UNIVERSITY OF NAIROBI

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

PROJECT NO. DMM 04/2015

PROJECT TITLE: DESIGN OF A HERBICIDE SPRAYER DRIVEN BY A TRACTOR PTO

FINAL YEAR PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING.

BY:

MADEGWA DENNIS MAGOMERE F18/1441/2010
KITAVI EUNICE MUMO F18/1450/2010

SUPERVISOR:
ENGINEER D. M. MUNYASI
DESIGN OF A HERBICIDE SPRAYER DRIVEN BY A TRACTOR PTO
DECLARATION
We declare that this project report contains our original work. To the best of our knowledge, this document details have not been presented in any other university for examination purposes.

Dennis Magomere Madegwa F18/1441/2010
Signature…………………………………………

Eunice Mumo Kitavi F18/1450/2010
Signature…………………………………………

Project Supervisor: Eng D. M. MUNYASI
Signature…………………………………………
DEDICATION
To our family and friends.
ACKNOWLEDGEMENTS

We would like to thank Almighty God for giving us grace, energy and knowledge throughout the project and undergraduate studies.

We greatly appreciate our project supervisor Eng D. M. Munyasi for his valuable guidance and support throughout the project research, analysis and writing the report. We also extend our sincere gratitude to Prof. Oduori and Eng. Nyangasi for their guidance and provision of useful materials for the project. Also we appreciate Technician Macharia from the department of Environmental and Biosystems Engineering for assisting us in field research and experiment.

Finally we thank our family and friends for their support and encouragement.
# CONTENTS

DECLARATION ........................................................................................................ iii
DEDICATION ........................................................................................................... iv
ACKNOWLEDGEMENTS ........................................................................................ v
ABSTRACT ........................................................................................................... viii
ABBREVIATION AND SYMBOL ........................................................................... ix

1.0 INTRODUCTION .......................................................................................... 1

1.1 BACKGROUND ............................................................................................ 1
  1.1.1 Selection and use of spraying equipments .............................................. 1
  1.1.2 Herb control methods ........................................................................... 1
  1.1.3 Spraying mechanisms ........................................................................... 2
  1.1.4 Application method ............................................................................... 3

1.2 Project justification ...................................................................................... 3

2 CHAPTER TWO .................................................................................................. 4

2.0 LITERATURE REVIEW ................................................................................ 4

2.1 BACKGROUND ............................................................................................ 4

2.2 COMMON SPRAYING METHODS ................................................................ 4
  2.2.1 Hand operated spraying ..................................................................... 4
  2.2.2 Powered spraying ............................................................................... 5

2.3 FACTORS AFFECTING PRODUCTIVITY .................................................... 9

2.4 SPRAYER COMPONENTS ............................................................................ 9

2.5 PROPOSED MACHINE DESIGN ............................................................... 16

2.6 CONCEPT DESCRIPTION ......................................................................... 16

3 CHAPTER THREE ............................................................................................. 18

3.0 MACHINE COMPONENTS DESIGN .......................................................... 18

3.1 DRIVES ...................................................................................................... 18
  3.1.1 Drive Design Considerations ............................................................... 18
  3.1.2 Advantages of belts drive over gear drives ......................................... 18

3.2 SYNCHRONOUS BELT ............................................................................. 20

3.3 SHAFT ......................................................................................................... 24

3.4 KEY ............................................................................................................. 27

3.5 TANK .......................................................................................................... 28

3.6 PUMP .......................................................................................................... 28

3.7 HERBICIDE DELIVERY SYSTEM ............................................................. 29
ABSTRACT

The control of competing vegetation is an important operation in the agricultural sector. Appropriate herbicide application can therefore be a cost effective weeding solution. Use of weed control is well established although manual methods of application still predominate. Manual methods are however tiresome and time consuming since only small amounts of chemicals are carried at a time.

In practice, farmers use tractors for cultivation, harvesting maize and sugarcane, shelling and threshing maize and wheat but hardly use them for spraying. This is because the sprayers that can be coupled to the tractor are expensive and rare to get.

In this project, a tractor PTO powered herbicide sprayer was designed using locally available materials and easy to fabricate.

It utilizes a tank around 400 litres made from High Density Cross Linked Polyethylene (XLPE). Chemical flows down from the tank through gravity to a 2 horsepower centrifugal pump which operates at 1450 rpm. This speed is achieved by stepping up speed of tractor PTO which operates at 540 rpm by use of synchronous belt through a shaft. From the pump the herbicide is pumped through appropriate piping to the valves then to the nozzles. The nozzles are made from stainless steel 1.5 meters apart and equally spaced along the boom. The system can be moved up and down by tractor hydraulics (tractor 3 point hitch) according to the size of the crops or the herbs.

The design also incorporated: synchronous belt drive of maximum pitch - 8mm, belt length - 1600mm, belt width - 20mm and center distance - 576 mm; belt pulley with small pulley pitch diameter - 80.16mm, 30 teeth/grooves and large pulley pitch diameter - 181.97mm, 80 teeth/grooves; Shaft of diameter - 14 cm made from 4140 cold rolled steel; Suction PVC piping of 2 inches and delivery PVC piping of 1.5 inches.

The design proposed here is cost effective, about kshs. 44,000 compared to available designs of ksh150, 000 to kshs 250,000. It can be used in different land terrains and it is user friendly. Its fabrication is simple and thus highly recommended.
ABBREVIATION AND SYMBOL

A – Area
V – Velocity
Q - Discharge
M - Bending moment at the point of force
d_o. Outer diameter
k - Ratio of inner to outer diameter of shaft.
F - Axial force (tensile and compressive)
α - Column action factor
k_b - Combined shock and fatigue factor applied to bending moment
k_t - Combined shock and fatigue applied to torsional moment.

σ_b – Stress
S_u - ultimate strength
S_y – yield strength
τ – shear stress
σ_a – Axial stress
F - Axial force (tensile and compressive)
α - Column action factor
k_b - Combined shock and fatigue factor applied to bending moment
k_t - Combined shock and fatigue applied to torsional moment.
TABLE OF FIGURES

Figure 2.1 knapsack hand sprayer .......................................................... 5
Figure 2.2 The tractor PTO ................................................................. 5
Figure 2.3 Tractor powered boom sprayer ........................................... 6
Figure 2.4 Aircraft sprayer: http://reveg-catalog.tamu.edu/05-Chemical.htm 7
Figure 2.5 Controlled Droplet Sprayer .................................................. 8
Figure 2.6 Boom tank ........................................................................ 10
Figure 2.7 Centrifugal pump ............................................................... 12
Figure 2.8 Nozzles ............................................................................ 13
Figure 2.9 Shaft .................................................................................. 15
Figure 2.10 Coupling ........................................................................ 16
Figure 3.1 belt design ......................................................................... 20
Figure 3.2 Synchronous belt and pulley dimensions ............................. 24
Figure 5.1 Shaft to be connected to the PTO and pump ...................... 40
Figure 5.2 picture showing the pump system enclosure and connection to the shaft 41
Figure 5.3 the tractor 3-point hitch that will host the pump and boom tank 41
Figure 5.4 The PTO point on the tractor .............................................. 42
Figure 5.5 Schematic diagram of simulation of the boom herbicide sprayer circuit of a centrifugal pump sprayer 43
CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND
Agriculture and to an extent of forestry play an important part in the economic growth in Kenya. According to the Ministry of Agriculture (2003), agriculture account for about 24 percent of the gross domestic income (GDP), as well as for 18 percent of wage employment and 50 percent of revenue from exports. These two sectors have however one major challenge facing it - herbicides.

Herbs and weeds attach themselves to roots of host plants and siphon nutrients and water intended for plant growth. This always leads to grain yield losses.

Several measures have been put in place to try and control the menace of the herbs and weeds. This is in the quest to improve crop generation and a high demand for food production.

1.1.1 Selection and use of spraying equipments
Spraying equipment should be selected on the basis of:
• Frequency of pesticide application,
• Availability of diluents (water, oil, kerosene, etc.),
• Availability of labour (human or animal power),
• Area requiring treatment,
• Characteristics of area (machine equipment for large areas, hand-operated equipment for smaller areas),
• Durability of equipment,
• cost of equipment,
• Availability of after sales service,
• operating cost, and
• Speed required treating an area (this will depend on type of crop, stage of crop growth, and volume of spray solution to be applied).

1.1.2 Herb control methods
Several ways have been put in place to control this. These include;

Traditional methods
• Uprooting and burning herbs before flowering
• Weeding
• Field sanitation
• Crop rotation
• Intercropping
• Organic matter usage
• Improved fallows
• Push-pull system

Modern methods

• Hand sprayers and atomizers
• Hand compressed sprayers
• Knapsack sprayers
• Tractor-mounted sprayer
• Motorized knapsack mist blowers
• Ultra low volume or controlled-droplet applicators (ULV/CDA)
• Fogging machines/fog air sprayers
• Hand-carried dusters
• Hand-carried granule applicators
• Power dusters
• Aerial application (Aircraft sprayers)
• Injectors and fumigation equipment.

The method employed mostly depends on the acreage of the farming land and farm inputs available. Big chunks of land will necessitate more convenient ways that mostly have to do with spraying of herbicide.

Although the use of herbicides is now well established in agricultural practice, manual methods of application still predominate. This applies well to small scale farming but becomes disadvantageous when it comes to large scale farming.

1.1.3 Spraying mechanisms

Sprayers are categorized according to the method by which the pressure is originated to force the liquid from any designated holding container. Commonly used type of spaying equipments includes;

• Hand-operated hydraulic sprayers (knapsack sprayers)
• Power-operated hydraulic sprayers (tractor-mounted sprayers)
• Air carrier sprayers (mist blowers)
• Electrodyne sprayers (electrostatic sprayers)
• Birky sprayers (Birky knapsack sprayers)
• Controlled-droplet application sprayers
• Dusters
1.1.4 Application method

Herbicide can be applied in a number of ways:

- Overall: application over the whole treatment area.
- Band: application in a band over or between crops
- Spot: application to an individual spot or around a crop
- Directed: application to hit a target weed and to avoid the crops

The majority of spraying equipment operated by the agricultural industry uses pressurized hydraulic (water based) spraying systems. This equipment can be used for;

- High volume application (HV): greater than 700 l/ha.
- Medium volume application (MV): 200 to 700 l/ha.
- Low volume application (LV): 50 to 200 l/ha.
- Very low volume application (VLV): 10 to 50 l/ha.
- Ultra low volume application (ULV): less than 10 l/ha.

1.2 Project justification

The objective of this project is to design a locally fabricated herbicide sprayer that is powered by a tractor power take off. This is in a view to boost the locally used methods that are manual based and thus enhance agricultural production. The machine is to provide the following advantages;

- High output rates.
- Suitable for large areas.
- Potential for reduced operator contamination.
- Improved operator ergonomics.
- Locally fabricated thus cheap on initial cost
- Save on man hours in large scale farming
- Saving on labour cost
- Improved efficiency and effectiveness
2 CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BACKGROUND

Agricultural production suffers severe losses from pests, plant disease and weeds. According to the data released by the Food and Agriculture Organization (FAO) of the United Nations and the ministry of Agriculture Livestock and Fisheries, pests and plant disease annually destroy one-fifth of the world’s agricultural produce, Kenya included. In a properly organized system, crop protection therefore is one of the most important means of increasing productivity of agricultural operations.

Current methods of plant protection fall in five categories; chemical, biological, agronomical, mechanical and biophysical.

Chemical methods of plant protection differ from others in their universal applicability and effectiveness with relativity low expenditure of labour and material. For these reasons they have come into widespread use.

The various methods of plant protection are complementary thus require a judicious blend of chemical, agronomical, biological and other methods. In certain cases occurring on large scale, it is necessary to destroy the pests and herbs on the large scale in the shortest possible time. In such cases, the use of chemical agents is the only recourse to save the crops.

Thus, in terms of suitability and effectiveness for eradication of pests and disease on the large scale, the chemical method is the principal method and, in certain cases, the only available method of crop protection.

2.2 COMMON SPRAYING METHODS

2.2.1 Hand operated spraying

These sprayers are the most widely used. They are small and compact. They include knapsack sprayers, compression sprayers, hand sprayers, and shoulder-slug compression sprayers which are lever-operated (piston/diaphragm type). Liquid is drawn through a valve into a pump chamber with the first stroke. When the lever returns to its original position, the liquid in the pump chamber is forced past another valve into a pressure chamber. The valve between the pump and the tank is closed during this operation to prevent the return of the liquid into the tank. A good seal between the pump and cylinder is obtained by a ‘cup washer’ or ‘O’ ring. As liquid is forced into the chamber, air is trapped in a part of the pressure chamber and compressed. This forces the liquid from the pressure chamber through a hose into the nozzle.
2.2.2 Powered spraying

Refers to typical large scale sprays usually 15 – 100 gallons. Could be low pressure, which is suitable when spraying a dry sub area or high pressure.

With power spraying, the source of power is either an electric or gasoline engine. The power can be transmitted to the pump by belts and pulleys, chains and sprockets, power take off assemblies, or direct drive. In all cases, the liquid is ejected by the action of a pump through hoses or wands and finally through a nozzle or through a group of nozzles. The most commonly used type of pumps are the centrifugal, gear and piston pumps.
Air Carrier Spraying

Involves a portable air carrier sprayers whereby light weight, two-stroke engine airplanes are used. The fan in these sprayers produces a high velocity air stream which is diverted through a 90° elbow to a flexible discharge hose. The most common nozzle fitted in these sprayers is the shear nozzle (gaseous energy nozzle). Air is drawn into the fan at a high speed and discharged through a flexible tube in which a liquid flow nozzle is mounted. As the high velocity air stream passes over the nozzle, it makes the emerging liquid break into droplets which then enter the air stream and are sprayed.

It is suitable for aerial spraying over large areas of any land terrain.
Birky sprayer

The Birky knapsack sprayer is the first low volume (LV) spinning disc sprayer which does not require batteries. The need to apply herbicides at very low volumes gave rise to this sprayer.

The spinning disc of the Birky sprayer is driven by air supplied by a pneumatic pump to a turbine. Since it has no batteries, it reduces spraying cost.

Controlled-droplet Application (CDA) Sprayers

These sprayers apply the correct size and uniform droplets on a given target area so that optimum use is made of the spray volume and dosage. It is a logical extension of the ultra low volume (ULV) concept.

To avoid contact with the spray, the drift operator must walk progressively up-wind across the field through non treated crops. The sprayer is held either with the handle across the front of the operator's body or over his shoulder, with the disc above the crop pointing downwind. The spinning disc is normally held 1 m above the crop. It may be necessary to hold it lower while spraying the first swath along the leeward side of a field in order to reduce the chemical's drift outside the treated area.
Electrodyne Sprayer (Electrostatic Sprays)

The functioning of the electrodyne sprayer is based on a system which atomizes and propels charged droplets of chemical spray by electrical forces set up between a nozzle with a positive high voltage charge. Since the charged droplets are readily deposited on the crop, the total deposit on the foliage can be significantly increased compared to uncharged sprays. The liquid herbicide is poured into a bottle and fed by gravity to the nozzle, where it picks up charged droplets (positive charges) generated by batteries. The liquid leaves the nozzle in a number of uniform ligaments which break up into electrically-charged droplets. The positively charged droplets move along curved electrical field lines towards and around the plants, covering the visible as well as hidden surfaces. The size of the droplets range between 20 and 200 microns.

Dusters

They are used for distributing dust formulations. They may be manually or power operated. Machines used for applying dusts mainly consist of a hopper (dust chamber) with an agitator, an adjustable orifice or other metering mechanism, and delivery tubes. Examples of dusters include; tree duster, row crop duster, all purpose duster, self propelled duster and motorized knapsack sprayer-cum-dusters.
2.3 FACTORS AFFECTING PRODUCTIVITY

A number of factors influence the work rate of herbicide spraying;

• **Speed of the prime mover;** This is in turn influenced by ground conditions which affect boom stability, turbulence and deposition, especially as speed increases.

• **Boom width;** Increasing the width of the application strip reduces the number of passes required to cover an area thus increasing the productivity of the sprayer. However, it is more difficult to keep wider booms level and at the correct spraying height.

• **Spray management systems;** Within defined parameters, travelling speed can be matched to site conditions, which can improve output in easier travelling conditions.

• **Spray volume;** Using low application rates will reduce the frequency and duration of re-filling, increasing productivity. However, lower-volume application rates may reduce efficacy in some conditions.

• **Availability of water;** A system for supplying the required water volume at the site is essential for refilling efficiency.

• **Tank capacity;** The dimensions of the tank are limited by the space available and the load capacity of the prime mover.

• **Maintenance;** The length of breaks during spraying.

2.4 SPRAYER COMPONENTS

Tank

The tank should have sufficient capacity to enable an extended period of spraying, reducing the frequency of refilling. It should have a sight gauge (and preferably a cab-mounted tank level gauge) so that diluents level can be assessed. The lower section of the tank should have a sump to ensure that the herbicide mixture (or water with direct injection systems) is directed to the delivery system without interruption. An agitator should be used to maintain the homogeneity of the mix. The tank should also be partitioned with baffles to reduce liquid surge, which will improve machine stability and reduce the creation of foam caused by mixture agitation. Tank protection and design should be adequate to prevent if the vehicle overturns. In our design, the tank is of 400 litres volume made from High Density Cross Linked Polyethylene (XLPE).
Control Valves

These valves are used to control and limit pressure and to control flow volume and direction. They are vital to a proper functioning sprayer. Relief valves limit maximum pressure of the sprayer and prevent damage. In addition to limiting pressure, the unloader valve unloads the pump (full flow at low pressure) to save energy and wear when the sprayer is idling and not calling for sprayer discharge. Throttling valves are used to control the amount of flow volume and boom selector valves control the active section of the sprayer boom. Flow control valves are available as manual or as electric valves. A constant pressure at a specified setting is an indicator that the sprayer system is working satisfactorily. The operator should therefore be able to read the pressure gauges and operate the control valves from inside the cab. The sprayer must be calibrated before the start of operations, checking the variables of swathe width (controlled by height) and travelling speed. Travelling speed is affected by site conditions and spray management control systems should be adjusted so that the flow of herbicide matches this speed.

Pump

The pump must be reliable and resistant to corrosion caused by herbicides. It should have an output capacity 20% to 25% higher than that required, so that it is not working at maximum capacity, which can lead to accelerated wear and overheating. These pumps are positive displacement pumps. They are self-priming, require automatic (spring loaded) bypass valve to control the pressure and to protect the equipment against mechanical damage if the flow is shut off. The recommended types for sprayers are;

1.) Piston or plunger pumps
   - Well suited for high pressure operation
   - More expensive than other types
   - Durable

Figure 2.6 Boom tank

http://www.ebay.com/bhp/boom-sprayer
2.) **Rotary pumps**
   - Suitable for low-pressure operation
   - Relatively inexpensive
   - Can be operated at suitable speeds for direct connection to tractor PTO

3.) **Centrifugal pumps**
   - High speed
   - High volume
   - Relatively cheap
   - Low pressure
   - Manufactured without any reduction gear arrangement

4.) **Others include**

   **Pneumatic pumps**- compress air in a hermetically sealed reservoir with the working fluid. Their components do not come into contact with the working fluid and work at high pressures

The Table below summarizes the pump characteristics

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>DIAPHRAM</th>
<th>PISTON</th>
<th>CENTRIFUGAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure(bar)</td>
<td>40</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>Maximum flow rate(l/min)</td>
<td>360</td>
<td>80</td>
<td>500</td>
</tr>
<tr>
<td>Relative durability</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Relative cost</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Displacement where used</td>
<td>Positive</td>
<td>Positive</td>
<td>Not positive</td>
</tr>
<tr>
<td>Formulation types</td>
<td>All</td>
<td>Not wettable powers</td>
<td>All</td>
</tr>
</tbody>
</table>

Filters

Filters are essential to trap unwanted particles and help prevent nozzles and pumps becoming blocked. They are usually situated at several different points in the spraying system: at the filler opening, on the suction line; between the pump and the pressure regulator or in the nozzle body. Filter aperture size is between 0.08 mm and 1 mm (20 to 200 mesh – the number of openings per linear inch). Larger filters are installed downstream from the pump, and become increasingly fine nearer the nozzles. Nozzle filters should have smaller openings than the nozzle orifices themselves.

Nozzles

Nozzle function and fitting
Nozzles play an important role in herbicide delivery. A number of nozzles are available for a range of spray patterns, flow rates and pressures to match site and application variables. It is always advisable to check that nozzle type is suitable for the product, crop and target application rate. The size and arrangement of the nozzles, the form of the spray pattern and the operating pressure will determine the size of droplets, trajectory, coverage and rate of application. The number and characteristics of nozzles must be matched to the capacities of the sprayer pump and tank. Nozzles can be made of stainless steel, brass or plastic. Nozzle wear can be identified by an increase in flow rate, often indicated by a slight drop in system pressure and a deterioration of the spray pattern. Nozzles should be changed when their flow rate (compared with new) increases by 10%.
Nozzle types

All nozzles are designed to give a set spray pattern and droplet size at a particular pressure and working height. The hydraulic pressure nozzle is the most commonly used type. It is designed to receive a pressurized flow of herbicide and to deliver the herbicide in a set spray pattern, which then breaks into a defined range of droplets. Other nozzle types such as the rotary atomizer, which produces a controlled droplet size, and the twin fluid nozzle, which incorporates air into the droplets, are also used.

Nozzles most commonly used on boom sprayers are:

Flat Fan Nozzles

Flat fan nozzles are used widely for broadcast spraying of herbicides and some insecticides. Spray droplets form a flat fan shape as they leave the nozzle. Because the fan shape has a tapered edge with less spray material at the outer edges, adjacent fan patterns must be overlapped to give uniform coverage. For maximum uniformity, fan overlap must be approximately 30%–50% at the target point. Nozzles are usually spaced 50 cm apart on the boom. The usual pressure is 0.1 to 0.4 Mpa. Lower pressures produce large droplets and reduce drift. Higher pressures produce the opposite.
**Even Flat Fan Nozzle**

The even flat fan spray nozzle is similar to a regular flat fan nozzle but applies spray materials uniformly across the entire pattern rather than tapering off at the edges. These nozzles are used mainly for banding herbicides over row crops and have spray angles of 40±, 80± or 95±. This nozzle is not suitable for broadcast applications.

**Flooding Fan (Deflector) Nozzle**

Flooding fan nozzles produce a wide-angle, flat spray pattern and are used for applying herbicides and chemical fertilizer mixtures. Their wide angle (110± –130±) allows wide spacing on the boom and lower boom height. Their large orifices produce large droplets and so reduce drift and clogging. They give best results in a pressure range of 0.07–0.25 MPa. The pattern is not as uniform as that of regular flat fan nozzles, and the width of the pattern changes more with pressure than it does with the regular flat fan. Coverage uniformity is improved when the nozzles are mounted to give 100% overlap (100% overlap is double coverage, i.e., each nozzle spray reaches to the center of each adjacent nozzle). Nozzle discharge may be directed at any angle from straight down to straight back.

**Hollow Cone Nozzle (Disc and Core Type)**

The hollow cone nozzle produces the second of the basic spray patterns, with the liquid concentrated on the outside edge of a conical pattern. Hollow cone nozzles usually are used to apply insecticides or fungicides to crops when penetration or complete coverage of the leaf surface is important. Drift potential is high with this nozzle because the droplets are very small. These nozzles usually operate from 0.25–1.0 MPa, depending on the nozzle type and the material being applied. The nozzle consists of a disc and a core that can be easily changed. The core gives the fluid a swirling motion before it is metered through the disk orifice, which results in the hollow cone pattern. Disc and core nozzles do not produce a uniform distribution for broadcast application and are better suited to banding or directed spraying.

**Full Cone Nozzles**

The full or solid cone is the third of the basic spray patterns. The nozzles produce a swirl and a counter swirl inside the nozzle that result in a full cone pattern. Full cone nozzles produce large, evenly distributed droplets and high flow rates. A wide full cone tip maintains its spray pattern through a range of pressures and flows. It is a low-drift nozzle, often used to apply soil-incorporated herbicides.

**Pneumatic Nozzles**

Pneumatic nozzles differ from hydraulic nozzles in that they combine two fluids, air and spray solution. Each fluid has a separate circuit that controls pressure and flow rate independent of the other fluid. The two fluids are combined inside a special tip. By proper choice of control pressures, one pneumatic nozzle can emit a wide range of flow rates and droplet sizes. It requires a number of hydraulic nozzles to equal the discharge range of one pneumatic nozzle. To retrofit
an existing sprayer with pneumatic nozzle requires additional air lines, an air compressor, controller and expense.

**Rotary Nozzles**

The rotary nozzle or *controlled droplet applicator* (CDA) has been used for years in aerial application but is a relatively new device for ground applications. The rotary nozzle atomizes the spray by using a rotating spinner and centrifugal force rather than forcing material through a hydraulic orifice. Rotary nozzles are of two basic types: the spinning disc, or cone, suitable for low flow, and the spinning cage or screen basket, used for flows of 0.5 dm$^3$/min or greater. An attractive feature of the rotary nozzle is that it forms relatively uniform droplets. This controlled droplet size minimizes drift and evaporation of the small droplets, and because there are few large droplets, reduces chemical loss from runoff and ineffective placement. The droplet size depends on the rotational speed of the spinning cone or disc. 2000 n/min produces droplets of approximately 200$\mu$m. Higher speed produces smaller droplets. By controlling the droplet size, the nozzle can be used to apply insecticides, herbicides, fungicides or growth regulators.

Nozzle flow rate is a function of nozzle type, orifice size and pressure.

**Shaft**

A *shaft* is a component of mechanical devices used to transmit rotational motion and power, usually of circular cross section. It provides the axis of rotation, or oscillation, of elements such as gears, pulleys, flywheels, cranks, sprockets, and the like and controls the geometry of their motion.

It is integral to any mechanical system in which power is transmitted from a prime mover, such as an electric motor or an engine via a power take off, to other rotating parts of the system.

*Figure 2.9 Shaft*

*Courtesy of Upper Kabete Campus, Department of Environmental and Biosystems Engineering*
Coupling

Coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power. Couplings do not normally allow disconnection of shafts during operation, however there are torque limiting couplings which can slip or disconnect when some torque limit is exceeded.

The primary purpose of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both. By careful selection, installation and maintenance of couplings, substantial savings can be made in reduced maintenance costs and downtime.

![Coupling Image](http://www.directindustry.com/prod/ktr/flexible-shaft-couplings-pump-14739-425470.html)

**Figure 2.10 Coupling**


2.5 PROPOSED MACHINE DESIGN

In the backdrop of the above available methods, it is proposed to design a method that will provide more convenience to the end user, locally available, ease in maintenance and use and that can be easily fabricated.

The proposed design is one which unlike the machinery available can be of use both in small scale and large scale farming. The fabrication is to be done using the local manpower and materials. This will enhance herb control thus leading to better crop production.

2.6 CONCEPT DESCRIPTION

The design is to be powered by a tractor PTO- power take off. They are available but under-utilized in spraying. The design provides ease of assembly and operation especially when it
comes to large scale farming. The sprayer can be adjusted according to the height of the crops since it has hydraulic energy system.

In general the proposed mechanism will be powered by the tractor power take off which will rotate a horizontal shaft driven at a speed of 540rpm. Owing to the available pumps in the market, this speed will be stepped up to 1450rpm by means of synchronous belts. The herbicide will be stored in a boom tank and then it flow to the pump through gravity. From the pump the chemical will be channeled to the nozzles via pipes under pressure. The planting has to be done in rows keeping in view track width of the tractor. It is suitable for use when the crop is small. The boom sprayer can be adjusted according to the height desired using the tractor 3 point tractor hitch. Fixed to the piping will be a pressure relief valve and pressure gauge to control the amount of pressure to the nozzles.

The sprayer essentially consists of a tank which is made of High Density Cross Linked Polyethylene, pump assembly, suction pipe with strainer, pressure gauges pressure regulators, air chamber, delivery pipe, spray boom fitted with nozzles and agitation system. The complete sprayer is mounted on 3-point linkages of the tractor and it uses high pressure and high discharge pump.

The concept design has the following components amongst others to be designed;

- Shaft
- Pumping system
- Piping system
- Control system
- Nozzles
- Boom tank
- Agitation system
3 CHAPTER THREE

3.0 MACHINE COMPONENTS DESIGN

3.1 DRIVES
There are several drives that are used to transmit power from, for example, motor or tractor PTO and to increase or reduce speed. These include; belt, chain and gear drives. They have several advantages and the choice of a drive depends on its application.

3.1.1 Drive Design Considerations
The design to deliver the required power from the tractor PTO will take into consideration the following basic objectives:
• Cost (initial price, replacement cost, total cost of ownership)
• Performance (speed, torque, power, acceleration)
• Efficiency (mechanical and electrical)
• Size, weight and space limitations
• Geometry (center distance, layout)
• Precision and accuracy
• Noise and vibration
• Environment (temperature, contaminants, etc.)
• Reliability and service life
• Customer satisfaction

3.1.2 Advantages of belts drive over gear drives
• Belts provide a wide power range (speed x force), making them a viable option in a wider range of applications.
• Belts offer higher operational speed and with nearly no speed variation and no backlash.
• Belts provide a wide range of available reductions, greatly expanding motor configuration options and enabling optimal motor selection for a given application.
• Belts are extremely quiet throughout their speed range.
• Belts offer a low acquisition cost and no routine maintenance.
• Synchronous belts with their high modulus tensile cords minimize dynamic elongation providing positioning accuracy of .002” to 0.15” for motion control applications. Belt re-tensioning is not necessary unless the motor has been removed or adjusted.
• Belts are highly resistant to abrasion and many corrosive substances.
• When properly installed, synchronous belts offer a near constant 98% efficiency over their useful life.
In addition, gears suffer the following disadvantages:

- Gears require periodic lubrication, a time consuming process requiring a significant amount of machine downtime.
- Gears wear and gear lubrication breaks down. Gear failure results in locking up the transmission and therefore the actuator, or stripped gears which allows the transmission to freewheel.
- Gears wear over time increasing backlash and noise. This wear also can create slack in the system that negatively impacts machine performance. This gradual wear ultimately reduces productivity.
- Although some cycloidal gears approach 97% efficiency, most gears are only 85 – 90% efficient. Some, such as worm gears, are as little as 60% efficient. Lower efficiency means more torque; and therefore, more power is required to perform the same amount of work.

From the above analysis, belts are the best for our sprayer mechanism. Examples of belt drives are; flat-belt drives, round belt drives and wedge belt drives. A belt drive transmits power between shafts by using a belt to connect pulleys on the shafts by means of frictional contact or mechanical interference.

Table 3.1 Comparison of belt performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flat belt drive</th>
<th>V belt drive</th>
<th>Wedge belt drive</th>
<th>Synchronous belt drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum efficiency</td>
<td>98%</td>
<td>80%</td>
<td>86%</td>
<td>98%</td>
</tr>
<tr>
<td>Maximum speed (m/s)</td>
<td>70</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Minimum pulley diameter(mm)</td>
<td>40</td>
<td>67</td>
<td>60</td>
<td>16</td>
</tr>
<tr>
<td>Maximum speed ratio</td>
<td>20</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Optimum tension ratio</td>
<td>2.5</td>
<td>5</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>

Reproduced from Hamilton, 1994
From the above comparison, synchronous belt drives are the best suited for our design because they have high efficiency, offer high power transmission due to accurate positioning in a compact drive envelope (no slippage).

### 3.2 SYNCHRONOUS BELT

![Belt Design Diagram](image)

**Figure 3.1 belt design**

#### DESIGN

1. Drive requirements
   a.) Driving machine : PTO via shaft
   b.) Rotational speed of the driven and driving machine
      - PTO 540 rpm
      - Pump 1450 rpm
   c.) Power capability
      - Pump 2 HP
   d.) Required: drive centre distance and machine shaft diameters

2. Design power
   Service factor, (from tables - appendix 1) for medium duty under 10hrs/day = 1.3
   
   \[ \therefore \text{Design power} = 1.3 \times 1.49 \text{ kw} \]
   
   \[ = 1.937KW \]

3. Belt pitch
   Pitch selection chart shows intersection of 1450 rev/min and 1.937 KW to be within the capability of 8 mm pitch. (Appendix 3)
4. Speed ratio

\[ \frac{1450}{540} = 2.67 : 1 \]

From tables (appendix 2)

5. Number of grooves on
   Driving pulley = 30
   Driven pulley = 80

6. Centre distance = 576 mm

\[
\theta_d = \pi - 2 \sin^{-1} \frac{D - d}{2C}
\]

\[
\theta_d = \pi - 2 \sin^{-1} \frac{0.18197 - 0.08016}{2 \times 0.576}
\]

\[ = 169.86^\circ \]

\[ = 2.965 \text{ rad} \]

\[
\theta_P = \pi + 2 \sin^{-1} \frac{0.18197 - 0.08016}{2 \times 0.576}
\]

\[ = 190.14^\circ \]

\[ = 3.319 \text{ rad} \]

Belt length

\[ L = \sqrt{4C^2 - (D - d)^2} + \frac{1}{2} (D\theta_P + d\theta_d) \]

\[ L = \sqrt{4 \times 0.576^2 - (0.18197 - 0.08016)^2} + \frac{1}{2} (0.18197 \times 3.319 + 0.08016 \times 2.965) \]

\[ L = 1.568 \text{ m} \]

The standard belt length available is 1600mm.

7. Power rating and belt width

Power rating for a 30 groove shows a value of 8.89 KW at 1450 rev/min for a 20 mm wide belt
Belt length factor for a 1600 mm belt = 0.90
Belt length factor × the table rating for 30 grooves gives

\[ \times 0.9 \times 8.89 = 8.001 \text{ KW} \]

Required belt width factor = \( \frac{\text{design power}}{\text{length corrected power rating}} \)

= \( \frac{1.937}{8.001} = 0.2421 \)

\( \therefore \) Next larger standard width factor for 0.2421, we use 1.00

Therefore belt width = 20mm (from appendix 3)

Mass of one belt is given by, \( m = A \times L \times \rho \)

Taking density, \( \rho = 1200 \frac{kg}{m^3} \) and \( 2\beta = 40 \) (from Shigleys Table 17-9)

\[ \text{mass, } m = 1200 \times 1.6A \]

= \( 1920A \)

Centrifugal tension in the belt is given by, \( T_c = mv^2 \)

\[ T_c = 1920A \times 125.44 = 240,844.8A \]

Maximum tension in the belt, \( T = \sigma \times A \)

The allowable stress, is 5.0 MPa

\( \therefore T = 5 \times 10^6 A \text{ MPa} \)

Tension on the belt on the tight side, \( T = T_t - T_c \)

\[ T_t = 4.759A \text{MPa} \]

Tension in the lower belt, \( \frac{T_t}{T_s} = e^{ue_{\alpha}} = 5 \)

\[ T_s = \frac{4.759 \times 10^6}{5} = 951,831.04 \text{ A} \]

Power transmitted, \( = 11000 = P = (T_t - T_s)V \)

\[ 11000 = (4.759 \times 10^6A - 951,831.04 A) \times 11.2 \]

\[ A = 258mm^2 \]

8. Shaft sizes

This is chosen from the information we have from the tables
30-8M-30  pitch diameter - 81.49,
Outside diameter- 80.16
Pulley type – 2F
Bush number 1615

80-8m- 30  pitch diameter - 203.72,
Outside diameter- 181.97
Pulley type – 9
Bush number 2517

The 30-8M-30 pulley uses a 1615 Taper lock bush. Maximum bore 42

The 80-8m- 30 pulley uses a 2617 Taper lock bush. Maximum bore 60

Final drive specification;

PTO –shaft pulley  80-8m- 30 HTD pulley
Pump pulley  30-8M-30 HTD pulley
Belt  8 Max pitch – Belt length – 1600mm

<table>
<thead>
<tr>
<th>Width</th>
<th>20mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre distance</td>
<td>576 mm</td>
</tr>
<tr>
<td>Groove angle</td>
<td>40</td>
</tr>
<tr>
<td>Length</td>
<td>1600mm</td>
</tr>
<tr>
<td>Coefficient of friction</td>
<td>0.2</td>
</tr>
<tr>
<td>Allowable tensile stress</td>
<td>5Mpa</td>
</tr>
</tbody>
</table>
### 3.3 SHAFT

The PTO system has a female coupling on one end and a male fitting on the opposite end. The female end is coupled to the male end of the application. The PTO system acts like an extension adaptor, with the male end replicating the female end of the application. The torque and speed signals are transmitted from the shaft to a static cover assembly.

General considerations we will use in the shaft design are:

1.) To minimize both deflections and stresses, the shaft length should be as short as possible and overhangs minimized.
2.) A cantilever beam will have a larger deflection than a simply loaded one for the same length, load and cross section. Straddle mounting is the better option but our shaft is will be a cantilever loaded due to design constraints.

Two methods have been adopted in shaft design:

- **Design based on strength,**
  Here, design is carried out so that stress on any location of the shaft should not exceed the material yield stress. However, no consideration for shaft deflection and shaft twist is included.

- **Design based on stiffness,**
  Basic idea on design based in such case depends on the allowable deflection and twist of the shaft.

The stress at any point depends on the nature of loading acting on it,

The stresses which may be present are as follows;

**Basic stress equation,** $\sigma_p = \frac{32M}{\pi d_o^3(1-k^4)}$

---

*Figure 3.2 Synchronous belt and pulley dimensions*
Where; \( M \) = Bending moment at the point of force
\( d_o \) = Outer diameter
\( k \) = Ratio of inner to outer diameter of shaft.

K=0 for solid shaft like our case. Thus our equation reduces to

\[
\sigma_b = \frac{32M}{\pi d_o^3}
\]

Axial stress, \( \sigma_a = \frac{4\alpha F}{\pi d_o^3(1-k^2)} \)

Where; \( F \) = Axial force (tensile and compressive)
\( \alpha \) = column action factor

Design of the shaft mostly uses maximum shear stress theory. It states that a machine member fails when the maximum shear stress at a point exceeds the maximum allowable shear stress for the shaft material.

Therefore,
\[
\tau_{max} = \tau_{allowable} = \sqrt{\left(\frac{\sigma_k}{2}\right)^2 + t_{xy}^2}
\]

ASME design code

The shafts are normally acted upon by gradual and sudden loads. Hence the equation is modified in ASME code by suitable load factors.

The shaft equation considering the above thus can be simplified to;

\[
\sigma_b = \frac{32M_{eq}}{\pi d^3}
\]

Where;
\[
M_{eq} = \frac{1}{2} \left[ M_b + \sqrt{M_b^2 + M_t^2} \right]
\]

Material used for the shaft is 4140 Annealed Cold Roll steel whose \( S_{ut} \) is 650 Mpa and \( S_{yt} \) is 450 Mpa

Tractor power for a required of the PTO at 540 rpm is 11Kw

\[
M_t = \frac{60 \times Kw \times 10^6}{2\pi n}
\]

\[
M_t = \frac{60 \times 11 \times 10^6}{2\pi \times 540}
\]
Calculating the reaction on the pulley,

\[ M_t = (T_t - T_s) \times \text{Radius of belt pulley} \]

\[ M_t = (T_t - T_s) \times 40.08 = 194522.708N/mm^2 \]

But \[ T_t = 5T_s \]

\[ \therefore T_s = 1213.13N \]

\[ T_t = 6066.7N \]

Net vertical force = 7279.83 N

For this design there is a key way hence permissible shear stress is reduced by 25%.

\[ \tau_d = \frac{16}{\pi d^3} [(k_b M_b)^2 + (k_t M_t)^2] \]

Where; \( k_b = \) combined shock and fatigue factor applied to bending moment

It is equal to 1.5 for gradually applied loading

\( k_t = \) combined shock and fatigue applied to torsional moment.

\( k_t \) is equal to 1 for gradually applied loading

Thus

\[ \tau_d = \frac{16}{\pi d^3} [(1.5M_b)^2 + (M_t)^2] \]

The value for \( \tau_d \) for 4140 Annealed cold roll steel shaft material is 400Mpa.

Factoring the reduction due to key ways this value reduces by 25% thus becomes 300Mpa.

Calculating for \( M_b \)
The bending moments, $M_b$

$$1.5 R_b = 7279.83 \times 0.2$$

$$R_b = 1455.97 \text{ N}$$

But, $R_a + R_b = 7279.83N$

$$R_a = 5823.86 \text{ N}$$

Bending moment,

$$= 1.5 \times 1455.97$$

$$= 2183.95N\text{m}$$

From,

$$M_{eq} = \frac{1}{2} \left[ M_b + \sqrt{M_b^2 + M_t^2} \right]$$

$$M_{eq} = \frac{1}{2} \left[ 2183.95 + \sqrt{2183.95^2 + 194522.708^2} \right]$$

$$M_{eq} = 98361.66$$

From,

$$\sigma_b = \frac{32 M_{eq}}{\pi d^3}$$

$$320 \times 10^6 = \frac{32 \times 98361.66}{\pi d^3}$$

$$\therefore d = 0.0975 \text{ m}$$

Diameter of the shaft will be 10 cm

### 3.4 KEY

For standard keys, according to IS: 2292 and 2293-1974 (Reaffirmed 1992).

Proportions of standard Parallel Tapered and Gib head keys.
3.5 TANK
It is a 400 litres tank made from High Density Cross Linked Polyethylene (XLPE). Its outer surface ensures maximum protection through molecular bonding. It’s rigid ensuring maximum protection from any leakage. It is resistant to chemical reaction and has a sight glass to monitor the level of the chemical solution. Water flows from the tank through gravity to suction pipe.

3.6 PUMP
The pump used is a centrifugal pump of 1450rpm and 2 horsepower.

From appendix 5, a pump of 1450 rpm has a discharge of;
\[66 \text{m}^3/\text{h}=0.01833 \text{ m}^3/\text{s}=18.33 \text{lters/s}\]
3.7 HERBICIDE DELIVERY SYSTEM

3.7.1 PIPING

The objective of piping design is to come up with the right pipe work fabrication and installation design that will deliver the right amount of herbicide. Of importance in the piping design are the following:

- Flow rate
- Pressure
- Pipe material
- Pipe dimension

The optimum pipe size is based on minimizing the sum of energy cost and piping cost. However, velocity limitations causing erosion or aggravating corrosion need to be taken into consideration. Sometimes, the line size must satisfy process requirements such as pump suction line. Although pipe sizing is mainly concerned with pressure drop, sometimes for preliminary design purposes when pressure loss is not a concern, process piping is sized on the basis of allowable velocity. When there is an abrupt change in the direction of flow (as in elbow or tees), the local pressure on the surface perpendicular to the direction of flow increases dramatically. This increase is a function of fluid velocity, density and initial pressure. Since velocity is inversely proportional to the square of diameter, high velocity fluids require special attention with respect to the size selection.

Material selection
First it is important to establish the fluid flowing and its effects on the type of material selected. The fluid is 97% water with the herbicide chemicals taking the least percentage. The most convenient material would be PVC pipe schedule 120 for delivery pipe and PVC schedule 80 for suction.

3.7.1.1 Suction Piping
Water flows to suction pipe from tank through gravity. The pipe chosen is PVC with the following properties:

- Strong and rigid
- Resistant to acids, alcohols and many other corrosive materials.
- Excellent physical properties and flammability characteristics.
- Low cost of ownership.
- Superior flow characteristics
Ideally, the flow entering a pump inlet should be of a uniform velocity distribution, without rotation and stable over time. Undisturbed flow is achieved by making the pipe length short. In summary, pump inlet piping should:

- Supply an evenly-distributed flow to the pump (the ideal approach is a straight pipe)
- Have suction pipe at least as large as the pump suction
- Have maximum liquid velocity = 8 ft/sec
- Be sized to provide sufficient NPSH Margin to the pump.
- Inject any pump bypass piping sufficiently upstream of the pump

From tables, for a 1450 rpm centrifugal pump, the range of flow output would be 8-205 m$^3$/hr. in our design we choose to work with 10 m$^3$/hr. The thickness should be enough to withstand the high pressure.

The suction pipe properties equally apply for the delivery pipes.
For the delivery pipes we choose PVC schedule 80 which is advantageous because they are light, tough and provide exceptional corrosion resistance. This high quality engineered thermoplastic results in substantial savings and continuing maintenance cost. It is rated to handle temperatures upto 140F. The pressure rating is 120 PSI to 1230 PSI = 827 Kpa – 8480 Kpa.

Flow velocity

\[ v = \frac{\pi \times Q}{3600 \left(\frac{d}{2}\right)^2} \]

From the table on appendix 5, the pipe will have the following dimensions

- Maximum pressure rating = 400 PSI = 27.58 bar
- Nominal pipe size (inch) = 2
- Outside diameter, = 2.375” = 60.325mm
- Wall thickness, (mm) = 0.218”= 5.5372mm
- Average internal diameter = 1.913” = 48.5902mm

\[ \therefore \text{velocity} = \frac{\pi \times Q}{3600 \left(\frac{d}{2}\right)^2} \]
\[ = \frac{\pi \times 10}{3600 \times (24.295 \times 10^{-3})^2} \]
\[ = 14.78 \text{ m/s} \]

**Bursting pressure**

It’s based on Barlow’s Formula
The safety factor of our pipe design using Barlow’s formula ranges from 1.5-10. We worked with a safety factor of 3.

The estimated length of the suction pipe is 2m, 2 inch nominal diameter and a pipe bursting pressure of 31.8 bar.

**Table 3.2 PVC Pipe Schedule 80**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot;</td>
<td>.405</td>
<td>.195</td>
<td>0.095</td>
<td>0.063</td>
<td>1230</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>.540</td>
<td>.282</td>
<td>0.119</td>
<td>0.105</td>
<td>1130</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>.675</td>
<td>.403</td>
<td>0.126</td>
<td>0.146</td>
<td>920</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>.840</td>
<td>.526</td>
<td>0.147</td>
<td>0.213</td>
<td>850</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>1.050</td>
<td>.722</td>
<td>0.154</td>
<td>0.289</td>
<td>690</td>
</tr>
<tr>
<td>1&quot;</td>
<td>1.315</td>
<td>.936</td>
<td>0.179</td>
<td>0.424</td>
<td>630</td>
</tr>
<tr>
<td>1-1/4&quot;</td>
<td>1.660</td>
<td>1.255</td>
<td>0.191</td>
<td>0.586</td>
<td>520</td>
</tr>
<tr>
<td>1-1/2&quot;</td>
<td>1.900</td>
<td>1.476</td>
<td>0.200</td>
<td>0.711</td>
<td>470</td>
</tr>
<tr>
<td>2&quot;</td>
<td>2.375</td>
<td>1.913</td>
<td>0.218</td>
<td>0.984</td>
<td>400</td>
</tr>
<tr>
<td>2-1/2&quot;</td>
<td>2.875</td>
<td>2.290</td>
<td>0.276</td>
<td>1.500</td>
<td>420</td>
</tr>
<tr>
<td>3&quot;</td>
<td>3.500</td>
<td>2.864</td>
<td>0.300</td>
<td>2.010</td>
<td>370</td>
</tr>
<tr>
<td>3-1/2&quot;</td>
<td>4.000</td>
<td>3.326</td>
<td>0.318</td>
<td>2.452</td>
<td>350</td>
</tr>
</tbody>
</table>


### 3.7.1.2 Delivery piping to nozzles

The pipe needed for delivery of the herbicide has similar material properties. The pressure being transmitted however is more and as such the material is to have superior properties than the suction pipe due to high pressure involved. Considering this, the chosen pipe is PVC pipe schedule 120 whose properties are:
- High pressure corrosion resistant
- Can be used at temperatures up to and including 140°F
- IPS sizes 1/2" through 8"
- Pressure rating (380 psi to 1010 psi)
- Generally resistant to most acids, bases, salts, aliphatic solutions, oxidants, and halogens
- Pipe exhibits excellent physical properties and flammability characteristics
- Schedule 120 heavy wall dimensions provide sufficient wall thickness

From the graph for PVC pipe schedule 120, a pipe with the following dimension was chosen.
Nominal pipe size (inches) = 1.5
Outside diameter, inches = 1.9" = 48.26
Internal diameter, inches = 1.423" = 36.1442mm
Wall thickness, Inches = 0.225" = 5.715mm
Maximum working pressure, = PSI 540= 37.23 bar

Using continuity equation,

\[ Q_1 = Q_2, \text{ this implies that } Q = V_1A_1 = V_2A_2. \]

The discharge from the pump is 18.33 litres/min [from graph; appendix 5] of internal diameter 36.1442mm [pvc schedule 120]
So,

\[ 0.01833 = V_2 \times \pi \times \left( \frac{36.1442}{2} \times 10^{-3} \right)^2 \]

\[ V_2 = 17.86 \text{ m/s} \]

This delivery pipe takes the chemical to control valve from which the delivery system is subdivided into three pipes of one inch each which deliver to nozzles.

\[ Q = V_3A_3 \]

\[ 0.01833 = V_3 \times \pi \times \left( \frac{22.6314}{2} \times 10^{-3} \right)^2 \times 3 \]

\[ = 15.189 \text{ m/s} \]

**Bursting pressure**

It’s based on Barlow’s Formula

\[ P = \frac{2st}{d_oSF} \]

\[ = \frac{2 \times 52 \times 10^6 \times 5.715 \times 10^{-3}}{48.26 \times 10^{-3} \times 3} \]
Table 3.3 PVC Pipe-Schedule 120

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2&quot;</td>
<td>.840</td>
<td>.480</td>
<td>0.170</td>
<td>0.236</td>
<td>1010</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>1.050</td>
<td>.690</td>
<td>0.170</td>
<td>0.311</td>
<td>770</td>
</tr>
<tr>
<td>1&quot;</td>
<td>1.315</td>
<td>.891</td>
<td>0.200</td>
<td>0.464</td>
<td>720</td>
</tr>
<tr>
<td>1-1/4&quot;</td>
<td>1.660</td>
<td>1.204</td>
<td>0.215</td>
<td>0.649</td>
<td>600</td>
</tr>
<tr>
<td>1-1/2&quot;</td>
<td>1.900</td>
<td>1.423</td>
<td>0.225</td>
<td>0.787</td>
<td>540</td>
</tr>
<tr>
<td>2&quot;</td>
<td>2.375</td>
<td>1.845</td>
<td>0.250</td>
<td>1.111</td>
<td>470</td>
</tr>
<tr>
<td>2-1/2&quot;</td>
<td>2.875</td>
<td>2.239</td>
<td>0.300</td>
<td>1.615</td>
<td>470</td>
</tr>
<tr>
<td>3&quot;</td>
<td>3.500</td>
<td>2.758</td>
<td>0.350</td>
<td>2.306</td>
<td>440</td>
</tr>
<tr>
<td>4&quot;</td>
<td>4.500</td>
<td>3.574</td>
<td>0.437</td>
<td>3.713</td>
<td>430</td>
</tr>
<tr>
<td>6&quot;</td>
<td>6.625</td>
<td>5.434</td>
<td>0.562</td>
<td>7.132</td>
<td>370</td>
</tr>
<tr>
<td>8&quot;</td>
<td>8.625</td>
<td>7.189</td>
<td>0.718</td>
<td>11.277</td>
<td>380</td>
</tr>
</tbody>
</table>


3.7.2 NOZZLES

The nozzle performs three functions on the sprayer:
- regulates flow;
- atomizes the mixture into droplets;
- Disperses the spray in a specific pattern.

Nozzle design

Our design involves use of broadcast/regular flat fan nozzle with a wide spray angle of 110 degrees. This spray angle provides increased overlap for better spray distribution and ability to run boom closer to the crop[target surface] to reduce drift potential. Drift is the movement and deposition of spray particles to non-target areas.

The working speed is supposed to be slow so as to provide more consisted results. Faster speeds reduce canopy penetration, increase dust and may cause drift problems.

The working pressure \( p \) (kPa) is related to the nozzle emission capacity \( q \) according to the following equation:

\[
q = \frac{md^2}{\sqrt{p}} \quad [\text{dm}^3/\text{min}]
\]
Where:

- \( m \) (0.15–0.65) is an efflux coefficient related to the construction characteristics of the nozzle

- \( d \) (mm) is the orifice diameter.

Hence the distributed volume may be varied by changing the nozzle (i.e., by varying \( m \) and \( d \)) or by adjusting the working pressure \( p \).

Although the discharge rate increases with pressure, it is not linear. The discharge rate for any nozzle is proportional to the square root of the pressure.

\[
\frac{q_1}{q_2} = \frac{\sqrt{p_1}}{\sqrt{p_2}}
\]

This characteristic is used in many spray controllers to achieve a constant spray rate as sprayer speed varies. However, large changes in nozzle flow are achieved most effectively by changing the orifice diameter. The nozzle orifice diameter, its operating pressure and other design features influence the size of the droplets that are dispersed.

**Nozzle Materials and Wear Life**

Nozzle life depends upon many factors: the hardness of the nozzle material, the type and size of the nozzle, the operating pressure, and the abrasiveness of the spray material.

In general, the harder the nozzle material, the longer its expected life. Also, the higher its cost.

**Delivery from nozzles**

Assuming nozzle orifice diameter of 2 mm.

Using continuity equation

\[ V_3A_3 = V_4A_4 \]

There are 3 nozzles in each delivery pipe

\[
\pi \times \left( \frac{22.6314}{2} \times 10^{-3} \right)^2 \times 15.189 = \pi \times (1 \times 10^{-3})^2 \times V_4 \times 3
\]

\[ V_4 = 42.68 m/s \]

Discharge from orifice = area \times velocity

\[ = \pi \times (1 \times 10^{-3})^2 \times 42.68 \]

\[ = 1.3409 \times 10^{-4} M/s \]
The volume flow rate is adjusted from the control valves and the pressure set from the pressure gauge.

3.8 AGITATOR

Many spray materials are suspensions of insoluble powders or are emulsions. Consequently our sprayer design will be fitted with an agitation system. This is meant to help in mixing of the solution.

For our system, we will use a hydraulic agitator.

A portion of the pump output is discharged into the spray tank through a series of jet nozzles or orifices located in a pipe along the bottom of the tank. The energy and turbulence from the jets provide the mixing action.

This type of agitation is advantageous because of its simplicity in integrating it into the system. The pressure released by the pump is sufficient to achieve this.

\[
V = 0.13409 \text{ L/s} = 8.045 \text{ L/min}
\]

The volume flow rate is adjusted from the control valves and the pressure set from the pressure gauge.
Figure 3.3 A schematic diagram of the boom herbicide sprayer circuit of a centrifugal pump
3.9 Acreage capacity

Calculating the size of land that can be sprayed for a full tank;

\[
GPM = \frac{\text{Speed (mph)} \times \text{nozzle loading (inches)} \times \text{gallons per acre}}{5940}
\]

Nozzle spacing = 0.75m = 29.5276 inches
Speed = 10 km/hr = 6.2137 mph
Discharge = 8.045 litres/ min = 2.124 gallons per min

\[
2.124\text{gpm} = \frac{6.213 \times 29.5276 \times \text{gpa}}{5940}
\]

\[
= 69.78 \text{gallons/acre}
\]
CHAPTER FOUR

4.0 COSTING

The objective was to design a locally fabricated tractor PTO powered herbicide sprayer that is cheap. From our research, the cost of our design was as below.

**TABLE 4.1 ESTIMATED COSTS as quoted from Technical trading centre Likoni road, Davis and Shirtliff River Road - Nairobi**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QUANTITY</th>
<th>ESTIMATED COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pump</td>
<td>1</td>
<td>Ksh. 5 000</td>
</tr>
<tr>
<td>1. Suction pipe</td>
<td>½ m @ 880 per meter</td>
<td>Ksh. 440</td>
</tr>
<tr>
<td>3. Delivery pipe</td>
<td>5m @ 968 per meter</td>
<td>Ksh. 4 840</td>
</tr>
<tr>
<td>4. Boom tank</td>
<td>400ltrs</td>
<td>Ksh. 4 000</td>
</tr>
<tr>
<td>5. Sprayer Boom pole stainless with Sprayer nozzles 1.5 mtrs. (3 nozzle)</td>
<td>3 pieces @ 700 per piece</td>
<td>Ksh. 2 100</td>
</tr>
<tr>
<td>6. PTO Shaft</td>
<td>1</td>
<td>Ksh. 6 000</td>
</tr>
<tr>
<td>7. Synchronous belt</td>
<td>1.6m @ 285 per meter</td>
<td>Ksh. 456</td>
</tr>
<tr>
<td>8. Synchronous timing belt pulley</td>
<td>2 pieces @ 265 per piece</td>
<td>Ksh. 530</td>
</tr>
<tr>
<td>9. Bearings</td>
<td>2 pieces @ 250 per piece</td>
<td>Ksh. 500</td>
</tr>
<tr>
<td>10. Control valve</td>
<td>3 pieces @ 400 per piece</td>
<td>Ksh. 1 200</td>
</tr>
<tr>
<td>11. Pressure gauge</td>
<td>1</td>
<td>Ksh. 3 100</td>
</tr>
<tr>
<td>12. Agitator</td>
<td>1 piece</td>
<td>Ksh. 250</td>
</tr>
<tr>
<td>13. Labour</td>
<td></td>
<td>Ksh. 5 000</td>
</tr>
<tr>
<td>14. Miscellaneous</td>
<td></td>
<td>Ksh. 10 000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>Ksh. 43 416</strong></td>
</tr>
</tbody>
</table>

The available boom sprayers in the market ranges between Ksh. 150,000 to Ksh. 250,000. Our design is much cheaper, Ksh 44 000, compared to the available brands and hence highly recommended for fabrication.
5 CHAPTER FIVE

5.0 DISCUSSION

The objective of this project was to design a herbicide sprayer that could utilize power from the many tractors used in farms for cultivation and threshing purposes. It is to be powered by the tractor power take off (PTO) of 11kw. The mechanism involves shaft for power transmission, the pump, valves, piping and nozzles that delivers the herbicide.

Various aspects of the design had to be researched so that the proposed machine could be cost effective and of greater efficiency. Most important was to research on many crops that are grown, whether it’s large scale or small scale and the level of mechanization in herbicide control. It’s evident that manual methods of herbicide control are still employed but these prove to be tiresome, time-consuming and hence unsuitable for farmers.

The research also revealed that many farmers use tractors to prepare their land for cultivation, harvesting and threshing maize and cons. This gave a reason to link between many available tractors and means of herbicide spraying hence the need for tractor PTO driven herbicide sprayer which is much faster, more efficient as it covers a wide range of crops.

In this design, power is generated by a tractor engine and then transmitted to a centrifugal pump through a shaft from the tractor PTO. This is achieved by engaging the tractor PTO gear by the driver. Boom assembly is fitted on the rear side of the tractor and can be moved up and down using tractor 3 point hitch.

Herbicide in the boom tank is sucked into the pump through a 2 inch pipe. A centrifugal pump at 1450 rpm with a discharge of 18.33litres/min is then used to discharge it to the nozzles. The tractor speed of 540 rpm is stepped up using the pulley diameter ratios that are connected to the shaft from the PTO using synchronous belts. The synchronous belts has a length of 1600mm, centre distance of 576 mm. Dimensions of the smaller pulley diameter is 80.16mm and the larger pulley diameter is 181.97mm. Herbicide from the pump is pumped to a 1.5 inch pipe at a velocity of 17.86m/s to control valves. The tank is fitted with hydraulic agitators to ensure efficient mixing of the chemical and has a sump at the bottom to ensure smooth flow to the suction pipe. The system is fitted with pressure relieve valves and the excess pressurized herbicide is taken back to the tank through a bypass pipe. From the control valves it is channeled to 3 pipes of 1 inch diameter at a velocity of 15.18m/s which can also be controlled from the control valves.

These pipes deliver the herbicide to 3 stainless steel nozzles that are 1.5m long and have 3 nozzles each. Each nozzle has a diameter of 2mm, a velocity of 42.68m/s and a discharge of 8.045litres/min. When the driver/operator is on the last row of the herbs and maybe one of the
nozzles will not be delivering to the crops, he or she can close the valve delivering to that specific set of valves thus saving on the herbicide.

However when handling the herbicide, care must be taken to avoid contamination. One should wear protective gear and nose muffs to avoid inhaling the chemical fumes. The shaft must also have a guard to avoid accidents when rotating.

![Figure 5.1 Shaft to be connected to the PTO and pump](image)
**Figure 5.2** picture showing the pump system enclosure and connection to the shaft

**Figure 5.3** the tractor 3-point hitch that will host the pump and boom tank
Figure 5.4 The PTO position on the tractor
Figure 5.5 Schematic diagram of simulation of the boom herbicide sprayer circuit of a centrifugal pump sprayer
5.1 CONCLUSION

A PTO tractor powered herbicide sprayer was designed at a cost of Ksh 44,000 compared to the available market price of between Ksh 150,000 to Ksh 250,000. It involved use of locally available materials, was locally fabricated and was simple to operate. It incorporated components like:

- Boom tank: 400 litres, High Density Cross Linked Polyethylene (XLPE)
- Synchronous belt drive: Maximum pitch - 8mm, Belt length - 1600mm, Belt width - 20mm, Center distance - 576 mm
- Belt pulley: Small pulley diameter - 80.16mm, 30 teeth/grooves
  Large pulley diameter - 181.97mm, 80 teeth/grooves
- Suction piping: PVC pipe schedule 80 - 2 inches
- Delivery piping: PVC pipe schedule 120 - 1.5 inches
- Nozzles: Stainless with Sprayer nozzles 1.5 meters (3 nozzles)
- Pump: Centrifugal pump, 1450 rpm, 2 horsepower, discharge of 18.33litres/sec.
- Shaft: Diameter - 14 cm, type - 4140 cold rolled steel.
- Tractor PTO: 540 rpm, power - 11kw.

The design is cheap, easily available and will help improve agriculture in control of weeds/herbs. The objectives of the design were therefore met.
5.2 RECOMMENDATION

It is recommended that in future design the boom sprayers are:

- Fitted with spray management system that enables moderate changes of travelling speed to take place without affecting large volume rate application.
- Used with systems or methods that monitor the accuracy of machine travel (and the area the herbicide is applied to) across the site to ensure effective spraying.
- Fitted with herbicide handling/mixing systems that reduce the risk of operator and environmental contamination.
- Used in a manner to minimize drift.
- Fitted with herbicide handling and cab system that improve operator ergonomics.
- Tested with the Agricultural Engineers’ Association national sprayer testing scheme.
REFERENCES

2. The International Commission of Agricultural Engineering, CIGR Handbook of Agricultural Engineering Volume 3 1999, Published by the American Society of Agricultural Engineering
4. www.fannozzle.com/product/nozzle-211.html
6. www.harvel.com/technical-support-centre/engineering-design-data/flowvelocity-loss/schedule-120
9. Fenner synchronous belts drives catalogue
12. Douglas Wright, Notes on Design and Analysis of Machine elements, February 2001 Department of Mechanical & Materials Engineering. The University of Western Australia.
APPENDIX

Appendix 1: Service factors for selecting belt drive

<table>
<thead>
<tr>
<th>TYPE OF DRIVEN MACHINE</th>
<th>Hours per Duty</th>
<th>Hours Per Day Duty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19 and under</td>
<td>Over 10 to 16</td>
</tr>
<tr>
<td>LIGHT DUTY</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>AGITATORS (uniform density), Bakery machinery, Dough mixers, Blowers except positive displacement, Centrifugal pumps and compressors, Belt conveyors, (uniformly loaded), Electric fans, Fans up to 7.5 kW, Paper machinery, Agitators, calenders, dryers, Printing machinery, Linotype machines, cutters, letterpress, Saws: Drum, conical, Woodworking machinery, Lathes, band saws.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDIUM DUTY</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>AGITATORS and Mixers (variable density), Belt conveyors (not uniformly loaded), Brick and clay machinery, augers, mixers, granulators, Fans over 7.5 kW, Generators, Line shafts, Laundry machinery, Punches, presses, shears, Printing machinery, Presses, newspaper, rotary embossing, flat bed magazine, Pumps: Positive displacement, rotary, Saws, Vibrating Machine tools.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEAVY DUTY</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>EXHAUST, positive displacement, Bucket elevators Centrifuges, Conveyor:</td>
<td>1.7</td>
<td>1.9</td>
</tr>
<tr>
<td>HEAVY DUTY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EKSET (machinery, such as machines, Compressors, piston, Crushers: Gyrotary, jaw roll, Hammers, Mill: Ball, rod, tube, rubber, Rubber machinery: Calender, extruders, mills.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From: Fenner synchronous belts drives catalogue
Appendix 2: Centre distance, grooves and belt length for synchronous belt design

From: Fenner synchronous belts drives catalogue
Appendix 3. Belt pitch and belt width selection

**BELT WIDTH FACTORS**

<table>
<thead>
<tr>
<th>Belt width mm</th>
<th>20</th>
<th>30</th>
<th>50</th>
<th>85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width factor</td>
<td>1.00</td>
<td>1.58</td>
<td>2.73</td>
<td>4.76</td>
</tr>
</tbody>
</table>

*From: Fenner synchronous belts drives catalogue*
## Appendix 4: Nozzle type, diameter and discharge

<table>
<thead>
<tr>
<th>Traffic Code</th>
<th>Guangdong Perth Metal HU Fan Nozzle Type / inlet connection size NPT or BSPT (YBSCO brand)</th>
<th>Equivalent orifice diameter MM</th>
<th>Guangdong Perth HU fan nozzle flow parameters l / min</th>
</tr>
</thead>
<tbody>
<tr>
<td>11001</td>
<td>HU1/8-SS11001 1/8 HU1/4-SS11001 1/4 HU3/8-SS11001 3/8 HU1/2-SS11001 1/2 HU3/4-SS11001 3/4 HU1-SS11001 1-2 inch</td>
<td>0.66</td>
<td>0.32 0.39 0.6 0.72</td>
</tr>
<tr>
<td>110015</td>
<td>HU1/8-SS110015SS110015SS110015SS110015SS110015SS110015SS110015SS110015SS110015SS110015SS110015</td>
<td>0.79</td>
<td>0.48 0.59 0.90 1.1</td>
</tr>
<tr>
<td>11005</td>
<td>HU1/8-SS11005 1/8 HU1/4-SS11005 1/4 HU3/8-SS11005 3/8 HU1/2-SS11005 1/2 HU3/4-SS11005 3/4 HU1-SS11005 1-2 inch</td>
<td>0.91</td>
<td>0.64 0.79 1.2 1.4</td>
</tr>
<tr>
<td>11003</td>
<td>HU1/8-SS11003 1/8 HU1/4-SS11003 1/4 HU3/8-SS11003 3/8 HU1/2-SS11003 1/2 HU3/4-SS11003 3/4 HU1-SS11003 1-2 inch</td>
<td>1.1</td>
<td>0.97 1.2 1.8 2.2</td>
</tr>
<tr>
<td>11004</td>
<td>HU1/8-SS11004 1/8 HU1/4-SS11004 1/4 HU3/8-SS11004 3/8 HU1/2-SS11004 1/2 HU3/4-SS11004 3/4 HU1-SS11004 1-2 inch</td>
<td>1.3</td>
<td>1.3 1.6 2.4 2.9</td>
</tr>
<tr>
<td>11005</td>
<td>HU1/8-SS11005 1/8 HU1/4-SS11005 1/4 HU3/8-SS11005 3/8 HU1/2-SS11005 1/2 HU3/4-SS11005 3/4 HU1-SS11005 1-2 inch</td>
<td>1.4</td>
<td>1.6 2.0 3.0 3.6</td>
</tr>
<tr>
<td>11006</td>
<td>HU1/8-SS11006 1/8 HU1/4-SS11006 1/4 HU3/8-SS11006 3/8 HU1/2-SS11006 1/2 HU3/4-SS11006 3/4 HU1-SS11006 1-2 inch</td>
<td>1.6</td>
<td>1.9 2.4 3.6 4.3</td>
</tr>
<tr>
<td>11008</td>
<td>HU1/8-SS11008 1/8 HU1/4-SS11008 1/4 HU3/8-SS11008 3/8 HU1/2-SS11008 1/2 HU3/4-SS11008 3/4 HU1-SS11008 1-2 inch</td>
<td>1.8</td>
<td>2.6 3.2 4.8 5.8</td>
</tr>
<tr>
<td>11010</td>
<td>HU1/8-SS11010 1/8 HU1/4-SS11010 1/4 HU3/8-SS11010 3/8 HU1/2-SS11010 1/2 HU3/4-SS11010 3/4 HU1-SS11010 1-2 inch</td>
<td>2.0</td>
<td>3.2 3.9 6.0 7.2</td>
</tr>
<tr>
<td>11015</td>
<td>HU1/8-SS11015 1/8 HU1/4-SS11015 1/4 HU3/8-SS11015 3/8 HU1/2-SS11015 1/2 HU3/4-SS11015 3/4 HU1-SS11015 1-2 inch</td>
<td>2.4</td>
<td>4.8 5.9 9.0 10.8</td>
</tr>
<tr>
<td>11020</td>
<td>HU1/8-SS11020 1/8 HU1/4-SS11020 1/4 HU3/8-SS11020 3/8 HU1/2-SS11020 1/2 HU3/4-SS11020 3/4 HU1-SS11020 1-2 inch</td>
<td>2.8</td>
<td>6.5 7.9 12.114.4</td>
</tr>
</tbody>
</table>

[www.fannozzle.com/product/nozzle-211.html](http://www.fannozzle.com/product/nozzle-211.html)
Appendix 5: Pump flow rate