power source. The weight of the device was weighted using a scale. The device was both weighted by itself and along with the pressure tank and regulator attached. The most important dimension for the device was its overall length and the diameter for the handle (excluding the pressure system). In addition, another integral part for the portability of SprAid was using small cartridges to store the solution. Also, the circuit board was powered by a 9-volt battery, which was conveniently housed by the casing of the device. Lastly, the portability was assessed by the ability for the SprAid device to be taken part and stored for travel.

## III. Discussion of Results

*A. Output Pressure Test*

Using Darcy's equation from section D of the methods, the theoretical output pressure was evaluated as shown in Table 1.

| Input Pressure (P1) | Observed Output Pressure (P2) | Observed Pressure Drop (P1-P2) | Theoretical Output Pressure (P2) | Percent Error |
|---|---|---|---|---|
| 60.00 psi | 40.00 psi | 20.00 psi | 59.99 psi | 33.32 % |
| 50.00 psi | 35.00 psi | 15.00 psi | 49.99 psi | 29.99 % |
| 40.00 psi | 26.00 psi | 14.00 psi | 39.99 psi | 34.98 % |
| 30.00 psi | 19.00 psi | 11.00 psi | 29.99 psi | 36.65 % |
| 20.00 psi | 6.00 psi | 14.00 psi | 19.99 psi | 69.98 % |

*Table 1.* The observed output pressure produced a significant pressure drop for the given input pressures. The theoretical output pressure indicates that the system was leaking out the pressure before the solution exerted out of the nozzle head.

The observed output pressures were used to determine the pressure drop experienced by the system. As it can be observed from the data, the SprAid system experienced a higher pressure-drop at increased pressures. Conversely, as the pressure decreased the pressure drop decreased as well, which signifies that the systems loses less pressure at lower input pressures. However, as the pressure dropped to 20.00 psi, the system became less stable and lost more pressure than expected. In comparison to the theoretical output pressure, the SprAid device lost pressure because there was leakage of $CO_2$ in the pressure valve and around orifice of the cartridge holder. This leakage resulted from the manufacturing process and has to be taken into consideration for the loss in pressure. In addition, a small part of the pressure loss resulted from the friction caused by the copper material. The frictional factor was calculated to be f= 0.34 which resulted in a static pressure loss due to friction of $h_L$=3.26*10^-3 psi. From the percent error calculated in Table 1, it was found that system became more stable at maintaining the given pressure as the input pressure increased. Although the pressure drop was less as the pressure decreased, the observed output pressure was relatively smaller than the input pressure, which in turn justifies for the higher percent error. Nonetheless, this test indicated that SprAid system could compensate for the pressure loss by simply increasing the input pressure. Nonetheless, the system maintained a Reynolds number of 187.88 indicating that the flow of the solution was laminar meaning that there were no cross currents in the direction of flow. Therefore, the SprAid was able to spray at pressures capable of covering a projected area and distance desired despite the pressure loss while keeping the flow of the solution in parallel layers.

*B. Pressure Safety Test*

According the ASME B31 equation, the maximum pressure allowed by the copper pipe used in the SprAid device was 3,988.5 psi. Since the pressure is regulated within the confines of 20-100 psi the device is able to operate well within a safe operational range. However, if the regulator fails to reduce the pressure from the tank source to less than 3,988.5 psi, the copper piping could potentially burst despite the reinforced casing that was added to surround the copper material.

*C. Rotational Test*

The rotational test confirmed the proper rotation of the cartridge holder. Each time the electrical circuit was initiated the cartridge holder rotated 90 degrees until it made a full revolution. This allowed, the solution of each cartridge to be dumped into the spray system and then rotate to a close position to prevent $CO_2$ gas from firing upward. It was concluded that rotational time for a complete revolution is approximately 19.5 seconds. The rate of turn of the stepper motor was measured to be 3.1 RPM with an angular velocity of 0.05 rad/ sec. The proper rotation of the cartridge holder by the electrical system allows the system to differentiate between solutions. In addition, the short rotational time for 1 revolution allows a user to operate the device in less than 20 seconds. Adding a larger stepper motor could increase the rotational speed while keeping enough torque to move the cartridge holder and provide enough time to completely dump each solution.

*D. Spread Diameter Test*

The spread diameter test was used to assess if the SprAid system was able to cover the projected areas ranging from 1 to 5 inches diameter with one single spray of a 4ml solution by just varying the pressure as shown in Figure 8.

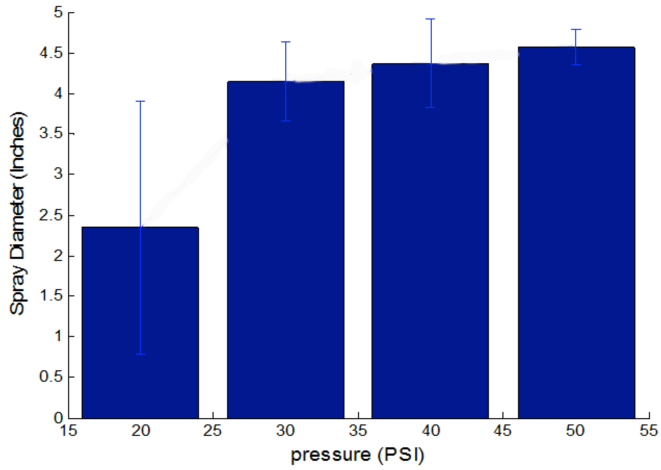


*Figure 8:* The figure above shows the spray diameter of a 4ml solution at varying pressures. By decreasing the pressure, the spray diameter decreased. Meaning, when the spray diameter decreased, the diameter change was proportional to the area of wound coverage, covered with that particular pressure variable. An increase in diameter, resulted in a smaller variance between trials. As such, this will allow the SprAid to provide a consistent coverage at pressures between 30 and 50 psi.

As observed, at 20-psi pressure the system was able to cover on average a diameter of 2.4 inches. However, at the 20-psi pressure there was a large variance calculated which indicates that the system may spray between 0.75 inches and 3.9 inches in diameter with less consistency. As the pressure was increased to 30 psi and higher, the variance decreased significantly partly due to a lower pressure drop as indicated in the output pressure test from the previous section. The lower variance implied that the system has a more consistent spray of 4 inches in diameter at 30 psi input pressure. As the pressure was increased to 40 and 50 psi, the diameter covered did not increase significantly. At a 40 psi input pressure the coverage diameter was roughly 4.25 inches and at a 50 psi input pressure it was 4.5 inches. The test confirmed that in fact by varying the input pressure the spray diameter can be regulated. The user can decrease the pressure input from the regulator to spray smaller areas. Subsequently, the system was able to cover up to a 4.5-inch diameter just shy of the 5-inch mark by increasing the input pressure to 50 psi. Therefore, the user can adjust the pressure from the regulator to cover areas ranging between 1 and 4.5 inches in diameter.

*E. Spray Range Test*

The spray range test was used to assess if the SprAid system was able to cover the a projected distance of up to 1 foot in length with one single spray of a 4ml solution at different pressure values as shown in Figure 9.

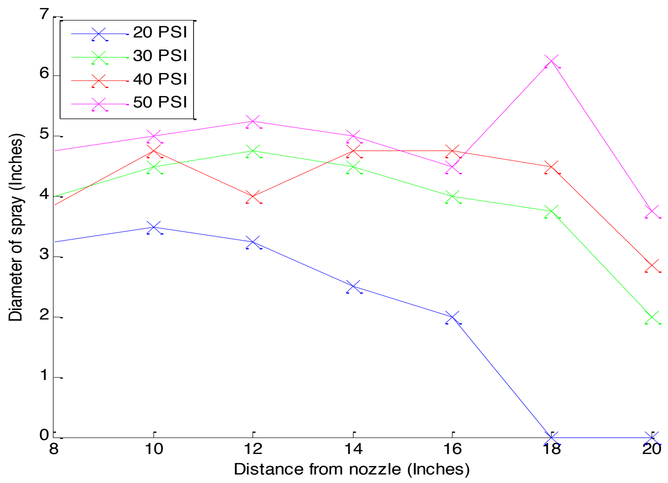


*Figure 9:* The figure above shows the pray diameter of a 4ml solution at varying distances for different input pressures. Depending on the target distance from the nozzle, its considered proportional to the spray area delivered to the target site. Increase in pressure, will allow for a more distant spray. However, below 30 psi will only cover up to 16 inches from the spray nozzle with some variance.

The results indicated that for a 20 psi input pressure, the spray diameter varies as a function of the distance. As the distance increases from 8 to 16 inches, the diameter covered keeps decreasing until it reaches a max distance where the coverage area is zero. However, for pressures between 30 and 50 psi, the spray coverage remains fairly constant between 4-5 inches in diameter as the distance increases from 8 to 16 inches. When the distance of the target is increased to 18 inches or greater the spray coverage decreases significantly. The test verified that the system can certainly cover a target placed 1 foot away. Also, it was determine that the optimum spray range was between 8 to 16 inches in length as it provided more consistent spray coverage for pressures ranging between 30 and 50 psi.

### *F. Portability Test*

A live demonstration was used to show that the device can be taken apart into three congruent segments, the pressure source, the pressure regulator and the spraying device which make it convenient to store and carry for travel. The spraying device weights approximately 5 pounds and when combined with the pressure tank and regulator it weights a total of 10 pounds which is light enough to be carried around while in use. Aside from its lightweight, the length of the device is only 1 foot and it has 1.4-inch diameter handle, which allowed for a convenient two-hand use. In addition, the device contained a cartridge holder on top to allow the use for small 4mL cartridges, which make it convenient to change out. The user can carry with several numbers of cartridges to use them when needed. Moreover, the circuit board is located in a holder, which was made as a part of the casing for the device. The circuit board is powered by a 9-volt battery which removes the need for an external power source and allows for the device to be wireless. The storage holder can simply opened by the user to change the battery when needed. These properties allow for the SprAid device to function indoors and outdoors. As shown in the live demonstration, the device can be assembled, operated, disassemble by a single user establishing its portability.

## IV. Conclusion

The current SprAid device contains two working parts. The first is a mechanical component capable of spraying solutions at regulated pressures between 20 and 50 psi. The second part is a motorized palate that can be activated to rotate three different solutions into the fluid housing of the spray gun where it can be stored until the solution is ready to be sprayed. Presently, the electrical circuit uses a stepper motor the cartridge holder 90 degrees, which is optimal for rotating between open and close positions to dispense fluid and retain pressure within the system. Turning the cartridge holder the right number of degrees prevents leakage of the fluid by feeding one of the solution directly into the pressurized system while keep the other two solutions locked into place. In this form, the SprAid device can differentiate between two solutions by allowing only one solution to be sprayed at a time. The results from the pressure output test indicated that pressure system exhibits a pressure loss from the manufacturing process; however, the user can compensate by increasing the input pressure while still keeping a laminar flow. As demonstrated from the spread diameter test, tuning the input pressure between the range of 20 and 50 psi can regulate the coverage area. Hence, the user can adjust the pressure from the regulator to cover areas ranging between 1 and 4.5 inches in diameter. As shown in the spray range test, the SprAid device has an optimum distance range between 8-16 inches away from the target that it can consistently cover up to 5 inches in diameter. Therefore, the SprAid was able to spray within the allowed pressures to cover the projected areas and distances desired despite some pressure loss. The SprAid device is able to dispense a variety of solutions with a viscosity near that of water at controlled pressures within one unified system. The system has potential use in medicine for treating superficial wounds since it has been shown that the delivery of sprayed solutions provides high spray area ratios and portability for travel and for use indoor or outdoors.

## Adminirstrative Section

### *A. Time Spent:*

*Spring Semester 2015*

1. *HW (1-2) = 2 days + 35 hours*
2. *Building Electronic System = 50 hours*
3. *Designing 3D casing = 10 hours*
4. *Building Spray System = 50 hours*
5. *Testing Spray System = 17 hours*
6. *Team meetings = Weekly 2-3 hours*
7. *Reports= 30 hours*

***Total Hours: 252 Hours***

*B. Budget*

1. Copper Material = $120.00
2. 3D print = Free
3. CO2 source and regulator = $190.00
4. Electrical Parts + Stepper Motor = $30.00
5. Autodesk = Free 3-year trial
6. Miscellaneous = $120.00

**Total Cost = $460.00**

*C. Team Member Roles*

Computer and Project Designer -Andrew Cedeno

The computer web manager is in charge of creating and adding changes to the team's website throughout the year. The role of the computer designer is to create the specified models using Autodesk software for the development of the SprAid device. The designer will prepare and implement the resources in which to use the 3-D printer to implement the fabrication of the design. As a project designer, he will incorporate the necessary functions and objectives into a working prototype. The project designer will collaborate with the team members to test and analyze the system using engineering principles.

Project and Team Manager – Richard Patrican

The design manager will be in charge of elaborating prospective ideas for the SprAid based on the defined objectives and functions. The manager will be in charge of allocating materials for the project and consulting with the faculty advisors Dr. Reagle and Dr. Wu. As the team manager, he will overlook the work completed to ensure that every group member is participating equally. In addition, as a Team Manager, he will provide feedback on the project and help direct the project as it moves forward.

Consultant and Research Manager- Nathan Jordan

The consulting manager will set due dates for assignments and meeting times for the group. The co-manager will review homework and maintain communication between the Senior Design professor and the group. The co-manager will keep track of the group progress and provide written documentation in the form of a report. The co-manager will provide support for the members of the group if they have issues within the project or outside the project. As a consulting manager he will be in charge of research and providing assistance within the process of fabrication and testing of the electrical and mechanical system.

*D. Future Directions*

Tubing can be minimized in size by industrializing the system through a solid body casting. Adding a self-sealing nozzle could minimize the pressure loss experienced by the system. The circuit needs to be refurbished to increase battery life. The pressure source could be made to fit inside the device by utilizing a Nano-Pressure regulator to increase the portability of the SprAid device.


## Acknowledgment

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