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Design and Fabrication of a Bicycle Sprayer

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***Abstract**: The bicycle sprayer designed for crop spraying is a pragmatic and environmentally friendly choice for small-scale farmers, providing both effectiveness and long-term viability. Engineered to be attached on a regular bicycle, this device enables farmers to easily traverse fields and agricultural area with minimal physical effort. The sprayer features a 20-liter tank, suitable for small-scale farms, equipped with a slide-crank pumping system and a precision nozzle assembly to ensure efficient spraying. Made from lightweight and sturdy materials, it is both cost-efficient and highly portable. The rear wheel's rotation is converted into translation motion of the rod and pump by the use of a slider-crank reciprocating mechanism. The bicycle sprayer doubles as a mode of transportation for farmers or users traveling to and from the farm, enhancing its utility. The bicycle sprayer provides an environmentally-friendly option for small-scale farmers, enhancing crop productivity and minimizing the risks associated with liquid chemicals for farmers or operators. Based on the performance outcome, the recently created sprayer is capable of covering an area of one hectare in one hour. It demonstrates improved spray consistency and achieves a 75% efficiency rate, as confirmed through a sequence of tests conducted on specific farms*.

Keywords: *Bicycle Sprayer, Eco-friendly, Sustainability, Slider-crank Mechanism, Traditional Knapsack.*

1. INTRODUCTION

Despite its rich agricultural heritage and a significant rural population engaged in farming (approximately 35%), Nigeria's agricultural sector remains largely reliant on traditional, often outdated, techniques. While this sector contributes substantially to the national GDP, the persistence of these practices presents a significant obstacle to further development and economic growth. [1]. Effective utilization of agricultural tools is often hindered by challenges such as pest control, organic fertilizer and micronutrient application, and irrigation management. While plant conservation remains crucial for yield optimization, diverse biotic factors including fungi, bacteria, viruses, insects, mites, nematodes, weeds, rodents, and granivores significantly impact crop production efficiency across various geographical contexts. The detrimental effects of agricultural pests, resulting in substantial yield losses, constitute a major constraint on overall agricultural productivity [2 - 5]. Current fertilizer and pesticide application strategies present significant opportunities for improvement within the agricultural sector. Traditional spraying methods often require substantial time and resource inputs, raising concerns about sustainability and efficiency. Failure to address these deficiencies could contribute to declining farm yields, potentially leading to increased food prices, diminished affordability, and negative impacts on overall standards of living [6]. Within agricultural machinery, sprayers constitute a diverse category of implements employed for the targeted application of various substances essential for plant growth and protection. These include insecticides, herbicides, fertilizers, and water. Agricultural sprayers encompass a wide range of designs, sizes, and technological capabilities, catering to specific needs in terms of application area and crop coverage. From compact, handheld units for spot treatments to large-scale machinery capable of efficiently treating vast fields, these implements play a crucial role in modern agricultural practices [7].

While widely employed, knapsack sprayers present several limitations for modern agricultural practices. Notably, their manual operation demands significant physical exertion and time investment, particularly for covering large areas [8]. The pressure reservoir mounted on the operator's back necessitates continuous pumping with one hand while manipulating the nozzle with the other, leading to potential fatigue and musculoskeletal issues in the hands, back, and neck, especially during prolonged use [9]. Additionally, the extended spraying time associated with knapsack sprayers contributes to increased operational costs and potentially exposes operators to pesticide inhalation or ocular exposure. Furthermore, the trend of rural-urban migration contributes to a shortage of manual labour, exacerbating the challenges associated with knapsack sprayer use. While alternative options like two-wheel or tractor-mounted sprayers exist, their high cost and potential inefficiency render them unsuitable for small-scale farms [10 - 11].

The design and operational characteristics of agricultural sprayers significantly impact their overall performance, particularly their ability to deliver pesticides consistently and effectively. Traditional spraying methods have been estimated to waste between 50% and 80% of applied pesticides, highlighting the need for improved sprayer technologies and application strategies [12]. The identified limitations of traditional spraying methods, including inefficient application and significant pesticide waste, necessitated the development of improved sprayer technologies. This demand ultimately led to the invention of the two-wheel bicycle sprayer, colloquially known as the bicycle sprayer.

The bicycle sprayer presents a portable and adaptable spraying technology, characterized by an adjustable boom, a fluid reservoir, a chain-and-sprocket system, and a cam follower mechanism that converts rotational motion into reciprocating motion for pump operation. This allows for the retrofitting of any existing bicycle, offering a cost-effective and readily available platform. The sprayed solution is housed within a securely mounted tank on the bicycle frame. As the bicycle is propelled forward, the cam follower generates reciprocating motion for the pump, pressurizing the fluid in the tank. This pressurized liquid is then expelled as a mist through nozzles mounted on the adjustable boom. The bicycle sprayer offers several advantages, including energy efficiency, ease of operation and maintenance, and reduced footprint compared to conventional tractor-mounted sprayers. Additionally, its adaptability allows for a wider range of applications compared to other sprayer types [13]. The bicycle sprayer exhibits multifaceted functionality, acting as both a spraying apparatus and a transportation device. This adaptability contributes to its time and resource efficiency. Additionally, its design permits simple assembly and disassembly, enhancing its operational practicality [14].

The development of the bicycle sprayer for pesticides, fertilizers, and other agricultural inputs aims to mitigate or eliminate the negative impacts associated with traditional spraying methods prevalent in the country. This innovative design represents a potential paradigm shift in local farming practices.

2. MATERIALS AND METHOD

2.1 Materials

Material selection plays a crucial role in determining the performance, sustainability, environmental impact, and cost-effectiveness of a design, while simultaneously ensuring adherence to design goals. The choice of materials for individual components is guided by their specific functional requirements. This selection process considers various factors, including mechanical properties (e.g., strength, ductility, thermal conductivity), manufacturing constraints (e.g., machinability, weldability), material availability, and ultimately, cost. In this investigation, mild steel, cast iron, rubber, and plastic were selected as the primary materials based on a comprehensive evaluation of these criteria.

The basic components of the bicycle sprayers are listed as follows:

i. Bicycle frame: Serves as the core structural component of the bicycle, functioning as the integration point for all its subsystems. This framework facilitates locomotion by transmitting forces generated by the rider while maintaining sufficient rigidity to endure the dynamic stresses encountered during operation.
ii. Pump: The knapsack sprayer incorporates a positive displacement pump, typically employing a piston-cylinder configuration. This reciprocating pump mechanism operates independently of the crank lever. The crank lever, however, facilitates the actuation of the pump by translating the user's applied force into a reciprocating motion on the piston rod, thereby generating pressurization within the sprayer tank.
iii. Crank Lever: The crank lever mechanism serves as the key element for transforming the operator's rotary input on the lever into a reciprocating vertical motion of the connecting rod.
iv. Mist Nozzles: Function as specialized fluidic devices that exploit the principles of Bernoulli's equation to achieve the transformation of pressurized liquid into a finely atomized spray.
v. Tank: The tank’s main function is to carry the liquid in the tank during spraying.
vi. Tank Carrier: Serves as a load-bearing structure, typically fabricated in a rectilinear open-box configuration. Key design considerations during material selection for the carrier frame prioritize a balance between minimizing weight and maximizing structural integrity to ensure adequate strength under operational loading conditions.
vii. Bearing: Serves as a critical component within the system, facilitating the low-friction transmission of rotary motion. It achieves this by providing a precisely engineered interface between the rotating shaft and the stationary connecting pipe. This interface minimizes frictional losses, ensuring smooth and efficient rotational movement of the shaft.

2.1.1 Design considerations

The design of agricultural equipment, including the Bicycle Sprayer, incorporates components that can be adjusted to optimize performance for different operating conditions. This consideration aligns with the modern trend of adaptable machinery. The following factors were specifically prioritized during the development of the Bicycle Sprayer:

i. Targeted plant/crop types: The sprayer's design features and functionalities cater to the specific needs of different plant species or crop varieties.
ii. Crop growth stages: The sprayer's adaptability allows for adjustments to accommodate varying plant sizes and spray requirements throughout their growth cycle.
iii. Planting density and spacing: The sprayer's configuration and application methods are tailored to ensure efficient coverage within diverse crop planting arrangements

2.2.1 Operation of the machine

The Bicycle Sprayer operates through a human-powered, reciprocating pump mechanism. The rider's pedalling motion drives the rear wheel, which transmits rotational motion via a shaft or bearing to a lever arm. This lever arm converts the rotary motion into linear displacement, actuating a piston pump located within the fluid reservoir. During the upward stroke of the piston, a vacuum is created within the cylinder, drawing liquid from the reservoir. The downward stroke compresses the liquid, forcing it through a hose and out of nozzles. A control valve regulates the flow and atomizes the liquid for efficient spraying. By manipulating this valve, the operator can initiate, stop, or adjust the spray intensity.

2.2 Method

2.2.1 Design of the slider-crank linkage

i. Velocity of the pump/slider

In reciprocating piston pumps, optimal performance is critically dependent on the interplay between pump speed and stroke rate. Notably, the reciprocating components responsible for powering the pump are designed to rotate at twice the speed of the pump itself.

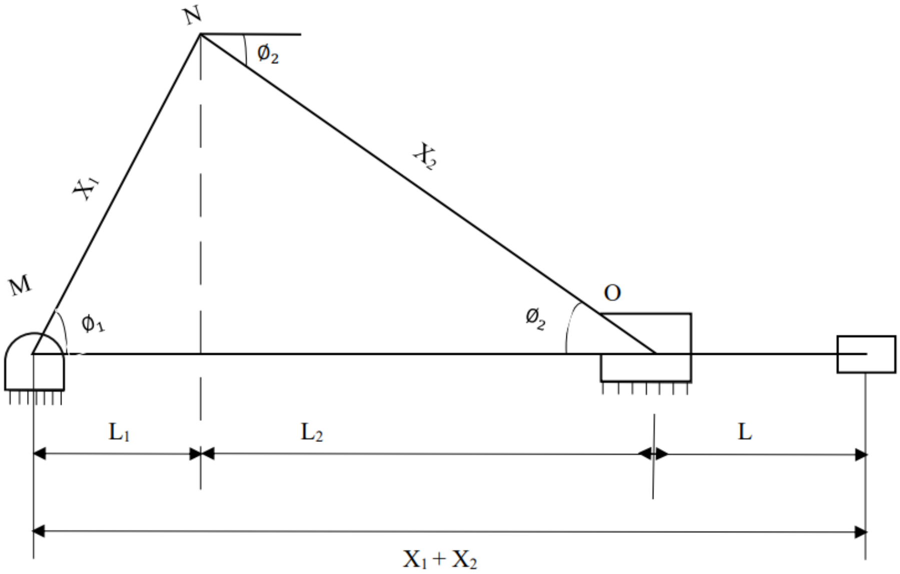

Figure 1: Free body diagram of the slider-crank.

Crank-slide mechanism parameters are;

x_1 is Length of the crank

x_2 is Length of the connecting rod

$\emptyset_1$ is the angle made by x_1 dispalcement

$\emptyset_2$ is the angle made by $x_2$dispalcement

L_1 is the adjacent length formed by $\emptyset_1$

L_2 is the adjacent length formed by $\emptyset_2$

L is the displacement of the slide

$$(x_1 + x_2) = \text{Total length between the slide and the crank} \quad (1)$$

$$L_1 = x_1 \cos \emptyset_1 \quad (2)$$

$$L_2 = x_2 \cos \emptyset_2 \quad (3)$$

$$L = (x_1 + x_2) - L_1 - L_2 \quad (4)$$

Assumed $\emptyset_1 = 45^0$ angle made by the displaced crank

$(x_1 + x_2) = 1010$ mm

Given $x_1 = 90$ mm

$x_2 = 920$ mm

$L_1 = x_1 \cos \emptyset_1$

$L_1 = 90 \cos 45$

$L_1 = 63.64$ mm

From Equation (4),

$L + L_1 + L_2 = (x_1 + x_2)$

$90 + L_1 + 63.64 = 1010$

$153.64 + L_1 = 1010$

$L_1 = 1010 - 153.64$

$L_1 = 856.36$ mm

From Equation (3),

$L_2 = x_2 \cos \emptyset_2$

$856.36 = 920 \cos \emptyset_2$

$\cos \emptyset_2 = 856.36/920$

$\emptyset_2 = \cos^{-1} 0.931$

$\emptyset_2 = 21.43^0$ (Angle made by the displacement of $L_{2.}$)

ii. Velocity of the crank

Crank Velocity $= V_1 = \omega_1 r$ (5)

$\omega_1 = \emptyset/t$ (6)

Where $\emptyset =$ The revolution per minute of the crank .

$t =$ time taken for a complete revolution

bicycle wheel average rpm = 25 – 30 rpm.

$\emptyset = 2\pi Rpm$

$\emptyset = 2\,\pi\,28 = 56\pi$

$\omega_1 = 56\pi/1 = 175.93$ rads^{-1}

From Equation (5)

$V_1 = \omega_1 r$

r = wheel radius = 310 mm = 0.31 m

$V_1 = 175.93 \text{ x } 0.31$

$V_1 = 54.54 ms^{-1}$

Crank Acceleration = 54.54/0.31 = 175.94 ms^{-2}

iii. Crank Acceleration

$\alpha = \omega_1{}^2 r$ (7)

$\alpha = 175.93^2 \text{ x } 0.31$

$\alpha = 9594.92$ ms^{-2}

iv. Angular velocity of the connecting rod

Calculating the connecting rod angular velocity, the below parameters are used:

$\omega_2 = (-x_1 \omega_1 \cos\emptyset_1)/x_1 \text{ Cos } \emptyset_2$ (8)

$\omega_2 = (90 \text{ X } 175.93 \text{ X Cos } 45)/1020 \text{ X Cos } 21.43 = 11.79$ rads^{-1}

v. Velocity of the Slide

$$V = (x_1\,\omega_1 \sin \emptyset_1 + x_2\,\omega_2 \sin \emptyset_2) \quad (9)$$

Where;

$x_1 = 90$ mm, $x_2 = 1020$ mm, $\omega_1 = 175.93\text{rads}^{-1}$, $\omega_2 = 11.79\text{rads}^{-1}$, $\emptyset_1 = 45^0$, $\emptyset_2 = 21.43^0$

$= (90 \text{ X } 175.93 \sin 45 + 1020 \text{ X } 11.79 \sin 21.43)$

$= 214.40 + 4393 = 4608$ mm/s.

$V = 4.6$ m/s.

vi. Slide acceleration

$$\alpha_2 = (x_1\omega_1{}^2\sin_{\emptyset 1} - x_1\alpha_1 \cos \emptyset_1 + x_2\omega_2{}^2\sin_{\emptyset 2})/x_2 \cos \emptyset_2 \quad (10)$$

$\alpha_2 = \{(90 \text{ X } 175.93^2 \text{ X } \sin 45) - (90\text{X } 9594.92 \text{ X} \cos 45) + (920 \text{ X } 11.79^2 \text{ X} \sin 21.43)\ \}/\{920 \text{ X } \cos 21.43\}$

$\alpha_2 = \{(90 \text{ X } 175.93^2 \text{ X } \sin 45) - (90\text{X } 9594.92 \text{ X} \cos 45) + (920 \text{ X } 11.79^2 \text{ X} \sin 21.43)\}/\{920 \text{ X } \cos 21.43\}$

$\alpha_2 = \{(1969732.8) - (610616.97) + (46724.16)\}/\{856.57\}$

$\alpha_2 = 1641.24 \text{ rads}^{-2}$

Linear acceleration $(a) = \alpha r$ (11)

Slider Radius $(r) = 0.055$m

Slider acceleration $= 1641.24 \text{ X } 0.055 = 90.3\text{ms}^{-1}$

vii. Loads on the bicycle (LOTB)

Point load on the bicycle (PLOTB) = Human weight (HW) + Total carrier load (TCL)
Average Human weight = 55kg
Total carrier load (TCL) = Carrier weight (CW) + Total tank weight (TTW).
Carrier weight (CW) = Weight of total angle steel length + Weight of the total square pipe length.
Angle steel unit meter weight = Unit meter weight of 40 x 40 x 3mm angle steel = 1.8kg/m.
Square pipe unit meter weight = Square pipe of 20 x 20 x 3mm = 2.51kg/m.
The angle steel total length used = 3.02m
Square Pipe total length used = 0.35m
Weight of the total angle steel length = unit meter weight x total length used = (1.8x3.02)
Weight of the total angle steel length = 5.436kg
Weight of the total square pipe length = unit meter weight x total length used = (2.51x0.35)
Weight of the total square pipe length = 0.8785kg

Carrier Weight (CW) = (5.436kg) + (0.8785kg)
Carrier Weight (CW) = 6.3145kg

Total Tank Weight (TTW)
TTW = Tank weight + Liquid weight
TTW = (5kg) + (20litres x 1kg) (Tank weight is according to manufacturer's specification)
TTW = (5kg) + (20kg)
Total Tank weight (TTW) = 25kg
Total carrier load (TCL) = Carrier weight (CW) + Total tank weight (TTW)
Total carrier load (TCL) = 6.3145kg + 25kg = 31.3145kg
Point load on the bicycle (PLOTB) = Human Load (HW) + Total carrier load (TCL)

= 55kg + 31.3145kg = 86.3145kg

Point Load in Newton = 86.3145kg x 9.81 ms^{-2} = 846.75N

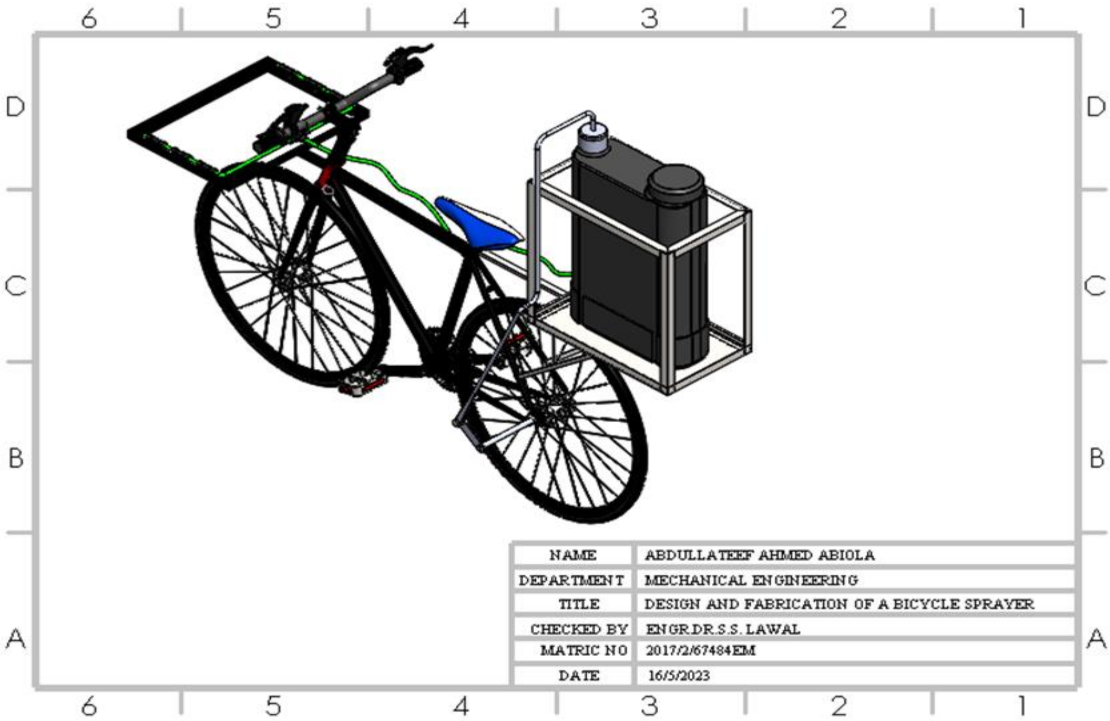

Figure 2: The isometric view of the Bicycle Sprayer

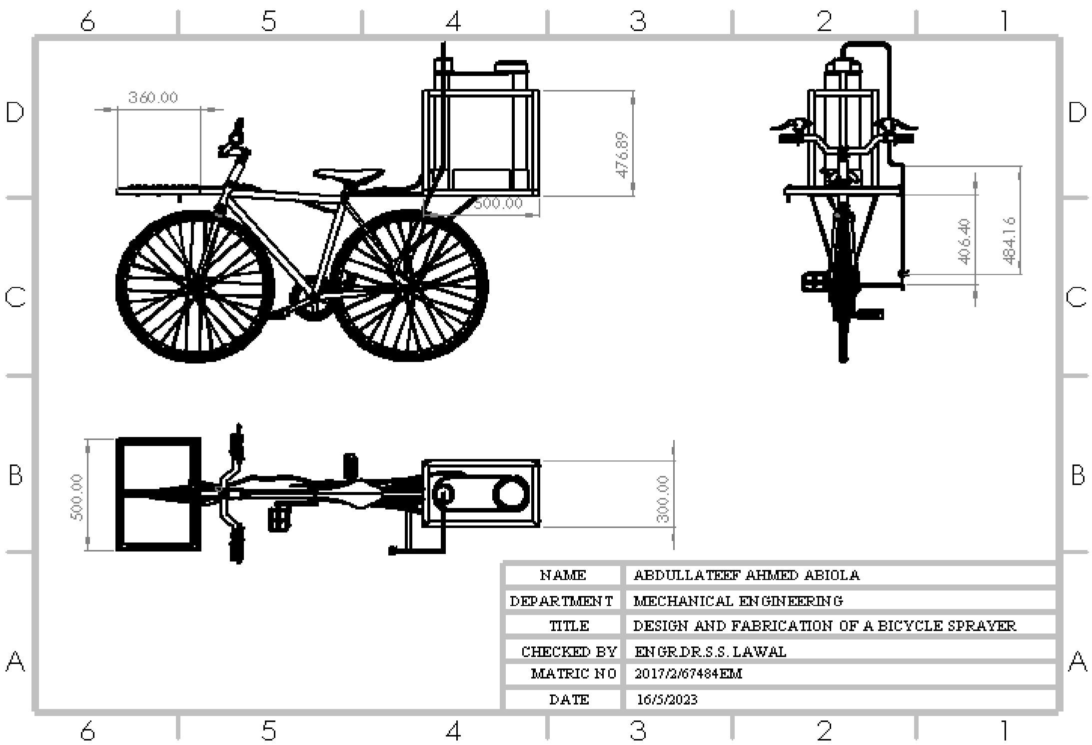

Figure 3: The bicycle sprayer orthographic view

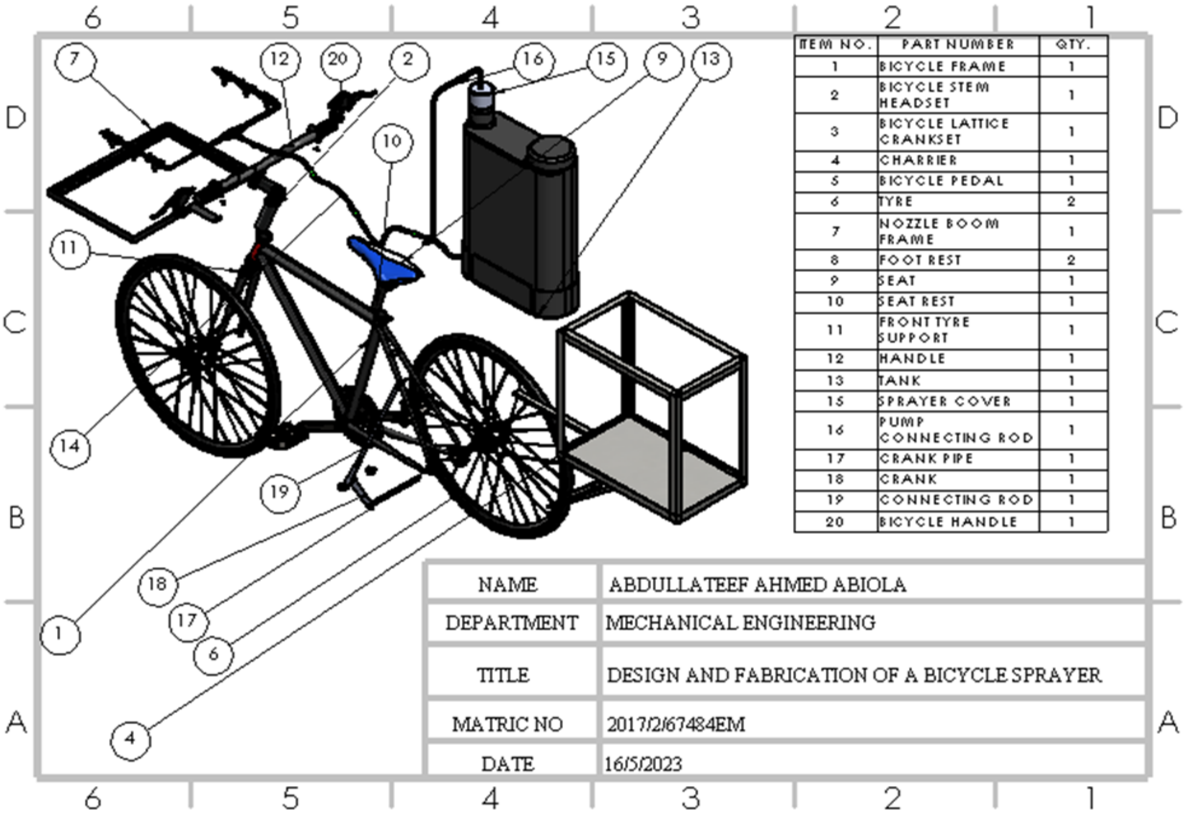

Figure 4: The bicycle sprayer exploded view

Figure 5: Model of the bicycle sprayer

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Performance and testing

Following its construction, the Bicycle Sprayer underwent field testing to evaluate its spraying performance under diverse conditions. A liquid mixture was utilized to simulate spraying material, and testing was conducted on farmlands with both flat and uneven terrain. While even and efficient spraying was observed on flat terrain, the uneven topography presented challenges to its operation. Nonetheless, the test results indicated the sprayer's effectiveness in delivering the target amount of liquid to crops with precise control over spray direction, minimizing waste, and maximizing coverage.

Field trials demonstrated the efficacy of the Bicycle Sprayer in achieving consistent delivery rates. Replicated tests confirmed its ability to dispense a predetermined volume of liquid through its nozzles while maintaining a set travel speed. These results suggest the sprayer's potential for accurate and reliable application in agricultural settings, potentially contributing to high-quality spraying outcomes.

Figure 6: Developed bicycle sprayer

3.1.2 Efficiency of the Bicycle Sprayer

The Bicycle Sprayer's efficiency was evaluated by calculating the ratio of its output to input, resulting in a 100% efficiency rating. Input refers to the volume of liquid mixture initially loaded into the tank, while output signifies the volume of liquid dispensed through the nozzles over a specific timeframe. During testing, the sprayer was filled to its maximum capacity of 20 litres and evaluated in three distinct locations.

i. **First test:**

Input = 15 litres
Output = 11 litres
Efficiency $(\eta_1) = (11/15) X\ 100 = 73.33\%$

ii. **Second test:**

Input = 15 litres
Output = 11.5 litres
Efficiency $(\eta_2) = (11.5/15) X\ 100 = 76.66\%$

iii. **Third test:**

Input = 12 litres
Output = 9 litres
Efficiency $(\eta_3) = (9/12) X\ 100 = 75.00\%$
The average efficiency is then calculated.
Efficiency $(\eta) = (\eta_1 + \eta_2 + \eta_3)/3$
Efficiency $(\eta) = (73.33 + 76.66 + 75)/3 = (224.99)/3$ = 74.99 = 75%

Field testing demonstrated the Bicycle Sprayer's efficient liquid utilization, with a 75% output-to-input ratio. This efficiency is attributed to the mist nozzle system, which facilitates extensive coverage while offering precise control over spray quantity and direction. Additionally, the sprayer's detachable design simplifies cleaning and maintenance, thereby minimizing downtime. Furthermore, the versatility of its multiple nozzles allows for the application of diverse mixtures in various quantities and patterns. Ultimately, the design and development process aimed to create a valuable agricultural tool that enhances yields and simplifies farm management, contributing to improved operational efficiency.

3.2 DISCUSSION

The Bicycle Sprayer represents a novel, manually operated spraying technology suitable for small to medium-scale farms. It offers several advantages over traditional sprayers, including continuous application across the crop area and reduced application time. Its adaptability allows for use on various vegetable crops, although limitations exist for plants exceeding the height of the bicycle's front wheel. The sprayer's efficiency stems from its multiple nozzles and the inherent speed achievable through cycling. It provides a spraying capacity of approximately 75 litres per hectare, despite having a modest tank capacity of 20 litres.

i. Limitations of the bicycle sprayer

a) Scalability and coverage: The Bicycle Sprayer's design focuses on small-scale applications and may not be suitable for larger farms or areas requiring extensive crop coverage. Its effectiveness will decrease with increasing field size and crop density.

b) Affordability: While designed to be cost-effective, the initial investment and potential need for additional equipment might present accessibility challenges for resource-constrained small-scale farmers, requiring further investigation into long-term cost comparisons with existing solutions.

c) Crop and environment versatility: The Bicycle Sprayer's performance may vary depending on crop type and field conditions. Further testing and adaptation might be necessary for optimization across diverse crop varieties and terrains.

d) Terrain limitations: Uneven or muddy terrain can significantly hinder the Bicycle Sprayer's manoeuvrability and spraying efficiency, limiting its applicability in such conditions.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The "Crank-Slider Mechanism" Bicycle Sprayer study presents a potentially valuable tool for small-scale farmers in remote locations with limited access to external power sources. Its fully mechanical design relies on readily available and affordable materials, potentially addressing the burden of manual pesticide application often faced by farmers. The project aims to minimize physical exertion during operation and requires minimal user training, promoting easy adoption.

Furthermore, the study proposes automating the pesticide spraying process to optimize labour efficiency and achieve uniform liquid distribution. Recognizing the critical need for user-friendly, effective, and affordable agricultural mechanization, particularly for pesticide and disease control equipment, the Bicycle Sprayer study seeks to contribute to improving the lives of small-scale farmers globally and potentially supporting sustainable agricultural practices. However, further research is necessary to rigorously evaluate its efficacy, usability, and economic viability under diverse conditions.

4.2 Recommendations

While the Crank-Mechanism Bicycle Sprayer demonstrates encouraging potential, several areas invite further exploration and development:

i. Enhanced terrain adaptability: Integrating rocker tires could improve obstacle clearance and maneuverability on uneven terrain, expanding the sprayer's operational scope.
ii. Increased coverage capacity: Enlarging the tank volume would extend the sprayer's operational range before refills, potentially enhancing efficiency.
iii. Precision spraying: Incorporating GPS and mapping technologies has the potential to improve spraying accuracy and minimize the risk of over- or under-application, maximizing chemical effectiveness and reducing environmental impact.
iv. Automated application control: Automated spray rate control could further enhance precision, minimizing the risk of excessive or insufficient chemical application, potentially leading to increased efficiency and reduced environmental impact.
v. Pressure management: Implementing a pressure relief valve in the pump cylinder could mitigate potential issues arising from increased pressure generation.

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