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Design, Construction and Testing of a Hand Operated Water Pump for Small Scale Farmers in Nigeria

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ABSTRACT: Accessible and affordable groundwater pumping devices are significant aspects of sustainable agricultural growth in Nigeria, owing to the fact that Nigeria is a developing country. Such groundwater pumping device is this hand operated water pump. This water pump is made with locally available materials. The major components of the pump is the pump frame made from angular bar mild steel, the pump chamber made of mild steel, the pump cylinder made of cast iron, the pump crankshaft made of hollow galvanized pipe, the connecting rod made of hollow galvanized pipe and the pump inlet and outlet made of plastic PVC pipe. The pump is strictly a one operator type of pump. The pump theoretical discharge was 1.83 L/s while the actual average discharge of the pump was 7.5×10^{-2} L/s at an average sump depth of 1.6 m. The pump volumetric efficiency is 123.3% and the pump efficiency is 75.84%. An average adult of 75.4kg is able discharge an average of 2.34 liters at the depth of 1.1 m sump, at 1.6 m sump depth the discharge was 2.28 liters while at a depth of 2.1m the average adult discharged 2.19 liters. The operation of the pump is dependent on the weight of the operator i.e. the weightier the operator the more water he/she can discharge through. The discharge results obtained for the sump depths of 1.1 m, 1.6 m and 2.1 m were used to plot the graph of discharge over time. Regression analysis shows that there is strong relationship between weight of operators and discharge for the pump; the variance of the pump was found to be 95.7%. The pump could be suitable to irrigate fragmented and small land holdings, especially to pump water from shallow depth to irrigate small plots, thereby serving the needs of small scale farmers. Performance of the pump can be improved when the driving pulley diameter is increased and the driven pulley diameter is decreased.

KEY WORDS: Groundwater pumping device; Reciprocating pump; Hand pump; Pump discharge; Volumetric and pump efficiency; Manual irrigation; Low cost irrigation.

I. INTRODUCTION

Water is a vital, essential component and constituent of life. Development and civilization of mankind has been promoted by the availability of water which has played a key role. That is to say scarcity of water hampers the development of mankind and settlements (Yannopoulos *et al*., 2015). Water could be found on the earth's surface in which case it is referred to as surface water, e.g. rivers, swamps, streams and lakes. Water may need to be transported from their source to the point of usage. Water-lifting devices could be used to take water from source such as river, lake or well, for purposes such as irrigation, drinking, industrial, bathing etc (Mogaji, 2016).

Water-lifting devices are categorized into two main types depending on the water source under consideration: surface or subsurface (Baumann, 2000). The height of accessibility is the major consideration point when choosing water lifting devices. Water lifting devices can be used to raise groundwater, rainwater stored in an underground reservoir, and river water etc (Brikke and Bredero, 2003). Water-lifting devices vary from animal powered to human powered; some of which are better than others for different purposes. Whereas prime-mover or power source are the most often preferred, the accurate choice of water conveyance and field distribution system can always have a greater influence on the effectiveness of any irrigation technology like a water pump (Fraenkel, 1986). The choice of water-lifting device for irrigation and other purposes is dependent on technical, financial, economic, institutional and social aspects. Such aspects include climate, the crop and

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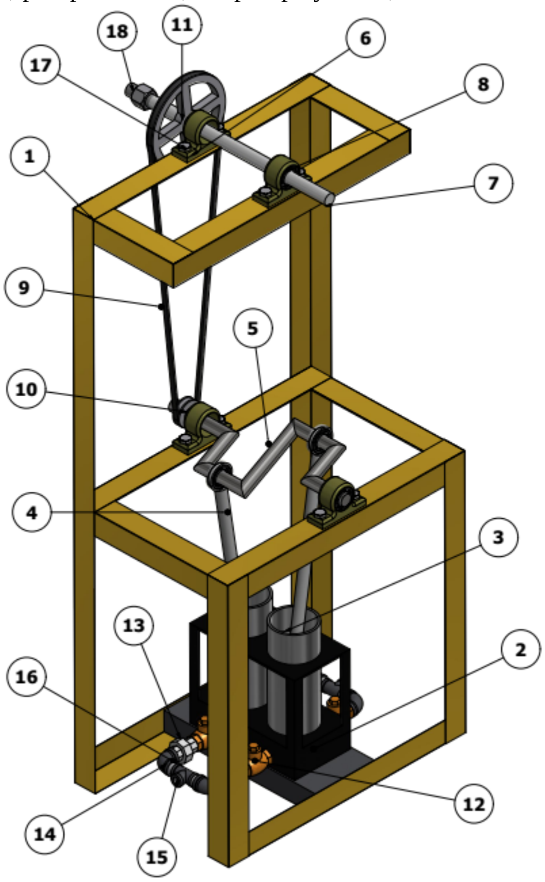
the area to be irrigated, the task to be completed, the cost of the device among other factors (Olley, 2008).
Manual piston pumps as the name implies are types of pump which uses the hand as the source of power to drive the reciprocating piston pump. These types of pumps are widely used in water pump, family life and production, water supply and agricultural irrigation (Nan, Jinli, Baohua, Hongwang, and Weiguang, 2012). Through the manual operation of the pumps, the suction required for their working is achieved (Nan *et al*., 2013). Generally, pumps are a popular medium of lifting water from both surface and subsurface sources to accessible point even though sometimes they (pumps) fail because of the movable parts they possess (Stewart, 2003). Manual pumps are of different types among which are hand pumps etc.
Hand pumps are pumps operated manually; these pumps use mechanical advantage and human power to transfer or move water (fluids) or air (gases) through different points. Such pumps are in wide use in most countries of the world for different purposes among which are industrial, leisure activities, irrigation and marine use (Sermaraj, 2006). These pumps are in different types which mainly operate on piston, diaphragm or rotary vane principle with a non-return (check) valve on the entry and sometimes on the exit ports to the chamber operating in opposing directions. Most of such pumps i.e. hand pumps have plungers or reciprocating pistons, and are positive displacement in nature. The major distinction of hand pumps is between the suction type which is the vertical distance between the fluid to be pumped and the centre of the pump; and pressure (lift) type which is the vertical distance between the pump and the delivery point.
Hand pumps have the capability of lifting small quantities of water from ground level to about 100 meters thereby allowing the water source to be sealed, reducing the risk for potential source contamination during water collection. Such peculiarity make the inexpensive hand pump an attractive option for rural water supply (Martin, 2006).

II. MATERIALS AND METHODS

In the initial stage of this research, the various components of the reciprocating pump were designed which include the frame, pump chamber, the pump cylinder, the crankshaft and the connecting rod and assembled as shown in figure 1.



PARTS LIST

ITEM	QTY	DESCRIPTION
1	1	frame assembly
2	1	pump manifold
3	2	Piston
4	2	connecting rod
5	1	crank shaft
6	4	Bearing Holder
7	1	shaft
8	6	Bearing
9	1	V-Belt
10	1	Grooved Pulley1
11	1	Grooved Pulley2
12	4	Valve
13	2	Adapter
14	4	90 Deg Elbow
15	2	Tee
16	4	pipe
17	8	Bolt
18	1	Nut

Figure 1: Assembled and labeled components designed of hand operated water pump

The designed has a similar working mechanism as a treadle pump but it (the pump) is a hand operated pump. This pump can be said to be the combination of the treadle pump and hand pump.
The pump was build with two cylinders stationed alongside each other. A junction box was used to connect these cylinders to both the suction and discharge pipes respectively. At the suction side of the junction box, two check valves were fixed to avoid the resurgence of water into the source. The same thing was done to the discharge side of the junction box.
Table 1 shows the design parameters of the pump which include the frame, the pump chamber, the pump cylinder, crankshaft and the connecting rod. These also include belt arrangement

Table 1: Design parameters of the hand pump

Name	Description
Frame	Made of angle bar; Height (1250mm) × Length (600mm) × Width (385mm)
Junction box	Constructed from steel; Length (262mm) × Width (141mm) × Height (60mm)
Pump cylinder	Fabricated of cast iron; Diameter (96mm) × Height (217mm) × Thickness (10mm)
Crankshaft	Made of hollow pipe; Diameter (24mm) × Length (380mm)
Connecting rods	Fabricated of galvanized hollow pipe; Diameter (25mm) × total length (388mm)
Suction pipe	Made of 60 mm diameter PVC pipe
Pulley arrangement	Double pulley made of mild steel; Large pulley diameter (184mm) × small pulley diameter (54mm)

A. Working principle
The pump operation is easy and one single adult with body weight of above 50 kg can operate the pump freely. By turning the driving pulley effort is added to the pump which creates vacuum in the cylinder thereby causing the check valve to open (i.e. the non-return valve at the inlet of the pump) and water enters into the pump chamber. When the driving pulley is turned again, the check valve at the inlet closes; then the check valve at the outlet opens to allow the water at the pump chamber to move out at positive pressure created by the pistons reciprocating movement. This action continues thereby sucking and discharging while the pump operates.

B. Pump testing and evaluation procedure
The pump's theoretical discharge was calculated foremost by using the area of the pistons, the length of stroke and crank speed of the driven pulley. The pump was tested at a certain suction head and operated by an average sized operator under normal operating conditions manually to obtain the discharge and pump efficiency, and then it was setup over different platforms with a circular sump at height of 1.1 m, 1.6 m and 2.1 m respectively and operated by five (5) persons of different body weights to obtain the pump discharge at those depths.
i. The theoretical discharge
The theoretical discharge was computed using Equation 1 (Nalluri *et al*., 1991)

$$Q = ANLs \qquad 1$$

Where;
Q = Theoretical discharge
N = Crank speed of the driven pulley
A = Area of piston = $\frac{\pi d^2}{4}$
d = diameter of the piston
Ls= Length of stroke

ii. Volumetric efficiency
The volumetric efficiency (η_v) is the ratio of the actual discharge to the theoretical discharge and is expressed by Equation 2 (Nalluri *et al*., 1991)

$$\eta_v = \frac{Q_a}{Q_t} \times 100 \qquad 2$$

Where;
η_v = volumetric discharge
Q_a = actual discharge

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Q_t = theoretical discharge

iii. The rate of discharge
The volume of water discharged per time of test was estimated using Equation 3

$$V = \frac{\pi D^2}{4} \Delta H \qquad 3$$

This equation was expanded to

$$V = \frac{\pi D^2}{4} (h_1 - h_2)$$

Where;
V = volume of pumped water (m^3)
D = diameter of the sump (m)
h_1 = initial level of water in the sump before pumping
h_2 = final level of water in the sump after pumping

C. Pump efficiency
The pump efficiency (η_p) is the ratio of actual output volume to the actual input volume of the water. The efficiency was computed by Equation 4

$$\eta_p = \frac{O_v}{I_v} \times 100 \qquad 4$$

Where;
η_p = Pump efficiency (%)
O_v = Actual output volume (m^3)
I_v = Actual input volume (m^3)
All the tests were conducted on the floor of the sump in the soil and water laboratory of the Department of Agricultural and Bioresources Engineerin, University of Nigeria Nsukka. All these tests were carried out under different suction heads (1.1 to 2.1m) and were replicated five times with different body sizes. The pump design allows it to vary the stroke length.

III. RESULTS AND DISCUSSION

Figure 2 shows the fully constructed hand operated water. The pump specifications are as presented on Table 2. The performance of the pump varied with the suction head. The discharge of the pump varies at different sump, at 1.1 m depth the discharge was 23.24 L/min, at 1.6 m depth the discharge was 22.84 L/min while at a depth of 2.1 m the discharge was 21.9 L/min.

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Figure 2: The fully constructed hand operated water pump

Table 2: Developed pump specifications

Parameters	Values
Swept piston area (A)	0.0071 m^2
Length of stroke (L)	0.09 m
Crank speed (N)	38 rev/min
Theoretical Discharge (Q)	1.83 L/sec
Volumetric efficiency	123.33 %
Pump efficiency	75.84 %

Pump test was performed at different at different depths with different operators of varying weight carrying out the test as presented on Tables 3, 4 and 5

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Table 3: Pump discharge of different operators at 1.1 m sump in liters

Time (s) Weight (kg)	30	60	90	120	150	180	210	240	270	300	Total (L)	Average(L)
59	2.3	2.3	2.24	2.23	2.2	2.11	2.01	1.8	1.62	1.43	20.24	2.024
65	2.43	2.4	2.32	2.3	2.22	2.12	2.1	1.9	1.7	1.52	21.01	2.101
76	2.67	2.65	2.62	2.6	2.54	2.3	2.2	2.1	2	1.81	23.49	2.349
85	2.8	2.8	2.72	2.65	2.6	2.45	2.43	2.3	2.1	1.93	24.78	2.478
92	3.11	3.1	2.98	2.82	2.78	2.72	2.7	2.5	2.34	2.21	27.26	2.726
75.4			Average								23.2356	2.3356

Table 4: Pump discharge of different operators at 1.6 m sump in liters

Time (s) Weight (kg)	30	60	90	120	150	180	210	240	270	300	Total (L)	Average(L)
59	2.27	2.26	2.22	2.19	2.16	2	1.9	1.74	1.6	1.38	19.72	1.972
65	2.4	2.37	2.3	2.26	2.19	2.1	1.9	1.74	1.66	1.45	20.37	2.037
76	2.62	2.58	2.54	2.5	2.47	2.3	2.18	2.08	1.9	1.78	22.95	2.295
85	2.76	2.75	2.7	2.64	2.58	2.4	2.39	2.28	2.07	1.86	24.43	2.443
92	3.08	3.04	2.95	2.78	2.73	2.68	2.6	2.47	2.28	2.15	26.76	2.676
75.4						Average					22.846	2.2846

Table 5: Pump discharge of different operators at 2.1 m sump in liters

Time (s) Weight (kg)	30	60	90	120	150	180	210	240	270	300	Total (L)	Average(L)
59	2.22	2.19	2.16	2.15	2.11	1.95	1.88	1.72	1.56	1.34	19.28	1.928
65	2.35	2.31	2.26	2.19	2.07	1.87	1.71	1.62	1.42	1.39	19.19	1.919
76	2.59	2.54	2.48	2.38	2.27	2.2	2.13	1.9	1.75	1.67	21.91	2.191
85	2.67	2.63	2.58	2.54	2.49	2.42	2.36	2.17	1.85	1.77	23.48	2.348
92	3	3	2.85	2.73	2.65	2.54	2.48	2.4	2.1	1.9	25.65	2.565
75.4						Average					21.9	2.1902

Graphical representations of the hand pump to show relationship between discharge and time. Figure 3, 4 and 5 shows that the relationship

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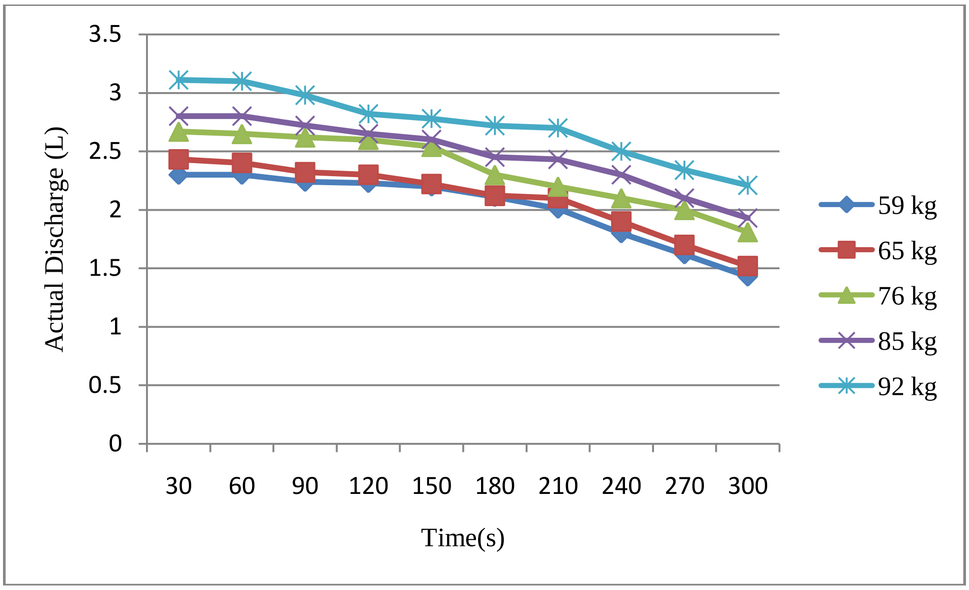

Figure 3: Pump performance at 1.1 m depth of sump

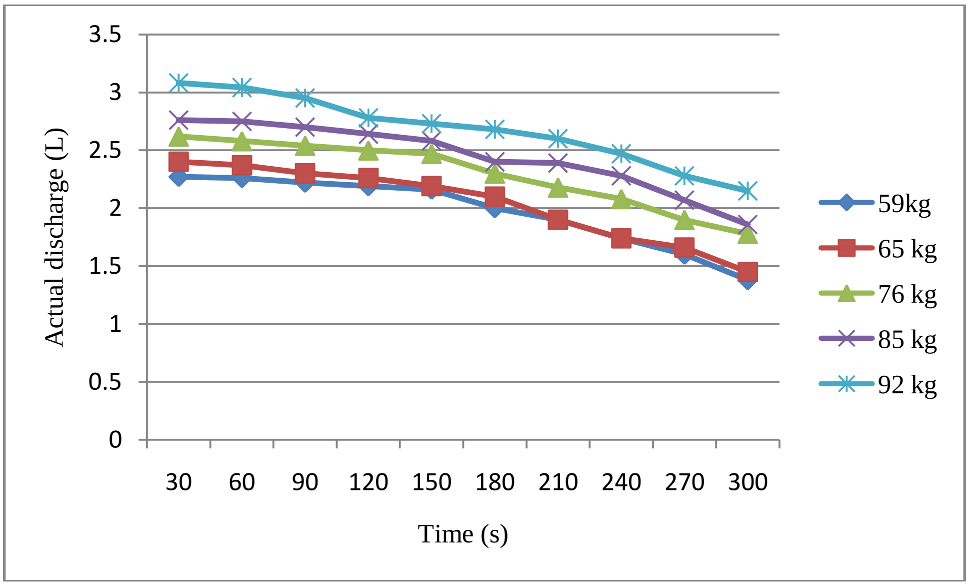

Figure 4: Pump performance at 1.6 m depth of sump

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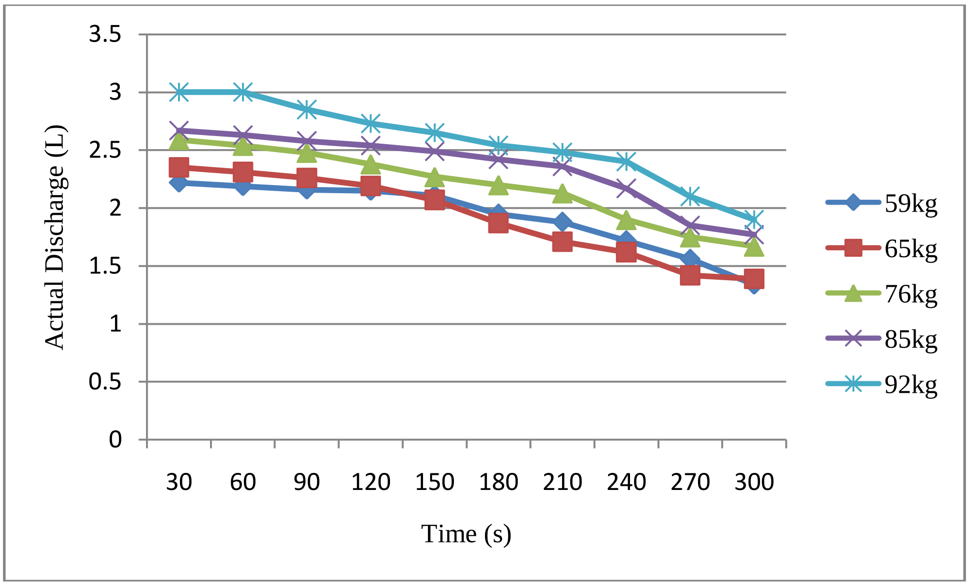

Figure 5: Pump performance at 2.1 m depth of sump

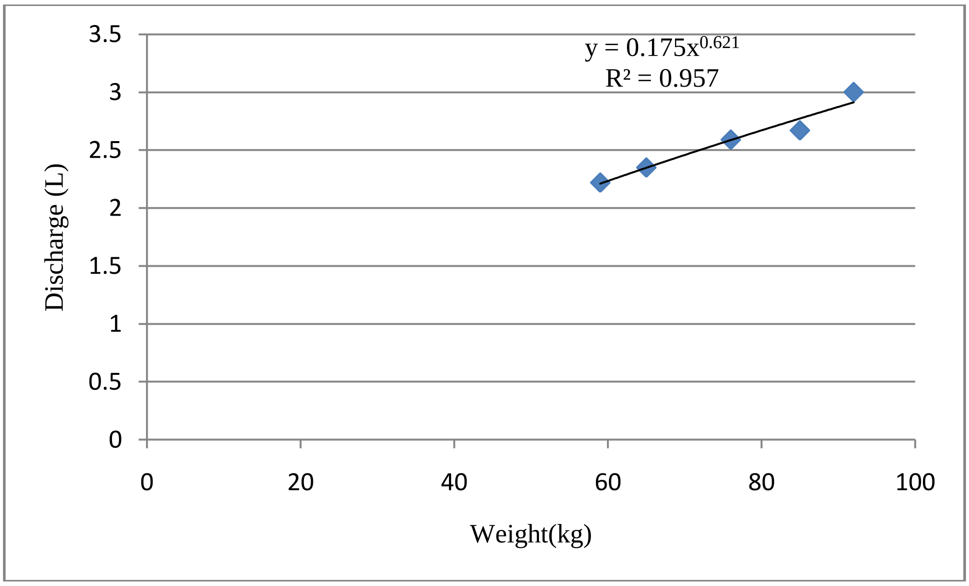

Figure 6: Relationship between weight of operator and discharge

The theoretical discharge of the hand operated pump was 1.83 L/sec as presented on Table 2. Considering the size of the cylinder diameter and the swept volume used for the pump, the result different when compared to the result obtained by Nalluri *et al*., (1991) where they obtained 1.4 L/sec at 0/6 m cylinder diameter with 0.1 m stroke length with 30 rpm crank speeds. The difference in result as observed is due to the length of stroke. When the suction limit was increased, the pump discharge declined steadily.

The pump was operated by five persons of weight 59 kg, 65 kg, 76 kg, 85 kg and 92 kg. The field experimental test indicated that the average pump discharge were 7.7×10^{-2}, 7.6×10^{-2}, and 7.3×10^{-2} from sump depths of 1.1 m, 1.6 m, and 2.1 m respectively when operated by an operator with an average weight of 75.4 kg as indicated by Tables 3, 4 and 5. These range of pumping are higher than those obtained by Nasir *et al*., (2004) which obtained 5.7×10^{-2}, this difference could because Nasir *et al*., (2004) did not use double reciprocating pistons or gear for the pumping. The results further indicated that the obtained pump discharge decreases with time for every operator due to energy loss as indicated by Figures 3, 4 and 5.

A regression analysis showed that there is strong relationship between the weight of operators and the discharge as presented on Figure 6 with proportion of variance of 95. 7%. The pump efficiency was obtained to be 75.84% under a sump depth of 1.1 m, the efficiency was found to decrease with the increase of sump depth. But Md. Serazul Islam *et al*., (2007) worked on manual pump for low lift irrigation and obtained an efficiency of 46.53%.

IV. CONCLUSION

Affordable, economical and efficient pumping technology can play an important role in the rural economy and sustainable food supply for the peasant farmer particularly during dry season. This task can executed by providing economical irrigation facility that can used to supply water to the farm for low income farmers. In this regard, a low cost double acting reciprocating pump was designed in the laboratory. The pump uses readily available materials which include pistons, valves, sleeves etc.

The theoretical discharge of the pump was found to be 1.83 L/s, which is above but in agreement with those obtained by other authors like Nalluri *et al*., (1991). The pump gives a discharge of 21.9 liters at 2.1 m sump depth, 22.846 liters at 1.6 m sump depth and 23.24 liters at 1.1 m sump depth respectively. The discharge of the pump can be increased if the swept volume and the length of stroke of the cylinder and the pistons are increased respectively. The pump has an efficiency of 75.84% and a volumetric efficiency of 123.3% respectively. The terms of the design, the pump highest discharge is at 1.1 m depth.

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