A TECHNICAL EVALUATION OF THE PERFORMANCE OF THE ZIMBABWE TREADLE PUMP BASED ON LABORATORY TESTS

Kosamu Nyoni*

ABSTRACT

The Zimbabwe treadle pump was brought to the Zimbabwe Irrigation Technology Centre (Z.I.T.C) for a performance test. This is in line with the mandate of the Z.I.T.C which is to control the quality of all equipment that is used in the irrigation industry. The research project sought to evaluate the following attributes of the pump: Its physical characteristics and its technical performance (its discharge rates at different total dynamic heads; its cadence at different total dynamic heads; its feasible maximum total dynamic head and its mechanical advantage. The methodology used was laboratory based following previous tests conducted at Z.I.T.C. Results showed that the pump's dimensions were generally comparable to those recommended. Pump discharge was inversely related to TDH, and followed a linear relationship of $TDH = -2.07Q + 15.40$ *with an* R^2 *value of 0.8824. The pump was shown to have an operating TDH range of 0-15.40m for a corresponding discharge range of 7.44* m^3 */hr -0* m^3 */hr. The pump's cadence was also inversely related to TDH, and followed a linear relationship of* $TDH = -0.15C + 16.81$ *with an* R^2 *value of 0.72. It also had an operating TDH range of 0-16.81m for a corresponding cadence range of 114.71strokes/minute- 0 strokes /minute. Its mechanical advantage was 1.53. The pump was found to be quite comparable to other treadle pumps that were subjected to a similar test.*

Keywords*: Zimbabwe treadle pump; Pump discharge; Cadence; Mechanical advantage; Ergonomics; Total dynamic head; Appropriate technology*

*Great Zimbabwe University

INTRODUCTION

The advent of the land redistribution in Zimbabwe saw an increase in the number of small-holder irrigation schemes. Most of these schemes did not have the appropriate technology and income in order to be established and to compete with commercial schemes. The high cost of establishment of irrigation systems is also a major factor that has led to the need to introduce cost saving technologies that are cheap for the ordinary smallholder farmer with inadequate resources. One such technology is the introduction of the treadle pump which is a scaled down version of the high powered modern irrigation technologies. Its introduction was seen as a small but significant revolution that took place in the small-scale irrigation sector in the developing world (Kay and Brabben, 2000). A treadle pump (Figure 1) is a manually operated twin cylinder reciprocating pump that uses leg muscle force exerted on treadles to push water through the piston out via a discharge spout (Chigerwe et al, 2004).

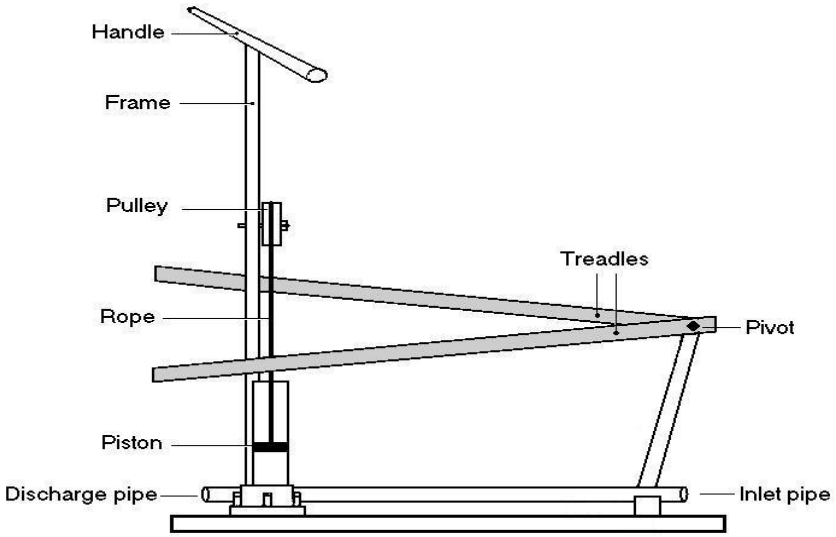

Figure 1**:** Basic components of a treadle pump

It is also defined as a foot operated single acting double cylinder piston pump for low lift irrigation (New Dawn Engineering, 2009).The pistons are connected to the pedals (treadles) by a rope, which passes over a pulley. Each treadle is connected to a piston moving in one of the two cylinders. A walking action on the treadles results in the pump operation. The operator stands on the pump to make full use of his or her body weight. It utilizes the positive displacement principle. The downward movement of the piston creates a partial vacuum that results in a definite quantity of water being sucked into the pump and discharged through the outlet spout. Compared to other manual lift devices, treadle pumps use human power relatively efficiently. Not only is the treadle pump easy to use but also incorporates an

element of flexibility in that it can be dismantled to allow for easy movement to the next position of use.

For many small farmers in the developing countries, the costs of buying, running and maintaining engine driven pumps are beyond their reach. Also with the erratic nature of the power sources in Zimbabwe, the use of a treadle pump can be an alternative to counter the unreliability of electricity power used to drive water pumps. Kay and Brabben (2000) indicated that treadle pumps could contribute to higher food production and create employment and income if pumps are produced locally and on a small scale. Lambert and Faulkner (1991) estimated that the area of 0.24 Ha was irrigable per operator per week using a treadle pump as compared to 0.03 Ha irrigable using watering cans for the same period and by operator. These estimations were based on existing FAO guidelines.

A number of treadle pumps are already being manufactured by various companies in Zimbabwe using locally available materials through their links with some non-governmental organisations. Most of these pumps have been sent to the Zimbabwe Irrigation Technology Centre (ZITC) in Harare so that their performances would be tested. These tests have revealed that suction heads exceeding 3 m make the pump quite difficult to operate (Savva et al, 2001). In a similar argument, delivery heads in excess of 6 m are also not recommended. This shows that treadle pumps can only be used where there are shallow water tables (Savva et al, 2001).

Manjengwa (2003) tested four treadle pumps that are used in most parts of Zimbabwe for technical performance under laboratory conditions. Performance evaluations are important not only for design engineers but also for farmers (Chigerwe et al, 2004). They form the basis for comparing commercial products (Bralts et al., 1985) and protect the user from false claims by manufacturers (Egan, 1997). These were namely: Masvingo pump, Money Saver pump, ITDG pump and the Super Money Maker (Super MM) pump (Chigerwe et al, 2004). The following parameters were computed: cadence, discharge rate, total dynamic head, and pump input power, pump output power, mechanical advantage and efficiency (Chigerwe et al, 2004). The following results shown in table 1 were obtained.

Table1: Average results of comparative treadle pump testing

Pump	**Lift**	**Head**	**Cadence**	**Discharge**	**Total dynamic head**	**Power input**	**Power output**	**Mechanical advantage**	**Efficiency**
	M	m	stroke/min	m^3/hr	m	Watt	Watt	-	%
Money Saver	2.1	2.6	69.8	4.2	5.4	166.8	48.2	2.9	31.9

Masvingo	2.1	2.6	40.8	3.0	5.3	77.2	29.6	2.1	45.3
ITDG	2.1	2.6	62.9	3.4	5.3	129.7	37.7	2.4	31.0
Super MM	2.1	2.6	46.6	1.4	5.4	119.1	15.8	1.0	14.1

(Adopted from Chigerwe et al, 2004)

In February of 2009, a treadle pump was brought to the Zimbabwe Irrigation Technology Centre in order to test its technical performance. The name of the treadle pump is called the Zimbabwe Treadle pump (Figure 2). The research project sought to evaluate the following attributes of the pump: Its physical characteristics and its technical performance (its discharge rates at different total dynamic heads; its cadence at different total dynamic heads; its feasible maximum total dynamic head and its mechanical advantage.

Definition of terms

- Discharge is the amount of water delivered by a pump per unit time. It is measured in m^3/hr.
- Total dynamic head is the sum of the suction head and the delivery head.
- Cadence is the frequency with which the treadles are moved up and down: One cycle is completed when a treadle bar is pushed down and rises once again to its starting position (DTU, 1991).
- Mechanical advantage is the ratio between the load and the effort needed to lift the load in a lever system. Alternatively, it is the ratio between the distance of the effort from the fulcrum and the distance of the load from the fulcrum. Mechanical advantage allows treadle pumps to be used by the widest range of operators and across varying pumping heads (DTU, 1991). The force exerted on the pistons by the operator can be varied by the operator moving along the treadles. In so doing, mechanical advantage between the operator and the cylinder will be varying (DTU, 1991)

Figure 2: The Zimbabwe Treadle pump

MATERIALS AND METHODS

The treadle pump tested was supplied to the ZITC by the Food and Agriculture Organisation (FAO).

Pump characteristics and inspection

The pump was to be physically inspected for constructional and operational defects and its dimensions measured with a tape measure before being subjected to the technical evaluation tests.

Technical evaluation of pump

The technical evaluation of the treadle pump was based on a combination of methods used by Lambert and Faulkner (1991) and by Thomas (1993). Five persons of different weights, two men and three women, operated the pump at different suction lifts and discharge heads. Suction lifts were varied between 0.5 m, 1m, 2m, 3m and 4m whilst delivery heads were varied between 0.5 m, 1m, 2m, 3m, 4m, 5m and 6m. The flow rate at these heads was measured. A petrol water pump was used to change the suction levels in the sump. During each test the suction level was kept constant by allowing a flow-back of pumped and measured water from the bucket back into the sump.

The delivery head was set by raising the end of the outlet pipe to a known height while the discharge was measured volumetrically. A 40 mm, class 6-polyethylene delivery pipe, 22.8 m long was used for the treadle pump. The capturing vessel used was a 15- litre bucket. The

time it took to get a known volume of 15-litres was recorded. By dividing the volume (15 l) by the time it took to fill the 15 litres, the discharge rate was determined. The number of strokes at each set delivery head and suction lift were also noted. The following parameters were computed: cadence, discharge rate, total dynamic head and mechanical advantage.

To calculate mechanical advantage, the following equation was used:

$$MA = \frac{Measurement\ from\ treadle\ to\ pivot(mm)}{Measurement\ from\ piston\ to\ pivot(mm)} \quad [1]$$

Pump Operators

Pump operators were selected on the basis of gender and weight. Two males and three females were chosen to do the pump operations (Table 2). The average weight of male and females at 18 years and above is 65 kg and 55 kg respectively (Ministry of Health, 2003).

Table 2: Pump operators by gender, weight, age and height

Operator No.	Name of operator	Sex	Weight (kg)	Age (years)	Height (m)
1	Mr. Desmark	Male	62	24	1.78
2	Mr. Kennedy	Male	59	32	1.75
3	Ms. Faith	Female	62.5	25	1.52
4	Ms. Gwara	Female	57	43	1.71
5	Ms. Gada	Female	55.5	25	1.55

RESULTS AND DISCUSSION

Zimbabwe treadle pump parameters and dimensions

The pump was inspected for constructional and operational defects and none were found. Its characteristics were measured and results are shown in table 3.

Table 3: Pump dimensions

Parameter	Dimension
Height of treadles above ground	450 mm
Treadle length	850mm
Handle height	1200 mm
Treadle to pivot	520 mm
Piston to pivot	340 mm
Stroke length	200 mm
Cylinder diameter	96 mm
Pulley diameter	150mm

Pump mass	15 kg

According to DTU (1991), parameters like treadle length, treadle to pivot length, piston to pivot length, cylinder diameter and stroke length have a direct influence on comfortability of use of pump (ergonomics). Treadle length, treadle to pivot length and piston to pivot length influence the pump's mechanical advantage for a given cylinder diameter. Stroke length directly influences cadence. The longer the stroke lengths, the smaller the cadence. Stroke lengths in the range 100-350mm are comfortable to operate (DTU, 1991). In the case of this pump, its stroke length was found to be 200mm and this is within the comfortable range according to DTU (1991).

The cylinder diameter of the pump was found to be 96mm (Table 3). This was close to the recommended cylinder diameter of 100mm for a 3-8m working head according to DTU (1991).

Height of treadles above the ground was measured when the treadles were at the same horizontal level. This measure was deemed important as it was discovered that this element influenced the adoption of the pump by societies. The higher the treadles are the more elevated will the operator be. Because of this element of the operator being elevated, women do not feel comfortable standing on the pumps for long periods. They feel exposed and consider it undignified (Kay and Brabben, 2000). In this case, the height of treadles was found to be 450mm.

Technical evaluation of pump

The following parameters were computed: Cadence (strokes/min), discharge rate (m^3/hr), total dynamic head (m) and mechanical advantage. Power input by the five users was each estimated at 35 watts (Kay and Brabben, 2000). A comparative analysis of the different pump operators at various suctions and delivery heads was then made based on these parameters. The treadle pump attained maximum discharge rate of 7.71 m^3/hr at suction lift of 1m and delivery head of 5m by operator 1. This was followed by that of 7.20 m^3/hr at suction lift of 0.5m and delivery head of 4m again by operator 1. Operator 1 was strong, heavier, healthy looking and was energetically doing his treadling. According to Thomas (1993), the amount of water that can be pumped depends on the effort and physique of the operator. From 2m suction lifts to 4m, individual results showed that discharge rates were decreasing. These individual results were rather off the general expectation as shown from previous ZITC reports of similar tests of treadle pumps where the highest discharges were obtained at 1m suction lift and 1m delivery head (Zirebwa and Zhakata, 1998). However, after averaging all

the individual results, the results then proved that the maximum discharges fell on 1m suction lift and 1m delivery head (TDH=2m) (See figure 3).

Minimum and Maximum discharge and cadence

Figure 4 below shows the maximum and minimum ranges for the discharge and the cadence of the pump operators at different suction heads.

Table 4: Minimum and Maximum discharge and cadence for the pump operators

Suction head	Discharge range (m^3/h)	Cadence range (Strokes/min)
0.5	3.86-7.20	53.57-98.82
1	4.91-7.71	68.18-108.75
2	2.40-6.75	53.33-112.94
3	2.92-5.68	50.36-110.67
4	1.93-4.91	35.45-110.77

Discharge Analysis

Curve of the total dynamic head (TDH) versus the discharge rate (Figure 3) showed that pump discharge was inversely related to TDH, and followed a linear relationship of TDH= $-2.07Q + 15.40$ with an R^2 value of 0.8824.This means that as the discharge (Q) increased, TDH also decreased linearly with a negative gradient of 2.07. This mathematical relationship also showed that when Q is reduced to $0m^3/hr$, TDH would be about 15.40 m. It also showed that Q of $7.44m^3/hr$ would be realised at a TDH of 0m. This depicts an operating TDH range of 0-15.40m with a discharge range of $0\text{-}7.44m^3/hr$.

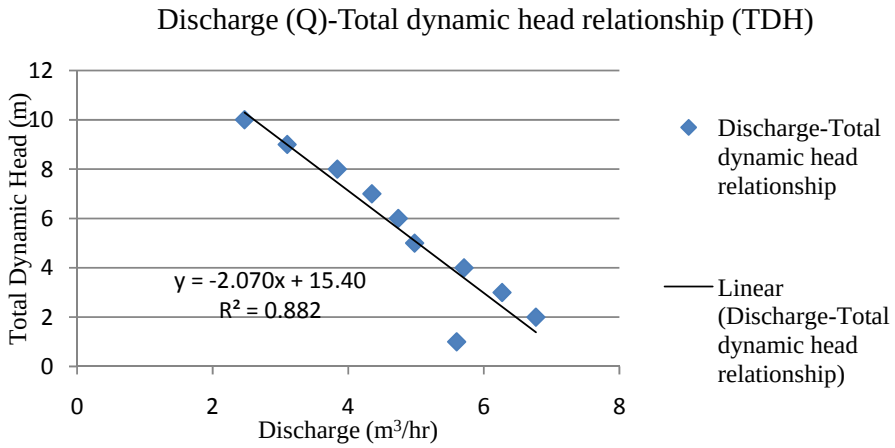

Figure 3: Discharge-Total Dynamic Head Characteristics

Cadence Analysis

Curve of the TDH versus cadence (C) (Figure 4) showed that the pump cadence was inversely related to TDH, and followed a linear relationship of TDH= $-0.15C + 16.81$ with

an R^2 value of 0.72.This means that as C increased, TDH also decreased linearly with a negative gradient of 0.15. This mathematical relationship also showed that when C is reduced to 0strokes/minute, TDH would be about 16.81 m. It also showed that the C of 114.71strokes/minute would be realised at a TDH of 0m. This depicts an operating TDH range of 0-16.81m with a cadence range of 0-114.71strokes/minute

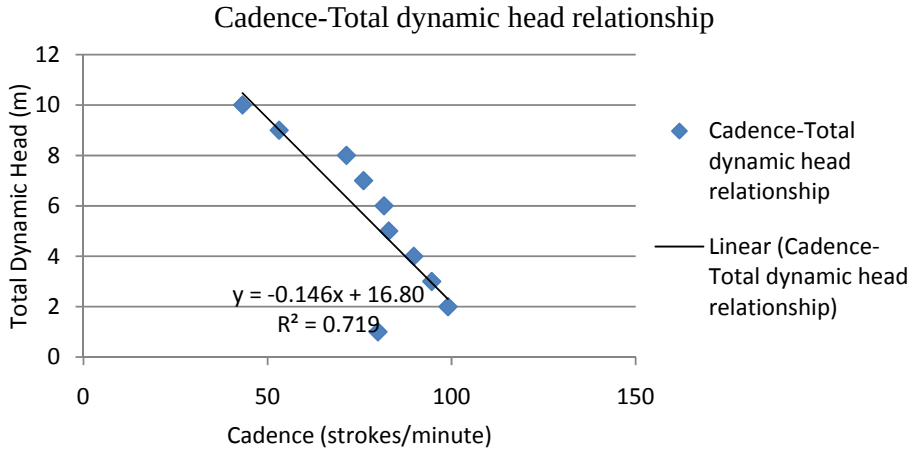

Figure 4: Cadence-Total Dynamic Head Characteristics

According to DTU (1991), a cadence of up to 60 strokes /minute is comfortable. In the case of the pump under study, this would give a TDH of about 8m and a discharge of about 3.58m^3/hr. Such results are reasonable and highly comparable to results of other treadle pumps laboratory tested.

Mechanical Advantage Analysis

The mechanical advantage of the pump was calculated from equation [1] as follows:

$$MA = \frac{520\ mm}{340\ mm}$$

=1.53

This result falls in the range of desirable M.A range given by Kay and Brabben (2000).

Comparing with Money saver treadle pump results

Test results by Manjengwa (2003) as shown in table 1 concluded that the Money saver treadle pump had the best results of performance. The performance results of the Money saver were compared with those for the Zimbabwe treadle pump for the same TDH.

Table 5: Comparison of performance results of the Money saver treadle pump and the Zimbabwe treadle pump for the same TDH of 5.4m

Name of treadle pump	TDH (m)	Q (m^3/hr)	C (strokes/minute)	M.A

Money saver	5.4	4.2	69.8	2.9
Zimbabwe treadle pump	5.4	4.8	76.1	1.5

Table 5 shows that for the same head, the Zimbabwe treadle pump had a higher discharge. Its cadence was however higher than that of the Money saver treadle pump. This meant that there were more cycles per minute done on the Zimbabwe treadle pump than on the Money saver treadle pump. There was also about twice as much mechanical advantage with the Money saver treadle pump than with the Zimbabwe treadle pump. Therefore, in terms of ergonomics, the Money saver is more comfortable to use than the Zimbabwe treadle pump. However, in terms of discharge, the Zimbabwe treadle pump is more superior.

CONCLUSIONS AND RECOMMENDATIONS

The study has evaluated the performance of the Zimbabwe treadle pump. This was done to enable farmers to decide on which treadle pump they would settle for which best appeals to their situation. False claims about the performance of a machine always disadvantage the farmer. This information provided about the Zimbabwe treadle pump has added to the vast performance information of treadle pumps which forms the basis for comparing commercial products (Bralts et al., 1985).

Results have also shown that the Zimbabwe treadle pump compared very well with the Money saver treadle pump which was shown by Manjengwa (2003) to be the best performer in selected categories. This comparison was however, admittedly crude since such a comparison is supposed to be done under exactly the same conditions according to Kay and Brabben (2000). Thus, it is recommended that a comparison test be done between the Zimbabwe treadle pump and the Money saver treadle pump.

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