KYAMBOGO UNIVERSITY

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FACULTY OF ENGINEERING

DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING

MODIFICATION OF A TYPICAL HAND WATER PUMP

CASE STUDY: RUKUNGIRIDDE - KIBOGA DISTRICT-CENTRAL UGANDA

BY

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A PROJECT DESSERTATION SUBMITTED TO KYAMBOGO UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A BACHELOR OF INDUSTRIAL ENGINEERING AND MANAGEMENT

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DECLARATION

I hereby declare that this piece of work is to the best of my knowledge, has never been submitted to any university or any other higher institution of learning for the award of a degree or any other academic qualification and describe my involvement as a student of Bachelor of Industrial engineering and management at Kyambogo University and all information contained in this proposal is certain and true of me.

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APPROVAL

The research project has been submitted for examination with my approval and done by SEMATA PETER, 14/U/8558/IEE/PE under my supervision.

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Supervisor: Ms. ATIMA ROSE

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ABSTRACT

A pump is a device that can be used to raise or transfer fluids (Rony et al., 2015). Pumps are selected for processes not only to raise and transfer fluids from one point to another, but also to meet some other criterion. The various water pumping systems available require sufficiently large effort of about 36Jouls depending on the manufacturer to be operated and an average person can use these pumps continuously only for a short time.

The ever increasing demand for energy has led to the formation of various advanced resources which produces a certain part of the required energy. One principal consumer of a large amount of energy is our household itself which is wasted in pumping water, irrigation purposes, etc. (Rony et al, 2015). It is in this context the importance of pendulum pump arises, by the use of which a large amount of energy can be conserved.

However the modified hand water pump with a pendulum only requires a minimum effort of about 13.7jouls to oscillate the pendulum and maintain these oscillations of 45strokes per minute.

The pendulum water pump is essentially developed for rural communities where there exist no electricity and the other means of pumping water are practically expensive for the people in the community however, further research as far as improving the operation and performance of the pumping system must be emphasized such that agriculture production is improved as well has applying the technology in other fields.

CHAPTER ONE
INTRODUCTION

1.1 Background of study

A pump is a device that can be used to raise or transfer fluids (liquids or gases), or sometimes slurries, by mechanical action (Kali et al., 2016). Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps. Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power. They come in many sizes, from microscopic for use in medical applications to large industrial pumps.

In the world, Mechanical water pumps serve in a wide range of applications such as; pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water cooling and fuel injection, in the energy industry for pumping oil and natural gas or for operating cooling towers, Irrigation to make dry lands agriculturally productive, chemical Industry to transport fluids to and from various sites in the chemical plant, Petroleum Industry: Used in every phase of processing of petroleum, its transportation, and separation of the impurities, Medical Field to pump fluids in and out of the body, etc. (Kali et al., 2016)

In Africa, water pumps are changing lives and building business in developing economies for example Kickstart, a company that develops new irrigation technologies and then puts them into the hands of local entrepreneurs. It puts sustainable water-delivery to crops into hands of small farm owners in East and West Africa (Citi BrandVoice, 2014). Brlisen pumps which are largely used in Africa require a range of power between 0.37kw to 4kw to provide water for irrigation as well as domestic use.

In Uganda, various innovations have been made towards developing suitable pumps to provide water for irrigation, home use, industrial use for example the solar pump designed by Engineering students of Makerere University as part of an irrigation project (Cedat, 2016). However, the innovations made and technologies today on the Ugandan market require a source of power such as a solar panel which is about 5million shillings to operate an expensive water pumping system worth 10million shillings or hydro electric power which itself has not been installed in Rukugiridde in Kiboga district in Uganda. The available manual water pump like the typical water pump (borehole) require a lot of human power of about 750wats depending on the manufacturer to pump water for domestic as well as irrigation purpose . this makes an average person to use this pump for only a short period of time and practically impossible to be used by people with disabilities and hence have not satisfied the water needs of people in rural areas especially were electricity is a problem, people are poor and human power can't build up to 36jouls to operate the manual pump

However with the modified typical water pump is a benefit to people in Uganda especially in Rukugiridde village in that it requires only 7kg input energy to the pendulum for starting the process of pumping, that swinging of the pendulum coverts 13.7 watt into input energy to the pump that is considerably minimum when compared 36jouls required to operate hand pumps. Typical hand pumps require sufficiently large effort and an average person can use the pump continuously only for few minutes like 30, but the pendulum pump requires only a minimum of the effort to produce an output energy of pump of 12.87joules because it is only required to oscillate the pendulum and can maintain these oscillations for almost 45stockes per minute, without any fatigue. The advantage of this invention compared to present hand pump solutions are: less force to start the pump, less water consumption, and both arms can be used to fetch the water

1.2 Problem statement

The various water pumping systems available require sufficiently large effort of about 220wats depending on the manufacturer and the person to be operated and an average person can use these pumps continuously only for a short time.

However the modified hand water pump with a pendulum requires only a minimum mass of 7kg to generate 206.53watts input to the pump and to oscillate the pendulum and maintain these oscillations of 45strokes per minute.

1.3 Objectives of study

1.3.1 General objective

To modify typical hand water pump

1.3.2 Specific objectives

i. To study the existing typical hand water pumps.
ii. To determine machine parameters
iii. To select, size the material and develop machine layout.
iv. To carry out a cost analysis.

1.3.3 Research questions

ii. What are the specifications of a typical hand water pump?
iii. What are the machine parameters?
iv. What is the nature, size of material and machine components to be used in the design?
v. What is the cost analysis?

1.4 Justification

i. The average person cannot use these pumps continuously for long time.
ii. Failure to be operated by aged and disabled people.
iii. The increased fatigue experienced by people when operating these typical hand water pumps.

1.5 Significance

The successful development of the machine has the following benefits to the community;

i. It controls the level of water in the protected area
ii. Dry lands are made agriculturally productive
iii. Less man power is required
iv. Continuous flow of water is achieved
v. It can be used in various pumping applications
vi. It can be operated without any external aid

1.6 Scope of study

The content scope of the project covered specifically the modification of a typical hand water pump and the project was conducted generally in Rukugiridde in Kiboga district in central Uganda. This project covered a period of 9months that is from August 2017 to May 2018.

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction

This chapter consists of the introduction to water pump, types of water pumps in existence, and overview of the reciprocating pump.

2.1 introduction to water pumps

According to Kali et al., (2016), a **pump** is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Water pumps are used to lift water to a height that allows users easy access to water. Water pumps can be used to raise groundwater, rainwater stored in an underground reservoir, and river water.

Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, come in many sizes, from microscopic for use in medical applications to large industrial pumps.

The pumping of water is a basic and practical technique, far more practical than scooping it up with one's hands or lifting it in a hand-held bucket. This is true whether the water is drawn from a fresh source, moved to a needed location, purified, or used for irrigation, washing, or sewage treatment, or for evacuating water from an undesirable location. Regardless of the outcome, the energy required to pump water is an extremely demanding component of water consumption. All other processes depend or benefit either from water descending from a higher elevation or some pressurized plumbing system (Nejbosa, 2001)

2.2 Types of water pumps in existence

Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps (Kali et al., 2016). In order to be successful, the pendulum hand water pump must offer a significant advantage over the existing technology. Communities should be able to choose from a range of water pumps, and each option should be presented with its advantages, disadvantages and implications.

The following are some of the water pumps in existence as retrieved from (WHO, 2003) “Water Lifting Devices”

2.2.1 Rope and bucket

This device is mainly used with hand-dug wells. A bucket on a rope is lowered into the water. When the bucket hits the water it dips and fills, and is pulled up with the rope. The rope may be held by hand, run through a pulley, or wound on a windlass. Sometimes, animal traction is used in combination with a pulley. Improved systems use a rope through a pulley, and two buckets – one on each end of the rope. For water less than 10 m deep, a windlass with a hose running from the bottom of the bucket to a spout at the side of the well can be used. However, the hygiene of this system is poorer, even if the well is protected.

It has a Range of depth of 0–15 m (or more sometimes) and it yields 0.25litres/s at 10 m. It is commonly used all over the world.

Potential problems associated with this type of water pump are; poor-quality rope deteriorates quickly (e.g. sisal rope lasts for only a few months); the bucket falls into the well – to prevent this, communities can keep a spare bucket and fit the bucket into a protective cage, such as that described by (Morgan, 1990); the hose breaks frequently in windlass-and-hose systems; poor hygiene, especially when the rope or bucket touches users' hands or the ground; communal wells tend to become more contaminated than family-owned wells, and the latter should be promoted whenever possible; the rope-and-bucket system is only suitable for limited depths.

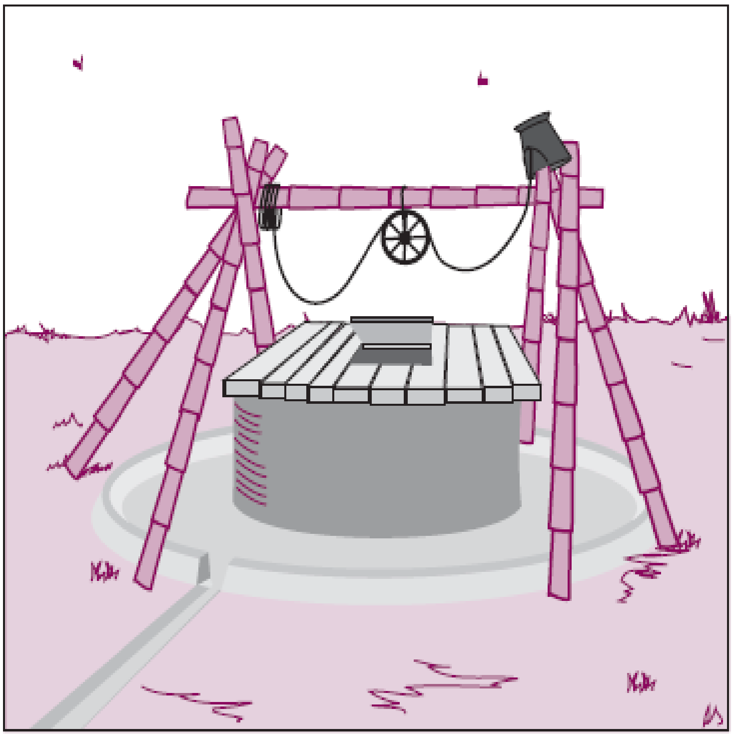


Figure 2.1: Rope-and-bucket lifting device

2.2.2. Bucket pump

The bucket pump is mainly used in drilled wells. It consists of a windlass over a 125 mm PVC tube, down which a narrow bucket with a valve in the base is lowered into the water on a chain. When the bucket hits the water, the valve opens and the water flows in. When the bucket is raised, the valve closes and the water is retained in the bucket. To release the water, the pump operator rests the bucket on a water discharger, which opens the valve in the base. The windlass bearings are made of wood.

It has a Range of depth of 0–15 m and its yield is relatively low and depends on well depth. It is commonly used in Zimbabwe and elsewhere.

Potential problems associated with this type of water pump are; loose valve parts; broken chain; stones thrown in the well by children; low discharge rates; contamination, especially with communal wells; chlorine for disinfecting the well may not be locally available.

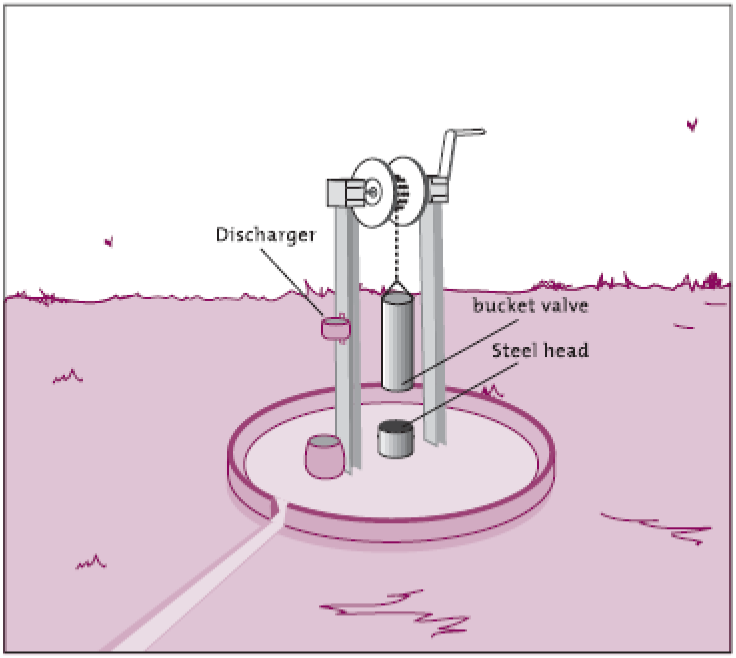


Figure 2.2: Bucket pump

2.2.3. Rope pump

The basic parts of a rope pump are a pulley wheel above the well, a riser pipe from under the water level to an outlet just under the wheel, and a rope with rubber or plastic washers. The rope comes up through the pipe, over the wheel, back down into the well and into the bottom of the pipe, completing the loop. When the wheel is turned, the washers move upwards and lift water into the pipe towards the outflow. Other important parts are an underwater rope guide that directs the rope and washers back into the pipe, and a frame that holds the pulley wheel. The rope pump can be made at village level using wood, rope and PVC tubing (or bamboo canes with the centres bored out). In Nicaragua, local industries produce an improved type of rope pump that has a metal wheel and frame, industry-made washers, and a guide block of concrete with ceramic and PVC tubes. About 25000 of these pumps have been installed in Nicaragua. Water can be lifted from as deep as 50 m and raised to 5m above ground level. Special models with 3-inch boreholes, and powered by windmills, bicycles, animal traction, electric motors or small gasoline engines, give good results.

It yields 0.6litres/s at 10 m, 0.15litres/s at 50m. It is usually used in rural and periurban areas of Nicaragua, Bolivia, Indonesia, Ghana, Burkina Faso and other countries.

Potential problems associated with this type of water pump are; the rope becomes worn because it is exposed to the sun (exposed rope needs to be protected), or because it is used heavily; the installation of the rope pump was poorly done and its performance is suboptimal; the pulley wheel malfunctions; the pistons, frame and guide block are of poor quality and do not function properly; traditional rope pumps have a lift of only about 10 m; users need to exercise care when using the pump as it is susceptible to contamination; although design and quality of construction may differ significantly, the rope pump can be low-cost, and operated and maintained at the village level.

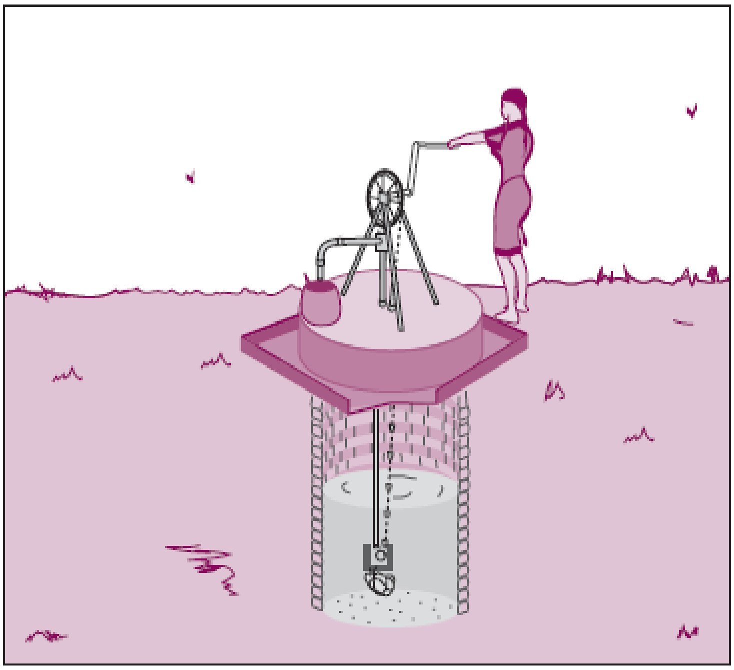


Figure 2.3: Rope pump

2.2.4. Suction plunger hand pump

A suction plunger hand pump has its cylinder and plunger (or piston) located above the water level, usually within the pump stand itself. These pumps must be primed by pouring water on the plunger. On the up-stroke of the plunger, the pressure inside the suction pipe is reduced and atmospheric pressure on the water outside pushes the water up into the pipe. On the down-stroke, a check valve at the inlet of the suction pipe closes and water passes the plunger through an opened plunger valve. With the next upstroke, the plunger valve closes and the water is lifted up by the plunger and flows out at the top of the pump, while new water flows into the suction pipe. The operational depth of this type of hand pump is limited by barometric pressure and the effectiveness of the plunger seals to about 7 m at sea level, less at higher altitudes. It yields 0.4–0.6litres/s at 7m and commonly used in Rural and low-income periurban areas where groundwater tables are within 7 m of the surface.

Potential problems associated with this type of hand water pump are; worn out washers, cupseals and bearings; excessive corrosion that causes pump rods to break, and leaks to appear in the rising mains; many pumps are of poor quality; the biggest drawback of suction pumps is that they can lift water to only about 7 m, and if the water table falls below that level, the pump becomes inoperable and must be replaced with a deep-well pump; contaminated water is often used to prime suction pumps; most pumps are designed for family use and are not sturdy enough for communal use.

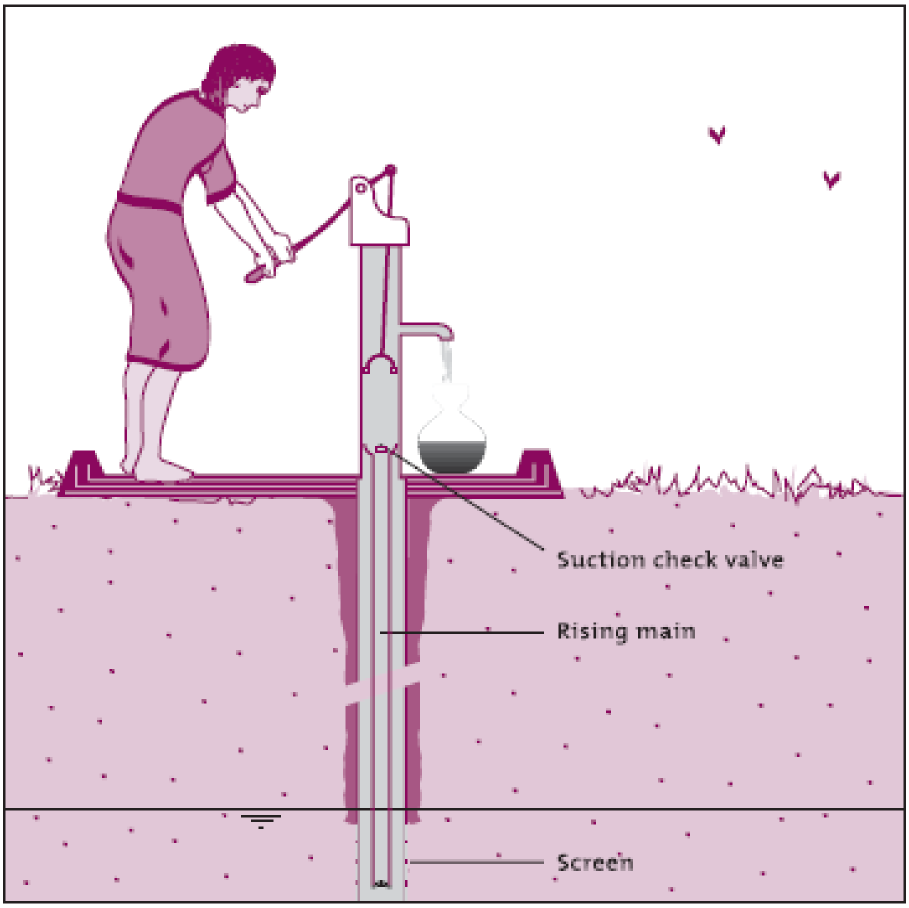


Figure 2.4: Suction plunger hand pump

2.2.5. Direct action hand pump

Direct action hand pumps are usually made of PVC and other plastics, and are installed on boreholes of limited depth. A plunger is attached to the lower end of a pump rod, beneath the groundwater level. The user moves the pump rod in an up-and-down motion, using a T-bar handle. On the up-stroke, the plunger lifts water into the rising main, and replacement water is drawn into the cylinder through the foot valve. On the down stroke, the foot valve closes, and water passes through a one-way valve in the plunger and is lifted on the next up-stroke. Because direct action hand pumps have no mechanical advantage, such as the lever or fly-wheel of a deep-well hand pump, direct action pumps can only be used to depths from which an individual can physically lift the column of water (about 12 m). However, the mechanical simplicity, low cost and lightweight construction makes these pumps well equipped to meet O&M objectives at the village level. It yields 0.25–0.42 litres/s at 12 m depth and commonly used in Rural and low-income periurban areas, where groundwater tables are within 12 m of the surface.

Potential problems associated with this type of hand water pump are; worn washers, plungers and foot valve parts; abrasion of the seal on the PVC cylinder and between the pump rod and rising main; broken or damaged handles; the maximum lift is limited to about 12 m; the force needed to pump the water may be too great for children, especially if the water table is below 5 m.

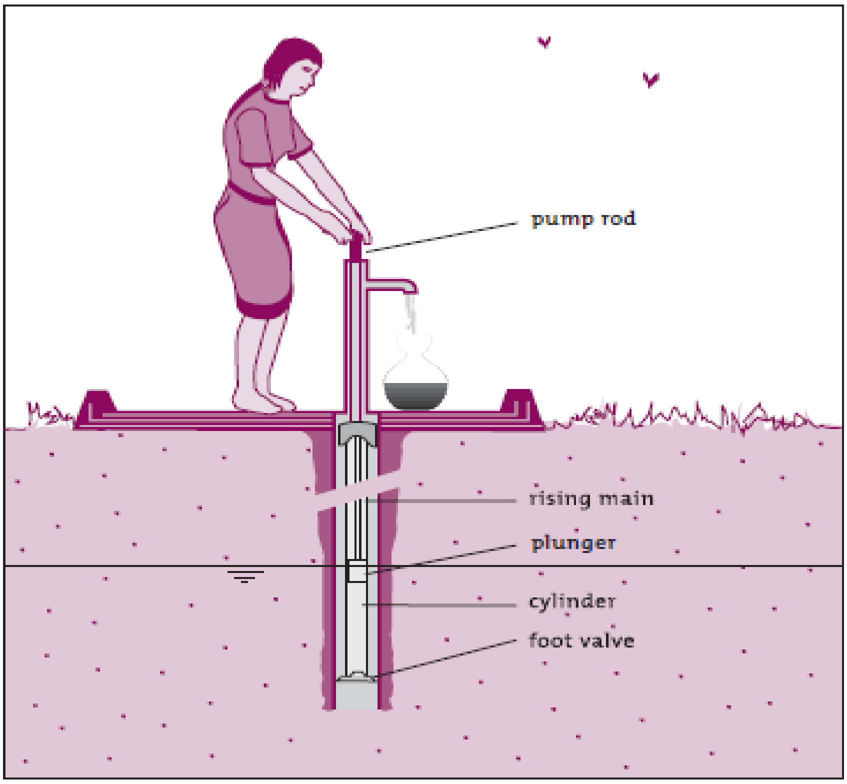


Figure 2.5: Direct action hand pump

2.2.6. Deep-well diaphragm pump

Inside a cylindrical pump body at the bottom of the well, a flexible diaphragm shrinks and expands like a tube-shaped balloon, taking the water in through an inlet valve and forcing it out through an outlet valve. The cylindrical pump is connected to a flexible hose which leads the water to the surface. Movement of the diaphragm is effected by a separate hydraulic circuit that consists of a cylinder and piston in the pump stand, and a water-filled pilot pipe, which is also a flexible hose. The piston is moved, usually by pushing down on a foot pedal, although conventional lever handles may also be used. When foot pressure is removed, the elasticity of the diaphragm forces water out of it, back up the pilot pipe, and lifts the foot pedal. Deep-well diaphragm pumps are still being improved, but most imperfections have been corrected. The principle of the pump is attractive because it allows thin flexible hoses to be used, making the pump easy to install or remove without the need for special tools or equipment. Replacing spare parts is usually easy; only the replacement of the diaphragm may need the assistance of a skilled mechanic. It is possible to install several pumps in a single well or borehole. It yields 0.50litres/s at 10 m depth; 0.32litres/s at 30 m; and 0.24litres/s at 45m and a useful life of eight years.

Potential problems associated with this type of water pump are; pedal rod guides and plunger seals need to be replaced frequently, and the plunger guides may wear out quickly; drive hoses often need to be re-primed because water leaks past the plunger seals, and the foot pedal then needs to be raised by hand; if solid particles enter the down hole pumping element it must be cleaned, since this will cause the diaphragm to stop working or even rupture.

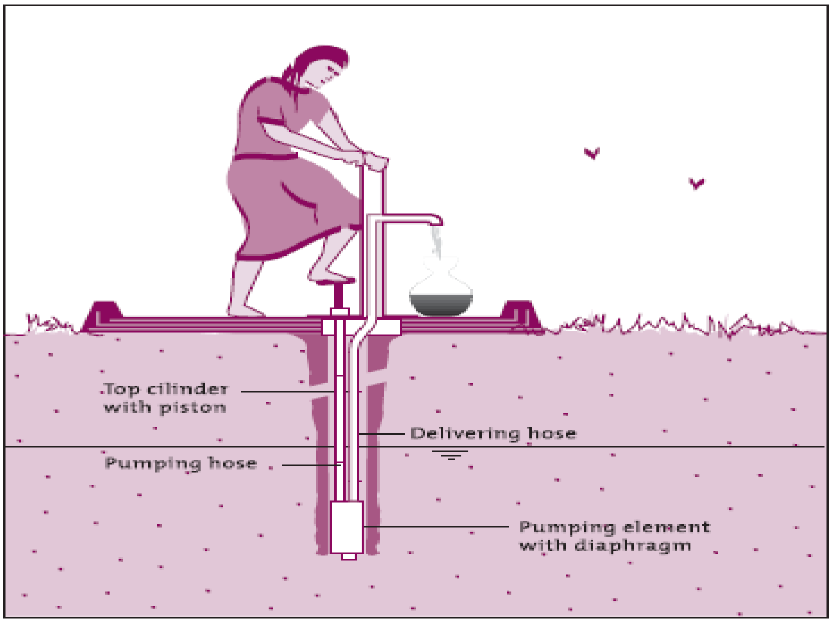


Figure 2.6: Deep-well diaphragm pump

2.2.7. Deep-well piston hand pump

With a deep-well piston hand pump, the piston is placed in a cylinder below the water level, which is usually 15–45 m below the ground. The pumping motion by the user at the pump stand is transferred to the piston by a series of connected pumping rods inside the rising main. On the up-stroke, the plunger lifts water into the rising main, and replacement water is drawn into the cylinder through a foot valve. On the down-stroke, the foot valve closes, and water passes the plunger and is lifted on the next up-stroke. The pumping height is limited only by the effort needed to lift the water to the surface. Nowadays, most pump cylinders have an open top. This allows the piston and foot valve to be removed through the rising main for servicing and repairs, while the rising main and cylinder stay in place.

Potential problems associated with this type of water pump the most common repair is replacing the plunger seals; there can be problems with the quality control of local manufacturers, especially in African countries; the hook-and-eye connectors of the pump rods tend to break more often than conventional connections, and the rods may also become disconnected, or bend spontaneously; corrosion is a problem, especially where the groundwater is aggressive, and it can affect the pump rods if they are not made of stainless steel, the rising main (if not galvanized iron tubing), the cylinder, the housing for the pump head bearing, and other pump stand parts; handles become shaky or broken, mainly because of worn-out bearings; the number of problems usually increases with increasing depth of the groundwater (the maximum lift for a pump varies according to the brand, but is usually 45–100 m).

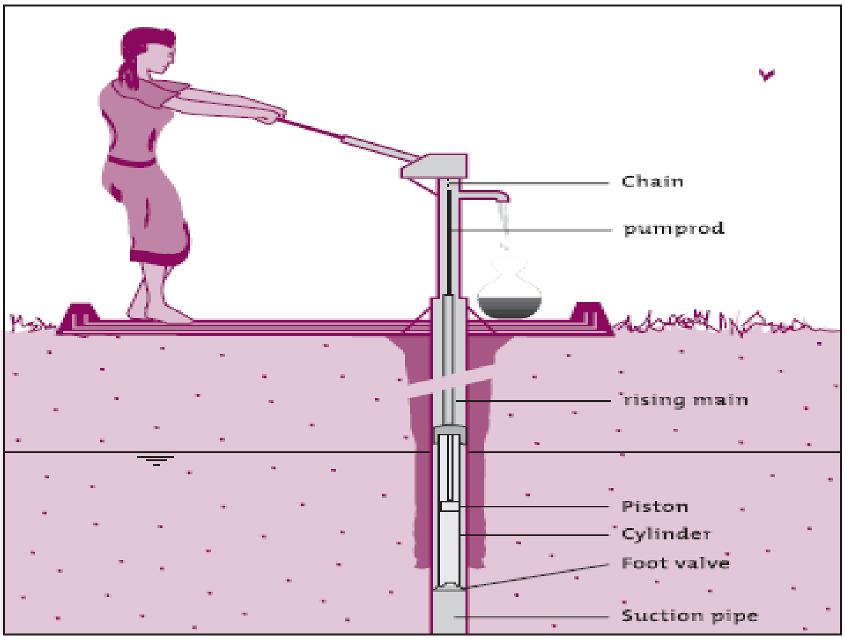


Figure 2.7: Deep-well piston hand pump

2.2.8. Centrifugal pump

The essential components of a centrifugal pump are the fast-rotating impeller and the casing. Water flows into the centre "eye" of the impeller, where centrifugal force pushes the water outwards, to the casing. The kinetic energy of the water is partly converted to useful pressure that forces the water into the delivery pipe. Water leaving the central eye of the impeller creates a suction, which draws water from the source into the pump. An impeller and the matching section of the casing is called a "stage". Several stages can be combined with a single shaft to increase the overall pressure (multiple-stage pump). The water passes through the successive stages, with an increase in pressure at each stage. Multiple-stage centrifugal pumps are normally used when water has to be pumped to a significant height (200 m or more). For deep well applications, the centrifugal pump and electrical engine are housed in a single unit. When the unit is to be located under the water level, a submersible pump will be required (see section 2.1.9).

Potential problems associated with this type of water pump are; debris, sand or other particles may enter the pump, causing abrasion damage; an inlet becomes clogged, causing cavitation; the pipeline system is damaged by severe surges in water pressure, caused by starting and stopping the pump abruptly; the pump and engine are badly aligned, causing the bearings to wear out quickly; the main limitations of a centrifugal pump are its cost, the need to ensure a reliable supply of electricity or fuel, and the need for skilled technicians to maintain and repair the pump. (Moniz & Girdhar, 2004)

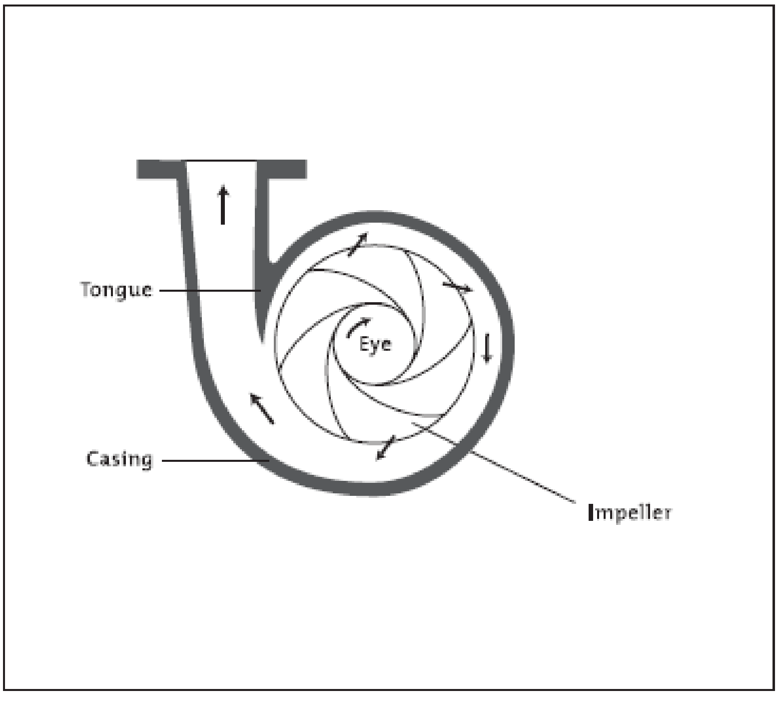


Figure 2.8: Centrifugal pump

2.2.9. Submersible pump

For deep-well applications, centrifugal pumps are housed with the electric engine in a single unit that is designed to be submerged. Usually, a multiple-stage pump is used. The multiple-stage pump is placed above a motor and under a check valve that leads to the rising main. Submersible pumps are self-priming, if they do not run dry. To prevent the pump from running dry, the water level in the well must be monitored, and pumping must be stopped if the water level drops to the intake of the pump. Power is delivered through a heavily insulated electricity cable connected to a switch panel at the side of the well. The power may come from an AC mains connection, a generator, or a solar power system. They have a range of depth of7–200 m or more and efficiency range of 40–70%.

Potential problems associated with this type of water pump are; sand or other particles may enter the pump and cause abrasion damage; the rising main may corrode; the pipeline system can be damaged by the severe pressure surges that result when the pump is started or stopped abruptly; the main limitations of a submersible centrifugal pump are its price, the need to maintain a reliable supply of electricity or fuel, and the high level of technology involved.

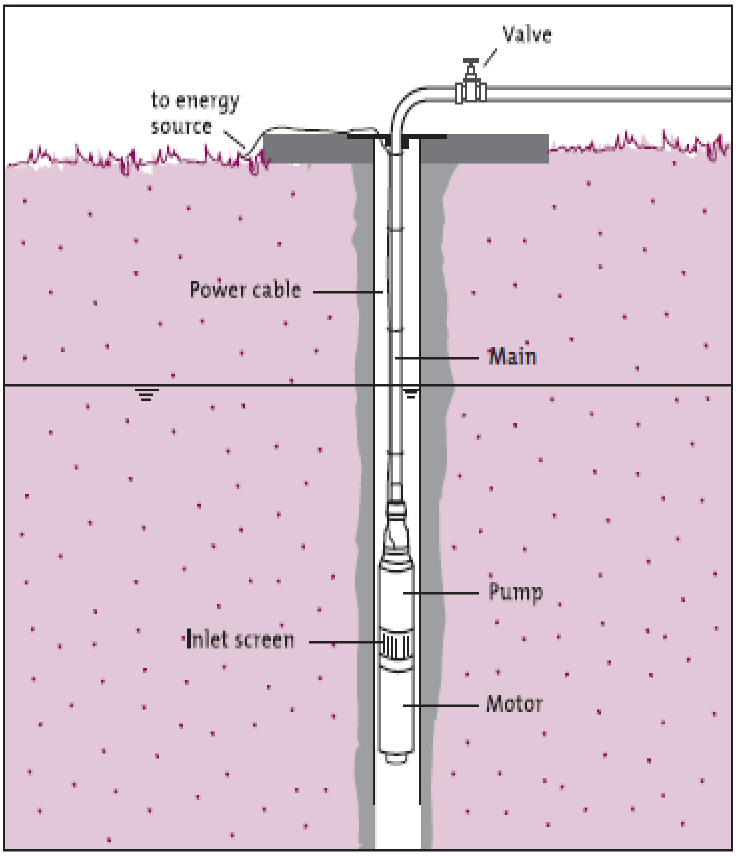


Figure 2.9: Submersible pump

2.3 Overview of the Reciprocating Pump

It is a positive displacement pump. It operates on the principle of actual displacement or ‘pushing’ of liquid by a piston or a plunger that executes a reciprocating motion in a closely fitting cylinder. These types of pump operate by using a reciprocating piston. The liquid enters a pumping chamber via an inlet valve and is pushed out via an outlet valve by the action of the piston or diaphragm.

Reciprocating pumps are generally very efficient and are suitable for very high heads at low flows. This type of pump is self priming as it can draw liquid from a level below the suction flange even if the suction pipe is not evacuated. The pump delivers reliable discharge flows and is often used for metering duties delivering accurate quantities of fluid.

2.3.1 Single acting reciprocating pump

If a reciprocating pump uses one side of the piston for pumping liquid, then it is known as a Single Acting Reciprocating Pump.

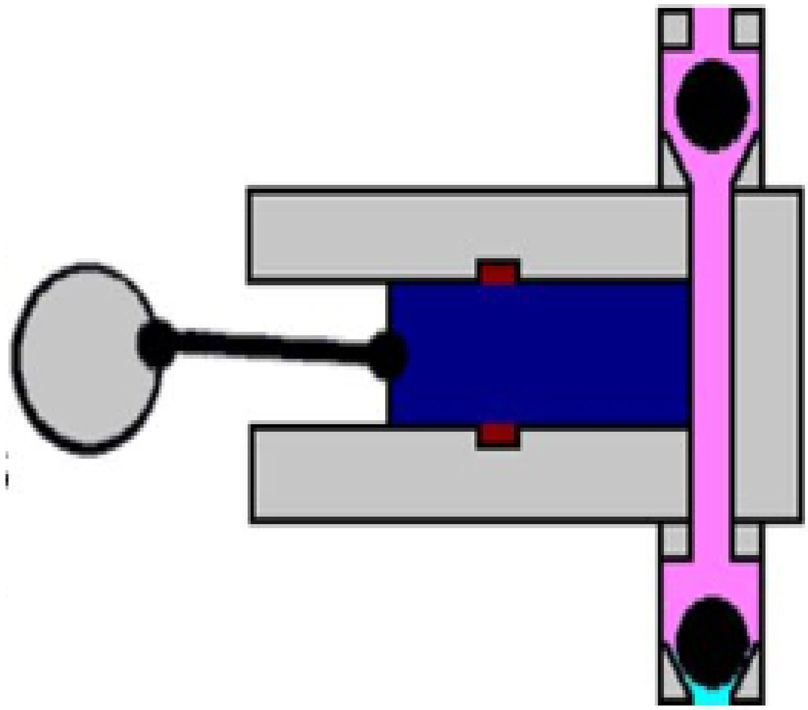


Figure 2.10: Shows a pendulum water pump

2.3.2 Principal components of a single acting reciprocating pump

1. **Cylinder, Piston, Piston Rod, Connecting Rod and Crank**

A single action reciprocating pump consists of a piston, which moves forwards and backwards inside a close fitting cylinder. The movement of the piston is obtained by connecting the piston rod to the crank by means of a connecting rod. The crank is rotated by an electric motor.

2. **Suction Pipe and Suction Valve**

Suction pipe is connected to the cylinder. Suction valve is a one way valve, i.e., non-return valve. It allows the liquid to flow in one direction only. That is, it permits the liquid from the suction pipe to the cylinder.

3. **Delivery Pipe and Delivery Valve**

Delivery pipe is connected to the cylinder. Delivery valve is also one non-return valve. It permits the liquid to flow in one direction only. That is, it allows the liquid from the cylinder to the delivery pipe.

2.3.2 Working Principle of a single acting reciprocating water pump

In a single-action reciprocating pump, liquid acts on one side of the piston only. A single-acting reciprocating pump which has one suction pipe and one delivery pipe; It is usually placed above the liquid level in the sump.

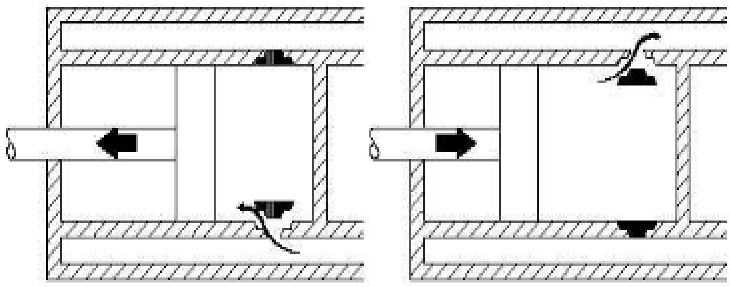


Figure 2.11: shows the Working Principle of a single acting reciprocating water pump

1. **Suction Stroke**

When the crank rotates from IDC to ODC the piston moves towards right in the cylinder. This is called suction stroke.

Now, the volume covered by the piston within the cylinder increases. On the free surface of water in the sump, atmospheric pressure acts. Thus there is a pressure different at the two ends of the suction pipe which connects the sump and the cylinder. This pressure difference between the free surface and inside of the cylinder causes the flow of water from the sump into the cylinder through the suction valve, which is kept open.

During this stroke, the non-return valve at the delivery side will be closed by the atmospheric pressure existing in the delivery pipe. At the end of this stroke, the cylinder will be full of water, the piston reaches the right end, which is called outer dead centre since, the water is continuously sucked into the cylinder, this stroke is called suction stroke. At the end of this stroke, since the pressure in the cylinder is atmospheric, the suction valve is closed.

2. **Return stroke or Delivery Stroke**

When the crank rotates the piston from its extreme right position starts moving towards left in the cylinder. This is known as Return or Delivery Stroke.

The movement of piston towards left increases the pressure of the liquid inside the cylinder to a pressure more than atmospheric pressure. Therefore, the Suction valve closes the delivery valve opens. The liquid inside the cylinder is forced into the delivery pipe through the delivery valve. Consequently, the liquid is raised to the required height. The liquid is discharged at every alternate stroke.

2.4. Components of a pendulum reciprocating water pump

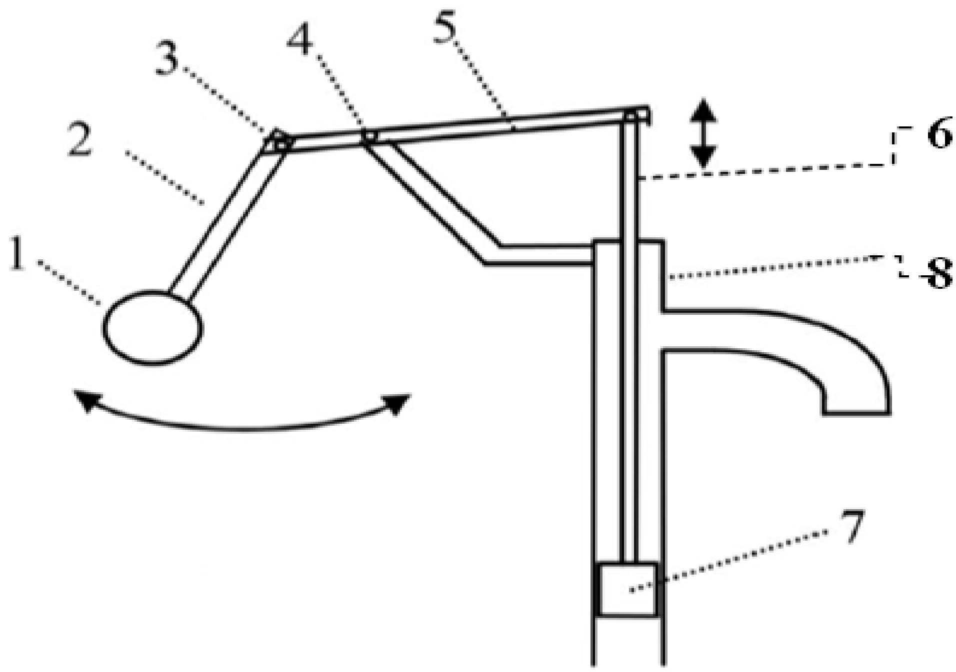


Figure 2.12: Working model of pendulum based water pump system

1. Pendulum bob
2. Pendulum arm
3. Arm joint
4. Link joint
5. Lever
6. Spring
7. Piston
8. Cylinder

Cycle Frame: It is the main component of the pump system and is made up of steel. The principal mechanism used for the construction of the pendulum pump is the slider crank mechanism and the frame converts the oscillating movement of the pendulum on one side to the reciprocating motion of the piston to the other side. The cycle frame consists of seven rigid links which converts the pendulum movement into the piston movement. Tension and compression springs are properly fixed to the frame.

Springs: The spring is an elastic object used to store mechanical energy. Here in the pendulum pump both tension and compression springs are used. It is the function of these tension and compression springs to stretch and compress according to the load applied.

Tension/Extension Spring: The spring is made to operate with a tension load, so that the spring stretches freely as the load is applied to it.

Compression Spring: This is made to operate with a compressive load, so that the spring gets shorter as the load is applied to it.

Non Return Valves: A non-return valve or a check valve or one-way valve is a valve that normally allows fluid (liquid or gas) to flow through it in only one direction.

Hose Collar: A hose collar is used to connect a hose to any other valves or openings. Here it is used to connect the hose to the non-return valves at the suction and delivery sides. A hose clamp or is simply called a clip which is used to attach and seal a hose onto a fitting such as a barb or nipple.

Nylon Tubes: Nylon tubes are connected to the delivery and suction ends of the reciprocating pump for the passage of water from the Pump and the delivery tank.

Weight Hanger: The weight hanger is used to hold the weights and it is the oscillating part of the system and thus it acts like a pendulum

CHAPTER THREE
METHODOLOGY

3.1 Introduction

This chapter presents the methodologies and instruments which were used in the project execution for each specific objective.

3.2 Research area

The project was conducted generally in Rukugiridde in Kiboga district in central Uganda and based on modification of a typical hand water pump with a pendulum which requires a minimum effort to operate.

3.3 Data Sources

Data was collected using different sources which included; the primary data source and secondary data source.

3.3.1 Primary data source

The primary data was the raw data which was collected from the field. The primary data sources were observation and interviewing.

3.3.2 Secondary data source

The secondary data source was derived from different write ups by different authors, which included journals, internet, library, and other relevant literature reviews.

3.4 Data collection methods/ tools

In this project, various tools and techniques were used during data collection and among these included; observation, interviewing, desk search, internet search, Library search, and consultation.

Table 3.1 below, summarizes the methodologies and instruments that were used in the project for each specific objective.

Table 3.1: Methodology and data instruments for each specific objective

OBJECTIVES	TOOLS/TECHINICS	DESCRIPTION	OUT COMES
1. To study the existing types of hand water pumps.	Observation Interviewing	Visited various water source areas and observe various pumps and their mode of operation. Interviewed people to determine the hardships account in the usage of existing pumps.	Effectiveness and Efficiency of the machine
2. To determine machine parameters.	Desk search Interviewing	Through searching different text books in the library and even visiting the internet enabled to determine machine parameters Interviewed both manufacturers and suppliers of parts to get information about size of components.	Accurate machine parameters were determined.
3. To select, size and develop machine lay out.	Desk search (Technical drawings from text books Sourcing parts)	Used technical drawings to develop the actual design. Obtaining components from spare parts dealers	A clear layout and design mechanism.
4. To carryout cost analysis.	Desk search (Use of published text books, internet, formulae log books) Interviewing	Use of material catalogue lists to determine the costs of the material. Interviewing the people in the field to determine the installation costs.	Total cost of the material required in making the machine. Payback period of the machine. Breakeven point of the machine. The net present value of the machine.

3.4.1 Desk search

This method involved the use of relevant published books, Internet, libraries articles, journals and other relevant literature reviews to obtain the required information about water pumps. This information required will involve; the types of existing water pumps, their specifications, advantages and disadvantages, how they are used in Uganda, Africa and world at large. The aim of doing this was to compare the existing water pumps with the modified one hence determining the efficiency and effectiveness of the modified machine.

3.4.2 Observation

This method involved visiting various water sources and observing various pumps and their mode of operation. This involved a survey in the selected field, by using the knowledge and experience the researcher identified the different problems associated with the current water pumps and hence discovered the effective ways of modifying the typical water pumps. The researcher used this method because it gives firsthand information since the researcher is involved.

3.4.3 Interviewing

This involved a one-on-one question and answer with both manufacturers and suppliers of various parts of the water pump to get information about size of components. Firstly, the researcher explained the purpose of the interview and its role, which enabled the individuals to express their ideas about the subject matter and this was guided by a set of unique structured questions (see appendix 1) set prior to the interview process.

3.4.4 Formulae

Using Bernoulli's equation to determine the power required by the pump

$$\boldsymbol{Power, P = \frac{\Delta PQ}{\eta}}$$

Where;

ΔP is the change in total pressure between the inlet and outlet (in Pa)

Q, the fluid flow rate is given in m^3/s

η is the pump efficiency, and may be given by the manufacturer's information

3.5 Data Analysis

For this h project, both qualitative and quantitative data analysis techniques were used.
The quantitative data was analysed through coding and entry into Statistical Package for Social Sciences (SPSS). The package enabled a number of variables to be analysed simultaneously.

On the other hand, qualitative data was analysed using casual methods like individual perceptions and understandings.

3.6 Payback Period

Even though the cost of the project was high for the local people, its profitability is realized after a short period of time

CHAPTER FOUR
PRESENTATION AND DATA ANALYSIS

4.1 Studying the existing hand water pumps

Determining the power required to operate the existing manual water pumps is important for both their efficiency and to match the prime mover. The power capabilities of humans at various ages and the durations are shown in the table 1 (Fraenkel et al.,1997). As we are interested in lifting 20 to 40litres at a time

Table 4.1: Table showing power capabilities of human beings

Age	**Human power by duration of effort (watts)**					
Years	5min	10min	15min	30min	60min	180min
20	220	210	200	180	160	90
35	210	200	180	160	135	75
60	180	160	150	130	110	60

4.1.1 Review of water lifting techniques and listing of candidate pumps

There were four different mechanical principles of transferring water from one location to another and these are shown below

Table 4.2 Summary of four mechanical means of lifting water

Direct lift:	By using a container to physically lift the water
Displacement	Water can be regarded as incompressible and can therefore be displaced
Creating a velocity head	Flow or pressure can be created by propelling water at high speed
Using the buoyancy of a gas	Passing air bubbles through water will raise the level of the surface

(Fraenkel P. , 1997)

Table 4.3: Summary of four existing types of handpumps

Type of handpump	Description
Tamana	This is a suction pump and was developed in Sri Lanka and makes use of standard PVC pipe fittings. (Whitehead, 2000)
DTU	It is a lifting pump with a simple bicycle pump modification using a leather washer as the piston (Thomas et al., 1997).
Enhanced Inertia	It is a lifting pump that has no piston and relies partially on the inertia of the water in the system. (Whitehead, 2000).
Harold	This is also a lifting pump that uses a non-contacting simple moulded cup (Whitehead, 2000) and does not rely on any fine precision to produce a lifting action.

Table 4.4 Manufacturing time and skill level required for the four designs

	DTU	Tamana	Harold	Enhanced Inertia
No of tools required	8	8	10	9
Time to manufacture (hrs.)	4	4	3	2
Skill level required	high	Medium	Low	Low
Total number of parts	13	15	13	12

(Whitehead, 2000)

Table 4.5: Performance comparison of the four handpumps

Variable	DTU	Tamana	Harold	Enhanced inertia
Internal diameter of rising main (mm)	39	39	39	39
Length of rising main (mm)	530	530	530	530
Stroke length (mm)	330	254	406	102
Kg force to lift water	8	7	1	1
No of cycles/Jerrican	134	114	159	142
Output Litres/min	7.55	11.6	8.93	8.43

Minutes to fill 20 Litre Jerrican	2.65	1.91	2.24	2.37
Apparent vol. efficiency	0.38	0.58	0.26	1.16
Reliability	low	low	Medium/high	High

(Whitehead, 2000)

Table 4.6: The manual hand pump specifications

Details	**Symbol**	**Units**	**Value**
Flow rate (discharge)	Q	$Litres\ s^{-1}$	0.167
Head (maximum)	H	M	6
Insider diameter	D	M	$32*10^{-3}$
Stroke length	l	M	0.3
Cadence	N	$Cycles\ s^{-1}$	1.167

To determine the power required for the hand water pump operating under the specifications in section above the following calculations are done

$$P_0 = En$$

Where Po = power (water Watts), E = Output energy, n = cadence in strokes per second and

$$E = mgH$$

Where m=mass of water lifted per cycle, g = gravity, H = head

But $m = v\rho$

Where v = swept volume of stroke, ρ is the density of water

Therefore the swept volume of half cycle is

$$v = \pi r^2 l = 3.142 \times 0.0195^2 \times 0.3 = 0.000358m^2$$

$$E = v\rho gH = 0.000358 \times 1000 \times 9.81 \times 6 = 21\,J$$

Therefore; $P_0 = En = 21J \times 1.167s^{-1} = 24.59Watts$

This power output indicates that the hand water pump have small efficiency in their operations and from the data above and the calculations it is seen that a 20 year old human is capable of producing 220Watts effort of duration of a minimum of 5minutes without performing any other task . This water is obtained at a fixed depth which its self is not applicable to some area

4.2 Determining machine parameters

4.2.1 Design specifications

For a pendulum water pump; water can be obtained at various heads by just varying the driving mass at the pendulum and lever distance along the pivot.

For example consider the head of 20ft = 6.096m using a pipe of 2.5inch = 0.038m to suck water to the ground level we can determine the mass needed,

Suction pressure required

$$P = h\rho g = 6.09 \times 1000 \times 9.81 = 59801.76\ Nm^{-2}$$

Suction force;

Force (F) = Pressure (P) × Cross section area (A)

Cross section area; $A = \pi\frac{d^2}{4} = \frac{\pi}{4}(0.038)^2 = 0.00114m^2$

Where; d is the thickness of pipe which is 1.5inches = 0.038m

Therefore the suction force of the pump;

$$F = 59801.76 \times 0.00114 = 68.17N$$

The above force is provided by the mass held at the end of the pendulum and this force varies depending on the positions and the angle swept by the lever

Assuming that the pivot is placed in the middle of lever,

Initial position;

Taking moments about the pivot

$68.17 * 0.5l = m \times 0.5l \times 9i.81$

$m = 6.949kg \approx 7kg$

Note; the position of the pivot on the lever affects the force being exerted on the piston.

Assuming the pendulum at 60^0 and the rod length is 3m, then the energy input into the pump is given by;

$$E_p = 2mgl = 27 \times 9.81 \times 1.5 = 206.01J\ (Power\ input\ to\ the\ piston)$$

Power output of the pump;

$$P_o = \frac{E_P}{n} = \frac{206.01}{1.167} = 176.530Watts$$

Therefore; Efficiency of the pump;

$$\eta = \frac{P_O}{E_p} \times 100\% = \frac{176.530}{206.01} \times 100\% = 86\%$$

4.3 Select, size the material and develop final machine layout

4.3.1 Conceptual Design Choice

The most suitable type of pump for this application was found to be a reciprocating pump because of its;

i. compact size,
ii. simplicity of design,
iii. relatively low cost,
iv. light weight and
v. Widespread availability of pumps and spare parts make it ideal for use in this project.

Reciprocating pumps are:

i. a well-established technology
ii. generally very efficient
iii. suitable for very high heads at low flows
iv. delivers reliable discharge flows and is
v. self-priming as it can draw liquid from a level below the suction flange
vi. Often used for metering duties delivering accurate quantities of fluid.
vii. And consequently their performance is well understood.

Table 4.7: Shows the pump performance data given in the Clarke TAM105 operating manual

Input Power	Operating Speed	Max. Head	Max. Suction Lift	Max. Flow Rate	Weight	Max. Height	Max. power
330W	2800rpm	35m	7m	40 l/min	7.2kg	50m	800W

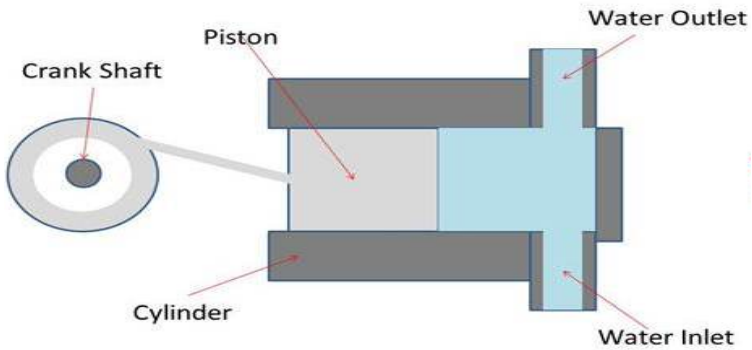


Figure 4.1: Shows a Reciprocating pump

4.3.2 Nature and size of the materials required

Table 4.8: Shows the nature and size of the materials required

S/No.	Component	Dimension	Suitable material	Reason for selection
1.	Reciprocating Pump	1	Cast iron	High strength
2.	Plate	1'' Ø	Steel	High strength
3.	Cylindrical pipe		Steel	High strength
4.	Thread bar	M16 50mm	Steel	High strength
5.	Connecting plate	1" Ø	Steel	High strength
6.	Tension springs	1	Metal	Operate with tension load, so that the spring stretches freely as the load is applied to it.
7.	Hose pipes	2.5''Ø	PVC	High Corrosion Resistance, flexible and low cost
8.	Binding wires	1mm thickness	Metal	Bind pipe line in to the steel structure

4.3.3 Individual component designs

Figure 4.2: Shows the design of Piston arm

Figure 4.3: Shows the Tension Spring

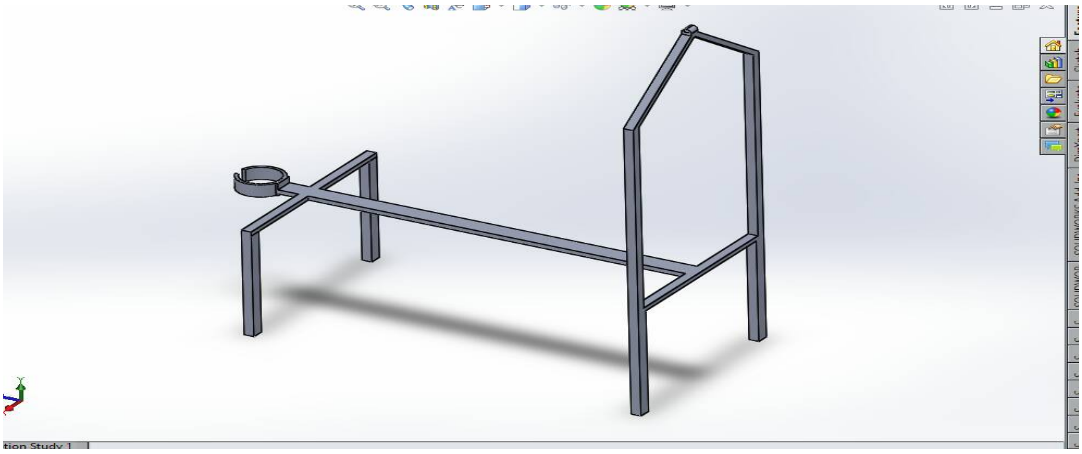


Figure 4.4: Shows the design of Main Frame

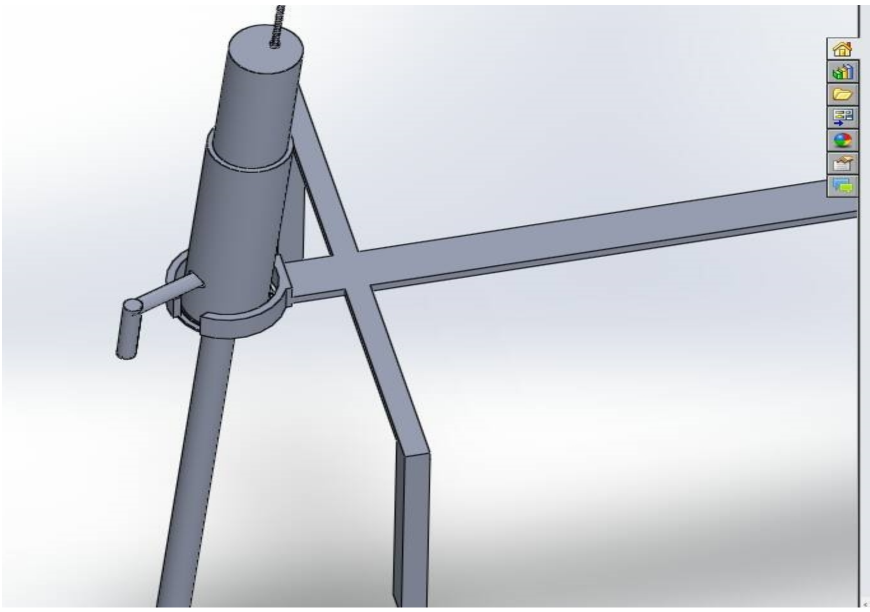


Figure 4.5: Shows design of connected Piston

4.3.4 Final layout of Pendulum reciprocating pendulum pump

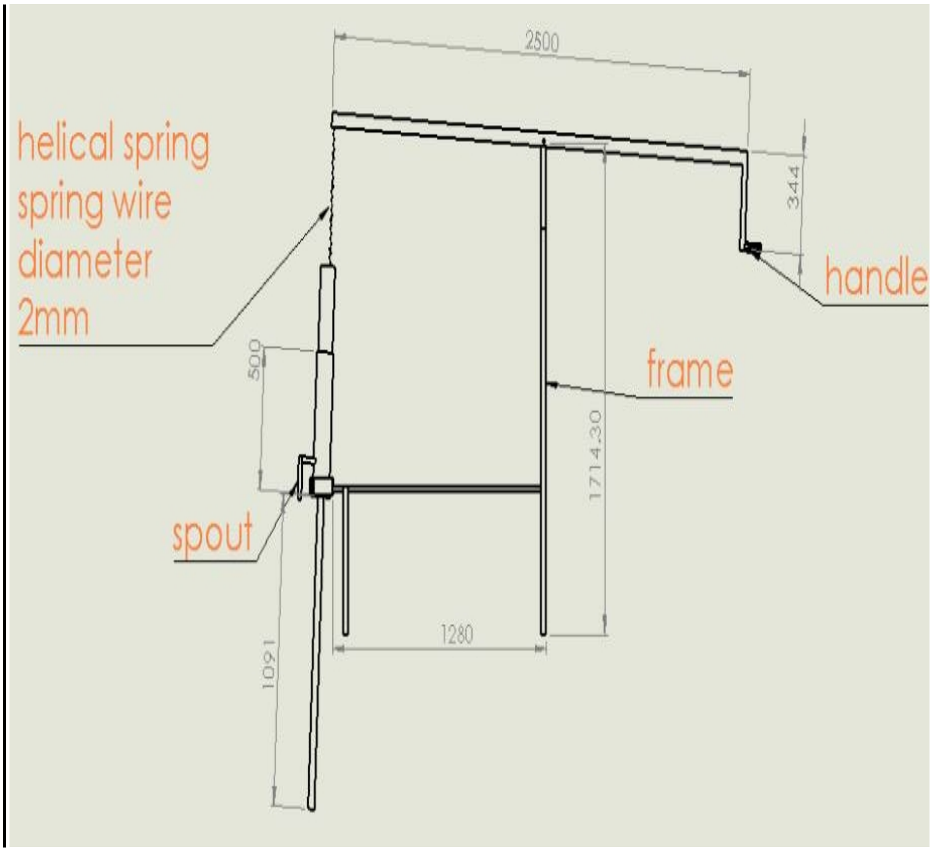


Figure 4.6: the design layout of a pendulum reciprocating pump

4.3.4 Operating principle

The pump is made of pendulum, two-leg lever and cylinder with the piston which pumps the water. Oscillation of the pendulum is maintained by periodical action of the human arm. Oscillation period of the pendulum is twice bigger than the period of the lever oscillation. Piston of the pump has reverse effect on the lever and damps its oscillation. Damping of the lever motion causes damping of the pendulum, but the work of the force damping the pendulum is less than the work of the forces which damp the lever.

Equilibrium position of the lever is horizontal, and the equilibrium position of the pendulum is vertical. Oscillation of the lever and the pendulum takes place in the same plane, vertical in reference to the ground.

Figure 4.7: Flow chart of pendulum water pump operation

4.4 Results and analysis

The various parameters that determine the output discharge of the pendulum pump are analyzed and the results are plotted. Analysis parameters include mass of pendulum, swing or displacement angle of the pendulum mass, and lengths of lever and the pendulum.

The table 4.9: shows the analysis of the swept angle by the mass

Position of the mass with respect to the lever	**Mathematical formula**	**Power input to the pump**
Initially	$Ep = mgl$	$Ep = 7 \times 9.81 \times 1.5$ = 103.005
At 30°	$Ep = \frac{2}{\sqrt{3}}mgl$	$Ep = \frac{2}{\sqrt{3}} \times 7 \times 9.81 \times 1.5$ =118.940
At 45°	$Ep = \sqrt{2}mgl$	$Ep = \sqrt{2} \times 7 \times 9.81 \times 1.5$ =145.671
At 60°	$Ep = 2mgl$	$Ep = 2 \times 7 \times 9.81 \times 1.5$ =206.010
At 90°	$Ep = 3mgl$	$Ep = 3 \times 7 \times 9.81 \times 1.5$ =309.015

4.4.1 Analysis of Mass of the Pendulum

Here, the discharge is found out by changing the mass of the pendulum by maintaining the maximum swing angle and maximum length of the pendulum.

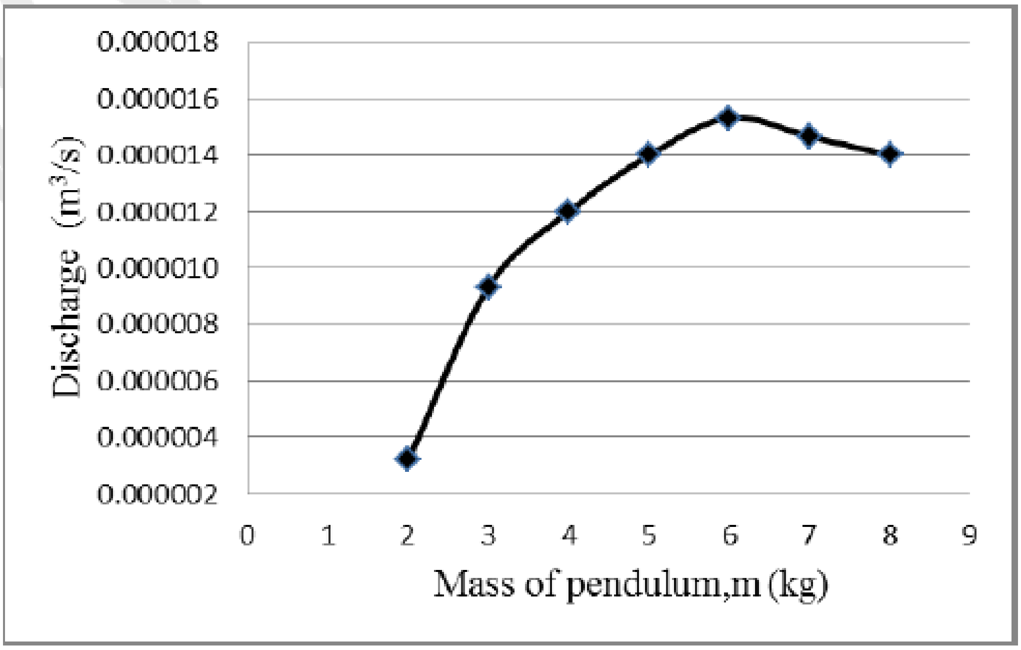


Figure 4.8: Shows Mass of pendulum (m) Vs Discharge (M^3/s)

4.5.2 Analysis of Length of the Pendulum

Here, the discharge is found out by varying the length of the pendulum without changing the mass of the pendulum and the swing angle.

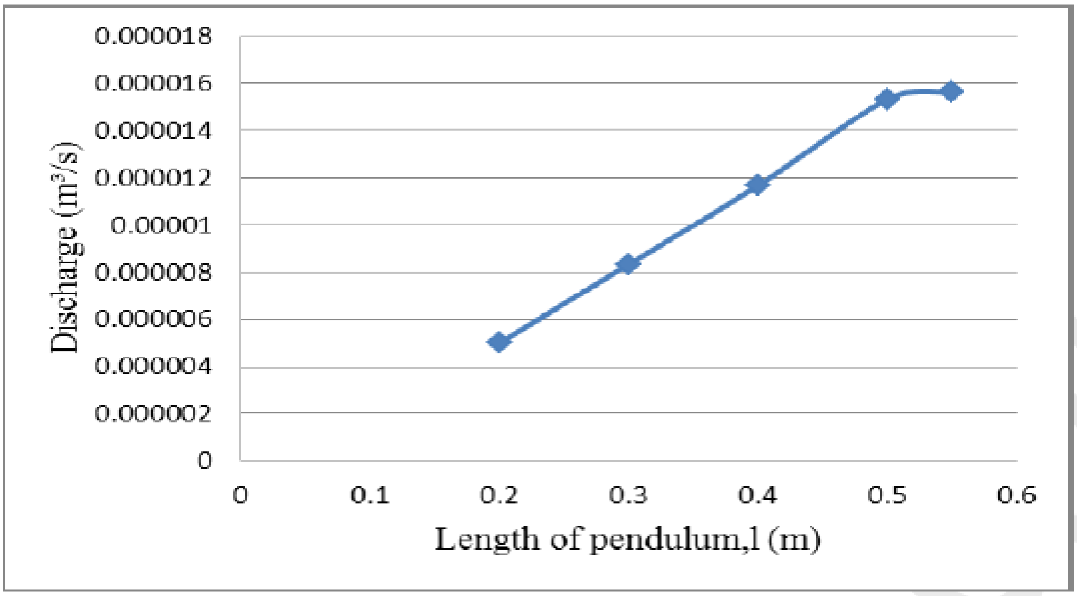


Figure 4.9: shows Length of pendulum (*l*) vs Discharge (m^3/s)

4. 5 Cost analysis for the project

4.5.1 Cost of the project

Table 4.9: Shows the Cost Estimate for the project

ITEM	**QUANTITY**	**UNIT PRICE (UG.SHS)**	**AMOUNT (UG.SHS)**
Reciprocating pump	1	250,000	250,000
Steel plate(1 inch diameter)	5 meters	50,000	250,000
Steel cylindrical piece	1	50,000	50,000
M16 5omm thread bar	1meter	100,000	100,000
Connecting plate	1/2meter	20,000	20,000
Tension springs	2	5000	10,000
Hose pipes of 2.5inch diameter	2	20,000	40,000
Paint	1litre	10,000	10,000
Fabrications + labour			100,000
Miscellaneous			150,000
Total			**980000**

4.5.2 The payback period

The cash flows = Maintenance cost+ Electricity

The cash flows = Shs. 300,000 + 0 = 300,000

$$\text{Payback period} = \frac{\textit{Total cost of the project}}{\textit{cash flows}}$$

$$= \frac{980{,}000}{300{,}000} = 3.2 \approx 3\text{years}$$

The payback is approximately a year and seven months which is a profitable venture for small scale farming.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter consists of the conclusions drawn from the project and the recommendations.

5.1 Conclusion

This project was about development of a pendulum reciprocating water pump for rural communities where there exists no electricity and other means of pumping water are expensive for an average family. Basing on the findings of the study, the following conclusions have been drawn;

With reference to the objectives of the project, the existing pumping methods were successfully reviewed which was achieved with the help of library search, internet and local information.

The different components were designed and selected and pendulum reciprocating water pump was assembled using Solid works 2012 and different formulas from different engineering textbooks. The design was specifically developed for use by people of Rukungiridde.

Cost Analysis: The cost analysis for the project was carried out and the payback period calculated. The project has a payback of one year and seven months and this shorter payback period will attract potential investors to invest in the project. From experimentation therefore, it can be concluded that the system is practically feasible.

5.2 Recommendations

With regard to the process undertaken in the compilation of this document, the observations made and the system developed, the following recommendations have been drawn;

1. The design should be adopted by farmers of Rukungiridde and other similar rural areas without electricity. This will enhance agricultural production since it will be carried out even during dry seasons.
2. Apart from using pendulum water pump for pumping water for irrigation, it can further be applied in other fields. These include; sewage plants-used in the collection and treatment of sewage; Chemical Industry -to transport fluids to and from various sites in

the chemical plant; Petroleum Industry-used in every phase of processing of petroleum, its transportation, and separation of the impurities; Medical Field- to pump fluids in and out of the body; Steel Mills-Cooling water in steel mills can be transported using a pendulum pump.

3. Further research should be carried out as far as pendulum based hand water pump is concerned as this could solve many problems in the agricultural and fisheries, health and energy sectors for this nation, with the majority of areas lacking access to electricity.
4. A proper maintenance schedule should be adhered to so as to get the best output of the machine. Necessary repairs need be done in time such that the pump is available all the time.
5. Development of operating, service, catalogue manuals for routine maintenance should be carried out.

REFERENCES

1. Cedat. (2016). Low-cost Irrigation Project. Kampala, Uganda. Retrieved from Cedat.mak.ac.ug.
2. Citi BrandVoice. (2014). *How a water pump is changing the lives of farmers in africa*. Retrieved from Forbes.com: http://www.forbes.com
3. Fraenkel, P. (1997). Water pumping devices. *IT Publications* .
4. Fraenkel, P., & Jeremy, T. *Water Pumping Devices - A Handbook* (3 ed.). Practical Action Publishing, 2006.
5. Fraenkel, P., & Jeremy, T. (1997). *Water Pumping Devices - A Handbook* (3 ed.). Practical Action Publishing, 2006.
6. Kali, C. R., Pradip, K. S., & Deepak, K. K. (2016). A Brief study on pendulum based pump. *International Journal of Modern Trends in Engineering and Research , 3* (4).
7. Moniz, & Girdhar, P. (2004). *"Practical centrifugal pumps design, operation and maintenance"* (1 ed.). Oxford: Newnes.ISBN 0750662735. Retrieved 3 April 2015.
8. Morgan, P. (1990). *Rural Water Supplies and sanitation.* Macmillan.
9. Nejbosa, S. (2001). A scientific paper on "FREE ENERGY OF OSCILLATING PENDULUM LEVER SYSTEM".
10. Robert, L. (1990). *How to Make a Rope-and-Washer Pump.* Practical Action Publishing-2006.
11. Rony, K. P., Steffin, G. S., & R, A. (2015). Fabrication and Analysis of a Pendulum Pump. *International Journal of Research in Engineering and Technology* , 1-2.
12. Thomas.T.H, McGeever, B., & and Members of URDT, K. U. (1997). Underground storage of rainwater for domestic use. *DTU Working Paper* (49).
13. Whitehead, V. (2000). The Manufacture of Direct Action Handpumps for use with Domestic Rainwater Harvest Tanks . *a DTU Technical Release No: TR.-RWH 09* .
14. WHO. (2003). *Chapter 4: Water Lifting Devices.* Linking Technology Choice with Operation and Maintenance.

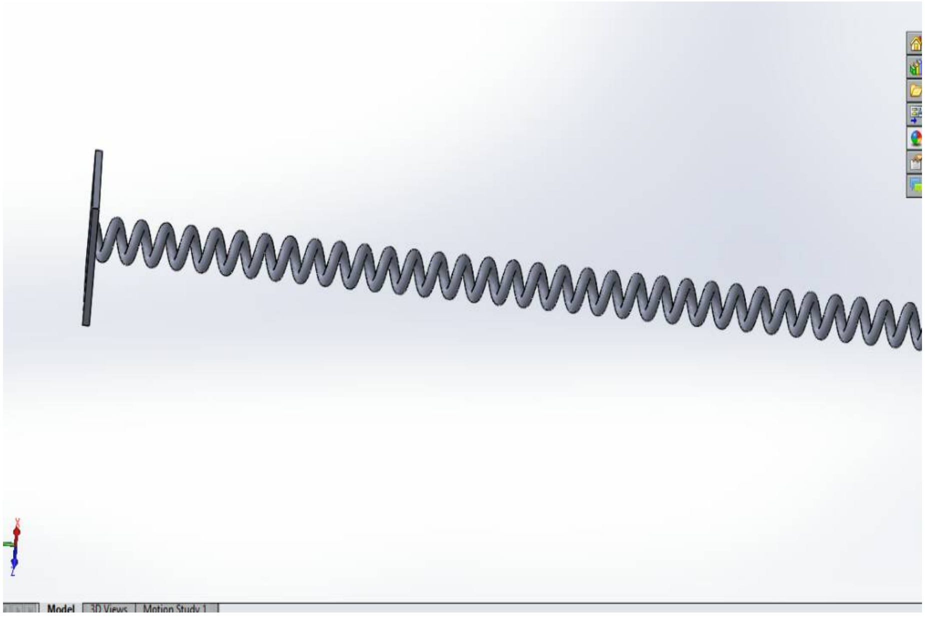
APPENDIX

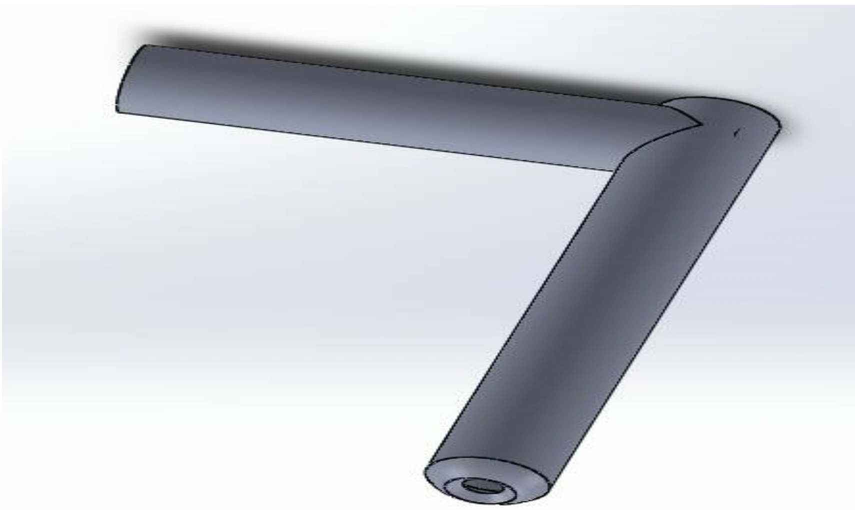
Appendix i: Observation Checklist

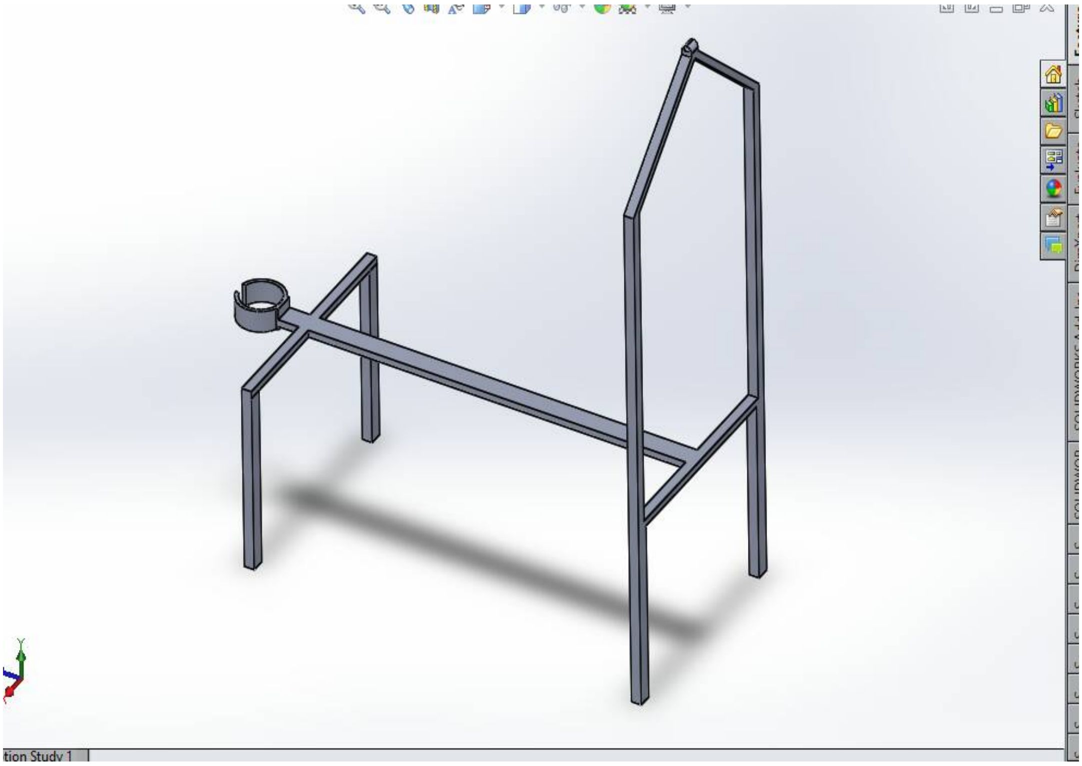
Table 7.1: Manufacturing time and skill level required for the four existing designs of handpumps

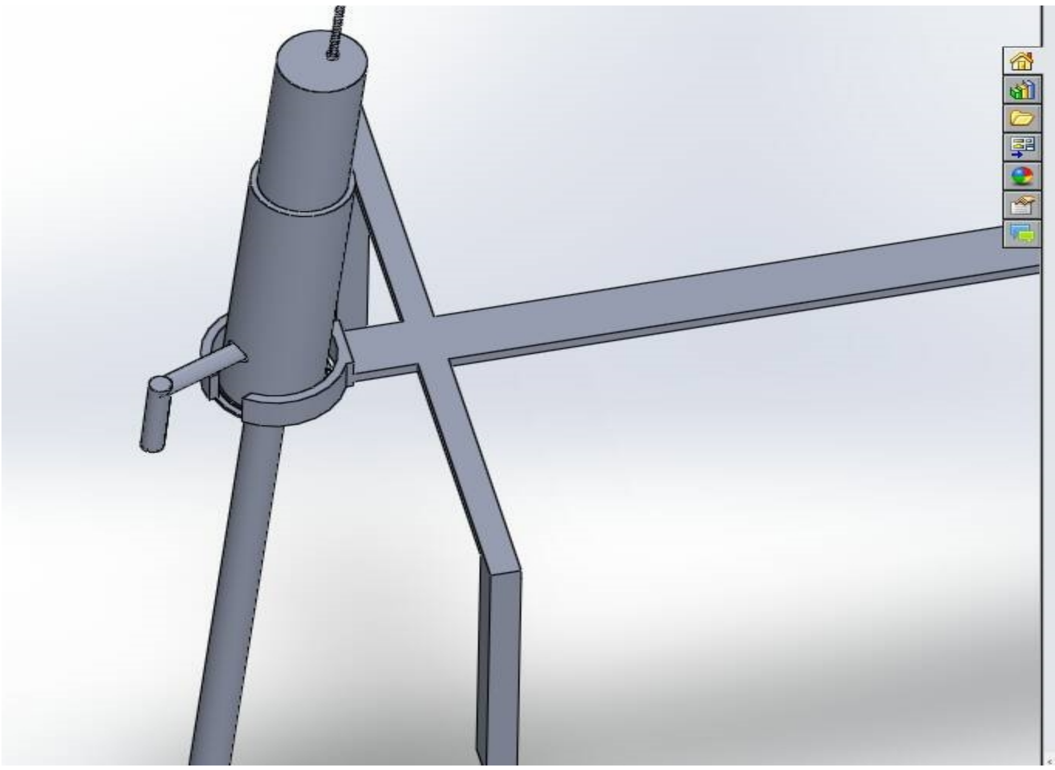
	DTU	Tamana	Harold	Enhanced Inertia
No of tools required	a) Less than 7 b) 8 c) 9 d) 10 e) More than 10	a)Less than 7 b) 8 c)9 d) 10 e)More than 10	a) Less than 7 b) 8 c) 9 d) 10 e) More than 10	a) Less than 7 b) 8 c) 9 d) 10 e) More than 10
Time to manufacture (hrs)	a) 2 b) 3 c) 4 d) More than 5	a) 2 b) 3 c) 4 d) More than 5	a) 2 b) 3 c) 4 d) More than 5	a) 2 b) 3 c) 4 d) More than 5
Skill level required	a) High b) Medium c) Low	a) High b) Medium c) Low	a) High b) Medium c) Low	a) High b) Medium c) Low
Total number of parts	a) 12 b) 13 c) 14 d) 15 e) More than 15	a) 12 b) 13 c) 14 d) 15 e) More than 15	a) 12 b) 13 c) 14 d) 15 e) More than 15	a) 12 b) 13 c) 14 d) 15 e) More than 15

Appendix ii: Different machine components






tion Study 1



Appendix iii: Final Machine layout