Performance and operation suitability of developed hand and pedal pump for low-lift Irrigation

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***Abstract*—This study was carried out in a laboratory to evaluate the performance and operational suitability of constructed hand and pedal pump for utilized in a small fragmented land. In market, there are many manually operated pumps but its have some problem on operation as well as cost involvement. Due to overcome these issues, different types of piston valves and check valves were constructed and tested at various suction heads in the laboratory to find out the best combinations of piston and check valves, which will gives more discharge rate, low input power requirement and high efficiencies. The pumps are constructed using local materials and skill. After several trials, Piston valve type-II (rubber flap mounted perforated cast iron disc of slot size 11mm and about 4 slot openings per 2.54 square cm) and check valve type-III (rubber flap mounted perforated cast iron disc of slot size 7 mm and about 10 slot openings per 2.54 square cm) were found to be suitable. According to the results, using above combination the average discharges of the pumps ranged from 113.58 to 68.71 lpm and 93.27 to 53.27 lpm against heads of 0.60 to 2.0 m for hand and pedal system, respectively; and the efficiencies of 45.57 and 46.53 percent were obtained for hand and pedal pumps, respectively, against a head of 1.65 m. During pedal system, the less input power was required than that of the hand system. Both in the hand and pedal pump operation, one adult man can operate it for a long time (more than 2 hours) continuously without being tired. It would be suitable to pump water from a shallow depth (<2 m) to irrigate small plots like vegetables and seed beds with less physical effort.**

Keywords—Performance; hand pump; pedal pump; suitability; irrigation

I. INTRODUCTION

In Bangladesh irrigated lands are fragmented due to increasing population and the poor farmers own small land holdings. The socio-economic condition of Bangladeshi farmer does not permit large scale irrigation investment. Hence, introduction of small scale irrigation like manually operated hand and pedal pumps can play a vital role for increasing food grain production in Bangladesh. Farmers who are able to buy a pump are capable to work more easily and quickly than that of DTWs and STWs. Acceptance of manually operated pumps has rapidly increased day by day all over Bangladesh. Such kind of irrigation technologies are operated and maintained by farmers themselves from their own capital for producing crop in the small fragmented lands.

The average small farm sizes spreading over a number of scattered plots are unsuitable to irrigate with a large size of stream. But, the manually operated technology with a small stream size is suitable for small and fragmented farm holding and involves less mechanical and maintenance problems. In fact the poor farmers represent 70% of population in Bangladesh and they own only 20% of total land [1]. Due to their extreme poverty, they are gradually joining the landless group. In this context, manually operated hand and pedal pumps are helpful for poor farmers to reduce poverty.

The current success of manually operated pump can be explained in terms of factors like appropriate design, low cost, effective marketing, and high cash returns [2]. Operation of the devices like treadle pump, rower pump, wheel pump, diaphragm pump, blower pump, etc. is very laborious and operators often complain about their suffering from various health hazards. Nobody can work at much over $1/5^{th}$ of a hp for very long [3]. According to survey report by Faruk and Pramanik (1995), many users of these devices complained about their health troubles and desired to get a better technology requiring less manual power and mechanical troubles [4]. Recently, Islam *et al.* (2007) design a pedal pump and found best results for small scale irrigation practices with shallow water depth [5]. Hence, a study is needed to develop the pump to make them uncomplicated and simple to ensure automatic participation of farmers. Depending on the skills of the farmers, manufacturing facilities, costs, socio-economic conditions, repair and maintenance facilities and sources of water, developed hand and pedal pumps appears to be suitable for low-lift irrigation purposes. Thus, the present study aims to evaluate the performance and operation suitability of the constructed pumps under different suction heads using various types of valves.

II. Materials and Methods

A. *Materials Required*

To construct hand and pedal pump for low-lift irrigation, the following materials were collected and the intended pump was constructed in a workshop:

a) PVC pipe (5 inch diameter for cylinder and 2 inch diameter for suction pipe)
b) Plastic discs for both piston and check valves
c) Cast iron discs for both piston and check valves
d) Rubber bucket
e) Rubber flaps
f) Wooden block (89 cm × 30 cm × 10 cm) for pump base
g) MS rod (for handle and foot board)
h) Angle bar
i) Flat bar
j) Nuts and bolts
k) Elbow

B. *Description of the Pump*

Wooden block of size 89 cm × 30 cm × 10 cm was used as the base to support the pump during operation. Fulcrum stand was made from angle bar having the height of 85 cm which inserted to the wooden base for holding pump handle. Pump cylinder (12.7 cm diameter) was made from PVC pipe and was fixed with the wooden base. Rubber flap mounted plastic discs (collected from PVC industry) and perforated cast iron discs (made at motor workshop) valves used both as check and piston valve. Pump discharges were allowed to flow through the outlet. The piston (Plunger) and check valves were made at PVC pipe industry and motor workshop with plastic discs and perforated cast iron discs. Rubber bucket placed in between plastic discs/perforated piston plate and follower piston plate to minimize the frictional losses between the valves and cylinder wall. The plunger valve was then attached with pump handle by mean of a connecting rod. Different types of piston and check valves and their description are presented in the Figs. 1 to 4 and Table 1. Various combinations were used to find the optimum types of valve for maximum discharge and reduce friction losses.

Plastic disc (PV$_i$)

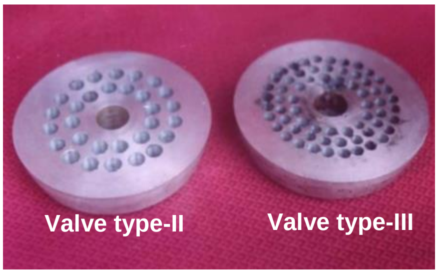
Cast iron disc of slots size 11 mm (PV$_{ii}$)

Cast iron disc of slots size 8 mm (PV$_{iii}$)

Cast iron disc of slots size 6 mm (PV$_{iv}$)

Follower piston plate and check plate: plastic disc (PV$_i$, CV$_i$)

Follower piston plate: moulded cast iron disc (PV$_{ii}$, PV$_{iii}$, PV$_{iv}$)



Perforated cast iron disc for check valve type-II (slot #10 mm) and III (slot #7 mm)

Fig. 1 Piston valve (PV) and check valve (CV) plate made with plastic disc and perforated cast iron disc for piston valve type-I, II, III and IV and check valve type- I, II and III.

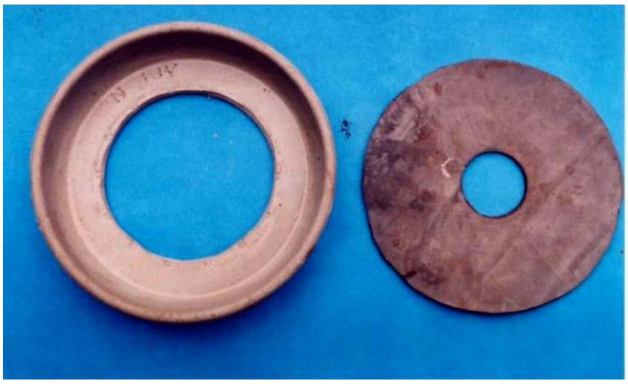


Fig. 2 Photographic view of rubber bucket and rubber flap.

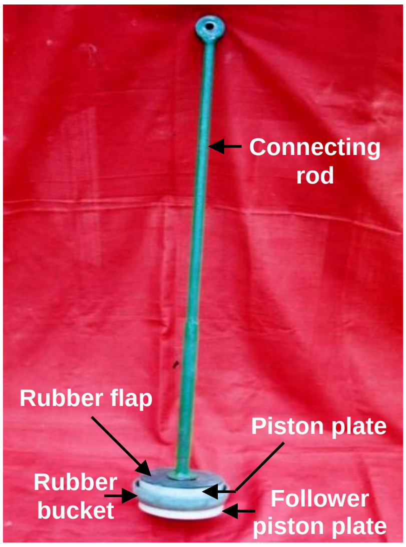


Fig. 3 Photographic view of piston valve assembly with connecting rod.

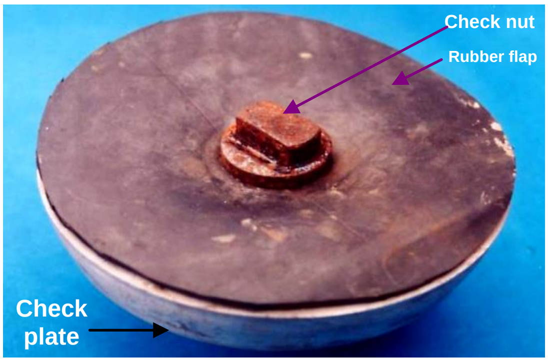


Fig. 4 Photographic view of check valve assembly

Pump handle was made using MS rod of 3 cm diameter having a length of 84 cm and two 21 cm length of flat bars. Two flat bars and MS rods were joined together by welding. The top portion of the arm was joined with a connecting rod and last portion of the arm was joined to the fulcrum stand by nuts and bolts. The connecting rod was made of MS rod which was 1.5 cm diameter having a height of 68 cm, last portion of the lever connected with a pedal board which was used to operate the pump with foot. After several test operations lever-arm ratio 4:1 was found suitable. The pedal board was made of MS rod. The hanging foot board (pedal) connected with the lever rod was used to move the lever downward with the foot pressure. An operator forced the pedal board downward with his foot which in turn causes the piston rod to move upward with piston plate. The size of this foot board (pedal) was 10x15 cm and was found comfortable to place foot on it. A five (5) cm PVC pipe was used as a suction pipe and was connected with the pump inlet using an elbow which was found suitable and comfortable.

Table 1 Description of piston and check valves

Piston valves

Valve type-I (PV_i)	:	Rubber flap mounted plastic disc.
Valve type-II (PV_{ii})	:	Rubber flap mounted perforated cast iron disc of slots size 11 mm and about 4 slot openings per square cm.
Valve type-III (PV_{iii})	:	Rubber flap mounted perforated cast iron disc of slots size 8 mm and about 8 slot openings per 6.45 square cm.
Valve type-IV (PV_{iv})	:	Rubber flap mounted perforated cast iron disc of slots size 6 mm and about 16 slot openings per 6.45 square cm.

Check valves

Valve type-I (CV_i)	:	Rubber flap mounted plastic disc.
Valve type-II (CV_{ii})	:	Rubber flap mounted perforated cast iron disc of slots size 10 mm and about 5 slot openings per 6.45 square cm.
Valve type-III (CV_{iii})	:	Rubber flap mounted perforated cast iron disc of slots size 7 mm and about 10 slot openings per 6.45 square cm.

C. *Principles of Pump Operation*

The operation of the pump is simple and one adult man can operate the pump easily. During the upward movement of the plunger a negative pressure (vacuum) is created in the cylinder and causes the check valve to open (i.e. the rubber flap moves upward) and water enters into the pumping chamber of the cylinder. When the plunger moves downward the check valve is closed due to positive pressure and a high pressure is created in the pump chamber due to compression of water which in turn opens (the rubber flap moves upward) the plunger valve and water flows across the plunger valve from the suction to the delivery side of the cylinder. Water thus accumulates in the cylinder on the upper side of the plunger valve. When the operator press the pedal with foot to move the lever downward, the plunger moves upward to create negative pressure in the cylinder and accumulated water is then discharged through outlet. In hand pump, an operator can press the handle downward with his hand instead of foot to operate the pump. Photographic views of the hand and pedal pumps showing different components and its operation are presented in Figs 5 and 6.

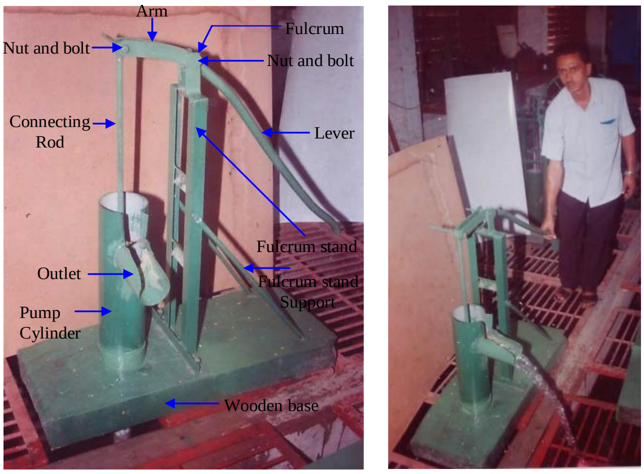


Fig. 5 Photographic views of the hand pump and its operation

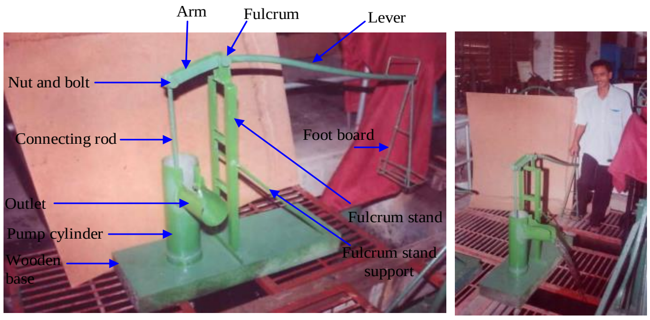


Fig. 6 Photographic views of the pedal pump and its operation

D. Test Procedure

The depth of static water level in the laboratory sump was measured directly by a graduated tape from centre of the suction pipe of pedal pump. During the operation of the pump, number of strokes was counted for a known time. The time was recorded by a stopwatch. Dividing the number of strokes by time spent, the pump speed (stroke/min.) was determined. Volumetric method was used to measure pump discharges. A graduated bucket was filled for a known period of time and the time was measured with a stopwatch. The pump discharge in m^3/s was calculated by dividing the amount of water by the measured time. For each suction head three trial data were taken. Slip of the pump is the difference between the theoretical discharge and actual discharge.

$$\%\,\text{slip} = \frac{\text{Slip of pump}}{\text{Theoretical discharge}} \times 100$$

Co-efficient of discharge, C_d of the pump was determined by using actual volume of water pumped per stroke and theoretical volume. The output power of the pump was calculated from the following expression:

$$P_o = \gamma g Q H$$

Where, P_o = out put power (kW), γ = unit weight of water (kg/m^3), g = acceleration due to gravity (m/s^2), Q = discharge (m^3/s), H = the static head (suction head + discharge head) in meters.

The power input of the pump was calculated from the following expression:

$$P_i = \frac{g\,W\,h}{1000\,t}$$

Where, P_i = input power (kW), g = acceleration due to gravity, W = weight imposed by the operator (kg), h = vertical distance (m) through which the lever move downwards due to foot pressure, t = time (s) required for the downward movement of the lever.

The efficiency of the pump was calculated from the following expression:

$$E = \frac{P_o}{P_i} \times 100$$

Where, E = efficiency (%), P_o = output power (kW), P_i = input power (kW)

Power losses in the pump are caused from the friction between the valves and cylinder wall, in valves fitting and expansion and contraction in pipes.

E. Performance Testing

The pump was tested at different suction heads and was operated manually by an average sized man under normal operating conditions. The pump was setup over a platform in a sump of cross section of 6 m × 3.5 m having the height 2.5 m. The suction head was varied by reducing the water level. The number of strokes that an operator is capable gives in one minute is termed as stroke per minute. For each operation head, water was collected in a large plastic bucket for a few minutes and the collected water was measured by a plastic jug graduated to litre marks. Each test was repeated thrice and in each case, operation period, number of strokes, and water volume were measured. Average discharge per revolution/strokes and discharge per minute (Q) were then calculated. The results of the experimentation have been presented as a graph and each point on a graph represents an average of three discharge rate if all three were within ±10 percent of their average. If one value did not fall within the limit, it was rejected and a new average taken for the remaining two discharges.

F. Pump Construction Cost

The costs of pumps were calculated on the basis of present market price and are presented below in Table 2.

Table 2 Item-wise cost of hand and pedal pump

Sl	Materials	Cost (Tk.)	
		Pedal pump	Hand pump
1	Handle/Lever (MS bar)	150	150
2	1.5 cm dia. connecting rod having 75 cm length	60	60
3	PVC cylinder with 5 inch diameter	100	100
4	Angle bar (4 kg) for pump support	160	160
5	Flat bar (2 kg) for arm	100	100
6	MS rod (3 kg for pedal pump and 2 kg for hand pump)	120	80
7	Cost of iron discs piston valves (10.5 cm dia. & 2.2 cm thickness)	150	150
8	Cost of iron discs check valves (10.2 cm dia. and 1.3 cm thickness)	100	100
9	Rubber bucket	25	25
10	Elbow	150	150
11	Rubber flaps	10	10
12	Nuts and bolts	40	40
13	Construction cost	500	450
Total		**1665**	**1575**

III. Results ans Discussion

Both the hand and pedal pumps were tested in the Hydraulic laboratory of the Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, under different suction heads using four types of piston values (PV_i, PV_{ii}, PV_{iii}, and PViv) and three types of check valves (CV_i, CV_{ii} and CV_{iii}) were used to find out the best one, which are shown in Table 1. The combinations used in this study were PV_i and CV_i, PV_{ii} and CV_{ii}, PV_{iii} and CV_{ii}, PV_{iv} and CV_{ii}, PV_{ii} and CV_{iii}, PV_{iii} and CV_{iii}, PV_{iv} and CV_{iii} respctively. The depth of water level (i.e. suction heads) varied from 0.60 to 2.0 m depending on laboratory facilities and the stroke length of the pedal pump was within 14-15 cm.

A. Performance Evaluation of Pumps

Using various sets of valves combination at different suction heads the performance test data of the hand and pedal pumps are shown in Table 3. Speed of the pump primarily depends on the ability of a pump operator. The highest discharge rates of the

Table 3.

Valves & Pump Type		Suction heads (m)	pump speed (spm)	Discharge rate (lps)	Slip of pump (Percent)	Coefficient of discharge	Power requirement (watt)	Pump efficiency (Percent)
Piston valve type I & Check Valve type I	Hand Pump	0.60	51	88.53	2.86	0.971	30.9	36.47
		2.0	45	53.28	25.77	0.742	47.0	40.37
	Pedal Pump	0.60	52	76.79	3.73	0.963	26.3	37.27
		2.0	47	47.90	26.75	0.732	41.3	41.35
Piston valve type II & Check Valve type II	Hand Pump	0.60	49	100.45	1.125	0.989	33.7	37.97
		2.0	46	66.10	17.59	0.824	55.0	42.83
	Pedal Pump	0.60	51	88.83	2.22	0.978	29.2	38.70
		2.0	49	56.96	18.86	0.811	47.9	42.33
Piston valve type III & Check Valve type II	Hand Pump	0.60	53	98.56	1.13	0.989	33.0	37.87
		2.0	46	60.71	18.02	0.819	51.3	42.17
	Pedal Pump	0.60	52	84.24	2.33	0.977	28.1	38.27
		2.0	48	53.83	19.08	0.809	44.5	43.13
Piston valve type IV & Check Valve type II	Hand Pump	0.60	54	93.28	1.84	0.982	31.9	37.30
		2.0	46	58.67	18.20	0.818	50.6	41.27
	Pedal Pump	0.60	51	80.35	2.48	0.975	27.1	37.83
		2.0	48	50.69	20.61	0.794	42.8	42.23
Piston valve type II & Check Valve type III	Hand Pump	0.60	52	113.58	0.798	0.992	37.8	38.30
		2.0	46	68.71	14.31	0.857	56.6	43.23
	Pedal Pump	0.60	51	93.28	1.78	0.982	29.9	39.83
		2.0	48	57.38	17.98	0.82	47.1	43.47
Piston valve type IV & Check Valve type III	Hand Pump	0.60	53	104.49	1.00	0.99	34.6	38.53
		2.0	43	62.91	15.75	0.843	52.5	42.73
	Pedal Pump	0.60	51	84.24	2.15	0.979	27.6	38.87
		2.0	48	53.83	19.52	0.805	45.1	42.57

Table 3 is the performance test data of hand and pedal pump for various types of valves sets at different suction heads hand and pedal pump were 113.58 and 93.27 lpm under the head of 0.6 m and lowest discharge rates were 68.71 and 57.37 lpm for the head of 2.0 m, respectively, when these pumps were operated with piston valve type-II and check valve type-III. For hand and pedal pump operation the minimum slip occurred with piston valve type-II and check valve type-III. The coefficient of discharges were found higher for both hand and pedal pump using same combination of valves that of other types of piston and check valves. The higher coefficient of discharge indicated that the pumping efficiency is higher. Comparing input power requirement, less power is needed for pedal pump operation. For hand and pedal pump, the highest efficiencies were obtained 45.57 and 46.53 percent under a head of 1.65 m, which is shown in Figure 7. Beyond 1.65 m suction head, the efficiency was found to decrease with the increase of suction head. It can be concluded that the optimum suction head is 1.65 m and the pumps are operated with piston valve type-II and check valve type-III showed the highest efficiencies. Pedal operation is comfortable and is not tedious as that experienced in hand operation.

For both hand and pedal pump operation inverse relationships were obtained among the discharge rate and power requirement with various suction head. The discharge rate was decreases and power requirement was increases with the increases of suction head which are shown in Figure 7. At a lower suction head, the pump could be operated with comfort and it produced higher discharge and less input power was required to operate the pumps.

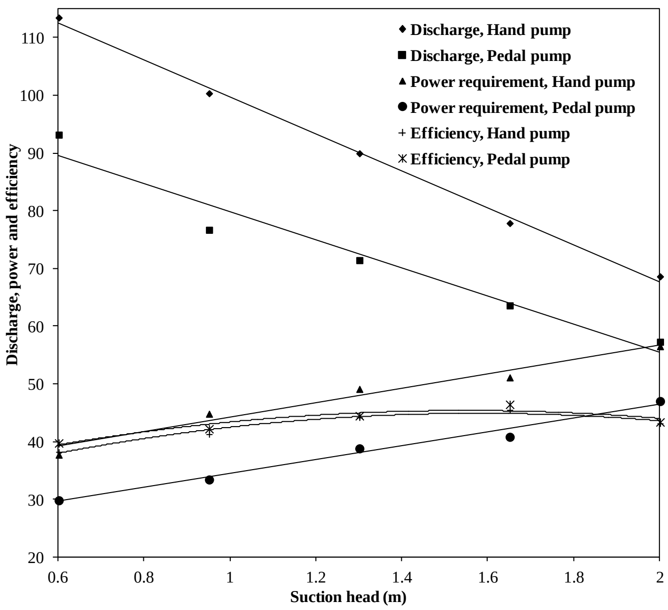


Fig 7 Relationships among the discharge rate, power requirement and efficiency with different suction heads

B. Operation Suitability of Pumps

The pumps are constructed to withdraw water from the lower suction head. For long time operation, pedal pump is possible with a high efficiency. The constructed pedal pump was found suitable for operation under a suction head up to 2 meters more than 2 hours. Islam (2004) worked on twin treadle diaphragm pump and showed suction head beyond 1.7 m depth the pump was failed to draw water and operator was unable to work more than 1.5 hour continuously [6]. The operation of the pedal pump was found more comfortable and suitability. It was quantified by the maximum operation time during which an average sized man can operate the pump without much physical troubles. When the pump operated using piston valve type-II and check valve type-III were found more suitable than those of compared to other types of valves due to their lower frictional losses and input energy requirement. Although, the hand pump gave the higher pumping rate as about 68.71 to 113.58 lmp but the pedal pumps are more capable though the pumping is less about 93.27 to 57.38 lpm, respectively under the suction head ranging from 0.6 to 2.0 m with piston valve type-II and check valve type-III; because of operation suitability of an operator. On the other hand, Islam (1995) worked on treadle pump and the discharge was found 65.4 lpm for a head of 1.12 m [7]. Also, Khan (1998) and Alim (1982) conducted on improved reciprocating hand pump and reciprocating wheel pump and they were investigated that the discharges were 33.95 and 50 lpm under a head of 1.14 m and 2 m, respectively [8-9]. Anwaruzzaman (1992) showed an average sized man can generate 0.1 hp or 93 w [10]. Therefore, the pump could be driven continuously for a long period because of less input power requirement for the pump operation than that of the power generated by a man. The highest efficiencies were obtained higher for both the hand and pedal pump operation using suction head of 1.65 m whereas Haq *et al*. (1994) worked on treadle pump and they found only 16 percent efficiency at low suction head [11].

Most of the agricultural lands in Bangladesh are fragmented. So, there is a good scope to use the hand and pedal pumps to lift water from low suction head. Both the pumps are capable to tap water from a shallow depth (up to 2 m) effectively and are, therefore, expected to be suitable to supply irrigation water in small fragmented land holdings as well as in small irrigation project areas. The pumps are portable and can easily be carried to the work place by an average sized adult man. The pump construction cost is low (hand pump: Tk. 1557 and pedal pump: Tk. 1665) due to availability of materials and skills in the local market. Operation and maintenance of the pumps are also simple almost to that like UNICEF No. 6 pump. Various parts of the pumps are also available at PVC pipe industry and so the pump could be installed at village level with a minimum cost. It could be pump subsurface water either for irrigation or drinking purposes. Therefore, it would be expected that the pumps due to its lower cost, operation suitability and higher efficiency may gain quick popularity if introduced in rural Bangladesh as well as some African countries in the rest world.

IV. CONCLUSIONS

Both the hand and pedal pump are used to irrigate small land and the following conclusions appear to be applicable for the construction and use of the pumps:

1. The efficiency of the pedal pump was higher than that of hand pump;
2. An operator is capable to work with it for a long time (more than 2 hours) continuously without being tired;
3. The pump is capable to tap water from a shallow depth (< 2 m) effectively and is , therefore, expected to be suitable to supply irrigation water in small fragmented land holdings as well as in small irrigation project areas; and
4. Construction cost of the pedal pump is also comparatively low.

V. RECOMMENDATION AND LIMITATION OF THE STUDY

This research would be undertaken for the further improvement of the pump. In this study, only a few trials were given to find out appropriate size of piston valve and check valve of the pump. The efficiency of the pump depends on size and type of valves and cylinder. The following recommendations are put forward in relation to the present study:

1. It is necessary to find out appropriate size (diameter and height) of cylinder and valves. Rubber flaps of different sizes and shapes may also be used to observe their effect on efficiency;
2. Accurate device to measuring input power should be employed in computing pump efficiency.
3. Concrete (1:2:4) base may be constructed in the field for the permanent installation of the pump.

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