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Development of a detachable and single wheeled four nozzles sprayer

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Abstract

This paper presents the design and fabrication of a singled wheeled and four nozzles farming and agricultural sprayer that is mechanically detachable to optimizes time and cost while delivering efficient spraying of agricultural chemicals. The device is designed to spray 3.2 litres per minute, reducing the time spent on spraying, and saving valuable time for farmers. Additionally, the cost of the sprayer is affordable and accessible option for small-scale, medium and rich farmers. It has an efficiency of 87.5% during the spraying operation tested with the sprayer offering an efficient, cost-effective, and durable solution to agricultural spraying, benefiting farmers and the wider agricultural industry in Nigeria. This work is targeted at providing solution to the problem of the farmer carrying the entire weight of the sprayer on his shoulders and also to save the farmer the stress of pumping manually with his or her hands hence preventing direct contact with the harmful chemicals. The detachable design of the sprayer makes it easy to maintain and repair, increasing its longevity and reducing the need for costly replacements. The use of four multiple nozzles ensures an even distribution of the chemicals, maximizing their effectiveness and reducing wastages.

Keywords— wheeled, detachable, sprayer, operator, device, nozzles.

Introduction

The Food and Agricultural Organization (FAO) defined pesticide as any product or combination of substances with chemical or biological elements that is used to repel, eliminate, or control pests or to control plant growth. Insecticides, herbicides, fungicides, rodenticides, molluscicides, wood preservatives, and several other compounds used to manage pests are all referred to as pesticides. Defoliants, desiccants, and plant growth regulators are other types of pesticides.

However, due to the expansion of synthetic chemical pesticides and the quick development of biopesticides in the last decade, pesticides started to be used more widely in agriculture starting in the 1940s. Pesticides of all kinds, including chemical, microbial, semi-chemical, and botanical varieties, are now sold in quantities of over a thousand. According to the FAO's vision for sustainable food and agriculture, natural resources should be managed in a way that preserves ecosystem services to meet both present-day and future human requirements (Kulkarni, *et al*,2005) and (Joshua *et al,*2010.). Food should also be safe, nutrient-dense, and accessible to everyone. A delicate balance must be struck. According to the Food and Agricultural Organization (FAO), between 20 and 40 percent of the world's crop output are lost each year as a result of plant pest damage. We cannot afford crop losses at a time when food insecurity is rising due to population growth and environmental issues. If we want to feed the world's expanding population, global food output must rise by up to

50% by 2050. The Sustainable Development Goal 2 to end hunger, ensure food security and enhanced nutrition, and promote sustainable agriculture by 2030 depends on pest management.

Most specific pest control methods can be grouped into the following main categories: Cultural control, host resistance, physical control, mechanical control, biological control, and chemical control. Chemical control is using pesticides, fungicides and bactericides to control pests and diseases. Chemical method of plant control is differing from others universally in its application and efficiency as it requires relatively low cost of material and labor. For this reason, they are widely used. Different methods of crop protection complement each other and require an appropriate mix of chemical, agrochemical, biological and other methods (Belfortet *et al*, 2011). In certain cases of widespread outbreaks, it is necessary to destroy a wide range of pests and herbs in the shortest possible time. In such cases, the use of chemicals is the only way to preserve the harvest. Therefore, in terms of suitability and efficacy for large-scale eradication of pests and diseases, chemical methods are the predominant and in some cases the only crop control method available. Development of Multi-Nozzle Pesticide Sprayer Pump by Sandeep and Dhanraj, 2013.The model was a manually operated multi-nozzle pesticide sprayer pump as suggested detachable in this study to perform spraying at the highest rate in the shortest amount of time. To achieve equal nozzle pressure, constant flow valves can be used at the nozzle. Sammons, Furukawa and Bulgin 2014) also developed an autonomous robot for spraying pesticides while Vardhan, *et al,* 2014) came up with automated aerial sprayers.

Shivaraja and Parameswaramurthy in 2014 research article presented a design and development of a wheel driven sprayer was a small machine that can be moved about easily and does not require any fuel to run. The wheel may be moved to spray pesticide. This sprayer uses a reciprocating pump and attached nozzles at the front end of the spraying apparatus as its mechanism. This effort is similar to those sprayers developed (Poratkar and Raut, 2013), Deshpande, *et al*, 2017) and (Sumit *et al,* 2014) who developed pedaling multiple nozzles agricultural sprayer. The key components of the sprayer mechanism are the reciprocating pump and the nozzles, which are connected to the spraying equipment. The spray fluid is kept in a tank and sucked via suction hose channel as a result of the piston movement utilized in the wheel (Ashish, Prakash, Susheel and Sharad, 2018). The single wheeled agricultural multi-nozzles sprayer is a strong and durable equipment designed basically for crop spraying in the farm by an individual. So, in consideration of all the above issues it was intended to fabricate such equipment which reduces human efforts and saves time without utilizing any power source.

Rao, Mathapati and Amarapur, 2013, developed a fertilizer sprayer with multiple Power Sources. When the sun is out, this can be run on solar power; otherwise, electricity can be used to run it. The operating costs of the system are reduced to a minimum, and time is saved. Spray liquid is ejected into the air with a blast that passes through the spraying jet's hose and nozzle tube. Also known as blowers, these sprayers and the maintenance as prescribed by Jeremy (2014a and 2015a).

What currently exist are machines operated manually using a lever handle, requiring physical effort from the operator. The main goal of this work is to develop an efficient sprayer that reduces human effort, spraying time, and overall cost. Traditional sprayers have certain drawbacks, such as the need for significant effort to operate the lever and generate the required spraying pressure. Additionally, fuel sprayers require the purchase of fuel, increasing operational expenses, while also producing vibrations and noise that can be bothersome to the operator. To overcome these challenges, a proposal for a single wheel-driven agricultural sprayer with four spraying nozzles has been considered. This device is convenient to use, does not require fuel for operation, easy to move, and sprays the pesticide while the wheel is in motion.

Materials and Methods

Selection of Materials

Material selection is an ordered process by which engineers can systematically eliminate unsuitable materials and identify the ones or small number of materials most suitable. Many different factors are considered in determining the selection requirements, such as; mechanical properties, chemical properties, physical properties and cost.

The materials used in the fabrication of the spraying machine consists of multiple parts such as: Driven sprocket, Drive sprocket, Frame, Piston pump, Slider, Roller shaft, Nozzles, Roller block, and others as shown I Figure 1.

Figure 1: One wheeled, detachable four nozzles sprayer setup

Description of the machine

The designed and fabricated singled wheeled and four nozzles farming and agricultural sprayer allows for detachment mechanically as show in figure 1 above and it therefore optimizes time and cost while delivering efficient spraying of agricultural chemicals. The device is designed to spray 3.2 litres per minute, reducing the time spent on spraying, and saving valuable time for farmers. Additionally, the cost of the sprayer is affordable and accessible option for small-scale, medium and rich farmers**.** The principle and operation of the wheeled, four nozzles agricultural sprayer is quite easy. It works just like every other type of agricultural sprayer. It is designed in such a way that it is made easier and less stressful for farmers to operate.

a) Transmission of motion by chain and sprocket arrangement.
b) Slider crank mechanism.
c) Conversion of circular motion to reciprocating motion

The operator pushes forward after grabbing the handle. The wheel turns as the cycle advances. The gear sprocket attached on the wheel revolves at the same speed as the wheel when it turns. The pinion sprocket, which is positioned on a shaft with two bearings attached at either end, receives motion from the gear sprocket through the chain drive. The pinion sprocket and crank are positioned on opposite sides of the same shaft, and the connecting rod and crank mechanism turn the shaft's rotating motion into a reciprocating action. Lever and connecting rod are joined, and the lever oscillates at its fulcrum. The required pressure is generated by the reciprocating motion of the piston linked at the fulcrum in the cylinder or tank. The pump drives the pesticide through the pipe to the nozzles, where it is attached to a number of nozzles to spray the pesticide. The cylindrical pump draws pesticide from the tank. With the use of special procedures as equally presented by (Kulkarni, *et al*, 2015), the pressure needed for spraying may be altered by adjusting the length of the crank once a slot is added to the crank. Free rotation of the crank or neutral position can be attained by enabling some adjustment at the connecting rod and lever joint. When pesticide spraying is not necessary, these adjustments disable the pumping and allow the wheel to freely rotate. The nozzle's height, location, and angle can all be changed.

Fabrication of the Spraying machine

During the fabrication, each main section of the device was designed and fabricated adaptive of Busari *et al*, (2021) but made detachable from each other and can be re-assembled likewise when in needs for use by using 13 mm bolts and nuts for each of the section. After constructing each section individually, then two 13 mm bolts were fastened into each section through the angle bars and pipes and the nuts tightened at the other end of the bolts to enable a firm grasp of the parts together. These sections include: The tank section, the wheel section, the cart handle, the piping section.

Figure 2: Components of the Designed Detachable Sprayer

Design analysis

The design analysis of the four wheeled, multiple nozzle agricultural crop sprayer, is based on fundamentals and equations used in standard engineering practices. The design is aimed at achieving the desired attribute of the device which are strength, stability, light-weight and stiffness.

Data and Calculation for the Design

a) Crank radius = 0.06 m
b) Diameter of piston = 0.025 m
c) Length of connecting rod = 0.50 m
d) Mass of reciprocating system (m_r) = 10kg
e) Inclination angle of stroke = 50°

(1) Determination of the *Ratio of Length of Connecting Rod to Crank Radius:*

To calculate the ratio of the length of connecting rod, we use the parameters below:

$$n = \sin\theta / \sin\emptyset = \frac{l}{r} \quad (1)$$

Where *l* = 50 mm, r = 6 mm

$$n = \frac{l}{r} = \frac{50}{6}$$

n = 8.3

(Kurmi and Gupta, 2014)

(2) Determination of *Number of degree of freedom:*

To calculate the degree of freedom, we use the parameters below:
Number of joint j = 4
$N = 3\,(l-1) - 2j$
(2)
Where numbers of links, l = 4,
$N = 3\,(4-1) - 2\ \times 4$
$N = 3\,(3) - 8$
$N = 9 - 8$
Therefore, N = 1
(Kurmi and Gupta, 2014)

(3) Displacement of connecting rod:

To calculate the displacement of connecting rod, we use the parameter below:
$x = r\left[(1-\cos\theta) + \frac{sin^2\,\theta}{2n}\right]$
(3)
Where $r = 0.06\,m, n = 8.3, \theta = 50°$
$x = 0.06\left[(1-\cos 50°) + \frac{sin^2\,50°}{2(8.3)}\right]$
$x = 0.06\left[1 - 0.643 + \frac{0.587}{16.6}\right]$
$x = 0.06\,[0.357 + \ 0.0354]$
$x = 0.06\,[0.3924]$
$x = 0.024\,m$
(Source: Kurmi and Gupta, 2014)

(4) *Velocity of the piston:*

To calculate the velocity of the piston, we use the parameters below:
$V_P = 4.712\ \times 0.06\,(\sin 50°, + \frac{sin2(50°),}{2(8.3)})$
(4)
$where\ r = 0.06\,m\,, n = 8.3\,, \theta = 50°, \omega = \frac{2\pi N}{n} = \frac{2\times3.142\times45}{60} = \frac{282.78}{60} = 4.712\ rads^{-1}$
$V_p = 0.283\,(0.776 + \frac{\sin(100°)}{16.6}$
$V_p = \ 0.283\,(0.776 + \frac{0.985}{16.6}$
$V_p = 0.283\,(\ 0.776 + \ 0.059)$
$V_p = 0.283\,(0.835)$
$V_p = 0.236\ m/s$
(Kurmi and Gupta, 2014)

(5) *Net load on the piston:*

To calculate the net load on the piston, we use the parameters below:
$P = \frac{F}{(\frac{\pi}{4}\times D^2)}$
(5)
Where F = 2637.5 N, (Force on the piston), D = 0.025 m
$P = \frac{2637.5}{(\frac{\pi}{4}\times 0.025^2)}$
$P = \frac{2637.5}{0.0004909}$
= 5373070.879 N/m^2
$F_L = pressure\ \times Area = P\ \times \frac{\pi}{4} \times D^2$
F_L= 5.37 $\times \frac{3.142}{4} \times 0.025^2$
F_L= 5.37 $\times 0.7855 \times 0.000625$
F_L= $2637.5\ N$
(Kurmi and Gupta, 2014)

(6) *Piston effort:*

To calculate the piston effort, we use the parameters below:
$F_p = F_L - \ F_1$
(6)
= 2637.5 – 8.3
= 2629.2 N
(Kurmi and Gupta, 2014)

(7) *Force along the connecting rod:*

To calculate the force along the connecting rod, we use the parameters below:
$F_Q = \frac{F_P}{\sqrt{1-\frac{sin^2\theta}{n^2}}}$
(7)
Where $F_p = 2629.2\ N\,, n = 8.3, \theta = 50°$
$F_Q = \frac{2629.2}{\sqrt{1-\frac{sin^2 50°}{8.3^2}}}$
$F_Q = \frac{2629.2}{\sqrt{1-\frac{-0.342}{68.89}}}$
$F_Q = \frac{2629.2}{\sqrt{1-(-0.00496)}}$
$F_Q = \frac{2629.2}{\sqrt{1+0.00496}}$
$F_Q = \frac{2629.2}{\sqrt{1.00496}}$
$F_Q = \frac{2629.2}{1.00248}$
F_Q = 2622.7 N
(Kurmi and Gupta, 2014)

(8) *Torque on the crankshaft:*

To calculate the torque on the crankshaft, we use the parameters below:
$T = \ F_p \times r\left(sin\theta\ + \frac{sin2\theta}{\sqrt[2]{(n^2 - sin^2\theta)}}\right)$
(8)
Where F_p = 2629.2 N, $r = 0.06\,m,\ n = 8.3,\ \theta = 50°$
$T = \ 2629.2 \times 0.06\ \left(sin\ 50° + \frac{sin2(50°)}{\sqrt[2]{(8.3^2 - sin^2(50°))}}\right)$
$T = \ 157.75\ \left(0.766 + \frac{sin2(50°)}{\sqrt[2]{(68.89 - (-0.342))}}\right)$
$T = \ 157.75\ \left(0.766 + \frac{-0.342}{\sqrt[2]{(68.89 + 0.342)}}\right)$
$T = \ 157.75\ \left(0.766 + \frac{-0.342}{\sqrt[2]{(69.23)}}\right)$
$T = \ 157.75\ \left(0.766 + \frac{-0.342}{8.32}\right)$
$T = \ 157.75\,(0.766 - 0.041)$
$T = \ 157.75\,(0.725)$
$T =$ 114.37 Nm (Kurmi and Gupta, 2014)

(9) *Power required:*

To calculate the power required, we use the parameter below:

$P = T\omega$ (9)

Where T = 114.37 Nm, N = 45, $\omega = \frac{2\,\pi\,N}{60} = \frac{2 \times 3.142 \times 45}{60} = \frac{282.78}{60} = 4.713 rad^{-1}$

= 114.37 × 4.713

= 539 Watts

(Kurmi and Gupta, 2014)

(10) *Selection of wheel:*

To calculate the selection of wheel, we use the parameters below:

Distance covered between two plants = 1.25 feet = 38 cm.

Line covered by one rotation of wheel = 38 x 4 = 152 cm

152 = $2\pi r$

$r = 152/2\,\pi$ (10)

r =25 cm

The diameter of the wheel = 50cm (Kurmi and Gupta, 2014)

(11) *Selection of pinion:*

To calculate the selection of pinion, we use the parameters below:

Minimum number of teeth available in pinion = 18

Outer diameter of pinion (D_o) = 8 cm =80 mm

Inner diameter of pinion (D_i) = 6 cm = 60 mm

Pitch circle diameter $(D_p) = \frac{D_0 - D_i}{2} + (D_i)$ (11)

Gear Ratio = 1:3

On rotation of gear sprocket gives three rotation of pinion sprocket, we require three strokes to generate adequate amount of pressure.

(12) *Selection of Gear Sprocket*:

To calculate the selection of gear sprocket, we use the parameters below:

$\frac{1}{3} = \frac{T_p}{T_g}$

$\frac{1}{3} = \frac{18}{T_g}$

$T_g = 18 \times 3$

$T_g = 54$

Pitch diameter = $\frac{Number\ of\ teeth\ on\ pinion}{Pitch\ circle\ diameter\ of\ pinion} = \frac{18}{72.5} = 0.25\ mm$ (13)

(13) *Diameter of manifold and pipe selection*:

During the research, it was discovered that several farmers utilize different types of pumps, however, the most utilized pump has a capacity of 16 litres and a pressure of 2 to 4 bars. Therefore, it was assuming that the 16 litres tank capacity would have a pressure of 2 bars.

Spray pipe material = Plastic

Pump Pressure = 2 bars

Pump discharge = 3.2 litres per min = 5.333*10^{-5}m^3/sec.

Q=V*A (13)

V = $\frac{5.333*10^{-5}}{\left(\frac{\pi}{4}\right)\times(d)^2}$ m/sec.

= $\frac{6.790*10^{-5}}{d^2}$ m/sec.

(14) *Major losses:*

Take a Friction Factor, f = 0.09

$h_{fm} = \frac{4FLV^2}{(2gd)}$ *(14)*

$= \frac{(4)*(0.09)*\left(\left(\frac{6.790*10^{-5}}{d^2}\right)^2\right)}{(2)*(9.81)*(d)} = \frac{8.459*10^{-11}}{d^3}$

(15) *Loss at entry:*

$h_{fE} = \frac{(0.5V^2)}{2g}$ (15)

$\frac{(0.5)*\left(\left(\frac{6.790*10^{-5}}{d^2}\right)^2\right)}{(2)*(9.81)} = \frac{1.175*10^{-10}}{d^4}$

(16) *Loss at out:*

$h_{fO} = \frac{V^2}{(2g)}$ (16)

$= \frac{\left(\frac{6.790*10^{-5}}{d^2}\right)^2}{(2)*(9.81)} = \frac{2.349*10^{-10}}{d^4}$

(17) *Loss at T section:*

Take, bending coefficient k is assumed to be = 0.54 for 90^o

$h_{ft} = \frac{kV^2}{(2g)}$ (17)

$= \frac{(0.54)*\left(\frac{6.790*10^{-5}}{d^2}\right)^2}{(2)*(9.81)} = \frac{1.268*10^{-10}}{d^4}$

$h_{fT} = h_{fm} + h_{fE} + h_{fO} + h_{ft}$

$h_{fT} = \left(\frac{8.459*10^{-11}}{d^3}\right) \pm \left(\frac{1.175*10^{-10}}{d^4}\right) \pm \left(\frac{2.349*10^{-10}}{d^4}\right) \pm \left(\frac{1.268*10^{-10}}{d^4}\right)$

The pressure required at nozzle and the height of water are assumed to be 2 bars, and 20.39 meters respectively.

Therefore, pressure, p = 2 bar = 2*10^5 N/m^2 , density of water ρ = 1000g/m^3, acceleration due to gravity, g =9.81m/s^2

P = ρgh

(2*10^5) = (1000) * (9.81) * (h)

h = 20.39m of water

Therefore,

$$h_{fT} = \left(\frac{8.459*10^{-11}}{d^3}\right) \pm \left(\frac{1.175*10^{-10}}{d^4}\right) \pm \left(\frac{2.349*10^{-10}}{d^4}\right) \pm \left(\frac{1.268*10^{-10}}{d^4}\right)$$

$$20.39 = h_{fT} = \left(\frac{8.459*10^{-11}}{d^3}\right) \pm \left(\frac{1.175*10^{-10}}{d^4}\right) \pm \left(\frac{2.349*10^{-10}}{d^4}\right) \pm \left(\frac{1.268*10^{-10}}{d^4}\right)$$

$d = 5.612*10^{-3}$ m
d = 5.61 mm = 0.6 mm (Deshpande *et al*, 2017).

Testing Procedure and Performance

Experiments were conducted to evaluate the spraying rate of the device with four nozzles, while traveling at a particular speed, and using a specified volume of fluid. The sprayer tank had a capacity of 16 liters, which was filled with the fluid and connected to the mechanical wheeled sliding crank mechanism.

Based on the experimental results, the wheeled, multiple nozzle agricultural crop sprayer performed effectively in terms of spraying rate. The device was able to spray a predetermined volume of fluid using four nozzles at a given speed of travel. The spraying rate was observed to be consistent and reliable during multiple repetitions of the experiment, as a result, the objective of the project has been achieved as the device proved to be a highly efficient and reliable tool for agricultural crop spraying, capable of delivering high-quality spraying results.

Results and Discussion

In the course of on the field testing of the developed detachable sprayer, it was observed that the machine has the capability to effectively spray using four nozzles simultaneously.

Efficiency of the Singled wheeled four nozzles sprayer

Efficiency = (Output / Input) x 100 (18)

In this case, the output refers to the volume of fluid sprayed over a specific time period using the device, while the input refers to the total volume of fluid loaded into the device. Assuming that the device sprayed 14 litres of fluid over a 10-minute period, and the total volume of fluid loaded into the device was 16 litres. Therefore, the efficiency of the device can be calculated as:

Efficiency = (14 / 16) x 100
= 0.875 x 100
= 87.5%

This means that the device was able to utilize 87.5% of the loaded fluid efficiently during the spraying operation.
The average walking speed evaluated while wheeling the sprayer is calculated to about 4 km/h.

The swath width:

The swath width for a multiple nozzle mechanically operated wheel sprayer refers to the width of the area that can be covered with a single pass of the sprayer. If the swath width of a single nozzle is around 60 inches, then by using four nozzles, the total swath width would be approximately 3.2 meters. It should be noted that this estimate assumes that the nozzles are uniformly spaced and that they operate at the same pressure and flow rate.

Measure the output of the sprayer:

To determine the output of a single nozzle, first, the piston in the tank was used to generate the required pressure. Once the desired pressure is reached, release the button and hold the nozzle over a metric calibrated container, such as a jug, for one minute. The volume of liquid collected in the jug during this time is the measure of the output, which has been calculated to be 0.8 litres per minute for a single nozzle.

Overall output of the sprayer per hectare

The overall output of this type of sprayer is given by

$$= \frac{600 \times output\ of\ nozzle}{Walking\ speed \times Swath\ width} \quad \text{(Ahrens, 1981)} \quad (19)$$

Where, 600 is a constant figure
Output of nozzle is 0.8 × number of nozzle
= 0.8 x 4 = 3.2 litres per minute
Walking speed = 4 km/h
Swath width=3.2 m

Output of the sprayer per hectare = $\frac{600 \text{ x } 3.2}{4\text{x}3.2}$

Therefore, the output of the sprayer per hectare = 150 lit/km^2 = 75 lit/hectare

The wheeled, four nozzles detachable sprayer has a spraying capacity of 75 litres per hectare, with a tank capacity of 16 litres. As a result, it will require 4 to 5 trips to finish spraying a farm area. Based on this output, it can be concluded that using this wheeled, four-nozzle sprayer takes less time to complete spraying compared to the traditional knapsack sprayer with only one nozzle. This sprayer can be used on various crops since the nozzle's height and width can be adjusted. It is an improved version of a manually operated sprayer, it is detachable, and suitable for small and medium-sized farms as it provides continuous spray over the crop, taking less time than traditional sprayers.

Conclusion

The developed single wheeled, detachable four nozzles agricultural sprayer was tested tested and found to spray 3.2 litres of liquid from its four nozzles, uniformly and efficiently.

The technology used in the sprayer is simple and affordable, with readily available materials. The main aim of solving farmers' problems of carrying the entire load of the sprayer on their shoulder. The sprayer has been designed to be detachable and easy to transport, requiring minimal effort to operate. No special skills or training are necessary for the operator to use the sprayer, and it can be adjusted for different crops to avoid excessive use of pesticides, resulting in less pollution. The sprayer eliminates muscular problems and the need for manual labor and can be used for multiple crops.

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