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Experimental study on performance characteristics of a small centrifugal pump

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ABSTRACT

A study on performance characteristics of a centrifugal pump was carried out in the hydraulic laboratory. A half horse power (hp) motor driven centrifugal pump was used. The performance characteristics of the centrifugal pump was tested under varying proportions of suction and delivery lifts for a wide range of total lifts. The pump was operated for a total lifts of 2.00, 4.00, 5.50 and 7.40 m. The results obtained reveal that for a given total lift, the efficiencies of the pump varied with the different ratios between suction and delivery lifts. For the total lift of 2.00 m, both the efficiency and discharge decreased with the increase of suction lift. For the total lifts of 4.00, 5.50 and 7.40 m, the maximum pump efficiency was obtained when the suction lift was at or around 2.00 m. This suggests that the pump operates more efficiently when the suction lift was at about 2.00 m, irrespective of delivery lift. The study results also showed that, the efficiency increased and discharge decreased, in general, with the increase of total lift. The variations of discharge due to variable ratios of delivery to suction lifts were more prominent for a low lift than the higher lifts. The performance characteristics of the centrifugal pump, used in this study, were similar to those reported earlier on some points, while it differed on some others.

INTRODUCTION

Pump is a device which lifts fluid like water, gas or slurries from lower level to a higher level by using force derived from an external source. Actually, pump is a hydraulic machine constructed for raising or transferring fluids, consisting essentially of a moving piece in a cavity or piston working in a cylinder, with valves properly placed for admitting or retaining the fluid as it is drawn or driven through them by the action of the piston. A pump converts mechanical energy into pressure energy. Early applications include the use of windmill or watermill to pump water. Today, the pump is used for irrigation, water supply, gasoline supply, air conditioning systems, refrigeration (usually called a compressor), chemical movement, sewage movement, flood control, marine services, etc (Hicks and Theodore, 1971). Because of the wide variety of applications, pumps have a plethora of shapes and sizes; from very large to very small, handling gases or liquids; from high pressure to low pressure, and from high volume to low volume capacities. Different kinds of pumps are available; according to their operating principle, head and discharge, specific discharge, direction of flow, etc (Karassik, 2001).

The pump which converts mechanical energy into hydraulic energy through centrifugal motion is known as a centrifugal pump. It is a rotor-dynamic pump that uses a rotating impeller to increase the pressure of a fluid. The fluid enters the pump impeller along or near the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits into the downstream piping system. Amongst modern pumps, centrifugal pumps are most

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widely used for irrigation purposes. They are used to pump water from reservoirs, lakes, streams and shallow wells. There are several kinds of centrifugal pump including radial-flow, mixed-flow, and axial flow (Whistler, 1960). Every centrifugal pump has two characteristics that are the same; each has an impeller that forces the liquid being pumped into a rotary motion, and each has a casing, which directs the liquid to the impeller. Centrifugal pumps are designed for either horizontal or vertical operation. A horizontal centrifugal pump has a vertical impeller connected to a horizontal drive shaft. These pumps are most common in irrigation systems because they are generally less costly, require less maintenance, easier to install and more accessible for inspection and maintenance than vertical centrifugal pump. Centrifugal pumps have many advantages, so they are widely used for lifting water for agriculture or municipal supplies. They are simple in construction, easy to operate, low in initial cost and produce a steady discharge (Michael, 1978). The disadvantages of centrifugal pumps are their relatively poor suction power and problem of developing cavitations (Zane Satterfield 2013). The proper selection of a pump depends on the pump efficiencies. Capacity, head, power, efficiency, required net positive suction head, and specific speed are parameters that describe a pump's performance. These parameters are also the basis of the pump characteristics curve. The pump characteristics curves, called pump performance curves, show the interrelations among capacity, head, power and efficiency of a pump. A typical characteristic curve shows the total dynamic head, brake horsepower, efficiency, and net positive suction head all plotted over the capacity range of the pump (Zane Satterfield 2013). The knowledge of the pump characteristics enables one to select a pump whatever may be the type, operates most satisfactorily under a head and at a speed for which it is designed and which is best adapted to particular conditions of operation and thus obtain relatively high value of efficiency with low operating cost. The vertical lifting distance of water for irrigation purpose varies widely. In some localities, water is lifted only a few meters, while in others, it is raised tens of meters. In irrigation practice, the maximum economic height of lift is determined by cost limitations, not by the mechanical or power limitations (Israelsen and Hansen, 1962).

Selection of a suitable water lifting device for a particular situation depends on the characteristics of the water source, size of the land to be irrigated, amount of water to be lifted, depth of the pumping water level, type and amount of power available, and the economic status of the farmers. In Bangladesh, there has been widespread use of shallow tubewell (STW), deep tubewell (DTW) and low lift pump (LLP) for irrigation of agricultural lands, particularly during the dry period (November to March). Irrigation pumps are used for lifting water either from surface or sub-surface sources. In small scale irrigation projects, LLPs are used to lift surface water and the pump units are moveable when the seasonal variation in water level occurs. Though the country has abundant surface water during wet season, large scale irrigation by using surface water has become difficult or practically impossible due to limited availability of surface water during dry season. Therefore, the use of groundwater for irrigation has become increasingly important. Groundwater is a predominant source of water supply in Bangladesh. In small and minor irrigation schemes, irrigation water supplies are generally provided with shallow tubewells, which lift water from underground. But, in many places, lifting of water with shallow tubewells is facing severe problem due to lowering of the water table. Observations compiled from 1985 to 2005 in Bangladesh indicated a declining groundwater level of greater than 1 m per year in urban and semi-urban areas around Dhaka and 0.1 to 0.5 m per year in the North-Central, North-Western and South-Western part of the country (Shamsudduha et al, 2009). Due to declination of water table in the dry season, farmers have to operate the pumps under increased suction lift. On the other hand, at the end of the dry season (March/April), the water level falls beyond the suction limit of the centrifugal pumps. A finding on water table monitoring (DPHE, 2012) shows that the water table has fallen beyond the suction limit in about 27% area in 2004. To cope up with this situation, farmers used to draw water by placing the STW in a pit, which is called a deep-set shallow tube well.

Many studies were conducted to evaluate the centrifugal pump performances under different operating conditions (Mahmud et al. 2012). In pump testing studies, the efficiency of a pump is evaluated against different lifts, without taking into account any consideration of proportionate division of total lift into suction and delivery lifts. A locally manufactured centrifugal pump was investigated in laboratory and prepared characteristic curves for different operating conditions (Alam and Shil, 2004). The minimum discharge of 8.41 L/s was obtained against a suction head of 5.40 m at 1300 rpm pump speed. The maximum efficiency was 26% at this condition. The maximum discharge was 11.52 L/s against a suction head of 2.90 m at 1300 rpm pump speed. At this condition, the efficiency of the pump was 20%. A low lift irrigation pump of 12 cm diameter with a 3 m long discharge pipe was evaluated the performance of the pump under six different speeds from 1250 to 2500 rpm under three total static heads of 1.0, 1.5 and 2.0 m (Kunthy and Gupta, 2000). The maximum efficiency obtained was 49.2, 47.1 and 44.3% at 2250 rpm for the corresponding total static head. A theoretical head discharge curve is very important to the real performance curve of a centrifugal pump on the basis of the analysis of the pump performance curve (Gang and Qin, 2004). If the absolute value of discharge turns to be very large, the real performance curve will be stable. On the contrary,

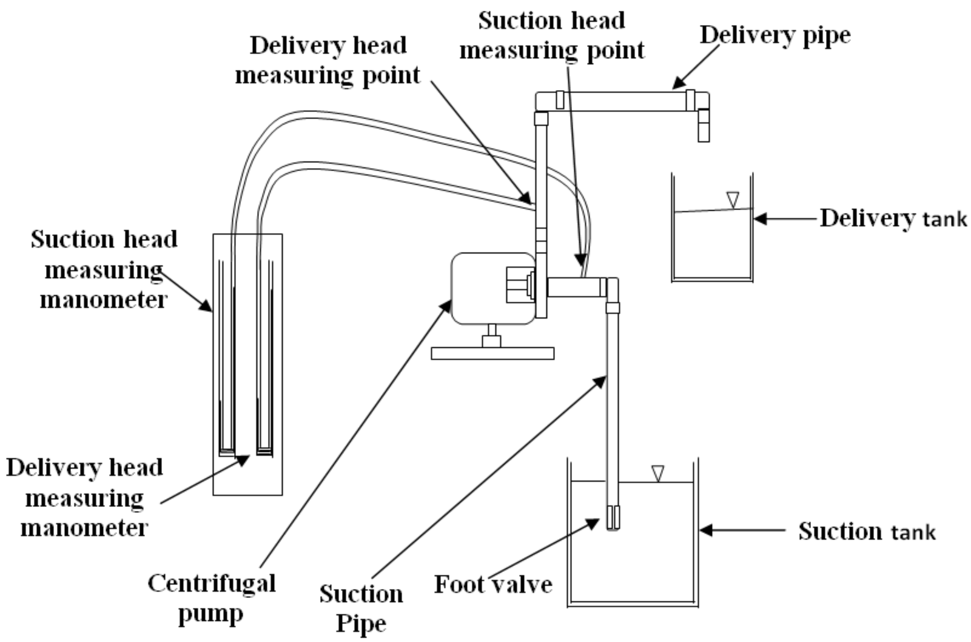


Figure 1. A schematic diagram of the experimental setup showing different technical elements.

if the absolute value gradually becomes small, the real performance curve will have a hump. Thus, the criterion for judging the existence of a hump on performance curve can be obtained. For a locally manufactured centrifugal pump, tested in laboratory (Islam, 2002), reported the efficiency of 27.5% at 1600 rpm; the minimum discharge of the pump was 19.5 L/s at the highest ten suction and delivery lift of 5.48 and 2.15 m, respectively. Some pumps comparative efficiency data were published. These publications had generally confined themselves to tabulating technical efficiency data of the pump without attempting to interpret it in user friendly terms. The characteristic curves of a pump give information about the capacity, system head, efficiency and power requirement of the pump. All these information are necessary for the selection of a pump (AMTEC, 1991; Hebbelthwaite, 1955; Inns, 1992; Reti, 1963). Two studies were conducted in Bangladesh Agricultural University with emphasis on variable proportions of suction and delivery lifts. The first one showed that, even for a constant lift, the efficiency of a pump does vary with the variation of suction and delivery lifts (Islam, 2008) and the second one showed that, at a given total lift, both the discharge and efficiency increased with the increase of delivery to suction lift ratio (Mahmud, 2008). These studies were conducted using the same pump.

The present study was undertaken with a different centrifugal pump, smaller than that used by (Islam, 2008; Mahmud, 2008). The objectives of this research were to evaluate the performance characteristics of the new pump under varying proportions of suction and delivery lifts for a wide range of total lifts and compare the findings with those reported by Islam (2008) and Mahmud (2008).

EXPERIMENTAL PROCEDURE FOR EVALUATING THE PERFORMANCE CHARACTERISTICS OF THE PUMP

Experimental setup

This study was conducted to evaluate the characteristics of a centrifugal pump against different lifts with a view to comparing the results with those obtained earlier with a different pump. The study was carried out in the hydraulic laboratory of the Department of Irrigation and Water Management, Bangladesh Agricultural University (BAU), Mymensingh. Figure 1 presents a schematic diagram of the experimental setup showing different technical elements.

Description of the pump

A small centrifugal pump consisting of a vertical impeller located inside a sealed impeller case was used for this work. A horizontal drive shaft from half (0.5) hp electric motor, used as a power unit, was directly coupled with the pump to drive the impeller. Both the inlet and outlet diameters of the pump were 2.54 cm (1.0 inch). The pump rotates at a rated speed of 2900 revolution per minute (rpm). The manufacturing company of the pump is

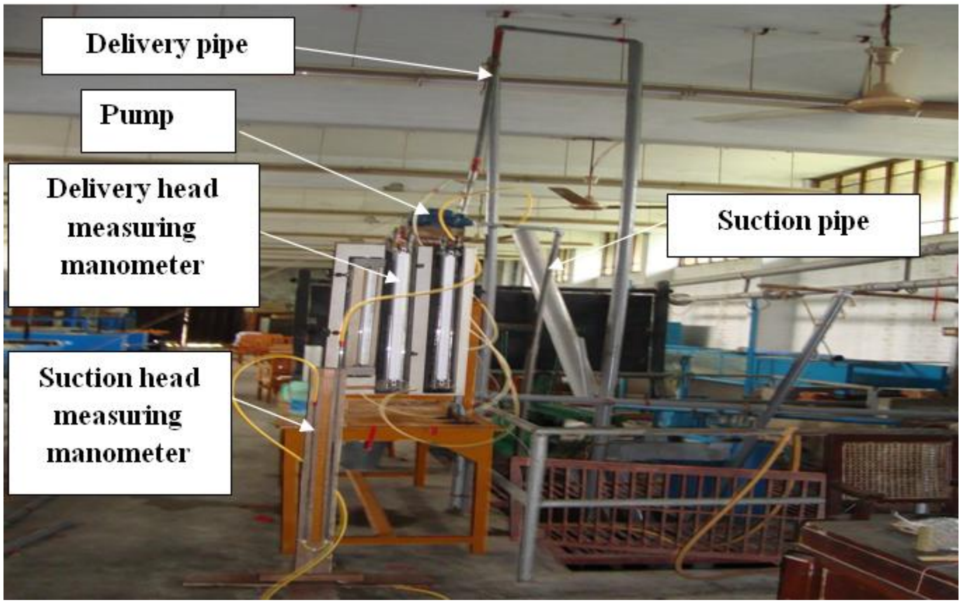


Figure 2. A photographic view of the pump with suction and delivery pipe arrangement.

"PEDROLLO" of Italy and the model name is Pump RKm 60. As a result of their construction characteristics, the high efficiency and continuous duty capabilities makes these pump ideal centrifugal pump are suitable for use in the domestic, agricultural and industrial sectors. All of the components in contact with the pumped liquid were constructed from stainless steel AISI 304, thus guaranteeing complete hygiene and maximum resistance against corrosion. Suitable for use with clean water and liquids that are not chemically aggressive towards the materials from which the pump is made. The pump should be installed in an enclosed environment, or at least sheltered from inclement weather. Applications of the pump were water supply systems, air conditioning systems, washing systems, cooling systems, water treatment plants and irrigation pumps. The efficiency flow rate range was up to 160 l/min (9.6 m^3/h) and head up to 23 m. Application limitation were temperature of the liquid from -10 to +90°C, ambient temperature da -10 to +40°C, manometric suction lift up to 7 m, and maximum working pressure 4 bar.

Arrangement of suction and delivery pipes

In this study, 2.54 cm PVC pipes were used both in the suction and delivery sides of the pump. GI nipple (diameter 2.54 cm), 90° PVC elbow (diameter 2.54 cm), curved GI elbow (diameter 2.54 cm), a foot valve (diameter 2.54 cm) and other necessary accessories were also used to complete the suction and delivery pipe arrangement. Photographic views of the pump with the suction and delivery pipe arrangement are shown in Figure 2.

Mercury manometer

Two separate mercury filled manometers were used to measure the heads developed by the pump in the suction and delivery sides. One manometer was used for measuring the suction head. It was connected to the suction pipe at a suitable position with a flexible tube. Another manometer was connected to the delivery pipe, also by a flexible tube, to measure the delivery pressure.

Reserve tank

A large underground water reservoir, available in the hydraulic laboratory, was used as reserve tank (water sump). There was provision for changing the water level of the tank as desired. A calibrated pipe was set in the inner side of the tank to measure the height of water level in different operating conditions.

Discharge measuring cylinder

A bucket was used to collect the discharged water from the pump and a stop watch was used to record the duration of collection. Two measuring cylinders, 1000 and 2000 ml capacity were used to measure the volume of collected water.

Energy meter

An Energy meter (HOSAF BRAND) was used to measure the consumption of electricity in Kilowatt-hour (KWH) of the motor which was directly connected to the pump. Two source side terminals and two load side terminals of the meter were connected to the source line and the motor, respectively. Four hundred and fifty revolutions per KWH is the specification of that energy meter. The wiring with meter and the motor was completed by twin core PVC (2X3/0.036) wire.

Switch board

A switchboard containing 5 ampere (amp) switch and socket was fitted to the wall. The switch was used to turn on or off the motor. The main switch was also used to connect or disconnect the circuit, prepared for operation of motor in case of over load.

Pump operation

The centrifugal pump used for this study was primed before going for operation. Priming was done by filling the pump and the suction pipe with water. Pump was started for operation after ensuring that the joints and connections on the suction pipe were properly sealed. After ensuring the proper arrangement of suction and delivery pipes and desired water level in the reserve tank, the pump was kept on operation. To prevent water entering into the suction manometer, the flexible tube which was connected to the suction manometer was placed above the priming water level and after taking all necessary data; the flexible tube was disconnected from suction pipe before stopping the pump.

Data collection procedure

In this work, in order to study the characteristics of the centrifugal pump, the pump was operated under four different total lifts. These were 2.00, 4.00, 5.50 and 7.40 m. For each of these total lifts, the pump was tested with three or four different combinations of suction and delivery lifts in order to observe the efficiency under varying ratios of delivery to suction lifts. In these tests, suction lifts were varied either by changing the depth of water level or the position of the pump, whereas delivery lifts were varied by varying the length of the vertical delivery pipe. Data on suction and delivery manometer readings, volume of water (milliliters) in the discharge collecting bucket with corresponding time and the input power required to operate the pump were recorded in each test.

The suction and delivery heads were recorded from the mercury manometers and converted to head of water. For the total lifts of 2.00, 4.00 and 5.50 m, data were collected by creating the facilities of changing suction and delivery pipe arrangements inside the laboratory. But for the total lift of 7.40 m, it was not possible to get required delivery and suction lifts inside the laboratory. To overcome this problem, delivery pipe was extended outside the laboratory so that higher delivery lift could be achieved.

The discharge was determined by collecting water directly or indirectly from delivery pipe into a bucket and dividing the volume by the time. The energy meter reading in KWH was recorded. This reading was divided by the corresponding time in hour to get results in KW, which was then converted into hp. All theoretical calculations (total suction and delivery head, total head, pump discharge, water horse power, input horse power, efficiency of the pumping unit) were calculated using mathematical equations as shown in equations Equation 1–9.

Total suction head

Total suction head (H_{st}) is defined as the sum of the suction lift (L_s) and suction loss (h_{fs}). This can be calculated from the pressure head, measured in the suction pipe. Pressure head in the suction pipe (Ps/ω), measured by a manometer at the same level of the pump centre-line, is a negative value. Measured pressure head can be related to L_s, h_{fs} and velocity head ($v^2/2$ g) as:

$$\frac{P_S}{\omega} + \frac{v^2}{2g} = -L_S - h_{fS} = -H_S \tag{1}$$

Where, v is the velocity of flow in the suction pipe (m/sec); L_s is the vertical distance between the pump centerline and water level in m; ω is the unit weight of water in (kg/m^3).

Thus, the suction head loss can be calculated from,

$$h_{fS} = -\frac{P_S}{\omega} - \frac{v^2}{2g} - L_S \tag{2}$$

Total delivery head

Total delivery head (H_d) is defined as the sum of the delivery lift (L_d) and the delivery head loss (h_{fd}) in the delivery pipe. Pressure head (P_d/ω) in the delivery pipe, if measured at the level of the pump centre-line, gives directly the total delivery head. Thus, H_d can be obtained from the measured pressure head as:

$$H_d = L_d + h_{fd} = \frac{P_d}{\omega} \quad (3)$$

Where, L_d represents the vertical distance (m) between the pump centre-line and the level of discharge. Head loss in delivery pipe can be obtained from,

$$h_{fd} = \frac{P_d}{\omega} - L_d \quad (4)$$

In this work, pressure head in the delivery pipe was measured by a manometer at a point, slightly above the centre-line of the pump. This difference was added to the pressure head to get the actual total delivery head.

Total head

Total head or the system head (H) is defined as the sum of the total suction head, total delivery head and the velocity head. Thus,

$$H = H_S + H_d + \frac{v^2}{2g} \quad (5)$$

$$= L_S + h_{fS} + L_d + h_{fd} + \frac{v^2}{2g} \quad \text{[From (1) and (3)]}$$

$$= (L_S + L_d) + (h_{fS} + h_{fd}) + \frac{v^2}{2g}$$

$$= L_T + h_f + \frac{v^2}{2g}$$

= Total lift + total loss + velocity head

Pump discharge

The discharge of a pump is the amount of water pumped per unit time. Discharge is also frequently called capacity or flow rate (Q). The discharge or capacity of the pump is calculated by the following formula:

$$Q = \frac{V}{t} \quad (6)$$

Where, V, volume of water stored in the discharge tank (litre); t, time required to fill that volume (sec).

Water horse power

Water horse power is the theoretical horse power required for pumping. It is the head and capacity of the pump expressed in terms of horse power. The output power or the water horse power is calculated using the following formula:

$$Whp = \frac{H \times Q}{76} \quad (7)$$

Where, Whp, Water horse power; H, total head (meter); Q, discharge (litre/sec).

Input horse power

Shaft horse power is the power required by the pump shaft. Again brake horse power is the actual horse power required to be supplied by the electric motor for driving the pump. With direct driven pump, as is the case in the present study, brake horse power equals the shaft horse power. It was not possible to measure the brake horse power separately in this study. Instead, the input power to the motor was measured by an energy meter. The energy meter gave readings in KWH. Dividing this reading by the operating hour of the pump the result found in KW was converted into input horse power (Ihp) using the following equation:

$$Ihp = \frac{KW}{0.75} \quad (8)$$

Efficiency of the pumping unit

Efficiency is the ratio of the power output to power input. The following formula gives the combined efficiency of the pump and the motor in percentage:

$$Efficiency = \frac{Whp}{Ihp} \times 100 \quad (9)$$

Where, Ihp is the input horse power.

ANALYSIS OF THE OBTAINED PERFORMANCE CHARACTERISTICS

Characteristics of the pump for different lifts

This study was carried out to evaluate the performance characteristics of a centrifugal pump and to compare the results with those observed earlier with a different pump. In order to do so, necessary tests of the pump under different operating conditions were carried out in the

Table 1. Pump efficiency for different delivery and suction lifts against a total lift of 2.00 m.

Delivery lift, L_d (m)	Suction Lift, L_s (m)	Lift ratio, (L_d/L_s) R	Delivery head loss h_{fd} (m)	Suction head loss, h_{fs} (m)	Total head loss, h_f (m)	Total head, H (m)	Water horse power, Whp	Input horse power, Ihp	Discharge, Q (ml/sec)	Efficiency, E (%)
0.50	1.50	0.33	0.063	0.64	0.676	2.75	0.018	0.462	505.4	3.96
1.00	1.00	1.00	0.207	0.60	0.807	2.87	0.020	0.462	541.3	4.42
1.50	0.50	3.00	0.247	0.71	0.984	3.03	0.024	0.458	590.5	5.13

laboratory. In each test, data on discharge, manometer readings and input power were recorded. Pump efficiency, total operating head and suction and delivery head losses were calculated from these data. The selected centrifugal pump was tested for total lifts (suction lift plus delivery lift) of 2.00, 4.00, 5.50 and 7.40 m with different combinations of delivery and suction lifts in order to observe the efficiency under varying ratios of delivery lift to suction lift. For each of these four total lifts, three or four different combinations of delivery and suction lifts were selected.

Table 1 presents the efficiency parameters of the centrifugal pump for the total lift of 2.00 m with various combinations of delivery and suction lifts. The selected combinations of delivery and suction lifts were 0.50 and 1.50 m, 1.00 and 1.00 m and 1 50 and 0.50 m, respectively.

In these tests, suction lifts were varied by changing either the depth of water level or the position of the pump, whereas delivery lifts were varied by varying the length of the delivery pipe. The relative proportions of delivery and suction lifts are represented by the lift ratio R, defined as the ratio of delivery lift to suction lift. Figure 3 shows plots of discharge and efficiency as a function of lift ratio, R.

The results show that, even for the same total lift of 2.00 m, the discharge and efficiency increase with the increase of R values. In these pump settings, discharge ranged from 505.4 to 590.5 ml/sec and efficiency from 3.96 to 5.13%. The maximum discharge of 590.5 ml/sec and efficiency of 5.13% were obtained with the maximum delivery lift of 1.50 m and the corresponding minimum suction lift of 0.50 m (R = 3.00).

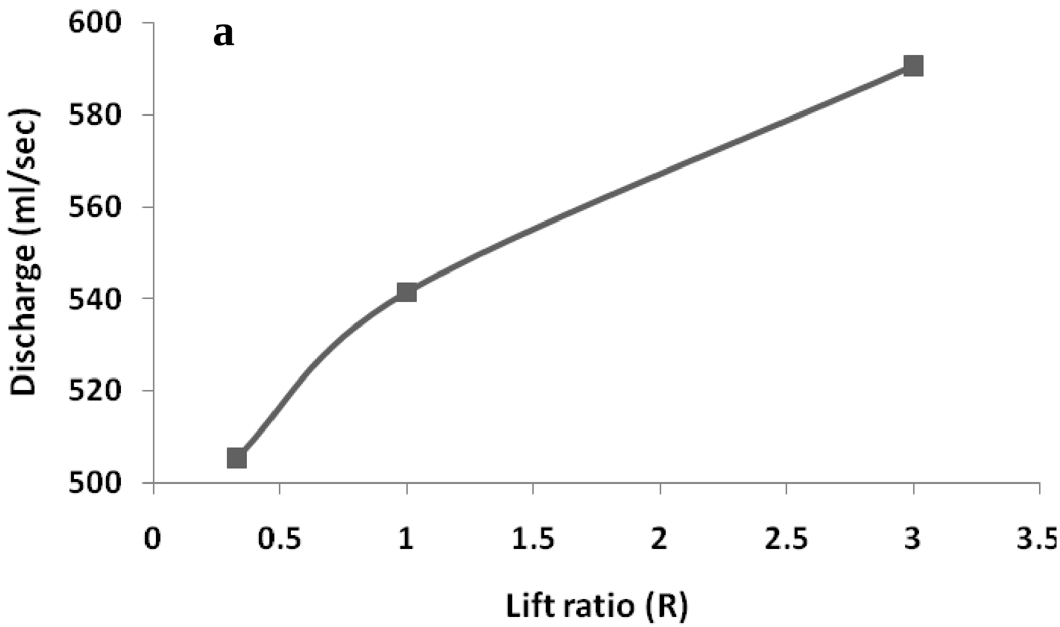
The results indicate that, for the total lift of 2.00 m, an increase of suction lift (with subsequent decrease of delivery lift) causes reductions of pump discharge and efficiency. In other words, the discharge and efficiency are directly proportional to the lift ratio R. These results are in agreement with those reported by Mahmud (2008). The water horse power (Whp) in these tests increases with the increase of lift ratio, but the Ihp does not show any clear trend with R values. The Ihp increases from 0.458 to 0.461 within the tested range of R, but the changes are not consistent. The results also show that, the h_{fd} increases with the increase of L_d. It was probably so, because the delivery lift was increased by increasing the length of the delivery pipe which contributed to an increase of frictional loss. Moreover, increased discharge with the increase of delivery lift also caused the frictional loss to increase. The h_{fs} decreases with the increase of suction lift (L_s), but not consistently. Total head loss (h_f), which is the sum of the delivery and suction head losses, consistently increases with the increase of R. Total head (H) also increases with the increase of R.

The test combinations of 2.90 and 1.00 m, 2.25 and 1.71 m and 1.81 and 2.25 m, respectively were designed to evaluate the pump efficiency for a total lift of 4.0 m which could not be exactly maintained during the work are presented in Table 2. The total lift varied around a value of 4.0 m.

The results show that, the discharge increases but efficiency decreases with the increase of lift ratio (Figure 4). Discharge in these tests follows similar trend as observed for the total lift of 2.0 m. However, the efficiency shows a different trend. Ihp in these combinations increases with the increase of R. This has contributed to reducing the pump efficiency with the increase of lift ratio. The discharge range from 535.7 to 546.6 ml/sec and the maximum discharge of 546.6 ml/sec is obtained with maximum delivery lift of 2.90 m and minimum suction lift of 1.00 m. The efficiency varied from 7.52 to 8.50%, the highest (8.50%) being obtained at the minimum lift ratio of 0.80, in which the suction lift was 2.25 m. The results showed that Whp decreased with the increase of R value. Whp is a product of discharge (Q), H and a constant. Discharge increased and total head decreased with the increase of R, for these settings of pump. The rate of decrease of total head was higher than the rate of increase of discharge. This resulted in overall decrease of Whp with the increase of R. The h_{fd} and h_{fs} did not follow any clear trend with R values in these tests.

Efficiency parameter values of the pump for a total lift of 5.50 m, with various combinations of delivery and suction lifts were 4.00 and 1.50 m, 3.25 and 2.25 m, 2.50 and 3.00 m and 1.75 and 3.75 m, respectively are presented in Table 3.

The results showed that, the discharge sharply decreases with the increase of lift ratio up to a value of R equal to 0.83. The minimum discharge at that point was 501.8 ml/sec. Beyond this point, the discharge again gradually increases with the increase of R (Figure 5).



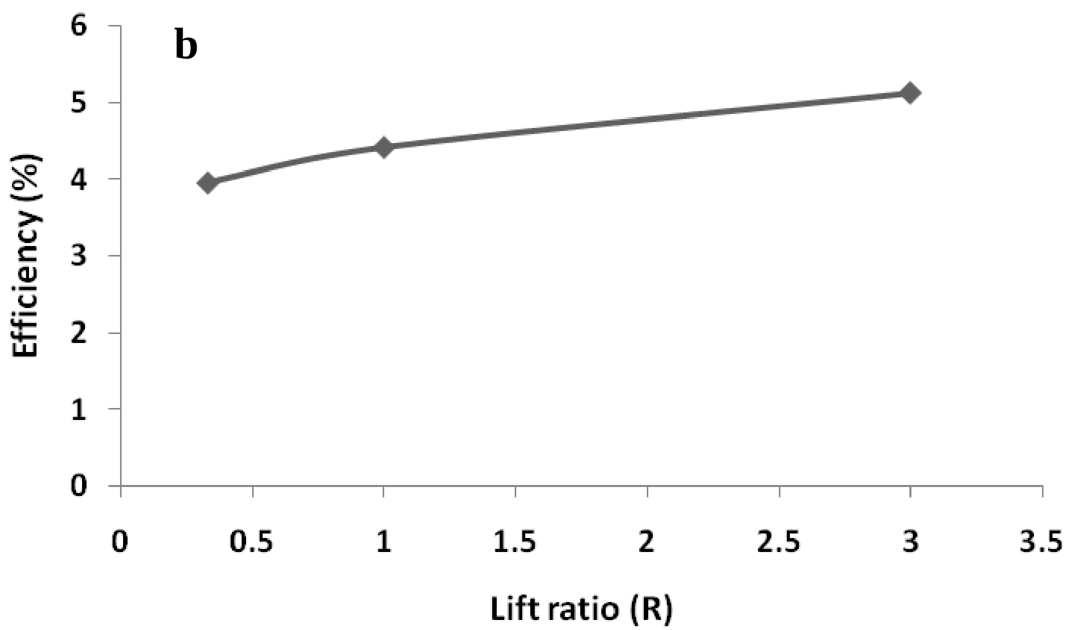


Figure 3. Pump characteristic diagrams for different lift ratios for the total lift of 2.00 m. a, Discharge versus lift ratio; b, efficiency versus lift ratio.

Table 2. Pump efficiency for different delivery and suction lifts against a total lift of 4.00 m.

Delivery lift, L_d (m)	Suction lift, L_s (m)	Lift ratio, (L_d/L_s) R	Delivery head loss, h_{fd} (m)	Suction head loss, h_{fs} (m)	Total head loss, h_f (m)	Total head, H (m)	Water horse power, Whp	Input horse power, Ihp	Discharge, Q (ml/sec)	Efficiency, E (%)
1.81	2.25	0.80	0.188	0.83	1.0178	5.14	0.0362	0.426	535.7	8.50
2.25	1.71	1.32	0.009	0.91	0.9187	4.94	0.0350	0.440	538.5	7.95
2.90	1.00	2.90	0.072	0.73	0.802	4.76	0.0342	0.455	546.6	7.52

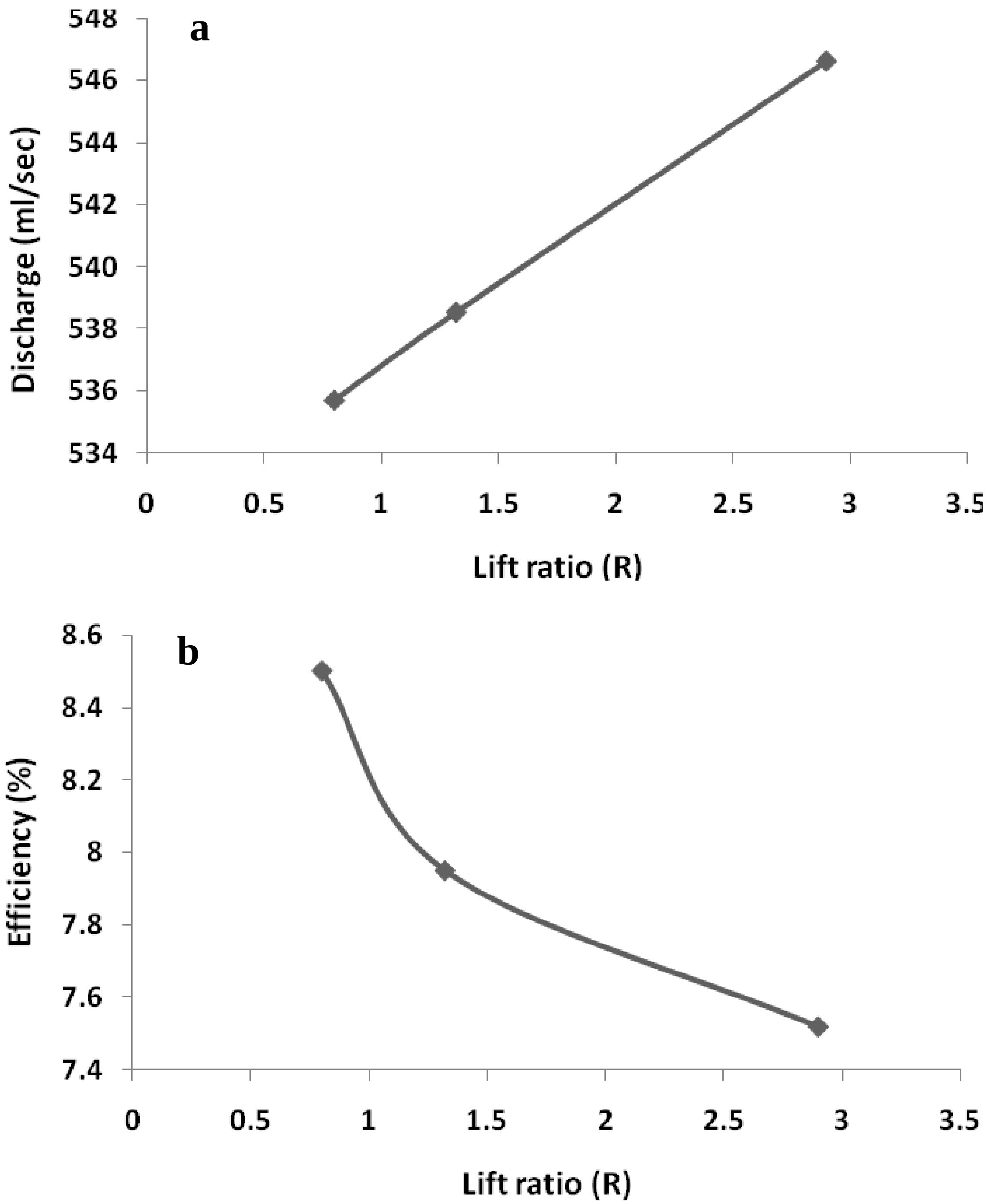


Figure 4. Pump characteristic diagrams for different ratios for the total lift of 4.00 m. a, Discharge versus lift ratio; b, efficiency versus lift ratio.

Table 3. Pump efficiency for different delivery and suction lifts against a total lift of 5.50 m.

Delivery lift, L_d (m)	Suction Lift, L_s (m)	Lift ratio, (L_d/L_s) R	Delivery head loss, h_{fd} (m)	Suction head loss, h_{fs} (m)	Total head loss, bh_{fb} (m)	Total head, H (m)	Water horse power, Whp	Input horse power, Ihp	Discharge Q, (ml/sec)	Efficiency E, (%)
1.75	3.75	0.47	0.103	0.66	0.763	6.31	0.044	0.445	525.2	9.81
2.50	3.00	0.83	0.1002	0.74	0.8402	6.39	0.042	0.435	501.8	9.72
3.25	2.25	1.44	0.0946	0.91	1.0046	6.55	0.044	0.424	511.0	10.39
4.00	1.50	2.67	0.1648	0.58	0.7448	6.30	0.043	0.435	514.9	9.82

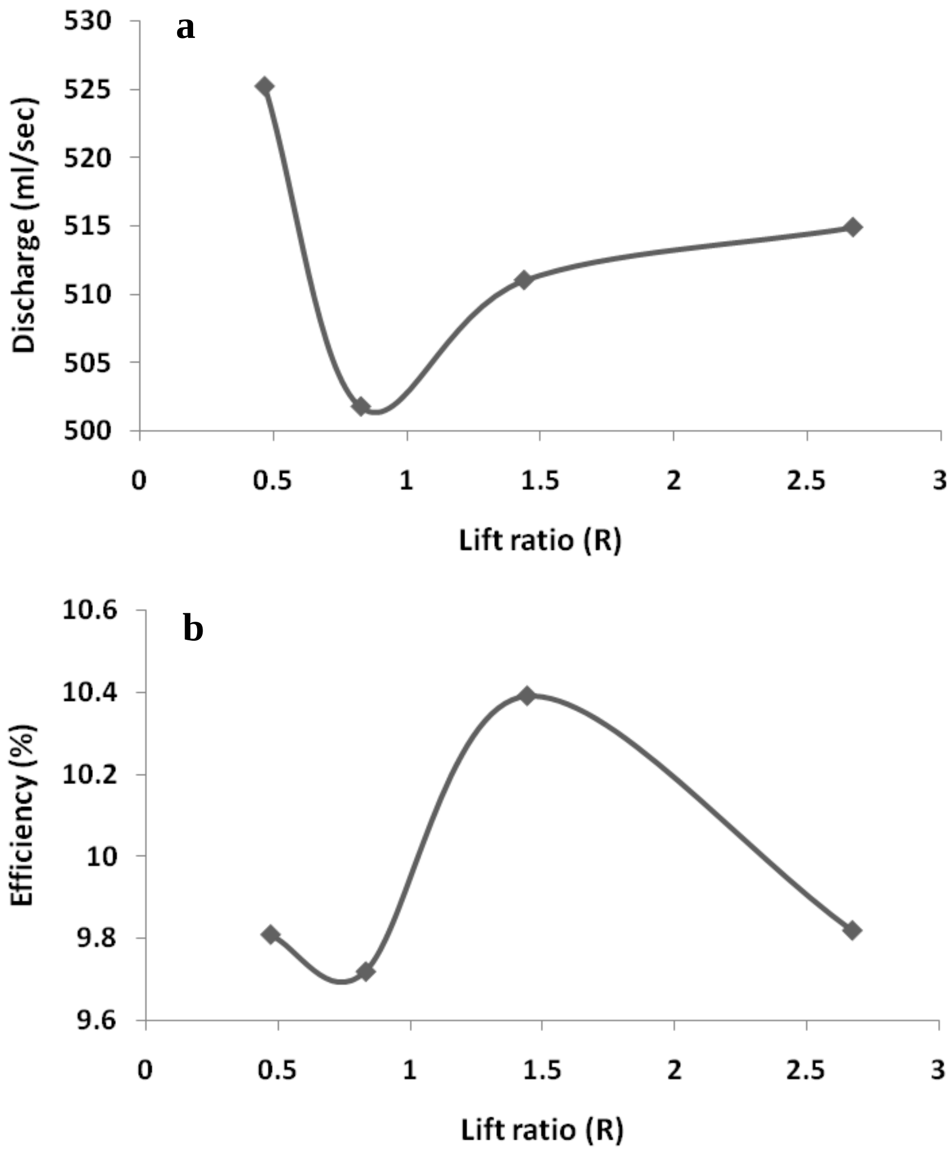
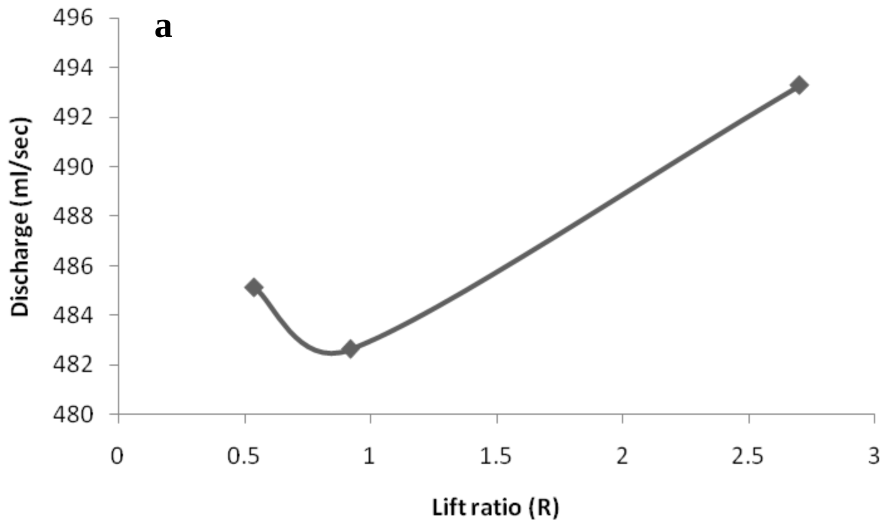


Figure 5. Pump characteristic diagrams for different lift ratios for the total lift of 5.50 m. a, Discharge versus lift ratio; b, efficiency versus lift ratio.

However, the maximum discharge of 525.2 ml/sec was obtained at the R value of 0.47 with corresponding delivery and suction lifts of 1.75 and 3.75 m, respectively. Pump efficiency did not follow any clear trend with R for this total lift of 5.50 m. Pump efficiency also initially decreased with the increase of R and attained the lowest value (9.72%) at an R value of 0.83. Thereafter, it increased to a peak of 10.39% at R equal to 1.44 and then decreased again with the increase of R. This indicates that, the pump operates at the highest efficiency when the suction and delivery lifts are 2.25 and 3.25 m, respectively.

These efficiency behaviors are different from those observed for total lifts of 2.00 and 4.00 m which also not in agreement with those reported (Mahmud, 2008). The results show that, the h_{fd} gradually decreases with the increase of lift ratio except for the maximum lift ratio of 2.67 at which the head loss is 0.165 m. The h_{fs} increases with the increase of R, except that (0.58 m) obtained at an R value of 2.67. The H also gradually increases with the increase of R except at the maximum R value of 2.67. The Ihp decreased with the increase of lift ratio, except at the maximum R value of 2.67. The Whp did not show any clear trend with the variations of delivery and suction lift ratio.

Table 4 presents the efficiency parameter values of the



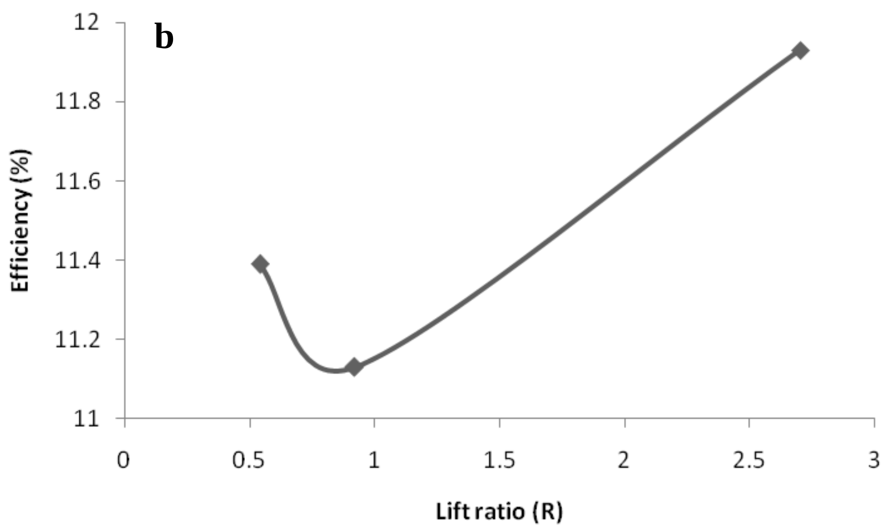


Figure 6. Pump characteristic diagrams for different lift ratios for the total lift of 7.40 m. a, Discharge versus lift ratio; b, efficiency versus lift ratio.

Table 4. Pump efficiencys for different delivery and suction lifts against a total lift of 7.40 m.

Delivery lift, L_d (m)	Suction Lift, L_s (m)	Lift ratio, (L_d/L_s) R	Delivery head loss, h_{fd} (m)	Suction head loss, h_{fs} (m)	Total head loss, h_f, (m)	Total head, H (m)	Water horse power, Whp	Input horse power, Ihp	Discharge, Q (ml/sec)	Efficiency, E (%)
2.60	4.80	0.54	0.162	0.54	0.702	8.15	0.052	0.457	485.1	11.39
3.55	3.85	0.92	0.208	0.64	0.848	8.29	0.053	0.473	482.3	11.13
5.40	2.00	2.70	0.282	0.56	0.842	8.27	0.054	0.450	493.2	11.93

pump against a total lift of 7.40 m with the delivery and suction lift combinations of 5.40 and 2.00 m, 3.55 and 3.85 m and 2.60 and 4.80 m, respectively.

Figure 6 shows both the discharge and efficiency of the pump initially decrease and then increase with the increase of R values. Lowest values of discharge and efficiency are obtained at an R value close to 0.92. Maximum discharge of 493.2 ml/sec and the highest efficiency of 11.93% were obtained at the lift ratio of 2.70. This shows that, the pump operates at the highest

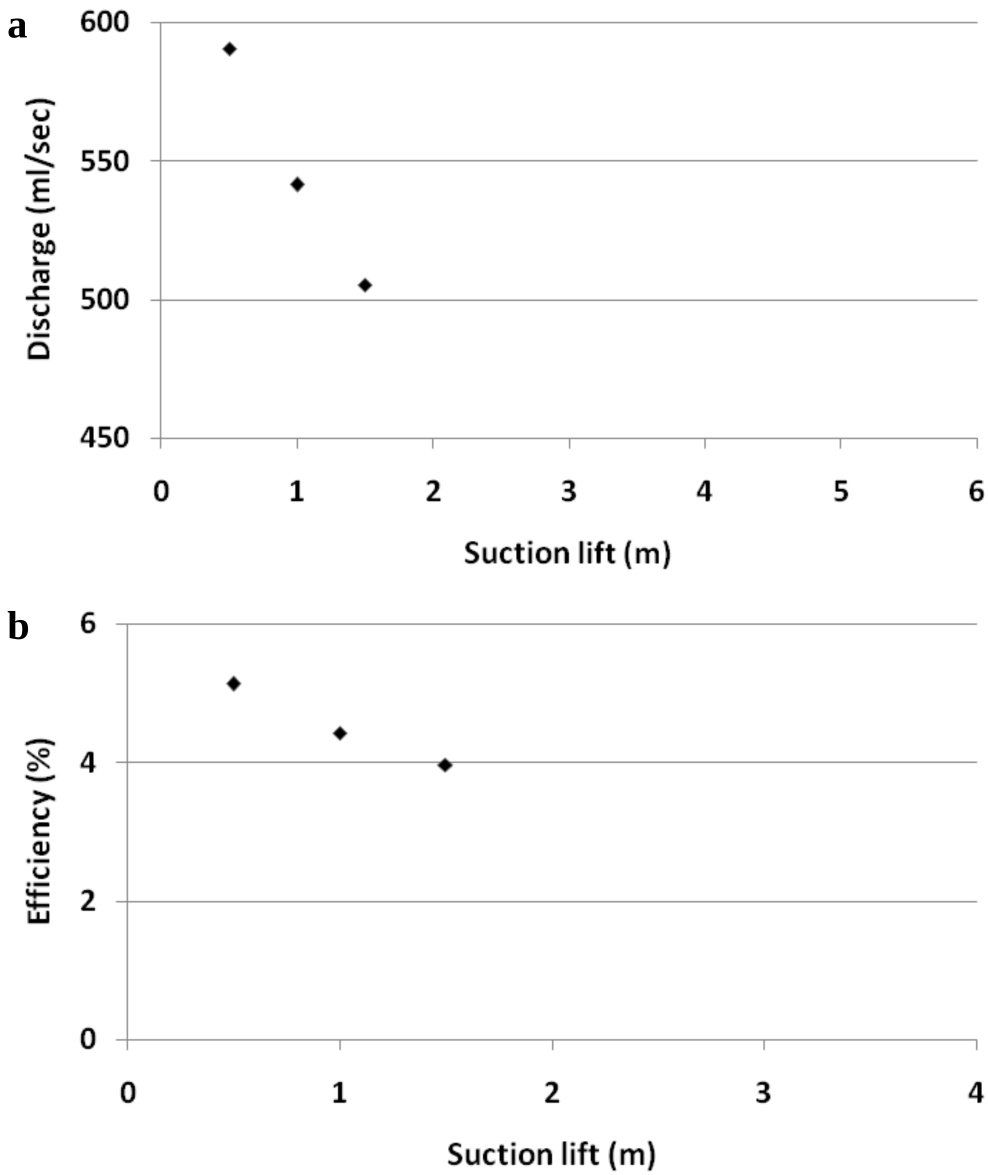


Figure 7. Pump performances for different suction lifts for the total lift of 2.00 m. a, Suction versus discharge; b, suction versus efficiency.

efficiency (11.93%) when the suction lift is equal to 2.00 m (R = 2.70) for the total lift of 7.40 m. The behavioral patterns of these efficiencies are different from those observed by Mahmud (2008). The h_{fd} continuously increased with the increase of R. However, the h_{fs}, h_f and H did not show any clear trend. In these pump settings, Whp gradually increased with the increase of lift ratio. However, the input horse power did not show any clear trend with the change of R.

The h_{fd} continuously increased with the increase of R. However, the h_{fs}, h_f and H did not show any clear trend. In these pump settings, Whp gradually increased with the increase of lift ratio. However, the input horse power did not show any clear trend with the change of R.

Pump characteristics for different suction lifts

Figure 7 presents plots of discharge and efficiency for different suction lifts for the total lift of 2.00 m. Similar diagrams are also plotted for each of the total lifts of 4.00, 5.50 and 7.40 m in Figures 8, 9 and 10, respectively. The figures show that, for the total lift of 2.00 m, both the discharge decrease and efficiency with the increase of

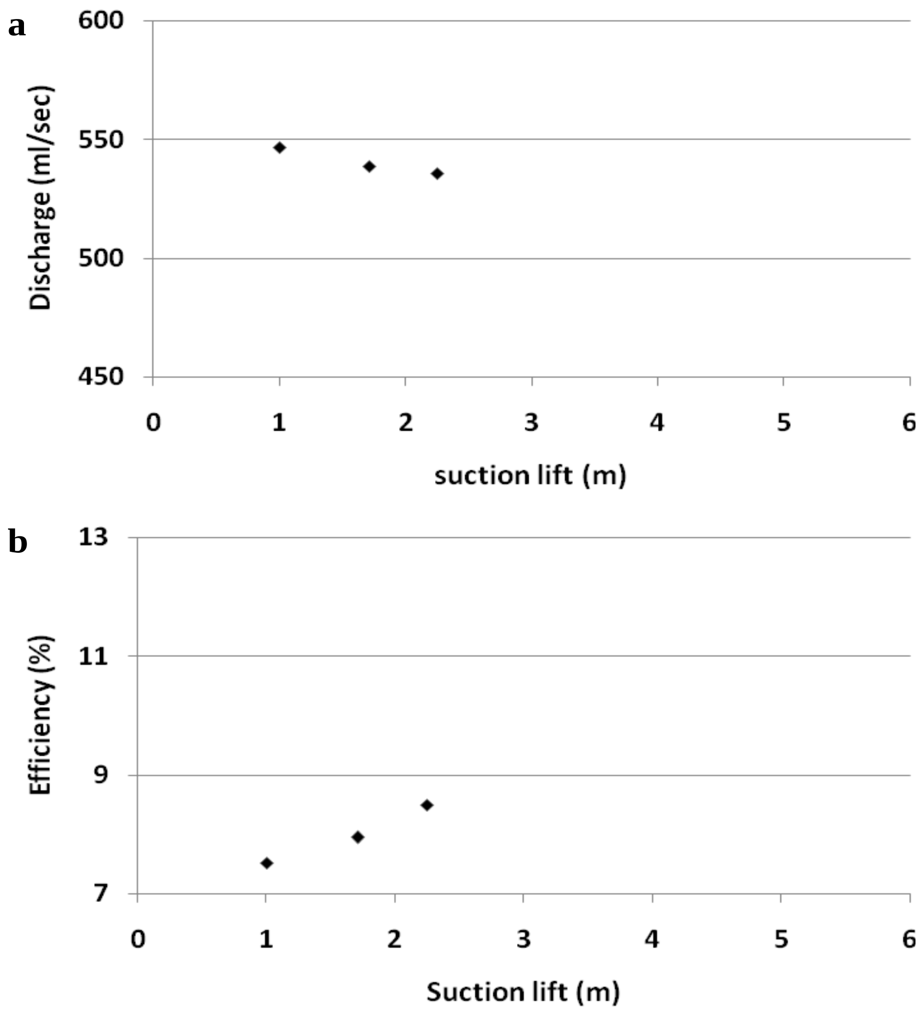


Figure 8. Pump performances for different suction lifts for the total lift of 4.00 m. a, suction versus discharge; b, suction versus efficiency.

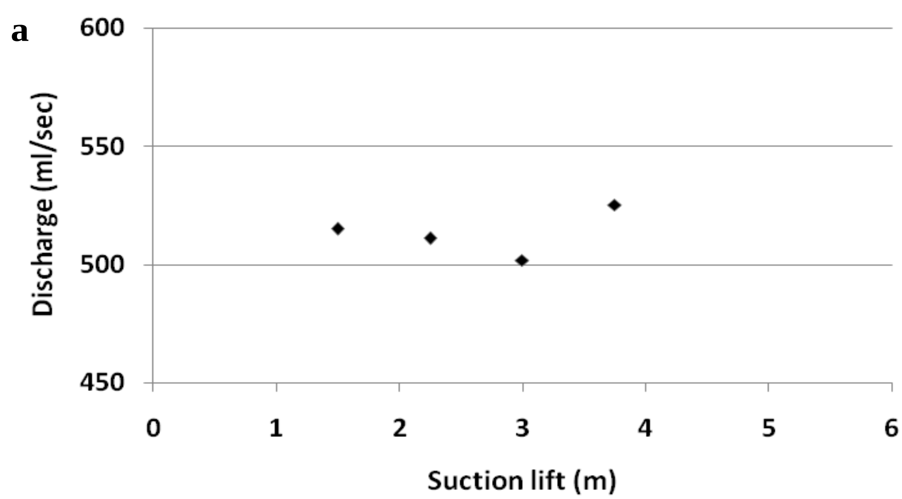


Figure 9. Pump performances for different suction lifts for the total lift of 5.50 m. a, suction versus discharge; b, suction versus efficiency.

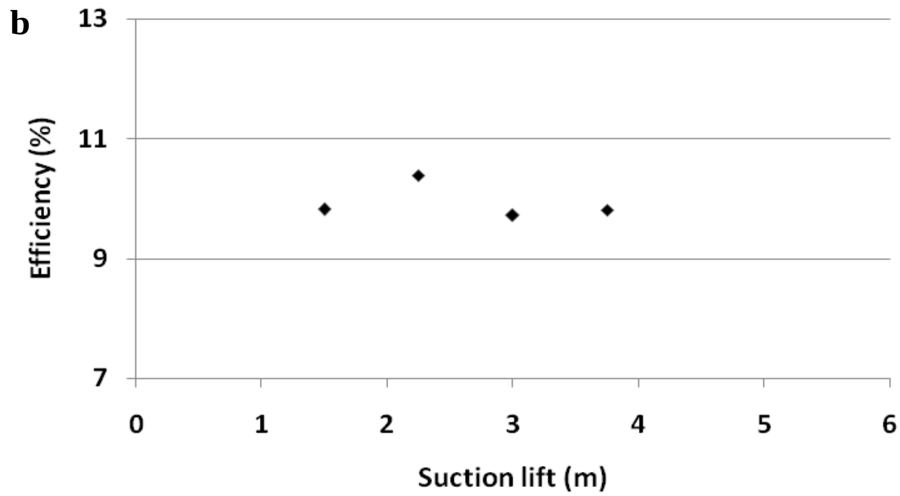


Figure 9. Contd.

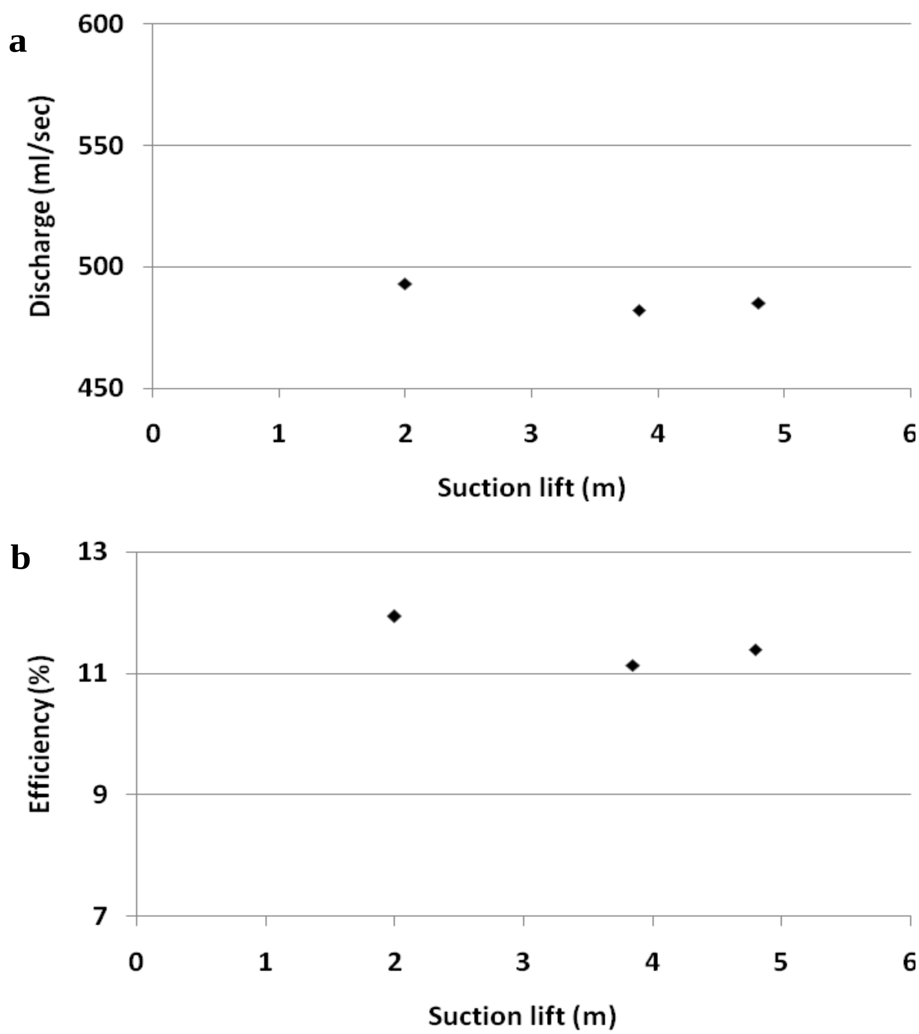


Figure 10. Pump performances for different suction lifts for the total lift of 7.40 m. a, suction versus discharge; b, suction versus efficiency.

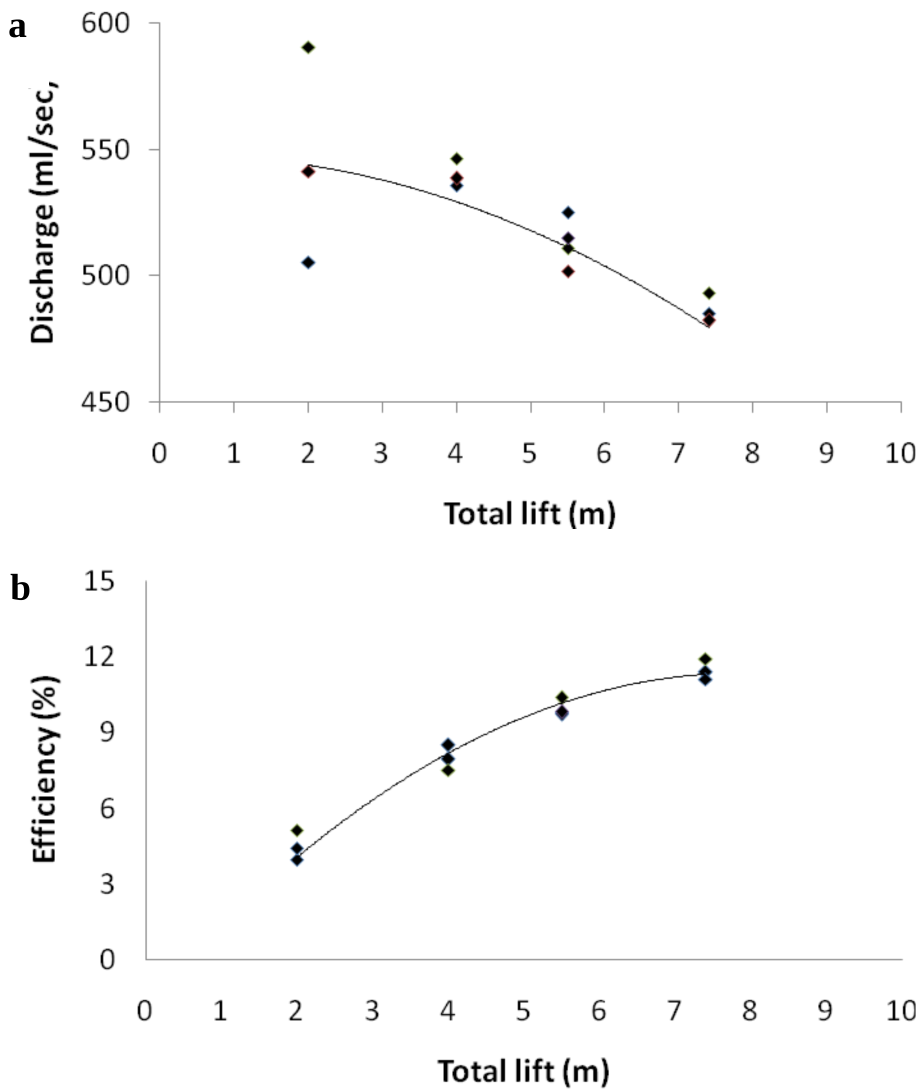


Figure 11. Pump performance against total lift. a, Total lift versus discharge; b, total lift versus efficiency.

suction lift. However, for the higher total lifts (4.00, 5.50 and 7.40 m) the maximum pump efficiency is obtained when the suction lift is at or around 2.00 m. This suggests that the pump operates more efficiently when the suction lift is at about 2.00 m, irrespective of delivery lift. No such pattern of behavior is evident with respect to discharge.

Pump characteristics for total lifts

Efficiency and discharge are plotted against total lifts (Figure 11). Trend lines fitted through the points show that the efficiency increases and discharge decreases, in general, with the increase of total lift. The scatter of the points of efficiency and discharge for a given total lift are due to variable values of R, as discussed earlier. The result also shows that, variations of discharge due to variable R values are more prominent for a low lift than the higher lifts.

Pump characteristics for lift ratio of 1.0

Table 5 presents efficiency characteristics of the pump for a constant lift ratio of 1.0 for different total lifts, ranging from 2.00 to 7.40 m. The discharge and efficiency varied from 590.5 to 483.1 ml/sec and 4.42 to 11.17% respectively due to suction lift at 1.0 m with respect to the pump speed.

Figure 12 presents plots of discharge and efficiency of

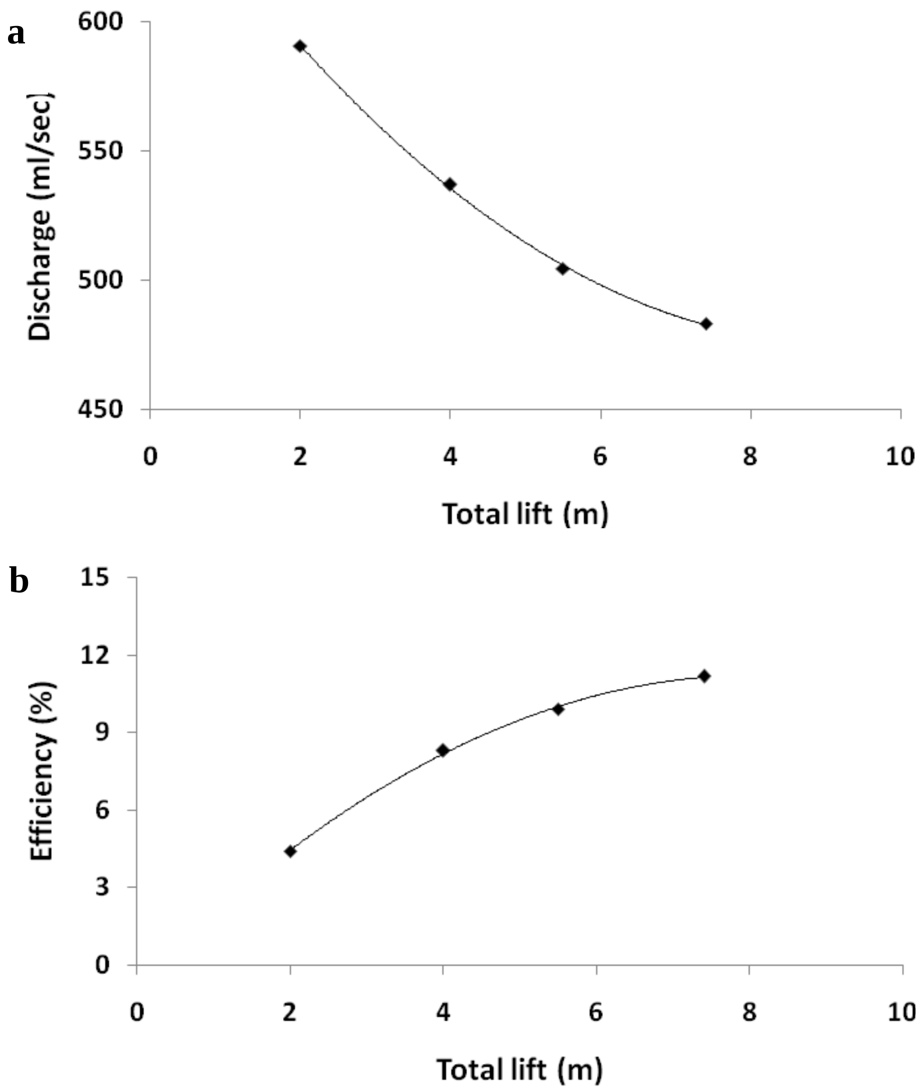


Figure 12. Pump characteristic diagrams under different total lifts for fixed lift ratio of 1.0. a, discharge versus total lift; b, efficiency versus total lift.

Table 5. Efficiency of the pump at the lift ratio of 1.0.

Total lift, L (m)	Total head, H (m)	Total head loss, h_f (m)	Discharge, Q (ml/sec)	Efficiency, E, (%)
2.00	2.87	0.87	590.5	4.42
4.00	5.06	0.98	536.8	8.29
5.50	6.43	0.89	504.4	9.90
7.40	8.29	0.85	483.1	11.17

the pump as a function of total lift. The result shows that the discharge gradually decreases and the efficiency increases with the increase of total lift. Generally, the discharge of a pump decreases monotonically with the increase of lift. Its efficiency increases with the increase of lift up to a certain peak value and then decreases with further increase of lift. It can be seen in this study only an increasing trend of efficiency with the increase of lift. This was so, because the test could not be continued for higher lifts (greater than 7.4 m) for which the highest possible efficiency could be achieved. This was not possible due to physical limitations in the laboratory.

Conclusion

Performance evaluation of a centrifugal pump varies under different operating conditions successfully investigated. In this work, a half hp motor driven centrifugal pump was tested in laboratory against various lifts to know the efficiency characteristics of the pump. For a given total lift, delivery to suction lift ratio affects the pump efficiencies and the total lift of 2.00 m, both the efficiency and discharge decrease with the increase of suction lift. However, these trends are not consistently observed for higher lifts. At total lifts of 4.00, 5.50 and 7.40 m, the pump operates at the maximum efficiency obtained when the suction lift is set at or around 2.00 m, irrespective of delivery lift. In these tests, the highest total lift was taken only up to 7.40 m. Further studies should be done for total lifts greater than this.

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