Wheel Spray Pump

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Abstract

This paper presents the design, fabrication, and performance evaluation of a low-cost, manually operated wheel spray pump developed for agricultural applications. Traditional spraying methods in agriculture, particularly for small to medium-sized farms, are often labour-intensive, inefficient, and pose health risks to operators due to direct exposure. The developed wheel spray pump aims to address these challenges by utilizing the rotational motion of a wheel to power a pumping mechanism, providing a continuous and uniform spray of pesticides, herbicides, or fertilizers. The project emphasizes simplicity in design, ease of operation, and affordability, making it a viable solution for farmers with limited access to powered machinery. This work, undertaken by final year diploma mechanical engineering students, highlights practical engineering principles applied to solve real-world agricultural problems.

Keywords: Wheel spray pump, agricultural sprayer, manual sprayer, mechanical design, farm equipment, sustainable agriculture.

I. INTRODUCTION

Agriculture is the backbone of many economies, and efficient crop management is crucial for food security. Among various agricultural practices, the application of pesticides, herbicides, and fertilizers is vital for protecting crops from pests and diseases and ensuring optimal growth. India, being a land of agriculture, comprises a significant number of small and marginal farmers. Around 65% of the population in the state depends on agriculture, and it provides 56% of the Indian workforce. The share of marginal and small farmers is around 81% and land operated is 44% as per 1960-61 data. Clearly, the maximum percentage of farm distribution belongs to the small and marginal category.

Small-scale farmers are very interested in manually lever-operated knapsack sprayers because of their versatility, cost, and design. However, these sprayers have certain limitations, such as difficulty in maintaining the required pressure, leading to operator back pain due to heavyweight. This equipment can also lead to misapplication of chemicals and ineffective control of target pests, resulting in loss of pesticides due to dribbling or drift during application. This phenomenon not only adds to the cost of production but also causes environmental pollution and imbalance in the natural ecosystem.

In contrast, traditional spray pumps often rely on electrical batteries or continuous manual lever operation for spraying pesticides. The proposed push-operated spray pump features a trolley with a specialized mechanism for translating rotary motion into reciprocating motion, which is then used to operate the pump lever. This system increases the pressure of pesticides, allowing them to be effectively sprayed. It is a device designed to sprinkle pesticides with minimal effort.

The limitations of conventional spraying equipment, such as their high cost, dependency on fossil fuels, and maintenance complexity, necessitate the development of simpler, more affordable, and efficient alternatives. This project focuses on designing and fabricating a wheel spray pump that leverages the forward motion of the operator to power the spraying mechanism. This innovative approach reduces manual labour, enhances spray uniformity, and offers an environmentally friendly solution by eliminating the need for external power sources or fuel. The handle is designed based on the height range of farmers, providing an ergonomic spraying session.

The primary objectives of this project were:

1. To design a mechanically efficient and ergonomically sound wheel spray pump.
2. To select appropriate materials for durability and cost-effectiveness.
3. To fabricate a working prototype using standard workshop practices.
4. To evaluate the performance of the developed sprayer in terms of spray coverage and ease of operation.

II. LITERATURE REVIEW

Existing agricultural sprayers range from simple hand-held devices to complex tractor-mounted boom sprayers. Manual knapsack sprayers are widely used due to their low initial cost, but they are limited by tank capacity, operator fatigue, and inconsistent pressure. Issues such as heavy weight leading to difficulty in lifting, fatigue due to prolonged use, and inconvenience caused by the large size of the pump are common. Poor selection and quality of equipment, combined with a lack of awareness and technical knowledge, inadequate maintenance, and poor field use, have led to unacceptable risks to the environment and human health.

Motorized sprayers, while more efficient, are expensive to purchase and operate, requiring fuel and regular maintenance, which can be prohibitive for small farmers. Motorized hydraulic knapsack sprayers can be sensible for high-value crops with multi-nozzle booms where prolonged manual pumping is not practical. Motorized mist blowers are used where the spray cloud needs to be projected vertically to treat trees, or horizontally for multi-row and bush crop spraying, and can also be adapted for granule application. Compression sprayers are necessary where field conditions make lever-operated machines impractical, such as on steep slopes and in dense crop foliage.

Research in agricultural machinery has focused on developing sustainable and efficient spraying solutions. Concepts like bicycle-mounted sprayers and push-cart sprayers have explored using human power for propulsion and spraying [1]. However, integrating the propulsion mechanism directly with the pumping action for continuous, uniform spraying often presents design challenges. This project aims to simplify this integration by directly coupling the wheel's rotation to a pump, thereby offering a novel approach to human-powered spraying.

A. About Pumps

The pump, at its recommended rotational speed, should have sufficient capacity to ensure that the sprayer operates efficiently when fitted with the largest recommended size of nozzles operating at the maximum rated pressure, plus an additional 20% to account for nozzle tolerances and to provide tank agitation. It should be possible to remove the pump from the sprayer without draining the tank(s). The pump should be permanently marked with maximum flow rate and operating pressure recommended and maximum rotational speed, name and address of manufacturer, model/type and year of manufacture.

B. Hand-Operated Sprayers

There are various types of hand-operated sprayers, broadly categorized into two groups:

1. **Sprayers with hydraulic nozzles:** Designed with systems to generate pressure at the nozzle to achieve correct atomization. With lever-operated sprayers, the main tank is not pressurized, but spray pressure is generated in a pressure chamber by constant pumping. With compression sprayers, the whole tank is pressurized prior to spraying. Diaphragm pumps are suitable and a durable option where applications are made through a single nozzle. They are also suitable for multi-nozzle booms where relatively low spraying pressures are adequate (1 bar). Piston pumps are suitable for single nozzle use and are preferred to diaphragm pumps for multi-nozzle use where higher pressures are required (up to 4 bars). Under-arm levers are preferred to over-arm levers except where crop conditions impede the movement of the lever.
2. **Rotary atomizers:** Generate spray droplets from a spinning disc or cup. These types typically apply low volumes of spray liquid per hectare. Low volumes mean that higher concentrations of spray liquid are applied, making them unsuitable for some products. They should never be used for parquet application as the concentrations are likely to exceed recommended dilution rates.

- Sprayer with centrifugal-energy nozzles
- Electrostatic spraying equipment
- Rope-wick herbicide applicators

Any sprayer carried on the back of the operator is called a knapsack sprayer. The commonly used manually operated knapsack sprayer will have one hydraulic pump working inside the container. The plunger works inside the replacement well attached at the bottom of the container, for easier maintenance.

III. DESIGN AND METHODOLOGY

The wheel spray pump is designed as a portable, push-type agricultural sprayer. The core principle involves converting the rotational motion of a ground wheel into reciprocating motion to drive a pump, which in turn draws liquid from a tank and delivers it to a nozzle for spraying.

A. Components

The main components of the wheel spray pump prototype are:

1. **Frame:** Constructed from mild steel square pipes, providing structural rigidity and supporting all other components.

- **Material:** Mild Steel (C.R.C.)

2. **Ground Wheel:** A standard bicycle wheel (20–26-inch diameter) is used, which provides the primary motive force.

- **Material:** Rubber (for tire), Metal (for rim/spokes)

3. **Power Transmission System:** A chain and sprocket mechanism (similar to a bicycle drivetrain) transmits power from the ground wheel to the pump. The selection of sprockets involves determining the required pump speed based on desired flow rate and pressure. For instance, if the ground wheel has T1 teeth on its sprocket and the pump shaft has T2 teeth, the gear ratio GR=T1 /T2 . A higher gear ratio would mean the pump rotates faster for each rotation of the ground wheel, potentially increasing pressure but requiring more effort from the operator. The gear

ratio is crucial for balancing effective spraying pressure with ease of pushing. This system utilizes a single slider crank mechanism for converting rotary to reciprocating motion.

- **Components:** Chain, Sprocket, Pulley, Crank, Shaft, Connecting Rod
- Materials: Crank (M.S.), Shaft (M.S.)

4. **Pump:** A small reciprocating (piston or diaphragm) pump is ideal due to its ability to generate sufficient pressure for atomization of the liquid and its relatively simple mechanical drive. Diaphragm pumps are often preferred for agricultural applications as they are less susceptible to damage from abrasive particles in the liquid and are generally more chemical-resistant. The pump's flow rate (e.g., 1−3 Liters/minute) and pressure (e.g., 2−5 bar) capabilities are key selection criteria, depending on the intended application and nozzle type. Compatibility with various agricultural chemicals (acidic or alkaline) is also a critical factor, influencing the choice of pump materials (e.g., rubber or synthetic diaphragms, stainless steel components).

- **Components:** Pump, Cylinder, Pressure Chamber
- **Materials:** Pump Cylinder (Brass), Piston Ring (Rubber), Pressure Chamber (Plastic)

5. **Liquid Tank:** A durable plastic tank (typically 10-20 liters capacity) to hold the spraying solution. It is securely mounted on the frame, ensuring stability during movement and preventing spillage.

- **Components:** Tank, Lid or Cap
- **Material:** Plastic (Polymer)

6. **Nozzle:** A spray nozzle, selected for its ability to produce a fine mist with a uniform spray pattern, essential for effective chemical application. Flat-fan or cone-shaped nozzles are commonly used in agriculture. The orifice size of the nozzle influences droplet size and spray angle.

- **Components:** Nozzle
- **Materials:** Nozzle (Plastic), Body & Cap (Brass/Engg. Plastic)

7. **Handlebar:** An ergonomic handle for pushing and manoeuvring the sprayer, designed to provide a comfortable grip and leverage.

- **Components:** Handle, Operating Lever

8. **Supporting Stand/Wheels:** Small caster wheels or a sturdy stand at the front to provide stability when stationary or for easier manoeuvrability, especially during turns.

- **Components:** Wheel (supporting)

9. Piping and Control:

- **Components:** Pipe, Hose nut, Hose nipple, Hose ferrule/clip, Hose, Valve, Suction Pipe, Delivery Pipe, Nozzle Support Pipe, Height adjustment pipe, Siphon, Bushing
- **Materials:** Pipe (Plastic), Hose nut (Brass), Hose nipple (Brass), Hose ferrule/clip (Steel), Hose (P.V.C.), Valve (Steel), Collar (Brass/Engg. Plastic)
- Cut-off Valves: Spring-activated (trigger control) or operated by means of a simple knob or trap.
- Extension Rod: Comes in varying lengths. For tree spraying, bamboo lances (brass stubs inserted into a hollow bamboo) are recommended.

B. Working Principle

When the operator pushes the trolley, the ground wheel rotates, and the pulley mounted on this wheel also rotates. This pulley is connected with another pulley by a V-belt. This second pulley is connected with a crank-slotted mechanism. This mechanism converts the rotary motion into reciprocating motion.

Due to the reciprocation of the piston, pressure develops in the hydraulic pump. In manual pump operation, this pressure is typically developed by oscillating the pump handle. With this mechanism, pressure can be easily developed in the pump continuously. The pressurized pesticide-water mixture then flows into the discharge line, and from there, it is expelled through the nozzle.

In simple terms, when the trolley is pushed, the wheel rotates, which in turn rotates the pulley connected via a belt to another pulley. This pulley then drives the crank, and thus the connecting rod oscillates on its fixed point, causing the pump piston to reciprocate. This action develops pressure inside the hydraulic pump, forcing the pressurized pesticide into the pump's discharge line. At the end of the discharge line, there is a cut-off valve by which the flow and pressure of the pesticide can be controlled.

The length of the discharge line is adjustable. By adjusting the position of the delivery pipe, the length of the discharge pipe can be increased or decreased. This allows for effective spraying regardless of the distance between crop rows. For instance, if the distance between two rows of plants is wide, the length of the discharge pipe can be increased to easily spray those rows. Conversely, if the distance is narrow, the pipe length can be decreased. This adjustability ensures effective pesticide application in varied field conditions.

C. Material Selection

Materials were selected based on availability, cost-effectiveness, strength, and corrosion resistance, considering the exposure to agricultural chemicals and outdoor conditions.

- Frame: Mild steel is used for the body parts. This material was chosen because it is more resistant to corrosion and allows for basic forming close to the end product's design. It provides a high strength-to-weight ratio, ease of fabrication (cutting, drilling, welding), and relatively low cost. It is then coated or painted for corrosion resistance.

- Tank: High-density polyethylene (HDPE) plastic is used for the product tank. Polymer materials typically have low densities and are chemically resistant, durable, lightweight, and impact-resistant, though generally not as stiff or strong as metallic and ceramic materials.
- Hoses: PVC or reinforced rubber, for flexibility, pressure resistance, and chemical compatibility with common agricultural sprays. Rubber is resilient and not easily corroded when in contact with water, making it a good material for tires and hoses.
- **Fasteners:** Galvanized or stainless-steel bolts, nuts, and washers are used throughout the assembly to prevent rust and ensure long-term structural integrity.
- **Bearings:** Standard ball bearings are used in the wheel hub and pump drive shaft for smooth operation and reduced friction.

D. Fabrication Process

The fabrication process involved several steps, predominantly utilizing basic workshop tools and techniques. Metal inert gas (MIG) welding was extensively used due to its ease of application and ability to produce good, clean weld surfaces.

1. Frame Fabrication: Mild steel square pipes are cut to precise lengths according to the design drawings. These pieces are then welded together using MIG welding to form the main frame structure, including mounting points for the tank, pump, and wheel axle. Care is taken to ensure all joints are strong and free from sharp edges.
2. **Power Transmission Assembly:** The larger sprocket is securely attached to the ground wheel's hub. The smaller sprocket is mounted on the pump's input shaft. The chain is then installed, and a tensioning mechanism (e.g., an idler sprocket or adjustable pump mount) is incorporated to maintain proper chain tension, preventing slippage and excessive wear.
3. **Pump and Tank Mounting:** The liquid tank is secured to the frame using brackets and straps, ensuring it is stable and accessible for filling and cleaning. The pump is mounted in a position that allows for efficient power transmission from the chain and easy access for maintenance.
4. **Plumbing:** Hoses are cut to length and connected between the tank outlet and pump inlet, and from the pump outlet to the spray nozzle. Inline filters are installed at the tank outlet to prevent clogging of the pump and nozzle. Quick-release couplings may be used for easier assembly and disassembly. A control valve is integrated near the handlebar to allow the operator to start and stop the spray.
5. **Handlebar and Supporting Components:** The ergonomic handlebar is attached to the main frame at a comfortable height for the operator. Small caster wheels are fixed at the front of the frame to enhance stability and manoeuvrability.
6. **Finishing:** All welded joints are ground smooth, and the entire mild steel frame is cleaned and then painted with a rust-inhibiting primer followed by a durable topcoat paint. This protects the frame from corrosion due to moisture and chemical exposure and improves the aesthetic appeal.

E. Prototype Photograph

The following photograph shows the fabricated prototype of the wheel spray pump.

Image 1: Wheel Spray Pump

F. Safety Considerations

Safety was a paramount consideration in the design. The enclosed chain and sprocket mechanism minimizes the risk of entanglement. The stable frame design prevents tipping. The operator's hands are kept away from the chemical stream by the long handle. Furthermore, the reduction in direct contact with chemicals (compared to knapsack sprayers) inherently improves operator safety. Proper warning labels for chemical handling would also be recommended for the final product.

G. Maintenance Aspects

The wheel spray pump is designed for minimal and easy maintenance. Routine maintenance includes:

- **Cleaning:** Thorough rinsing of the tank, hoses, and nozzle after each use to prevent chemical residue buildup and clogging.
- **Lubrication:** Regular lubrication of the chain and sprockets to ensure smooth operation and prevent rust.

- **Inspection:** Periodically checking all connections, hoses, and the pump for leaks or wear and tear. Replacement of worn-out components like diaphragms or seals in the pump would be a straightforward process.

IV. RESULTS AND DISCUSSION

The fabricated wheel spray pump prototype was tested for its operational feasibility and performance under simulated field conditions. Initial trials demonstrated that the sprayer could be easily pushed by a single operator, and the spraying mechanism functioned effectively, delivering a consistent spray.

A. Ease of Operation

The ergonomic design of the handlebar, positioned at an optimal height, and the smooth rolling action of the large ground wheel contributed significantly to the ease of pushing the sprayer across varied terrains typical of agricultural fields. Operator fatigue was notably reduced, especially over extended periods, as the weight of the tank is borne by the wheel, unlike carrying a knapsack sprayer. This allows for longer operational times and greater area coverage per session. Muscular problems are removed as there is no need to operate a lever continuously by hand.

B. Spray Efficiency and Coverage

The chain-driven pump provided a consistent flow rate and maintained stable pressure, resulting in a uniform spray pattern. This consistency is crucial for effective chemical application, minimizing wastage and ensuring adequate coverage of crops.

- **Flow Rate:** During trials, the pump delivered an average flow rate of approximately 2.5 Liters/minute at a consistent operator walking speed of 3 km/hr.
- **Pressure:** The spray pressure was maintained at around 3 bar, which is sufficient for effective atomization without excessive drift.
- **Coverage Width:** Initial observations indicated that a single pass covered a width of approximately 1.2 - 1.5 meters, depending on the chosen nozzle type and the operator's walking speed. This translates to an estimated area coverage of 360 - 450 m2/hour (approximately 0.036 - 0.045 Hectares/hour), which is a significant improvement over manual knapsack spraying.
- **Droplet Size:** The nozzle produced a fine mist, with estimated droplet sizes in the range of 150-250 micrometres, which is optimal for pesticide application to maximize adherence to plant surfaces and minimize runoff.

C. Comparison with Manual Spraying

The wheel spray pump offers several distinct advantages over traditional manual knapsack sprayers:

- **Reduced Labor:** Eliminates the need to carry heavy tanks on the operator's back, transferring the weight to the wheel, thereby significantly reducing physical strain and fatigue. The suggested model has removed the problem of back pain.
- **Increased Efficiency:** Allows for faster and more consistent coverage of larger areas due to continuous spraying and reduced operator exhaustion. An operator can cover more ground in less time. The suggested model has a greater number of nozzles which will cover maximum area of spraying in minimum time & at maximum rate.
- **Uniform Application:** The mechanical pumping mechanism ensures a more consistent pressure and spray pattern throughout the operation, leading to a more even distribution of chemicals and better efficacy. The c.f. valves can also be applied which help in reducing the change of pressure fluctuation and c.f. Valves helps to maintain pressure.
- **Safety:** Reduces direct chemical contact with the operator's body (back and shoulders) and minimizes inhalation risk as the operator is positioned behind the spray plume.

D. Limitations

During testing and design analysis, some inherent limitations were identified:

- **Manoeuvrability in Tight Spaces:** The overall length of the unit, while advantageous for stability, might make it challenging to manoeuvre in very small plots, closely spaced rows, or areas with dense, irregular obstacles.
- **Ground Clearance:** Obstacles or very uneven terrain could potentially interfere with the wheel or the lower parts of the frame, requiring operators to lift or navigate carefully.
- **Pump Selection:** The performance of the sprayer is highly dependent on the quality and specifications of the chosen pump. An under-dimensioned pump will lead to poor spray quality, while an oversized pump might make the unit too heavy or hard to push.
- **Dependent on Operator Effort:** While reducing fatigue, the continuous spraying still relies on the operator's physical effort to push the unit, which might be a limiting factor for very large farms.

E. Cost Analysis

One of the primary aim of this project was to develop an affordable solution. A preliminary cost analysis for the prototype fabrication indicated the following approximate costs (values are illustrative and subject to local market rates):

Component	Quantity	Estimated Cost (₹)
Main structure	01	1800
Wheel	01	300
Shaft	02	100
Chain	01	300
Fasteners	As per design	200
Sprocket	02	450
Bearing (ball)	-	40
Pump	01	2000
Nozzle	01	40
Pipe	01	130
Transportation	-	500
Lever	01	100
Wheel (supporting)	05	130
Valve	01	20
Crank	01	20
Total Estimated Material Cost		**6130**

Note: Fabrication labour costs are not included as this was a student project.

This cost analysis highlights that the wheel spray pump can be manufactured at a significantly lower cost compared to motorized sprayers, making it accessible to a wider range of farmers.

V. ADVANTAGES AND FUTURE SCOPE

A. Advantages

- **Cost-Effective:** Low manufacturing cost due to simple design and readily available, standard components, making it an economically viable option for small-scale farmers.
- **Eco-Friendly:** Operates purely on human power, eliminating the need for fossil fuels and thus reducing carbon emissions and operational costs related to fuel.
- **User-Friendly:** Simple mechanical design makes it easy to operate and maintain, even for farmers with limited technical knowledge, requiring minimal training.
- **Versatile:** Can be easily adapted for various agricultural chemicals (pesticides, herbicides, liquid fertilizers) and different crops by simply changing the nozzle.
- **Improved Safety:** Less direct contact with hazardous chemicals for the operator and reduced physical strain, leading to better long-term health outcomes.
- **Adjustability:** Proper adjustment facility in the model with respect to crop height helps to avoid excessive use of pesticides, which results in less pollution.

B. Future Scope

1. **Adjustable Nozzle Height Mechanism:** Incorporating a simple, quick-release adjustable mechanism for varying the nozzle height. This would allow the sprayer to be adapted for different crop heights (e.g., from ground-level vegetables to taller plants) and optimize spray coverage.
2. **Multiple Nozzles / Small Boom:** Designing an attachment for a small boom with two or three nozzles. This would significantly increase the spray coverage width per pass, further improving efficiency for larger fields. The suggested model with more nozzles will cover maximum area of spraying in minimum time & at maximum rate.
3. **Variable Speed Pump Control:** Exploring mechanical or simple gearing mechanisms (e.g., a multi-speed gear hub) to allow for varying pump speed based on the operator's walking speed. This would ensure a more consistent spray pressure regardless of the terrain or operator pace.
4. **Tank Capacity Optimization:** Designing for larger tank capacities (e.g., 25-30 litres) while rigorously maintaining the unit's stability and ease of movement, possibly by optimizing the weight distribution.

5. **Advanced Material Usage:** Investigating the use of lighter and stronger materials for the frame (e.g., aluminium alloys) to further reduce the overall weight, making the unit even easier to push and transport.
6. **Quantitative Performance Validation:** Conducting more detailed quantitative tests, including field trials across different crop types and terrains, to precisely measure spray pattern uniformity, droplet size distribution, area coverage per unit time, and chemical savings compared to traditional methods.
7. **Integration of Monitoring:** For more advanced versions, exploring simple, low-cost sensors to monitor tank level or basic pump pressure, providing feedback to the operator.
8. **Nozzle Improvement:** Using imported hollow cone nozzles in the field for better performance.

VI. CONCLUSION

The project successfully designed, fabricated, and tested a functional wheel spray pump for agricultural applications. This innovative approach demonstrates a practical and sustainable solution to the challenges faced by small and medium-scale farmers regarding efficient and safe chemical application. The prototype effectively addresses issues of labour intensity, uneven spray coverage, and operator exposure associated with traditional methods by leveraging human power through a simple mechanical system. The suggested model has successfully removed the problem of back pain by eliminating the need to carry the tank. It also offers increased coverage area and consistent pressure, contributing to reduced muscular problems as there is no need to operate the lever manually. As a final year diploma project, it showcases the ability of students to apply fundamental mechanical engineering principles, such as power transmission, fluid mechanics, and material selection, to develop an impactful solution for the agricultural sector, offering a significant improvement in efficiency and ergonomics at an affordable cost. This project serves as a strong foundation for further development towards a commercially viable and widely adopted agricultural tool.

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