Performance Evaluation of Lever and Wheel Type Manual Reciprocating Pump for Irrigation Uses

Salihu Bala Tajiri*, KabiruMoyi, Abdu Tsoho

Mechanical Engineering Department, College of Engineering, Umaru Ali Shinkafi Polytechnic, Sokoto, P.M.B. 2356, Sokoto Sate, Nigeria.

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Abstract: A pump a any device that collect fluid (water, air, slurry) from a supplier or reservoir and deliver to a collector using virtually mechanical means. Reciprocating pumps work in similar way the piston of internal combustion engine does. Pumps are very vital for irrigation purpose to reduce the stress involve in watering crops on the farm during the dry season. This paper compares the performance of a wheel type manual reciprocating pump with a lever type. 10, 20, 30, 40 and 50 strokes were used for each and the amount of water collected were noted down for each of the pumps at the end of every specified cycle or stroke. It was observed that at the end of 10 strokes wheel type pump delivered 125 litres of water, while lever type delivered 20 litres. At 30 strokes it was 45 litres against 75 litres and at 50 cycles wheel type delivered 95 litres and lever type delivered 110 litres of water. The efficiencies were calculated to be 26.67% for wheel type pump and 46.675 for the lever type pump. Both are above a recent experiment performed on a reciprocating pump, with an efficiency of 17.87%.

Keywords: Pump, Reciprocating, Manual, Stroke, Suction, Discharge, Irrigation.

INTRODUCTION

A pump is a device used to move fluids (liquids or gases) or sometimes slurries by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps (PVC, 2011).

Irrigation is the replacement or supplementation of rainwater with some other source of water (Demirbas, 2008). The main idea behind irrigation systems is that your lawns and plants are maintained with the minimum amount of water required (Docs.google.com, 2010).

Water is a fragile natural resource and we have to incorporate methods to conserve it and not over-use it (Engineering Sciences, 2007). The implementation of an irrigation system will help conserve water, while saving you time, money, preventing weed growth and increasing the growth rate of your lawns, plants, crops and flowers (Cooper, 2009).

Firstly, we should ask ourselves what is the control of capillary (CCRF) in irrigation and fertilization, a relatively new concept in the irrigation engineering (Fao.org., 2011). According to World Bank (1997), agronomist of wise Irrigation system, the control and management of irrigation in CCRF is to keep the moisture in the soil saturation and ability to field, through the issuance of separate and Computable drops by pulses (risks of not more than 2 minutes). With this low voltage humidity (under osmotic potential), the water is quickly and easily available for plants and the oxigeno-aqua relationship is at the optimum level, suitable for the growth and root development (Fao.org., 2011).

Pumps must have a mechanism which operates them, and consume energy to perform mechanical work by moving the fluid. The activating mechanism is often reciprocating or rotary. Pumps may be operated in many ways, including manual operation, electricity, an engine of some type, or wind action (Karassik, Messina, Cooper and Heald, 2001).

Positive displacement pumps, unlike centrifugal or roto-dynamic pumps, will in theory produce the same flow at a given speed (RPM) no matter what the discharge pressure. Thus, positive displacement pumps are "constant flow

machines". However due to a slight increase in internal leakage as the pressure increases, a truly constant flow rate cannot be achieved (Karassik *et al.*, 2001).
A positive displacement pump must not be operated against a closed valve on the discharge side of the pump, because it has no shut-off head like centrifugal pumps. A positive displacement pump operating against a closed discharge valve will continue to produce flow and the pressure in the discharge line will increase, until the line bursts or the pump is severely damaged, or both (Cooper, 2009).

A relief or safety valve on the discharge side of the positive displacement pump is therefore necessary. The relief valve can be internal or external. The pump manufacturer normally has the option to supply internal relief or safety valves. The internal valve should in general only be used as a safety precaution. An external relief valve installed in the discharge line, with a return line back to the suction line or supply tank, is recommended (Ahmad, 2008 and PVC, 2011).

According to Karassik et al., (2001) and Fao.org (2011), the positive displacement principle applies in the following types of pumps:Rotary Lobe Pump, Reciprocating Pump, Progressive Cavity Pump, Rotary Gear Pump, Piston Pump, Diaphragm Pump, Screw Pump, Gear Pump, Hydraulic Pump, Vane Pump, Regenerative (Peripheral) Pump, Peristaltic Pump, Rope Pump and Flexible impeller.

Reciprocating pumps are those which cause the fluid to move using one or more oscillating pistons, plungers or membranes (diaphragms), and restrict motion of the fluid to the one desired direction by valves (Cooper, 2009). Pumps in this category range from simplex, with one cylinder, to in some cases quad (four) cylinders or more. Many reciprocating-type pumps are duplex (two) or triplex (three) cylinder. They can be either single-acting with suction during one direction of piston motion and discharge on the other, or double-acting with suction and discharge in both directions. The pumps can be powered manually, by air or steam, or by a belt driven by an engine. This type of pump was used extensively in the early days of steam propulsion (19th century) as boiler feed water pumps (Ahmad, 2008 and pumpsandsystems.com, 2015). Reciprocating pumps are now typically used for pumping highly viscous fluids including concrete and heavy oils, and special applications demanding low flow rates against high resistance. Reciprocating hand pumps were widely used for pumping water from wells; the common bicycle pump and foot pumps for inflation use reciprocating action (Docs.google.com, 2010).

These positive displacement pumps have an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pumps as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant given each cycle of operation (Cooper, 2009).

Reciprocating pumps can be classified based on the following (Cooper, 2009):1. Sides in contact with water: (a) Single acting Reciprocating pump; (b) Double acting reciprocating pump. 2. Numbers of cylinder used: (a) Single cylinder pump; (b) Twocylinders pumps; (c) Multi-cylinder pumps.

Types of Reciprocating pumps

The following are commonly known types of reciprocating pumps (Karassik *et al.*, 2001):

Single-acting reciprocating pump: This has one suction valve and one discharge valve. When the piston is moved backward, suction happens and when it moves forward, the delivery valve opens up to discharge the liquid.

Double-acting reciprocating pump: Unlike single acting pump, here there are two suction and delivery valves. When the piston is moved forward or backward, with each stroke, both suction and expulsion happen simultaneously.Thus, it requires two inflow pipes and two outflow pipes. Some of the common applications of these kinds of pumps are in Salt Water Disposal, Well Service, Descaling, Hydraulic Fracturing, and Oil & Gas Pipelines (Karassik, 2007).

Double acting – Air and Steam pumps: These are double acting pumps where steam, air or gas is used to transmit power to the liquid through the piston. They can operate at any point of pressure and flow, within a flexible range. Because of these features, steam driven pumps are mostly used in the refineries for pump-out service, with low NPSH and the fluids used are hydrocarbons mostly with high viscosity and high temperature (Karassik, 2007).

Simplex, Duplex, triplex, Quintuplex Pumps: Many reciprocating type pumps are simplex (one), duplex (two) or triplex (three) cylinder. Duplex pumps are usually used where the two pumps can be used alternatively. Such pumps are commonly used in oil-line pumping, mine de-watering, and chemical and petroleum products transfer, but has many more applications. A triplex pump consists of three plungers, with the aim of reducing the pulsation of a single reciprocating pump. Quintuplex pumps are designed with a gear case that assists in a high-pressure task. Common applications of which are in cement slurries, sand-laden fluids, crude oil, acids, mud and other oil well-servicing fluids (John, 2010).

Plunger Pumps: a reciprocating plunger pushes the fluid through one or two open valves, closed by suction on the way back.

Diaphragm Pumps: similar to plunger pumps, where the plunger pressurizes hydraulic oil which is used to flex a diaphragm in the pumping cylinder. Diaphragm valves are used to pump hazardous and toxic fluids.

Piston Displacement Pumps: usually simple devices for pumping small amounts of liquid or gel manually. An example is the common hand soap pump.

Radial piston pump

Plunger pumps are reciprocating positive displacement pumps. They consist of a cylinder with a reciprocating plunger in them. The suction and discharge valves are mounted in the head of the cylinder. In the suction stroke the plunger retracts and the suction valves open causing suction of fluid into the cylinder. In the forward stroke the plunger pushes the liquid out of the discharge valve (Karassik *et al.*, 2001).

Metering Pumps: A metering pump is usually used where the rate of flow of the liquid needs to be adjusted in a specific time period. Most of the metering pumps are piston driven and are called Piston pumps. Piston pumps can pump at a constant flow rate against any kind of discharge pressure. Both Piston pumps and Plunger pumps are reciprocating positive displacement pumps that use a plunger or piston to move fluid/substance through a cylindrical chamber (pump-zone.com, 2011).

Reciprocating Pumps can also be classified according to the number of cylinders: Single cylinder and double cylinder pump. They are also sometimes classified according to their operation, known as simple hand-operated reciprocating pump & power-operated deep well reciprocating pump.

Problem Statements

Food shortage is the leading cause of inflation to any society, as the life of all the citizens are tie to food. There is hardly any much impact on the inflation if the is shortage of power supply or petroleum product.As a result, after the farming season, farmers go ahead to farm additional, during the dry season and they will be watering the crops artificially using any available means. Buckets, and various implements can be used. But this is labourous and time consuming.This call for the fabrication of this manual pump, which will reduce the labour and time consumption associated with the crude methods (Engineeringnews.co, za, 2011).

Aim and Objectives

The aim of the project is to fabricate and test a lever and wheel type manual reciprocating pump that will be used for irrigation in the rural areas, where fuel and electricity could be problems.Thiscan be achieved through the following objectives:

- Fabricate a simple lever type manual reciprocating pump for irrigation purpose
- Fabricate a simple wheel type manual reciprocating pump for irrigation purpose
- To test the fabricated pumps and compare their performances

Design and Calculation

We are concern with the liability, reliability, ergonomics and aesthetic nature of the component to be produced.

Design of the Cylinder

The circumferential stress in the cylinder wall is considered to be:

$$\sigma_C = \frac{\text{Total Pressure}}{\text{Resisting section}} = \frac{PdL}{2tL} = \frac{Pd}{2t} \text{---1}$$

Where P = intensity of the internal pressure; L = length of the cylinder shell, d = Diameter of the cylinder shell; t = Thickness of the cylinder shell. Longitudinal stress on the cylinder wall is considered to be (Pumps.org, 2011):

$$\sigma_L = \frac{\text{Total Pressure}}{\text{Resisting section}} = \frac{P\pi d^2}{4\pi dt} = \frac{Pd}{4t} \quad \text{---2}$$

Design of the Piston

The movement of the piston is similar to that of internal combustion engine. The displacement of the piston is considered to be (Pumps.org, 2011):

$$X = R\,(1 - \cos\theta) + \frac{R^2 \sin^2\theta}{2L} \text{---3}$$

Where: X = Piston displacement, R = Crank length, L = length of connecting rod, θ = crank angle

Length of Stroke is given as (Pumps.org, 2011):

$$S = \sqrt{(1+R)^2 - d^2} - \sqrt{(1-R)^2 - d^2} \text{---4}$$

Where: S = length of stroke, R = Crank length, d = diameter of cylinder. Linear velocity of the piston is considered to be (Pumps.org, 2011):

$$V = R\omega\left(\sin\theta + \frac{R\sin^2\theta}{2L}\right) \text{---5}$$

Where ω = Angular velocity. Linear acceleration is considered to be (Pumps.org, 2011):

$$A = R\omega^2\left(\cos\theta + \frac{R\cos^2\theta}{L}\right) \text{---6}$$

Inertia force on the piston is considered to be (Pumps.org, 2011):

$$F_i = \frac{12WV_c^2}{gAR}\left(\cos\theta + \frac{R\cos^2\theta}{L}\right) \text{---7}$$

Where W = total weight of the reciprocating parts, A = area of the piston, g = acceleration due to gravity, V_c = Velocity of crank pin, L = length of the connecting rod, R = Crank length

Design of the connecting rod

The connecting rod is considered to be acting upon forces similar to column with pin-pin ends, subjected to an internal bending load due to inertia of the oscillating rod. The stress due to the column action is considered to be (Pumps.org, 2011):

$$\sigma = \frac{F_c}{\frac{A(1-\delta y\, L^2)^4}{4n\pi^2 ET_c}} \text{---8}$$

Where; $F_c = \frac{P}{\cos\theta} = \frac{P}{\sqrt{1 - \frac{(R\sin\theta)^2}{L}}}$ this is the force acting along the center line of the connecting rod.

Discharge from the pipes

The discharge is given as (Pumps.org, 2011):

$$\mathbf{Q} = \frac{\mathbf{LAN}}{\mathbf{60}} \quad \text{-----}14$$

Where L = length of the stroke of the piston, A = cross sectional area of the piston; N = Number of revolutions per minute of the Prime mover. Force of piston in forward stroke

$$\mathbf{F_f = WH_sA} \quad \text{-----}15$$

Force of piston in backward stroke

$$\mathbf{F_b = WH_dA} \quad \text{-----}16$$

Work done by the pump

$$\mathbf{W_p = WQ\,(H_s - H_d)} \quad \text{-----}17$$

Where H_s = suction head of the pump, H_d = Delivery head of the pump, A = area of the piston, W = Specific weight of the liquid, Q = Discharge of the liquid. Velocity of water in the pipes is equal to velocity in the cylinder. So that (Pumps.org, 2011):

$$\mathbf{V_{pp}} = \frac{\mathbf{A\ x\ V_{ps}}}{\mathbf{a}} = \frac{\mathbf{A}}{\mathbf{a}}\,\mathbf{R\omega\,(sin\theta} + \frac{\mathbf{R\,sin^2\theta}}{\mathbf{2L}} \quad \text{-----}18$$

Acceleration of water is given as (Pumps.org, 2011):

$$\mathbf{a_{pp}} = \frac{\mathbf{A}}{\mathbf{a}}\,\mathbf{R\omega^2\,(cos\theta} + \frac{\mathbf{R\,cos^2\theta}}{\mathbf{L}} \quad \text{-----}19$$

Weight of water in the pipe is given as (Pumps.org, 2011):

$$\mathbf{W_w = WaL} \quad \text{-----}20$$

Mass of water is given as (Pumps.org, 2011):

$$\mathbf{M_w} = \frac{\mathbf{WaL}}{\mathbf{g}} \quad \text{-----}21$$

Acceleration force is given as (Pumps.org, 2011):

$$\mathbf{F_a} = \frac{\mathbf{WaL}}{\mathbf{g}}\ \mathbf{x}\ \frac{\mathbf{A}}{\mathbf{a}}\ \mathbf{x\ R\omega^2\,(cos\theta} + \frac{\mathbf{R\,cos^2\theta}}{\mathbf{L}}\mathbf{)} \quad \text{-----}22$$

Intensity of pressure due to acceleration is give as (Pumps.org, 2011):

$$\mathbf{P_a} = \frac{\mathbf{WL}}{\mathbf{g}}\ \mathbf{x}\ \frac{\mathbf{A}}{\mathbf{a}}\ \mathbf{x\ R\omega^2\,(cos\theta} + \frac{\mathbf{R\,cos^2\theta}}{\mathbf{L}}\mathbf{)} \quad \text{-----}23$$

Acceleration pressure head is given as (Pumps.org, 2011):

$$H_a = \frac{L}{g}\ x\ \frac{A}{a}\ x\ R\omega^2\,(cos\theta + \frac{R\,cos^2\theta}{L}) \quad \text{-----}24$$

Where A = area of the cylinder, a = area of the piston; ω = angular velocity of the rotating crank, r = radius of the rotating crank; L = length of pipe.

Materials and Method

Materials used for the fabrication were: mild steel pipes, Mild steel plate, mild steel sheet, steel rod, bolts and nuts, skin, wood, Paint.The methods used for the fabrication were welding, bolting and assembly. After the assembly and finishing, the two pumps were tested and data collected.

Fig. 1: The Picture of the two Types of Pumps Fabricated and Used for Test.

Results and Discussion

Table 1: Amount of Water Delivered per Cycle

S/No	Number of Cycle	Volume of Water (litres)	
		Wheel Type	Lever Type
1	10	15	20
2	20	30	35
3	30	45	70
4	40	60	90
5	50	95	110
Total	150	245	325

From the table 1, it can be seen that the rate of discharge of each of the two pumps are:

Wheel type = $\frac{245}{150} = \mathbf{1.63\ Litre/Cycle}$

Lever type = $\frac{325}{150} = \mathbf{2.35\ Litre/Cycle}$

From the calculation above, it can be observed that the lever type pump has better output compared to the wheel type. The data on table 1 are used to generate the graph on figure 1 below.

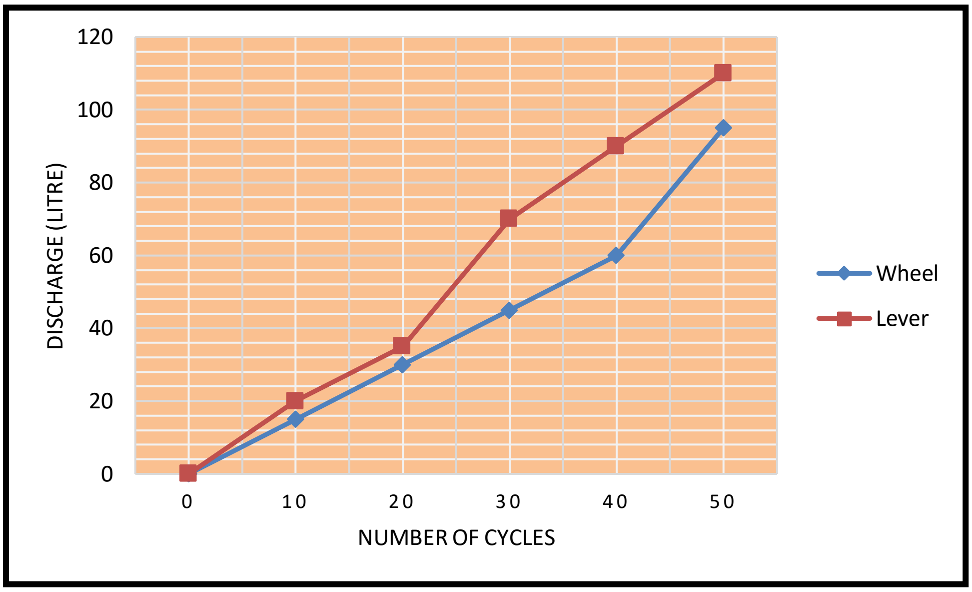

Fig. 2: Amount of Water Discharged (Litre) against Number of Cycles

From the figure 2 above, it can be observed that the rate of discharge of the pump with lever prime mover is more than that of wheel mover. From the beginning of the test till the end, it is above the wheel type pump. The least was 20 litres, while that of wheel was 15 litres. The highest discharge was 95 and 110 litres for wheel and lever type pumps. As for the lever pump the proportionality stops after 20cycles, while in the case of the wheel pump, the proportionality continued up to 40 cycles. At their proportionality limits their rate of pumping is the slope of the lines, which are 1.8 litres/cycle and 1.45 litres/cycles for lever and wheel pumps respectively.The efficiencies are:

$$\eta_{\text{wheel}} = \frac{\text{actual delivery} - \text{expected delivery}}{\text{expected delivery}} \text{ x } 100\% = \frac{95 - 75}{75} \text{ x } 100\% = \mathbf{26.67\%}$$

$$\eta_{\text{lever}} = \frac{\text{actual delivery} - \text{expected delivery}}{\text{expected delivery}} \text{ x } 100\% = \frac{110 - 75}{75} \text{ x } 100\% = \mathbf{46.67\%}$$

Conclusion

From the above results it is concluded that lever pumps deliver more pumping power than wheel type. Although, the wheel type is easier to operate, with less fatigue, which can allow a user to operate it for long time without getting tired? The efficiencies are 26.67% for wheel type pump and 46.67% for lever type pump, which indicated the better performance of the lever type pump.Both are at higher side above the recent experiment performed on an existing reciprocating pump, which gave an efficiency of 17.87%

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