

Development of a Mobile Liquid Spraying Machine for Small and Medium Scale Crop Production

Olayinka Mohammed Olabanji

Department of Mechanical Engineering, Federal University of Technology, Nigeria
Email: obayinclox@gmail.com

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Abstract: This article presents the design, simulation, fabrication and performance evaluation of a liquid spraying machine for application of pesticides in a small and medium scale crop plantation. In this article, components of the conceptualized spraying machine were modelled and assembled in SolidWorks CAD environment. The modelled components were designed in order to obtain design parameters for simulation. An extensive simulation on the stress and strain analysis was carried out on the designed components. The significance of the simulation is to predict the structural integrity and performance of the component parts of the machine before fabrication. The components were fabricated from locally sourced material in order to ensure a lower cost of production. The fabricated spraying machine was tested and the performance indicated that a field efficiency of 79% is obtainable in an average time of 1374 s to spray a maize crop field area of 1813 m² having an average crop height of 0.52m. Further observations from the performance analysis also show that the field efficiency of the spraying machine drops to a value of 75% when used in a crop field area of 2206.3 m². This is an indication that the spraying machine's efficiency will reduce as the field area increases. In essence, the significance of the approach presented in this article is to ensure that the simulation predicts the performance of the design and the fabrication of the spraying machine using locally sourced material will ensure lower cost of fabrication.

Index Terms: Machine Design; Liquid spraying machine.

1. Introduction

It is an established fact that improved crop production can be achieved by an effective combination of machinery and human. To successfully implement this combination, mechanical and electrically driven equipment are developed to improve farming operations and economic production of crops [1]. There is no doubt that the use of these machinery has improved productivity and reduce operational drudgery in crop production. An example of this type of equipment is the spraying machine that has replaced manual labour of liquid applied to the plantation. Effective application of pesticides and water to plants is an important aspect of crop production that cannot be overemphasized [2, 3]. One of the challenges faced by small and medium-scale farmers is the non-availability of low-cost and effective spraying machines that can be used to apply water and pesticides to crops. Aside from the fact that the small and medium scale farmers demand a low-cost spraying machine, they usually prefer these machines to be operated at a stress-free condition and low maintenance cost [4]. The manual spraying machine (Fig. 1a) that is usually carried by farmers would have been a sustainable solution to pesticide application but considering the wide coverage and range of dispersion of liquid required in crop plantations its usage is limited to household applications. Conversely, there are large and automatic spraying machines (Fig. 1b) that can provide wider spray coverage but they are expensive to purchase and maintained due to their size and embedded features. In order to meet up with this demand, there is a need to continually develop effective and low-cost spraying machines for application in crop production. Hence, spraying machines will improve agricultural productivity in terms of speed, safety, convenience and accuracy.

Three major factors are usually considered in the design of spraying machines. These factors are; capacity of the liquid storage device, the power required to drive the pump and the boom size variations [5]. The capacity of the liquid storage goes a long way in the determination of the overall size and application of the spraying machine. The choice of a spraying machine is a function of the liquid storage capacity considering the size of the crop plantation to be sprayed. However, larger storage capacity also requires more rigid frames and structures that tend to increase the total weight of the spraying machine. Also, an increase in the weight of the spraying machine will increase the cost of the mobility of the machine when it is needed to spray wide coverage.



Fig. 1. Spraying Machine

The power required to propel the pump is a major determinant for estimating the running cost of the spraying machine. Since the pump is responsible for creating a dynamic force that will increase the liquid velocity and boom pressure, then it is usually desired to use a high-pressure pump that will increase the liquid boom to wider coverage. However, pumps of this nature are expensive and require high cost of maintenance in terms of the power required to propel it. The effectiveness of the spraying machines used in crop production is a function of how the pump delivers constant flow and pressure to the liquid and its ability to handle several types of liquid without corrosion and leakage [6]. In order to ensure uniformity and even distribution of liquid and pesticides, spraying machines are required to have different nozzles that will provide different flow rates, spray angles, droplet sizes and patterns. In practice, nozzle selection is based on droplet size which is a function of the type of liquid being sprayed, coverage and prevention of liquid from leaving the target area [7]. Basically, flat fan, flood raindrop, full cone and hollow cone are the types of the nozzle. Further, droplets from nozzles are categorized as fine, medium and coarse droplet depending on their application. Fine and medium droplets are applied for post-emergence leaf surface coverage and herbicides/pesticides application respectively. One major problem of nozzles is the rate of orifice wear which is usually caused by increased flow rate through the nozzles as a result of increased fluid pressure [8, 9].

To this end, the objective of this article is to present the design, simulation, fabrication and performance valuation of a mobile liquid sprayer for crop production in small and medium scale crop production. This will solve the problem of non-availability of spraying machine in farms for small and medium scale crop production. The designed spraying machine aims at attaining wide spread or coverage of the liquid and mobility of the entire spraying machine during operation. To achieve this aim, the pump is propelled by a two-stroke internal combustion engine which can be operated at a low cost. Although the spraying machine is conveyed by means wheels but the discharge hose of the machine is long enough to accommodate spraying for a wider coverage because the fluid force from the pump provides high liquid velocity. Although several spraying machines are in existence but they are expensive to maintain and require high cost of installation. However, the design in the present study has limitations in the aspect of limited volume of liquid chemical that can be carried per batch in its tank. This limitation is as a result of reducing the overall weight of the machine so that it can be manually moved in order to reduce power consumption due to mobility. Hence, the remainder of the article is structured as follows. A brief description of the designed sprayer is presented in section two followed by design analysis of its components in section three and its simulation in section four. Performance evaluation of a prototype of the designed sprayer is presented in section five while the article is concluded in section six.

2. Literature Review

Several efforts have been made in the development of liquid spraying machines for crop production. However, observations showed that these spraying machines are design based on the user requirements that are peculiar to the problem solved. Among numerous designs of spraying machines that have been designed for small and medium-scale agricultural purposes, some designs have been identified from different authors in the literature. Awulu and Sohotshan [10] developed an electrically operated knapsack sprayer a twelve volts electric water pump, accumulator battery and a power transmission system made up of belt drive. The spraying machine was evaluated to have a flow rate of 531ml and application rate of 250 l/ha over a spray distribution area of 0.000675 m^2 . Also, the evaluation indicated that the decrease in the liquid head caused a decrease in flow rate and the efficiency of the sprayer decreased as the voltage of battery decreases. An application rate of 250 l/ha in 4.17hrs . is dependent on the walking speed which is estimated to be 0.7 m/s . An automatic sprayer has also been developed for greenhouse by Refigh, *et al.* [11] using a robot to steer the system. The robot was guided by hot water piping rails which move along the pipe rows. The robot is able to force and back along the hot water piping rails of rows in greenhouse avoiding the expensive and complicated navigation systems. Further, the design of spraying machines conveyed by means of wheels has been identified as a technique to achieve mobilization of spraying machines [5, 12, 13]. In some designs, the peddling of the wheels is converted to a torque that creates the impact force required to drive the pump [14]. One of the shortcomings of the manually pedaled wheel design type of spraying machines is the provision of adequate impact force required by the pump. Also, since these machines are manually pedaled, the capacity of the tank is usually designed to be low in order to ensure that the driver is not

undergoing stress while peddling the machine. Also, since the operator of the sprayer is the driver, these sprayers are designed to use multi-point nozzles for uniform distribution of the liquid [12]. Efforts made to improve the impact force of the pump is conversion of solar energy to electricity that supplies current to the DC motor of the pump to run at the required speed. Sun radiations incidents on solar panel consisting of photovoltaic cells converts the solar energy of the sun to electric energy required by the pump [5]. Further improvements in the use of solar powered spraying machines can be identified from the slight increase in electric power generated for driving the pump to a value of 20W [15, 16]. However, the initial cost of installation of the solar powered system is on the high side. An example of spraying machines operated mechanically is the application of sprocket mounted on rear shaft to actuate piston inside cylinder which is positioned in the tank. Also, the assembly consists of four wheels out of which two are mounted on front shaft and two are mounted as guide wheel at rear end [17]. Considering these designs of spraying machines, it can be observed that there is a need to develop sprayers with high volume capacity for small and medium scale crop production. Also, the sprayers are expected to be operated at low cost with high electrical power to drive the pump to impact more force and increased velocity of the liquid in order to have a wider coverage of spraying.

3. Methodology

The methodology applied in this article involves design of component parts of the spraying machine which is followed by simulation of the parts. The results obtained from the simulation guides the fabrication process in order to ensure that the frame of the machine did not buckle during operation. In order to simplify the readability and flow of information in the article, the methodology is divided into different sections as follows. The technical highlight of the design is a spraying machine with a wide coverage and a tank capacity that can be manually moved without being propelled. In view of this, a target volume of 100 litres is used with a wide coverage of 1813 m^2 in an average time of 1374 s . Further, there are no major differences between the simulation of the component parts and the real implementation in the fabrication because the simulation predicted the right dimension of the parts to be fabricated and the parts did not fail during operation.

3.1 Description of the Spraying Machine

A CAD model of the designed spraying machine is presented in Fig. 2. Components of the machine are the frame, liquid storage, prime mover and pump. The frame is attached to the wheels and can be moved manually by means of a handle. It supports the prime mover and the pump while the liquid storage is positioned on it.

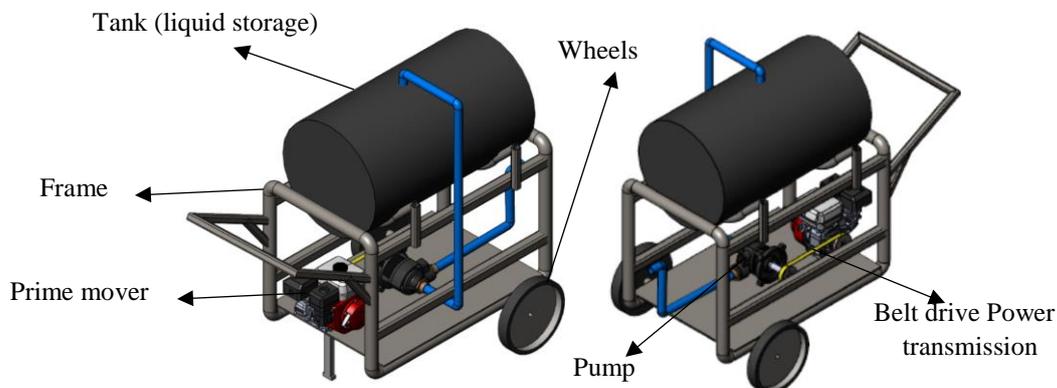


Fig. 2. CAD Model of the Designed Spraying Machine

3.2 Design of Components of the Spraying Machine

3.2.1 Tank

A design consideration that is necessary for the design of the tank is weight and strength of the material from which the tank is fabricated. The material is expected to be strong and have a light weight in order to withstand the internal pressure created by turbulence of the fluid force and reduce the total weight of the machine when loaded with liquid. Since the diameter of light weight tanks is greater than the thickness of its material, then it can be considered as a thin-walled cylindrical tank. A sectional view of the tank is presented in Fig. 3. Considering a cylindrical tank with a target volume (V_t) of 100 litres (0.1 m^3) having a standard diameter (d_t) of 0.4 m , [18] the length (L_t) of the cylindrical tank obtained from equation 1 is expected to be greater than the diameter in order to ensure even weight distribution on

the frame of the spraying machine. It is necessary to determine the weight of the tank without loading (W_t) and when it is fully loaded (W_{tL}) in order to know the weight acting on the frame as presented in equations 2 and 3 respectively.

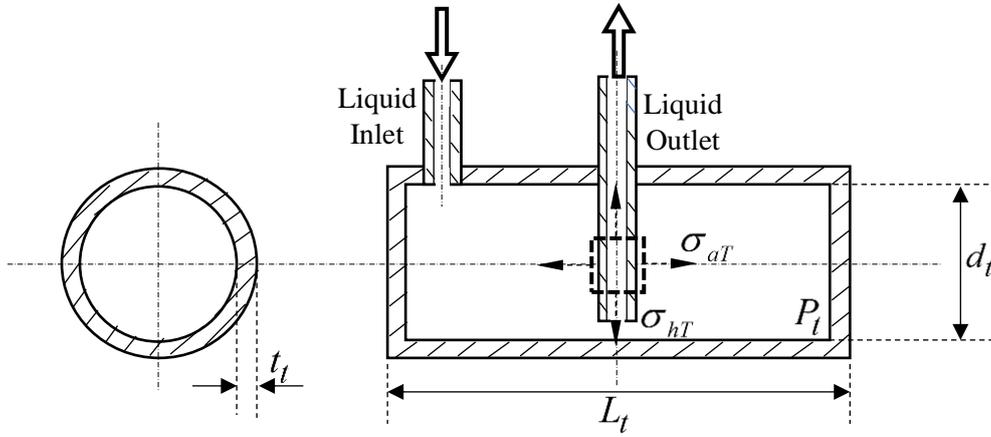


Fig. 3. Tank

$$L_t = \frac{4V_t}{\pi d_t^2} \quad (1)$$

$$W_t = \pi t_t d_t \rho_t g [L_t + 2] \quad (2)$$

$$W_{tL} = W_t + W_w = g \pi d_t \left[[\rho_t t_t (L_t + 2)] + \frac{\rho_w d_t L_t}{4} \right] \quad (3)$$

Where W_w and ρ_w is the weight and density of the water in the tank. Considering Figure 3, the axial stress (σ_{aT}) and circumferential or hoop stress (σ_{hT}) acting on the cylindrical tank can also be obtained from equations 4 and 5 respectively. These stresses are dependent on the internal pressure (P_t) of the liquid in the tank. The internal pressure is a function of the liquid's density and the length of the tank as presented in equation 4. It increases as the length of the tank increases. The theoretical thickness of the tank is a function of the axial and hoop stress as presented in equations 5 – 7 [19, 20].

$$P_t = \rho_w (L_t - 0.3) * 10^2 \quad (4)$$

$$\sigma_{aT} = \frac{P_t d_t}{4 t_t} \quad (5)$$

$$\sigma_{hT} = \frac{P_t d_t}{2 t_t} \quad (6)$$

$$t_t = \frac{P_t d_t}{2 \sigma_{hT}} = \frac{P_t d_t}{4 \sigma_{aT}} \quad (7)$$

Further, since the liquid stored in the tank contains chemicals which may be corrosive over time, then the thickness of the tank obtained in equation 7 should consider the corrosion allowance (C), permissible stress in the storage tank (σ_t^{ps}) and the joint efficiency (J_{eff}) [21]. Hence, the permissible stress and actual thickness of the tank (T_{actual}) can be obtained from equations 8 and 9 respectively.

$$\sigma_t^{ps} = \frac{1000 P_t d_t}{2 J_{eff} (t_t - C)} \quad (8)$$

$$T_{actual} = \frac{1000P_t d_t}{2J_{eff} \sigma_t^{ps}} + C \quad (9)$$

3.2.2 Frame

The frame supports the weight of the tank at full load (W_{tL}), internal combustion engine and pump without buckling. Since the tank is supported at both ends (Fig. 4), then the load acting on each of the support (S_i) can be obtained from equation 10. If the distance of the tank support to the edge of the frame ($D_t|_{edge}$) changes along the length of the tank, then the shear forces (S_f) and bending moments (B_m) along the length of the frame can be obtained from equations 11 and 12 respectively while the bending moment at the center of the frame (B_m^C) can be obtained from equation 13. These shear forces and bending moments are harnessed to construct the shear force and bending moment diagram respectively [19].

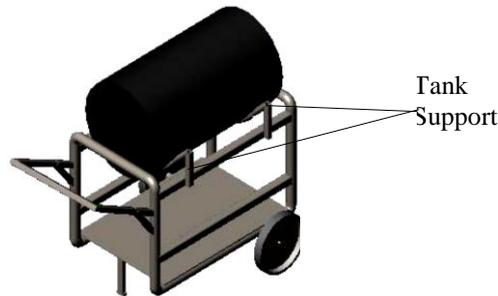


Fig. 4. Frame

$$S_i = \frac{W_{tL} L_t}{2} \quad (10)$$

$$S_f = W_{tL} \left[\frac{L_t}{2} - D_t|_{edge} \right] \quad (11)$$

$$B_m = S_i D_t|_{edge} \left[1 - \left[1 - \frac{D_t|_{edge}}{L_t} + \frac{d_t}{4 D_t|_{edge} L_t} \right] \right] \quad (12)$$

$$B_m^C = \frac{S_i L_t}{4} \left[1 + 2 \left[\frac{d_t^2}{4 L_t^2} \right] - \frac{\pi d_t^2}{L_t} \right] \quad (13)$$

The weight of the tank at full load can be considered as a compressive axial load which acts on the frame column. In order to ensure that the frame column does not buckle, the axial stress (σ_{axial}) must not exceed critical stress ($\sigma_{critical}$) which is a function of the slenderness ratio of the column as presented in equation 14. The slenderness ratio is a function of the length (L) and radius of gyration (k) of the column. The axial stress is dependent on the applied compressive axial force which is created by the weight of the tank when it is fully loaded [19].

$$\sigma_{cr} = C_{ends} \pi^2 E \left[\frac{L}{k} \right]^{-2} \quad (14)$$

C_{ends} and E are the coefficient for type of connection at each end of the column and the modulus of elasticity of the column material respectively.

3.2.3 Pump, Hose and Nozzle

The liquid flows in the machine through pipes from the tank to the pump which impacts the fluid velocity required by the nozzle. A schematic diagram of the hose and pump layout in the spraying machine is described in Fig. 5.

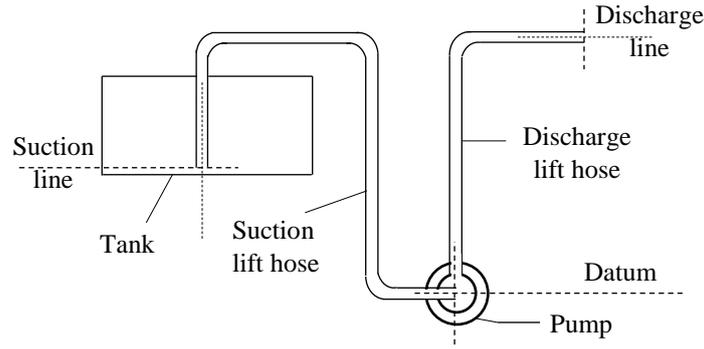


Fig. 5. Pump and Hose Layout

The total head loss in the piping (T_{hp}) is the summation of head losses in suction (H_S) and discharge (H_D) lines. The head loss in suction line is a summation of the head losses due to suction lift (S_L) and frictional force in suction pipe (h_{sp}^f) and the velocity head in suction line (h_s^v) [22]. Similarly, the head loss in the discharge line is a summation of the head losses due to discharge lift (D_L) and frictional force in the discharge pipe (h_{dp}^f) and the velocity head in discharge line

(h_d^v). Hence, the total head loss due to piping can be obtained from equation 15.

$$T_{hp} = S_L + h_{sp}^f + h_s^v + D_L + h_{dp}^f + h_d^v \quad (15)$$

The velocity head in suction and discharge lines in equation 15 are obtained by applying Bernoulli's equation for datum-suction and datum-discharge lines respectively. The head loss due to frictional force in the suction and discharge pipe is a function of the suction (D_{sp}) and discharge (D_{dp}) pipe diameters as presented in equations 16 and 17 respectively.

$$h_{sp}^f = \frac{4S_L h_s^v \left[0.005 + \frac{0.005}{4.725D_{sp}} \right]}{2gD_{sp}} \quad (16)$$

$$h_{dp}^f = \frac{4D_L h_d^v \left[0.005 + \frac{0.005}{4.725D_{dp}} \right]}{2gD_{dp}} \quad (17)$$

Further, if there is no agitation in the tank, then the velocity at suction point is negligible and the velocity at discharge (V_D) can be obtained from extended Bernoulli's equation when applied between the suction and discharge point as presented in equation 18.

$$V_D = \left[2g \left[\frac{P_s - P_d}{\rho g} + [Z_s - Z_D] + [H_s - H_D] \right] \right]^{\frac{1}{2}} \quad (18)$$

Where P_s and P_d are the pressures at suction and discharge respectively, while Z_s and Z_D are the heights of the suction and discharge above the datum. Hence, the volumetric flow rate of the pump (Q_{pump}) can be obtained from the diameter of the hose and discharge velocity. Likewise, the mass flow rate is also obtained from the density of the liquid and the volumetric flow rate. The Water Horse power of the pump (WHP_{pump}) which is the pump's output can be obtained from the total head loss in the system, specific weight and volumetric flow rate of the liquid as presented in equation 19. The pump's efficiency (γ_{pump}) and its specific speed (η_{ss}^{pump}) can be obtained from equations 20 and 21 [22].

$$WHP_{pump} = \frac{\pi \rho g T_{hp} V_D D_{sp}^2}{4} \quad (19)$$

$$\gamma_{pump} = \frac{WHP}{SHP} \Big|_{pump} \quad (20)$$

$$\eta_{ss}^{pump} = \frac{N_{pump}^{in} Q_{pump}^{1/2}}{T_{hp}^{3/4}} \quad (21)$$

Where SHP and N_{pump}^{in} are the shaft horse power and number of revolutions of the pump shaft which are obtained from the operating parameters of the internal combustion engine acting as prime mover to the pump. Further, if the volumetric flow rate of the pump is conveyed completely to the nozzle, then it is possible to obtain the inlet diameter of the required nozzle (d_{nozzle}^{in}) considering a conical nozzle with sharp throat entrance with coefficient of discharge (C) as described in equation 22. Also, the jet break-up index of the nozzle (I_{jet}^b) can be obtained from equation 23. It is necessary because it assists in providing uniform coverage and minimize presence of excessively large drops of liquids.

$$d_{nozzle}^{in} = \left[\frac{4Q_{pump}}{[2\pi g C^2 D_L]^{\frac{1}{2}}} \right]^{\frac{1}{2}} \quad (22)$$

$$I_{jet}^b = \frac{P_d}{[10Q_{pump}]^{0.4}} \quad (23)$$

3.3 Tank and Frame Simulation

A static simulation is needed in order to predict the performance of the designed components. The parameters obtained from the design analysis are captioned in the drafted model in SolidWorks simulation by specifying the type of material and specifying the constraints and forces acting on them. In each case, results are obtained for Von Mises stress, deformation analysis and strain of the members.

3.3.1 Tank Simulation

In order to predict the performance of the designed tank, the weight obtained from equation 2 is captioned with an internal pressure obtained from equation 4. Other parameters such as diameter, length and material thickness obtained from the design analysis are applied in developing the tank model. Plain carbon steel with properties presented in Table 1 is selected for the simulation due to

its availability and less cost of purchase. Other simulation parameters for the development of the mesh model (Fig. 6) are presented in Table 2. Results obtained for the maximum and minimum stress, static displacement and static strain of the tank are presented in Figs. 7 - 9 respectively.

Table 1. Tank Material Property

Material type	Plain Carbon Steel
Yield strength	2.20594e+08 N/m ²
Tensile strength	3.99826e+08 N/m ²
Elastic modulus	2.1e+11 N/m ²
Poisson's ratio	0.3
Mass density	7,800 kg/m ³
Shear modulus	7.9e+10 N/m ²

Table 2. Tank Simulation Parameters

Mesh Type	Solid Mesh
Element size	30.583mm
Tolerance	1.529mm
Total Nodes	28522
Total Elements	16574
Maximum Aspect Ratio (AR)	112.19
% of elements with AR<3	7.28
% of elements with AR>10	53.1



Fig. 6. Mesh Model of Tank

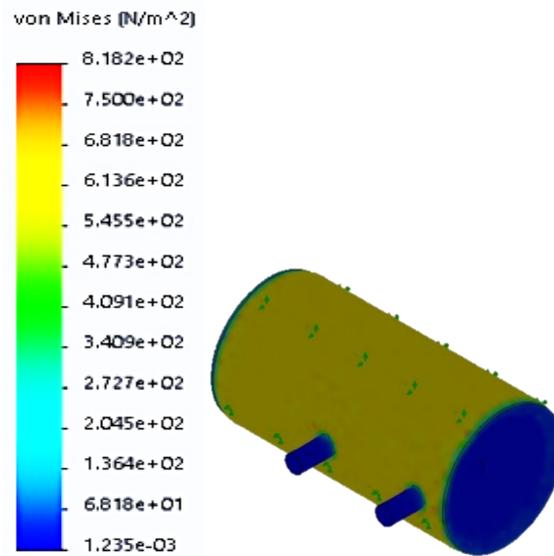


Fig. 7. Von Mises Stress

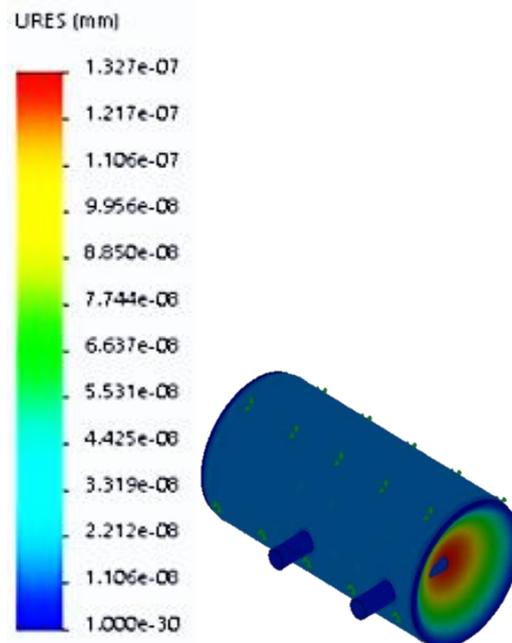


Fig. 8. Displacement (URES)

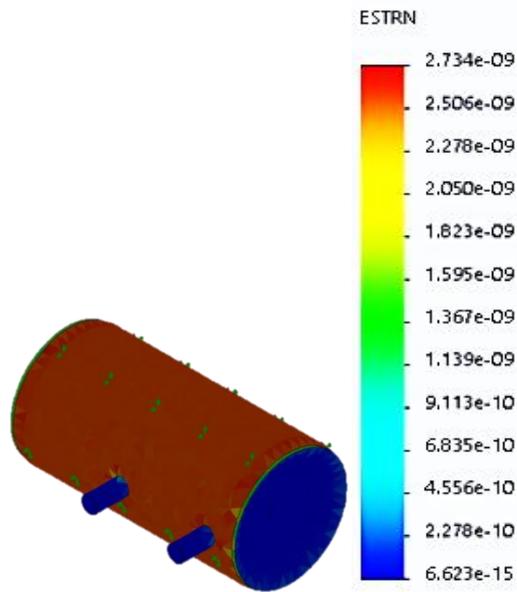


Fig. 9. Strain (ESTRN)

3.3.2 Frame Simulation

In order to depict the behaviour of the frame while in operation, it was simulated to carry the tank when it is fully loaded (Fig. 10) by using the values of the tank weight obtained from equation 3. The material of the frame (Table 3) and simulation parameters for the development of the curvature-based mesh model (Fig. 11) are presented in Table 4. The reason for using this type of mesh is because the frame is a has different solid bodies joined together. Results obtained shows that with a resultant force of 820 kN acting on the frame, the maximum and minimum axial stress, static displacement and static strain of the frame are presented in Figs. 12-14 respectively.

Table 3. Frame Material Property

Material Type	AISI Annealed 4340 Steel,
Yield strength:	$4.7\text{e}+008\text{ N/m}^2$
Tensile strength:	$7.45\text{e}+008\text{ N/m}^2$
Elastic modulus:	$2.05\text{e}+011\text{ N/m}^2$
Poisson's ratio:	0.3
Mass density:	7850 kg/m^3
Shear modulus:	$8\text{e}+010\text{ N/m}^2$

Table 4. Frame Simulation Parameters

Mesh Type	Mixed Mesh
Maximum Element size	30 mm
Minimum Element size	6 mm
Total Nodes	72557
Total Elements	42540

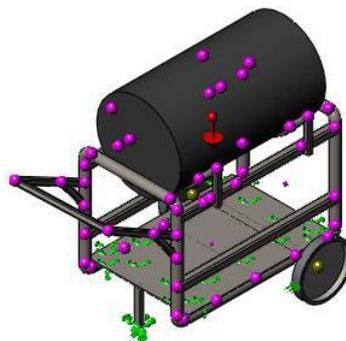


Fig. 10. Frame Loaded with Tank



Fig. 11. Mesh Model

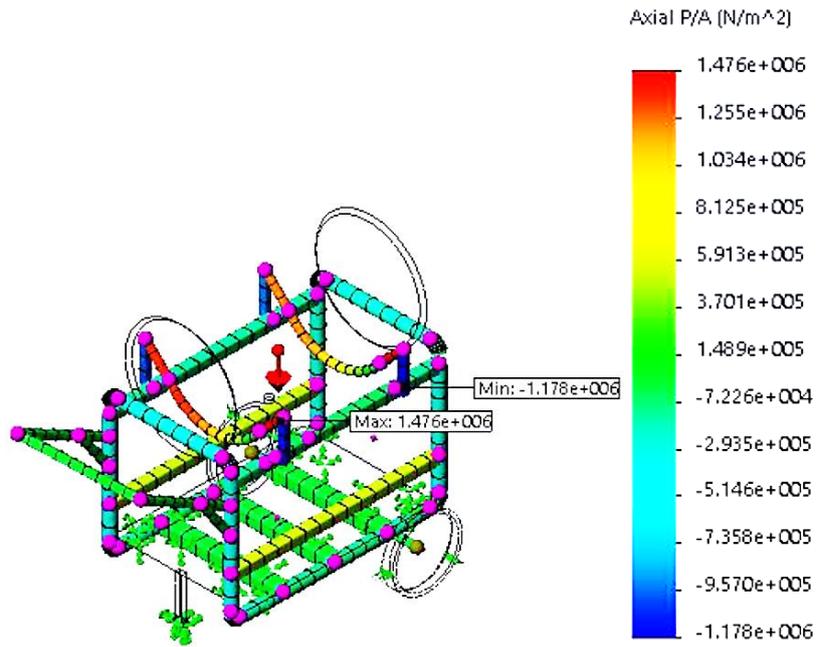


Fig. 12. Axial Stress on Frame

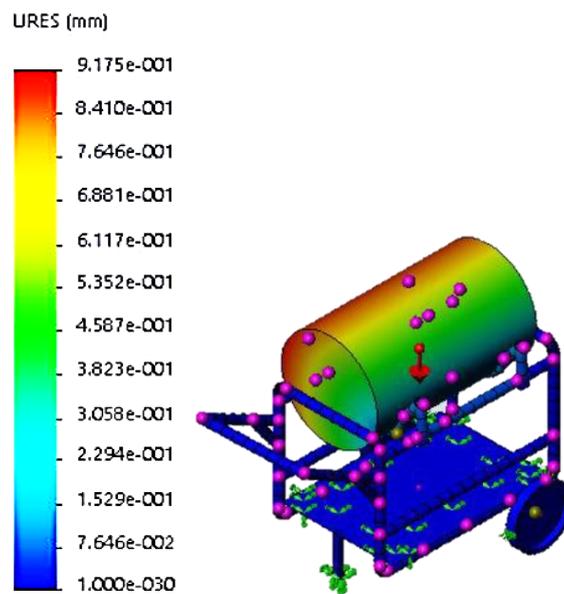


Fig. 13. Displacement

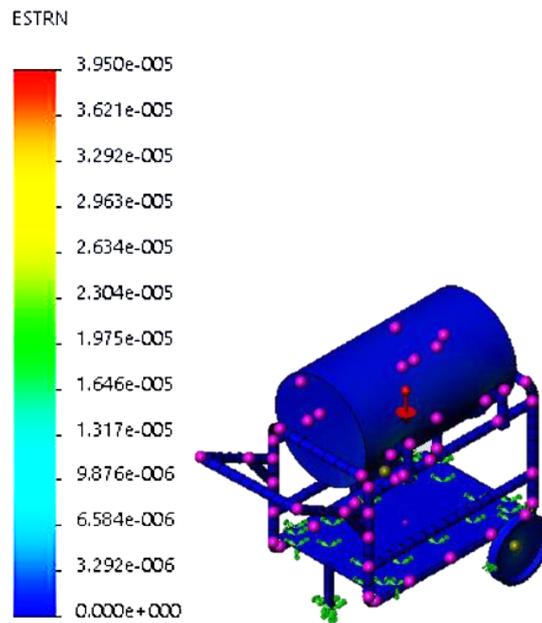


Fig. 14. Strain

4. Fabrication and Performance Evaluation

The designed spraying machine was validated by fabrication using locally sourced materials in order to ensure that the cost of fabrication is not high (Fig. 15). The performance of the fabricated spraying machine was evaluated on three small scale maize production sites using *Tempo Hot Fog* pesticide. The dimensions of the land space were obtained by direct measurement in order to know the area of spraying space in each test case. Although the dimensions of the land obtained did not produce a perfect square or rectangular shape but the longest length was assumed and adopted for

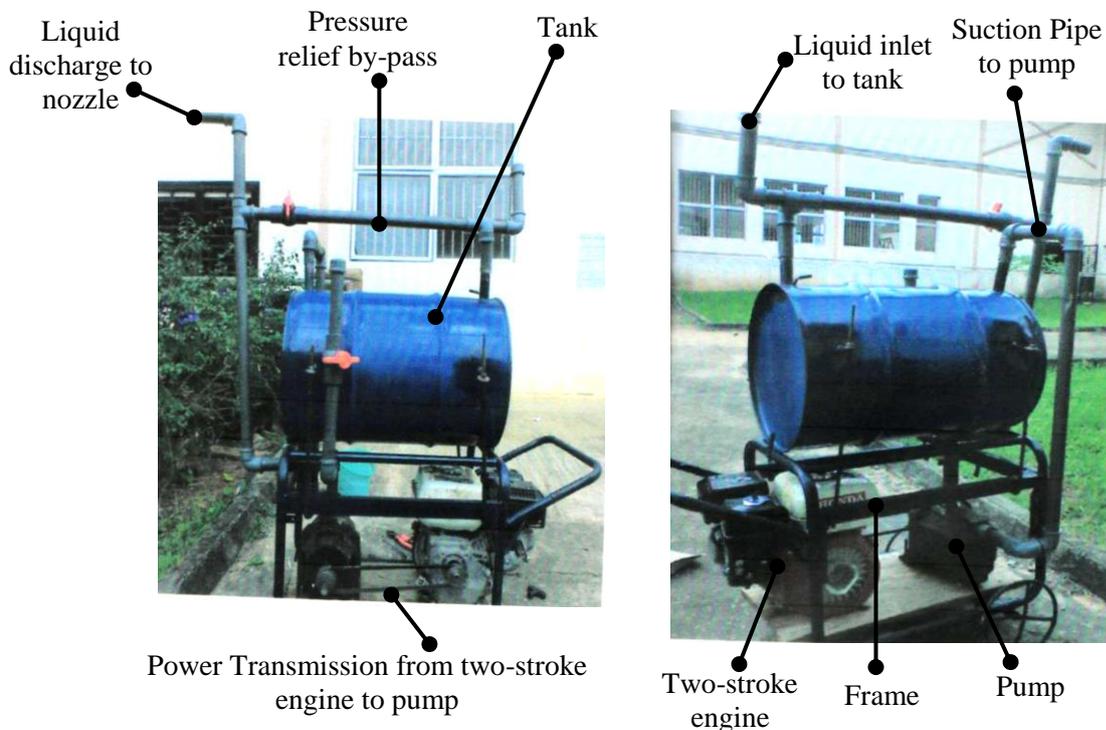


Fig. 15. Fabricated Spraying Machine

computation of the area. In order to evaluate the fabricated spraying machine in terms of operational performance, its field efficiency was determined using the actual and theoretical field theory [23, 24]. Using only water with no pipe and

nozzle attached to the discharge port of the spraying machine, the two-stroke engine was operated at a speed of 105 rad/sec (1000 rpm) and the total volume of water in the tank (0.1 m^3) was discharged in 175 secs . This indicates that the pump discharge pressure is sufficiently high. Hence a pressure relief bypass is provided to divert some portion of the flow back into the tank in order to reduce the discharge pressure. A detailed analysis for the performance of the spraying machine is presented in Table 5. The Actual Field Capacity (A_{fc}^s), Theoretical field capacity (T_{fc}^s) and field efficiency of the spraying machine (η_f^s) is obtained from equations 24-26.

$$A_{fc}^s = \frac{A_{area}}{T_{area}} \quad (24)$$

$$T_{fc}^s = \frac{F_w * V_{pump}}{10} \quad (25)$$

$$\eta_f^s = \frac{A_{fc}^s}{T_{fc}^s} \quad (26)$$

Table 5. Performance Evaluation Results

S/N	Parameters (Units)	Site 1	Site 2	Site 3	Performance
1	Average Crop Height (m)	0.52	0.46	0.58	0.52
2	Average Crop Spacing (m)	0.30	0.36	0.28	0.31
3	Field Length (m)	62.7	73.3	65.4	67.13
4	Field Width (m)	23.8	30.1	26.6	26.83
5	Field Area (m^2)	1492.3	2206.3	1739.6	1812.73
6	Time to spray field (s)	1228	1575	1320	1374.33
7	Number of Tank loadings	4	5	4	4.33
8	Actual Field Capacity (m^2/s)	1.22	1.40	1.32	1.31
9	Theoretical Field Capacity (m^2/s)	1.49	1.88	1.67	1.68
10	Field Efficiency	0.82	0.75	0.79	0.79

$$\eta_f^s = \frac{A_{fc}^s}{T_{fc}^s} \quad (26)$$

Where A_{area} , T_{area} , F_w and V_{pump} are the crop field area, time to spray the crop field area, crop field width and velocity of the pump respectively. The velocity of the pump in equation 25 was obtained from number of revolutions of the internal combustion engine (N_{engine}) transmitted to the input shaft of the pump and diameter of the pump's input shaft (D_{sp}) as presented in equation 27.

$$V_{pump} = \frac{\pi D_{sp} N_{engine}}{60} \quad (27)$$

Considering the results obtained in Table 5, it can be stated that the fabricated spraying machine has a field efficiency of 79% with an average time of 1374 s to spray a maize crop field area of 1813 m^2 having an average crop height of 0.52 m . It can also be observed that the field efficiency of the spraying machine drops to a value of 75% when used in Site 2 where the crop field area is 2206.3 m^2 . This is an indication that the spraying machine's efficiency will reduce as the field area increases. Further, considering the results obtained from the simulation and the performance of the machine in operation, it can be implied that the simulation results assisted in determining the strength of the frame required to carry the total weight of the tank without buckling. Also, the limitation in the developed machine is that, there is a limit to the volume of the liquid that can be carried because it has to be manually pushed and positioned while a maximum field area of 2206.3 m^2 is sprayed. This is also an indication that, an increase in the volume of the tank will make the frame of the machine buckle thereby decreasing the life span of the machine. In essence, it can be stated that a maximum axial stress of $1.476 \text{ E}6 \text{ N/m}^2$ must not be exceeded in order to avoid buckling of the frame. This implies that the total weight of the tank and the liquid should not exceed this value. However, considering mobility of the spraying machine it is advisable to keep the total weight below this value in order to reduce the stress of pushing the machine on the field.

5. Conclusion

The importance of applying machinery to carry out operations in crop production cannot be overemphasized. The reduction in stress undertaken to apply pesticides on crop and improved yield of crop production are justification for this present study. In this article, a spraying machine is designed, simulated and fabricated to spray pesticides on a maize crop plantation. Performance evaluation of the spraying machine indicates that it has an efficiency of 79% when used on a crop field area of 1813 m^2 . The fact that the spraying machine completed the operation in an average time of 1374.3 s (23 mins), signifies that it can improve application of pesticides in crop production and reduce human drudgery. Further, the results obtained from the performance evaluation of the machine also indicates that the machine may not be suitable when applied on a large area of crop field. Considering the work done in this present study and the methodology presented in the article, future work is still possible in the aspect of automation of the design. Also, the mobility aspect of the fabricated machine can also be improved upon by improving the wheel design and using wheels that do not require more energy to push or pull. This will assist in improving the volumetric capacity of the entire spraying machine. Further simulations of the spraying machine using light weight non-corrosive materials for the tank design will improve the overall performance of the machine because the volume of the tank will be increased and this will in turn increase the coverage area of the machine. Additionally, this will also reduce the labour involved in propelling the machine. In essence, fabrication of the machine for commercialization will consider simulations in the aspects of improved wheel design and use of light weight and non-corrosive material for the tank design.

References

- [1] Chen, G., *Advances in agricultural machinery and technologies*. 2018, Australia: CRC Press.
- [2] Azizpanah, A., A. Rajabipour, R. Alimardani, K. Kheiralipour, B. Ghamari, and V. Mohammadi, *Design, construction and evaluation of a sprayer drift measurement system*. *Agricultural Engineering International: CIGR Journal*, 2015. 17(3).
- [3] Friedrich, T., *Agricultural sprayer standards and prospects for development of standards for other farm machinery*. 2001.
- [4] Bhatkar, M.A.K., P. Khope, and P. Chaudhari, *Design and Working of Adjustable Manually Push Operated Pesticide Spraying Machine*. 2016.
- [5] Malonde, S., S. Kathwate, P. Kolhe, R. Jacob, N. Ingole, and R.D. Khorgade, *Design and Development of Multipurpose Pesticides Spraying Machine*. *Journal of Advanced Engineering and Global Technology* ISSN, 2016(2309-4893).
- [6] Raut, L.P., S.B. Jaiswal, and N.Y. Mohite, *Design, development and fabrication of agricultural pesticides sprayer with weeder*. *International Journal of Applied Research and Studies*, 2013. 2: p. 1-8.
- [7] Liu, J., X. Liu, X. Zhu, and S. Yuan, *Droplet characterisation of a complete fluidic sprinkler with different nozzle dimensions*. *Biosystems Engineering*, 2016. 148: p. 90-100.
- [8] Butts, T.R., L.E. Butts, J.D. Luck, B.K. Fritz, W.C. Hoffmann, and G.R. Kruger, *Droplet size and nozzle tip pressure from a pulse-width modulation sprayer*. *Biosystems Engineering*, 2019. 178: p. 52-69.
- [9] Chu, H., R. Zhang, Y. Qi, and Z. Kan, *Simulation and experimental test of waterless washing nozzles for fresh apricot*. *Biosystems Engineering*, 2017. 159: p. 97-108.
- [10] Awulu, J. and P. Sohoshan, *Evaluation of a developed electrically operated knapsack sprayer*. *International Journal of Science and Technology*, 2012. 2(11): p. 769-772.
- [11] Refigh, A., D. Kalantari, and H. Mashhadimeyghani, *Construction and development of an automatic sprayer for greenhouse*. *Agricultural Engineering International: CIGR Journal*, 2014. 16(2): p. 36-40.
- [12] Anupam, M., W. Amar, K. Chaitanya, P. Nikhil, M. Rahul, G. Vijay, and S.N. Gandhare, *Design and Fabrication of Paddle Operated Multi-Point Pesticide Spraying Machine*. *International Journal of Advances in Engineering & Scientific Research*, 2015. 2(2): p. 1-7.
- [13] Kiran, C.H., S. Rajesh, R. Abhishek, R. Gowtham, and Amar, *Fabrication of Multipurpose Pest Sprayer*. *International Journal of Research and Scientific Innovation* 2018. 5(5): p. 12-15.
- [14] Vishakha, B., G. Mahesh, P. Pratibha, P. Karan, and J.K. Firdos, *Multipurpose Manually Operated Automatic Spraying and Fertilizer Throwing Machine*. *International Journal for Research in Applied Science & Engineering Technology*, 2017. 5(4): p. 1452-1464.
- [15] Charvani, S., K. Sowmya, M. Malath, P. Rajani, and K. Saibaba. *Design And Fabrication Of A Solar Sprayer*. in *National Conference on Innovative Trends in Science and Engineering*. 2017.
- [16] Akshay, M. and G. Waghmare. *Design and fabrication of solar operated sprayer for agricultural purpose*. in *National Conference on Innovative Trends in Science and Engineering*. 2016.
- [17] Sanjay, S., R. Sridhar, M.T. Syed, and V. Harshitha, *Design and Fabrication of Mechanical Pest Sprayer*. *International Journal of Innovative Research in Science, Engineering and Technology*, 2015. 4(10): p. 194-197.
- [18] Couper, J.R., W.R. Penney, and J.R. Fair, *Chemical Process Equipment-Selection and Design (Revised 2nd Edition)*. 2009: Gulf Professional Publishing.
- [19] Brown Jr, T.H., *Marks' calculations for machine design*. 2005: McGraw-Hill.
- [20] Shigley, J.E., *Shigley's mechanical engineering design*. 2011: Tata McGraw-Hill Education.
- [21] Chattopadhyay, S., *Pressure vessels: design and practice*. 2004: CRC press.
- [22] Bloomer, J.J., *Practical fluid mechanics for engineering applications*. 2000: Marcel Dekker.
- [23] Bihari, D.N., D.N. Bihari, and M.M. Kumar, *Concepts and Applications in Agricultural Engineering*. 2007: International Book distributing Company.

- [24] Karale, D., U. Kankal, V. Khambalkar, and A. Gajakos, *Performance evaluation of self propelled boom sprayer*. International Journal of Agricultural Engineering, 2014. 7(1): p. 137-141.

Author's Profile



Olayinka Mohammed Olabanji received his B.Eng. and M.Eng. degree in mechanical engineering from the Department of Mechanical Engineering, Federal University of Technology Akure, Nigeria, in 2008 and 2012 respectively, and the Ph.D. degree in Industrial Engineering from the Tshwane University of Technology, Pretoria West, South Africa, in 2016. He is currently a Senior Lecturer and a Researcher with the Department of Mechanical Engineering, Federal University of Technology. He is also an adjunct researcher with the Department of Industrial Engineering and the Gibela Research Chair in Manufacturing and Skills Development with the Tshwane University of Technology (TUT), South Africa. He has reviewed papers for various Conferences and

Journals, including the 29th and 30th CIRP Design Conference and *Journal of Engineering, design, and Technology* Emerald. His research interests include mechanical engineering design, advanced manufacturing, automation, sustainable design and decision making.

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