Performance evaluation of a hand pump with provision of a sealed secondary water sump

Amaresh Sarkar*, Madan Kumar Jha

(*Agricultural & Food Engineering Department, Indian Institute of Technology Kharagpur, Kharagpur, PIN – 721 302, West Bengal, India.*)

Abstract: Nowadays, a large number of water lifting devices and pumps are available for lifting water or other liquids from a lower elevation to a higher elevation. However, none of the available hand pumps use a secondary water sump or any other such kinds of devices which increase the efficiency of hand pumps. Also, measurement of operating forces during performance evaluation of hand pumps is often missing. In this study, a commonly used hand pump was fitted with a 54-liter capacity sealed secondary water sump and its performance was evaluated. The secondary water sump was linked with the shallow well which served as the source of water during experimentation. The experimental results indicated that the provision of a secondary water sump for a hand pump results in a significant reduction in the input power; thereby it requires lesser operating force. The experiments also revealed that the secondary water sump of larger capacity requires lesser force to operate the pump. However, the output powers in both the cases viz., with and without secondary water sumps were found to be approximately same. It is concluded that the provision of a secondary water sump fitted with a hand pump provides more comfort in operating hand pumps.

Keywords: Hand pump, secondary water sump, pump efficiency

Citation: Sarkar, A., and M. K. Jha. 2015. Performance evaluation of a hand pump with provision of a sealed secondary water sump. AgricEngInt: CIGR Journal, 17(3): 166-175.

1 Introduction

Hand Pumps have been given a high profile in the quest to provide potable water to the world's burgeoning rural population by leading players in development like the World Bank, UNICEF and a plethora of international non-government organizations (Parry-Jones et al., 2001). Hand pumps are low-speed pumps. They vary in their design; however, most of them are positive displacement pumps and have reciprocating pistons or plungers. (Lal, 1969; Michael and Khepar, 1999).

A state-of-the-art review of hand pump designs is briefly discussed here. Force and Lift Hand Pump is a suction pump which can draw water from up to 8 m depth and can lift up to 10 m delivery head (AIC, 1961). Shallow Well Hand Pump is used to lift water from a max depth of 7 m (SKI, 1961). Tara Direct Action Hand Pump is designed by UNICEF is designed for lifting water from bore wells with the static water level not exceeding 15 m (SKI, 1961). Diaphragm Hand Pump was originated in France and was developed by Vergnet S.A. It is also known as Vergnet Hand Pump. The pump is powered by foot using a pedal (WA, 1981). Non-Piston Pump is a high lift and mono progressing cavity hand pump (WA, 1981). Extra Deep Well Hand Pump is exclusively used for extracting water from greater depths. It is also called Meera Vlom India Mark IV. It is suitable for static water levels varying from 50 to 90 m (AOVI, 1982). India Mark III Deep Well Hand Pump is an improved version of VLOM (Village Level Operation and Maintenance) version of the India Mark II Hand Pump (AOVI, 1982). Rower Pump is a manually operated, suction piston pump used for drawing water from low-level springs, shallow wells, river beds and open water (SWSFL, 1982). Consallen Hand Pump was made in U.K. It can lift water

Received date: 2014-10-03 **Accepted date:** 2015-08-04

***Corresponding author: Amaresh Sarkar,** Department of Agricultural Engineering, College of Agriculture Tripura, Lembucherra, Agartala, PIN –799 210, India. Tel: +91-9436349675. E-mail: amaresh.sarkar@gmail.com

up to 60 m depth (CWWHP, 1983). Afripump is based on the Volanta Pump technology and also called Volanta-Afripump (WC, 1986). Awassa Hand Pump was initially designed in Ethiopia in 1988. The pump basically consists of a drive unit and a pump unit connected by flexible plastic piping and works by hydraulic action (NRCC, 1988). Rope Pump consists of a loop of nylon rope with rubber gaskets attached to it. It is manually operated by rotating a wheel, which pulls the rope through the pipe (TTD, 1990). Volanta Flywheel Hand Pump was developed by Jansen Venneboer, which is used for community water supply and is suitable for lifting groundwater from up to 100 m depth. The pump is manually operated with a large flywheel (JVBV, 1990). Inertia-Lift Village Pump is neither a piston nor a vacuum pump. Water is delivered on both up and down strokes (EZIA, 1991). Bush Hand Pump can be used for depths up to 100 m. It is also called "POV-RO 2000 Pump" in Nepal, "Zimbabwe Hand Pump" in Zimbabwe, and "Bush Pump" in Liberia (LC, 1998).

1.1 Advantages of hand pumps

The main advantage of hand pumps is that they are one of the most economical and simple solutions for providing a collective supply of drinking water in rural areas and suburban environments. They also help to eliminate the risks of people, and children, in particular, falling into open wells. They also improve the conditions of hygiene under which water is drawn off, by eliminating the use of buckets of uncertain cleanliness, thereby limiting diseases associated with contaminated water.

1.2 Price of hand pumps

The criteria for choosing a hand pump should be based on the possibility of easily finding spare parts and people able to maintain or repair it. There will thus be a need to first gather certain information such as the pump's type use for family, small community, village, the depth of the well or borehole, the delivery head, the desired pump flow rate, the price range acceptable to the community. Indeed, the price of hand pumps varies, depending on the way they are manufactured, their use and their resilience. Their price also most often varies according to the depth of the well or borehole and the country.

1.3 Community involvement in maintaining hand pumps

The user involvement is vital for the long-term effectiveness of hand pumps. The best way to achieve this is by the appointment of a pump caretaker among the pump users who is self-motivated, after proper training and the supply of a tool kit, will carry out the duties namely to perform regular inspections daily, to train people how to use the pump properly, to make simple repairs or replacements, to keep a supply of spare parts, and to ensure that surplus water is drained away (World Bank, 1986)

1.4 Objective of the Study

The extensive review of literature revealed that a large number of hand pumps designs are available for lifting water from a lower elevation to a higher elevation. However, none of these hand pumps uses a secondary water sump or any such kind of device which increases the efficiency of hand pumps. Therefore, the present study was carried out with the following objectives: (i) to evaluate the performance of a hand pump fitted with a sealed secondary water sump under different suction heads, and (ii) to evaluate the effect of the capacity of secondary water sumps on the hand pump performance. It is evident from literature review that the present study is a novel one. The finding of this study is of great importance because the proposed improvement in the hand pump system is expected to provide an efficient design of widely used hand pumps.

2 Materials and methods

2.1 Working principle

At the beginning of pumping, water was delivered from the secondary water sump which is placed at the ground surface or just below the ground surface. Hence, the suction head is very low and required operating force is very low. In this situation, when the negative pressure inside the air tight secondary water sump becomes more than the minimum suction force to lift water from the primary water sump due to water withdrawal by pumping, then the non-return valve of the secondary water sump gets open and water from the primary water sump is lifted to the secondary water sump continuously. In this way, in every 10 to 12 pumping complete strokes (comprises one upward stroke and one downward stroke of the piston) interval, water is lifted to the secondary water sump from the primary water sump. Thus, no additional force is directly required to lift water from the primary water sump to the secondary water sump. Therefore, the operating force of the hand pumps fitted with a secondary water sump is very less in comparison to that without a secondary water sump.

2.2 Experimental setup

To ensure the viability of the proposed design of the improved hand pump system, an experimental setup was developed in the Field Water Management Laboratory of Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, West Bengal, India located at 22° 20' 23” N latitude, 87° 19' 30” E longitude and 37 m altitude from mean sea level. The experimental setup consisting of a shallow well hand pump, a secondary water sump fitted below the suction port, and a tension dynamometer fitted between the handle and top of the piston rod is shown below in Figure 1(a) and the experimental setup without fitting any secondary water sump is shown in Figure 1(b). The experimental site has flat topography with fine loamy soil. The inner diameter of the experimental open well is 2.4 m and depth is 7 m, with a masonry lining wall. The open well has provision of electric operated pump for quick water lifting and refilling for experiments with different suction heads.

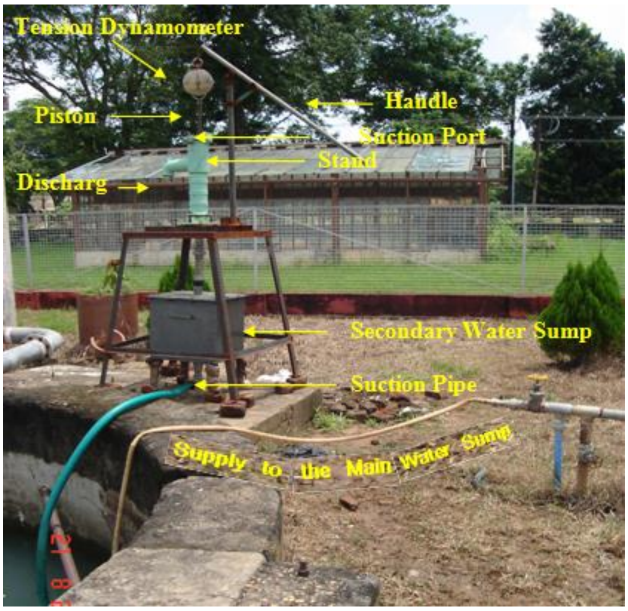

Figure 1(a) Experimental setup of the hand pump fitted *with* a 54-L MS secondary water sump

Figure 1(b) Experimental setup of the hand pump *without* a secondary water sump

The specifications of the hand pump and its accessories used in experiments are given below in Table 1. Experiments were conducted on the hand pump without a secondary water sump as well as with a 54-liter metallic secondary water sump made of mild steel (MS) and a 25-liter metallic secondary water sump made of galvanized iron (GI) by pumping water from different suction heads of an open well having maximum depth of 7 m. Actual operating force, time and volume of water delivered per 10 strokes under different static suction heads were recorded. Five sets of these measurements were taken for each static suction heads. Discharge per downward stroke was also recorded. Operator's body weight was 58 kg and the same operator was used for the entire pumping operations with usual normal strokes by using a single hand for static suction heads of 1.0 m to 3.5 m and double hand for static suction heads of 4 m to 6 m.

Table 1 Specifications of the hand pump setup

Description	Specifications
1. Cylinder material	Cast iron
2. Piston diameter, cm	9
3. Stroke length, cm	20
4. Delivery head, cm	40
5. Inner diameter of the corrugated plastic suction pipe, cm	3.6
6. Effective effort distance of the handle, cm	96
7. Effective load distance of the handle, cm	24
8. Mechanical advantage of the handle	4.0
9. Actual length of the effort side of the handle, cm	100
10. Actual length of the load side of the handle, cm	25
11. Length of the handle, m	1.25
12. Weight of the handle, kg	2.0
13. Range of the tension dynamometer, kg	0 to 200
14. Materials of cup seal and flapper valve	Nitrile rubber
15. Total weight of the piston and piston rod, kg	1.05

Randomly chosen 54 liters capacity secondary water sump (SWS) made of mild steel and 25 liters capacity water sump made of galvanized iron are shown in Figure 2(a) and Figure 2(b), respectively. The specifications of the two secondary water sums are summarized below in Table 2. The 54 liters capacity cubical secondary water sump was locally fabricated with an outer dimension of 38.12 cm × 38.12 cm × 38.12 cm, wall thickness 3.18 mm and has four extended legs at the bottom four corners. In the 54-liter SWS, the inlet is fitted upward at the center of the bottom surface and an outlet is fitted downward at the top surface. The 25 liters capacity cylindrical sump was chosen from locally available sumps with 27 cm diameter, 1.27 mm wall thickness and has no extended legs at the bottom surface. In the 25-liter capacity SWS, the elbow inlet and outlet pipe were fitted upward at the top surface because of not having any extended legs and difficulty to fit extended legs over the low wall (surface) thickness. Both the secondary water sumps have one inlet and one outlet, both fitted with 32 mm inner diameter GI pipe of 3.2 mm wall thickness.

Figure 2(a) 54 liters capacity SWS; Figure 2(b) 25 liters capacity SWS

Table 2 Specifications of the secondary water sumps used in the study

Sl. No.	Capacity, L	Material	Shape	Outer Dimensions, cm	Wall Thickness , mm
1	54	MS (Mild Steel)	Cubical	38.12 × 38.12 × 38.12	3.18
2	25	GI (Galvanized Iron)	Cylindrical	27 diameter and 44 height	1.27

2.3 Measurement of operating forces

The actual force required to raise the piston can be measured directly from a tension dynamometer which is fitted in between the top of the piston rod and the handle. The handle of a hand pump works as a first class lever. Therefore, the force required to raise the piston is more than the force applied to the handle. Thus, the actual force required to the handle was calculated as:

$$F_{ah} = \frac{F_{aus}}{MA} \quad (1)$$

Where, F_{aus} = actual force required during upward stroke (N); F_{ah} = actual force required to the handle during upward stroke (N); and MA = mechanical advantage of the handle (dimensionless).

The actual force required to lower the piston (i.e. to raise the handle of the hand pump) during downward stroke was calculated as:

$$F_{ads} = W_{eh} - (W_{lh} + W_p) \quad (2)$$

Where, W_{eh} = weight of effort side of the handle (N); W_{lh} = weight of load side of the handle (N); and W_p = weight of the piston and piston rod (N).

The weight of effort side and load side of the handle was calculated as:

$$W_{eh} = \frac{a}{(a+b)}(W_h) \quad (3)$$

$$W_{lh} = \frac{b}{(a+b)}(W_h) \quad (4)$$

Where, a = actual length of the effort side of the handle (m); b = actual length the load side of the handle (m); and W_h = total weight of the handle (N).

2.4 Calculation of discharge and volumetric efficiency

The actual volume of water delivered per 10 strokes was collected in a bucket and then measured by using measuring cylinders. The volume of water to be delivered in an upward stroke of the piston is equivalent to the swept volume of the piston. Similarly, in a downward stroke of the piston, a stroke length equivalent distance of the piston rod is immersed in water; as a result an equivalent volume of water gets displaced as discharge. This volume of water delivered per downward stroke of the piston is very less in comparison to the volume of water delivered per upward stroke of the piston. The theoretical volumes of water delivered in an upward stroke and in a downward stroke were calculated as (Lal, 1969; Michael and Khepar, 1999):

$$V_{us} = (A_p - A_r)\, S \qquad (5)$$

$$V_{ds} = A_r\, S \qquad (6)$$

Where, V_{us}= theoretical volume of water delivered during an upward stroke (m^3); A_p = cross-sectional area of the piston (m^2); A_r = cross-sectional area of the piston-rod (m^2); S = stroke length of the piston (m^2); and V_{ds} = theoretical volume of water delivered during a downward stroke (m^3).

Therefore, the theoretical total volume of water delivered in a complete stroke (one upward and one downward) is:

$$V_t = V_{us} + V_{ds} \qquad (7)$$

Where, V_t = theoretical total volume of water delivered per stroke (one upward and one downward) of the piston (m^3).

Moreover, the volumetric efficiency of a hand pump was calculated as (Lal, 1969; Michael and Khepar, 1999):

$$\eta_{Vol} = \left(\frac{V_a}{V_{th}}\right) \times 100 \qquad (8)$$

Where, V_a = actual volume of water delivered in a complete (one upward and one downward) stroke (m^3); and V_{th} = theoretical volume of water delivered in a complete stroke (m^3).

2.5 Calculation of input power, output power, and overall efficiency

One complete stroke (one stroke) of the hand pump comprises one upward stroke and one downward stroke of the piston. The duration of one upward stroke is the time required to move the piston from bottom dead center to top dead center in the piston cylinder. Similarly, the duration of one downward stroke is the time required to move the piston from top dead center to bottom dead center in the piston cylinder. In an upward stroke, the piston works for water suction force and against piston friction and gravity. However, in a downward stroke, the piston works against piston friction towards gravity only. Therefore, the force required in a downward stroke of the piston is very less in comparison to an upward stroke of the piston. Each upward stroke is always followed by one downward stroke. The frequency of strokes of any hand pumps may be estimated as the number of complete strokes per unit time. The 'input power', 'output power' and 'overall efficiency' of the hand pump was calculated as:

$$P_i = \left(\frac{F_{aus}}{T_{us}} + \frac{F_{ads}}{T_{ds}}\right) S \qquad (9)$$

$$P_o = \gamma\, H_t\, (Q_{aus} + Q_{ads}) \qquad (10)$$

$$\eta_{overall} = \left(\frac{P_o}{P_i}\right) \times 100 \qquad (11)$$

Where, P_i = input power to the hand pump (W); P_o= output power of the hand pump (W); $\eta_{overall}$ = overall efficiency of the hand pump (%); F_{aus} = actual force required during an upward stroke (N); F_{ads} = actual force required during a downward stroke (N); T_{us} = duration of one upward stroke (s); T_{ds} = duration of one downward stroke (s); Q_{aus} = actual volume of water delivered in an upward stroke (m^3); Q_{ads} = actual volume of water delivered in a downward stroke (m^3); γ = specific weight of water (N/m^3); H_t (total pumping head) = H_s +H_d + H_f (m); H_s = static suction head (m); H_d = static delivery head (m); and H_f = major and minor friction head losses on the suction and delivery sides (m). The friction head losses due to roughness of the inner surface of pipe network, viscosity and density of the flowing fluid, etc. for a hand pump system are practically negligible because of low flow rate of water and hence, they were not considered during total head calculation.

2.6 Evaluation of the effect of secondary water sump capacity on the pump performance

The effect of different sizes/capacities of secondary water sumps on the performance of a hand pump was assessed by comparing the results of the experiments of hand pump fitted with a randomly chosen 54 liters metallic (MS) and locally available 25 liters metallic (GI) secondary water sumps.

3 Results and discussion

3.1 Performance of the hand pump with 54-liter and 25-liter secondary water sumps

The experiment on the hand pump with a 54 liters metallic secondary water sump revealed that the pump was able to lift water up to 6.0 m static suction head (Figure 3). However, the experiment on the hand pump with a 25 liters metallic secondary water sump was done mainly to check the effect of capacities of secondary water sump on the hand pump performance. Therefore, the experiment on the hand pump with a 25 liters metallic secondary water sump was done up to 2 m static suction heads only. The operating forces of the hand pump *with* and *without* a 54 liters metallic secondary water sump were found to vary from 23 to 57 kg_f and 40.5 to 82 kg_f, respectively for the static suction heads of 1.0 to 6.0 m (Figure 3). On the other hand, the operating forces of the hand pump *with* 25 liters metallic secondary sump were found to vary from 35 to 47.5 kg_f for the static suction heads of 1.0 to 2.0 m. It is worth mentioning that beyond 2.0 m suction head, the 25-liter capacity galvanized iron secondary water sump started to collapse due to its small wall thickness.

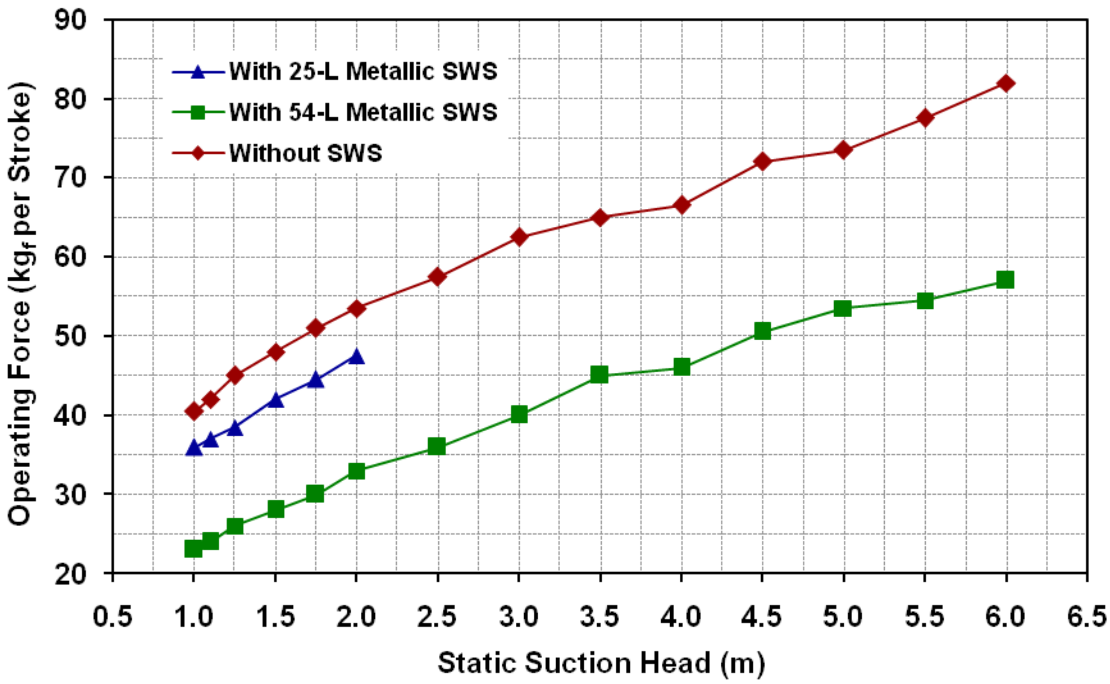

Figure 3 Variation of operating force with static suction heads of the hand pump *without* and *with* randomly chosen 54-L and 25-L metallic secondary water sumps

The ‘input power’ and ‘output power’ of the hand pump *without* a secondary water sump and *with* 54 liters and 25 liters metallic secondary water sumps are shown below in Figure 4.

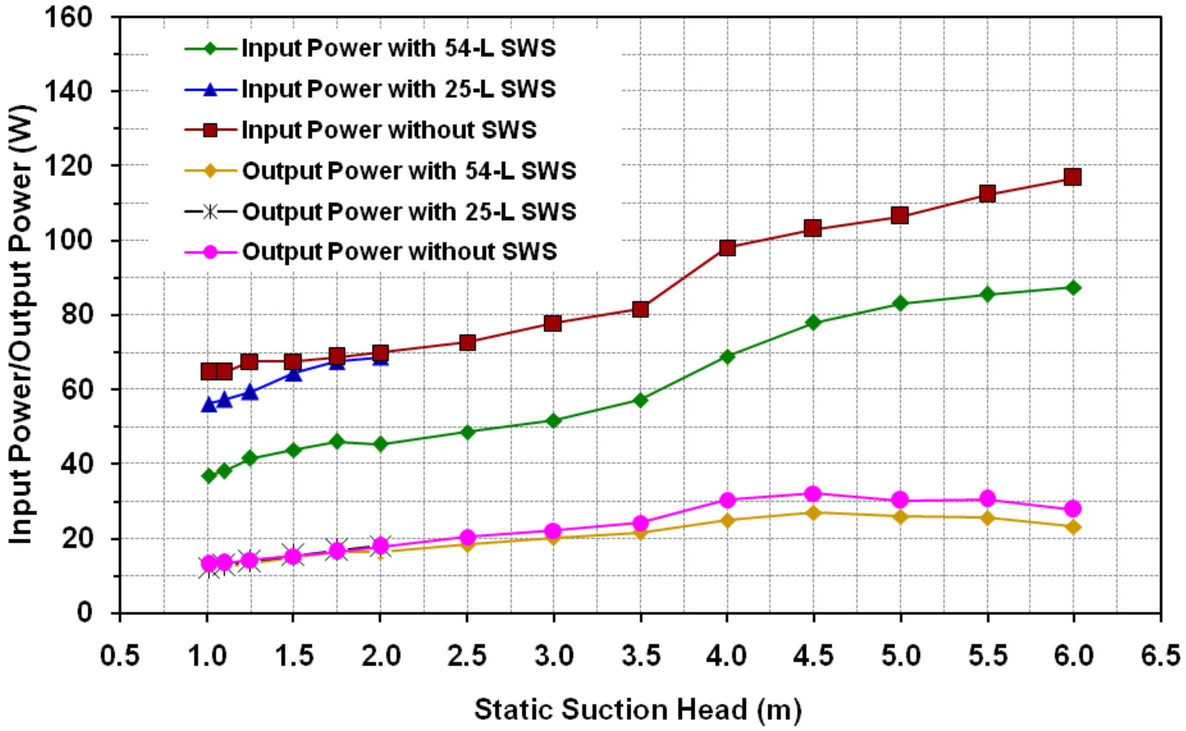

Figure 4 Variation of input and output powers with static suction heads of the hand pump *without* and *with* randomly chosen 54-L and 25-L metallic secondary water sumps

It is apparent from Figure 4 that the hand pump fitted with a secondary water sump requires considerably less input power compared to the hand pump without a secondary water sump. It is also evident that larger the capacity of secondary water sump, lesser is the force requirement to operate the pump. However, the output power in both the cases remains approximately same. The volumetric efficiency of the hand pump *with* and *without* 54 liters metallic secondary water sump varied from 83.97 to 37.86% and 93.12 to 48.87%, respectively for the static suction heads of 1.0 to 6.0 m (Table 3). Further, the overall mechanical efficiency of the hand pump *with* and *without* a randomly chosen 54 liters metallic secondary water sump varied from 31.65 to 26.51% and 19.94 to 23.77%, respectively for the static suction heads of 1.0 to 6.0 m (Figure 5). The maximum mechanical efficiencies of the hand pump *with* and *without* 54 liters metallic secondary water sump were found to be 39.08% and 30.96% at the static suction heads of 3 m and 4 m, respectively.

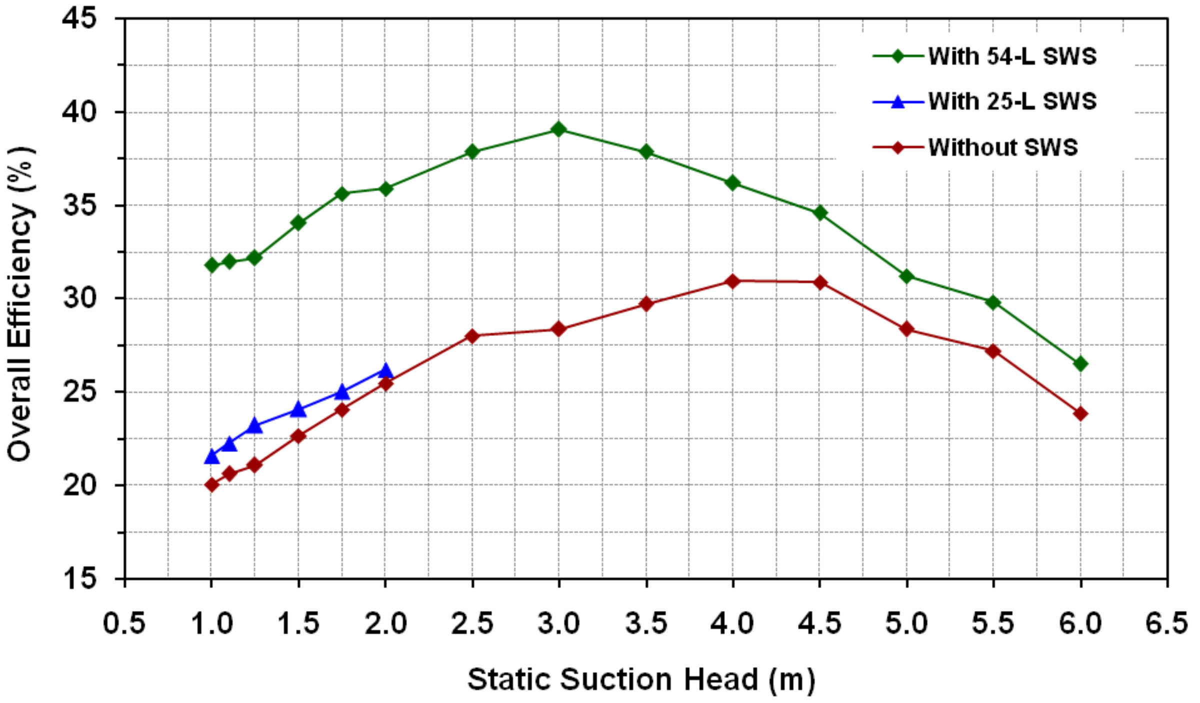

Figure 5 Variation of overall efficiency with static suction heads of the hand pump *without* and *with* randomly chosen 54-L and 25-L metallic secondary water sumps

Table 3 Volumetric efficiency of the hand pump *with* and *without* 54-L metallic secondary water sump (SWS) under different static suction heads

Static Suction Head, m	Volumetric Efficiency, %	
	With 54-L SWS	Without 54-L SWS
1.0	83.97	93.12
1.5	80.62	91.68
2.0	79.08	90.74
2.5	75.31	88.74
3.0	73.68	83.30
3.5	70.02	79.10
4.0	60.70	74.91
4.5	57.20	72.62
5.0	49.60	61.7
5.5	44.15	57.20
6.0	37.86	48.87

3.2 Effect of the capacities of secondary water sump on the pump performance

The experiments on the hand pump with the randomly chosen 25 liters GI and 54 liters MS secondary water sumps revealed that a higher capacity secondary water sump requires less operating force and hence, less input power as compared to a smaller capacity secondary water sump (Figure 4). However, the output power remains more or less same for both types of secondary water sumps. Therefore, the hand pump fitted with a larger capacity secondary water sump appreciably enhances the overall efficiency of the hand pump.

4 Conclusions

Based on the performance evaluation of a hand pump with and without sealed secondary water sumps, the following conclusions are drawn:

(1) The experiments on a hand pump fitted with a sealed secondary water sump revealed a significant reduction in the input power to operate the pump.

(2) It was also found that the use of larger capacity secondary water sump requires lesser operating force to operate the pump or lesser input power than the smaller capacity secondary water sump.

(3) The output powers in both the cases namely *with* and *without* a secondary water sump are approximately same.

(4) Overall, the provision of a secondary water sump for a hand pump significantly increases its overall efficiency and provides more comfort in operating the hand pump.

Acknowledgements

The authors are very thankful to the erstwhile Head, Department of Agricultural & Food Engineering, Indian Institute of Technology (IIT) Kharagpur, West Bengal, India for providing financial support and other facilitates for carrying out this research.

References

Ajay Industrial Corporation (AIC). 1961. Force and Lift Hand Pump. India,http://www.ajayindustrial.com/play-and-pump.html#force (accessed on June 14, 2007).

AOV International (AOVI). 1982. **Extra Deep Well Hand Pump,** India Mark II Deep Well Hand Pump and India Mark III Deep Well Hand Pump. India, http://www.aovinternational.com/hand-pumps.html (accessed on June 26, 2007).

Consallen Water Wells and Hand Pumps (CWWHP). 1983. Consallen Hand Pump, U.K., http://www.consallen.com/handpumps/ (accessed on June 14, 2007).

EZI- Action (EZIA). 1991. Hand Pump Power Measure, Hamilton, New Zealand, http://www.nzpump.com/eziaction_hand_pumps (accessed on June 4, 2007).

Jansen Venneboer B.V. (JVBV). 1990. Volanta Flywheel Hand Pump. Jansen Venneboer B.V., The Netherlands, www.volanta.nl (accessed on July 24, 2007).

Lal, J. 1969. *Hydraulic machines*. Metropolitan Book Co. (Pvt.) Ltd., Delhi, India.

Lifewater Canada (LC). 1998. The Bush Hand Pump. Canada, http://www.lifewater.ca/drill_manual/Section_13.htm (accessed on June 14, 2007).

Michael, A.M., and S.D. Khepar. 1999. *Water well and pump engineering*. Tata McGraw-Hill Publishing Co. Ltd., New Delhi, India.

National Research Council of Canada (NRCC). 1988. Awassa Hand Pumps. Canada, http://members.shaw.ca (accessed on June 8, 2007).

Parry-Jones, S., R. Reed, and B. H. Skinner. 2001. Sustainable hand pump projects in Africa. A Literature Review, Water Engineering and Development Center (WEDC), Loughborough University, U.K.

S.K. Industries (SKI). 1961. Tara Direct Action Hand Pump. India, www.skipumps.com (accessed on June 18, 2007).

SWS Filtration Ltd. (SWSFL). 1982. Rower Pumps. U.K., http://ds.dial.pipex.com/swsfilt/rower/index.htm (accessed on July 24, 2007).

Technology Transfer Division (TTD). 1990. The Rope Pump. Nicaragua, S.A., http://www.ropepump.com/images/TechnicalDrawings.pdf (accessed on July 22, 2007).

Water Aid (WA). 1981. Diaphragm Hand Pump and Non-piston pump. Water Aid-Water for Life, Technology Notes, U.K., http://www.wateraid.org/~/media/Publications/Handpumps.ashx (accessed on July 24, 2007).

Watsan Consult (WC). 1986. **Afripump.** The Netherlands, http://www.watsan.com/show_detail.php?key=19&sgrp=0 (accessed on June 20, 2007).

World Bank. 1986. Rural Water Supply Hand Pumps Project, Community Water Supply — the Hand Pumps Option, World Bank.