PERFORMANCE OF MULTI-LAYERS COIL PUMP

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ABSTRACT

The present experimental study is concerned with the design and testing of multi-layers coil pump to obtain the pump performance under different design parameters. These include method of winding the hose around the drum in multi-layers, inlet and outlet position, hose inner diameter, drum diameter. For this purpose, a coil pump was designed, constructed and tested. The experimental results showed that the three layers coil pump has better performance than single and two layer pumps. In addition, improved pump performance is obtained when the pump inlet placed at the top end in the case of multi-layer pumps. Moreover, increase the coil hose inner diameter and/or drum outer diameter results in better coil pump performance.

INTRODUCTION

Coil pump is considered one of the non-conventional water pumping devices which, in practical situations, use non-conventional energy sources. The driving power for this partially immersed pump is provided by flowing water streams, creeks or rivers.

Hoffman (2002) reviewed the history of coil pump pointing out the significant contributions through the years. A very old idea for a simple pump was invented by Archimedes (287 BC-212 or 211 BC) had a name "Archimedes Snail Pump" which is at least 2,000 years old. In the book entitled "Cyclopedia of Science and Arts", Reese (1819) described a similar idea for this simple pump invented by Andrew Wirtz in 1746. The coil in his invention was connected to the rigid tube, which serves both as a drive shaft and as a discharge tube. When the pump was rotated, water was raised to a much higher level, significantly above the point where the Archimedean Snail pump discharged. This pump can also be configured to run in a horizontal position with the discharge pipe rising vertically. In this case a separate means is provided to turn the pump and a rotary seal is used so that the discharge pipe can remain stationary as the coil rotates.

In the literature there are few theoretical and experimental studies related to the coil pump [Kulasinghe (1994), Blelcher (1996), and Weir (2001)]. A simple laboratory pump developed by Mortimer and Annable (1984). A theory was produced which satisfactorily predicts the behavior of the coil pump. A low cost stream powered version of the pump was built and successfully tested in a local stream. The pump operated with a stream velocity as low as 0.40 m/s, but a reduced performance was obtained. Recently, detailed review of the previous work related to the coil pump was given by Abdel-Basier (2005) and Kassab et al. (2005) and there is no need to repeat it again.

Kassab et al. (2005) studied the performance of a single layer coil pump under variable operating parameters. These parameters were the pump rotational speed, the submerged ratio, and the number of coils. In addition, Kassab et al. compared their experimental results with theoretical results obtained by other investigators and found good agreement.

From the previous review, it is clear that there is nothing in the literature related to the multi-layer coil pump. Moreover, there are many other important parameters which are believed to have effects on the coil pump performance. Consequently, the aims of the present study are the design of multi-layers coil pump as well as determining its performance under variable design conditions. Therefore, the following parameters are considered:

- Using Multi-layer of coiled hose.
- Inlet and outlet positions of multi-layer pump.
- Hose inner diameter.
- Drum diameter.

EXPERIMENTAL SETUP AND PROCEDURE

The experimental setup used in the present study is schematically shown in Fig. 1. This experimental setup is designed and constructed to study the performance of the coil pump under various design conditions. It consists of a flexible hose (14) wrapped around a P.V.C cylindrical drum (11). The drum is partially submerged into a water tank (13). The submergence ratio is controlled to be constant by the float control valve (9). One end of the wound flexible hose is open and come in contact with water when rotating, forming the pump inlet. The other end of the hose is connected to a steel hollow shaft (6) forming the axis of rotation of the drum. The outlet of the coil (water and air) passes through nonreturn valve (17) and Tee connector (18) to the rotating central hollow shaft.

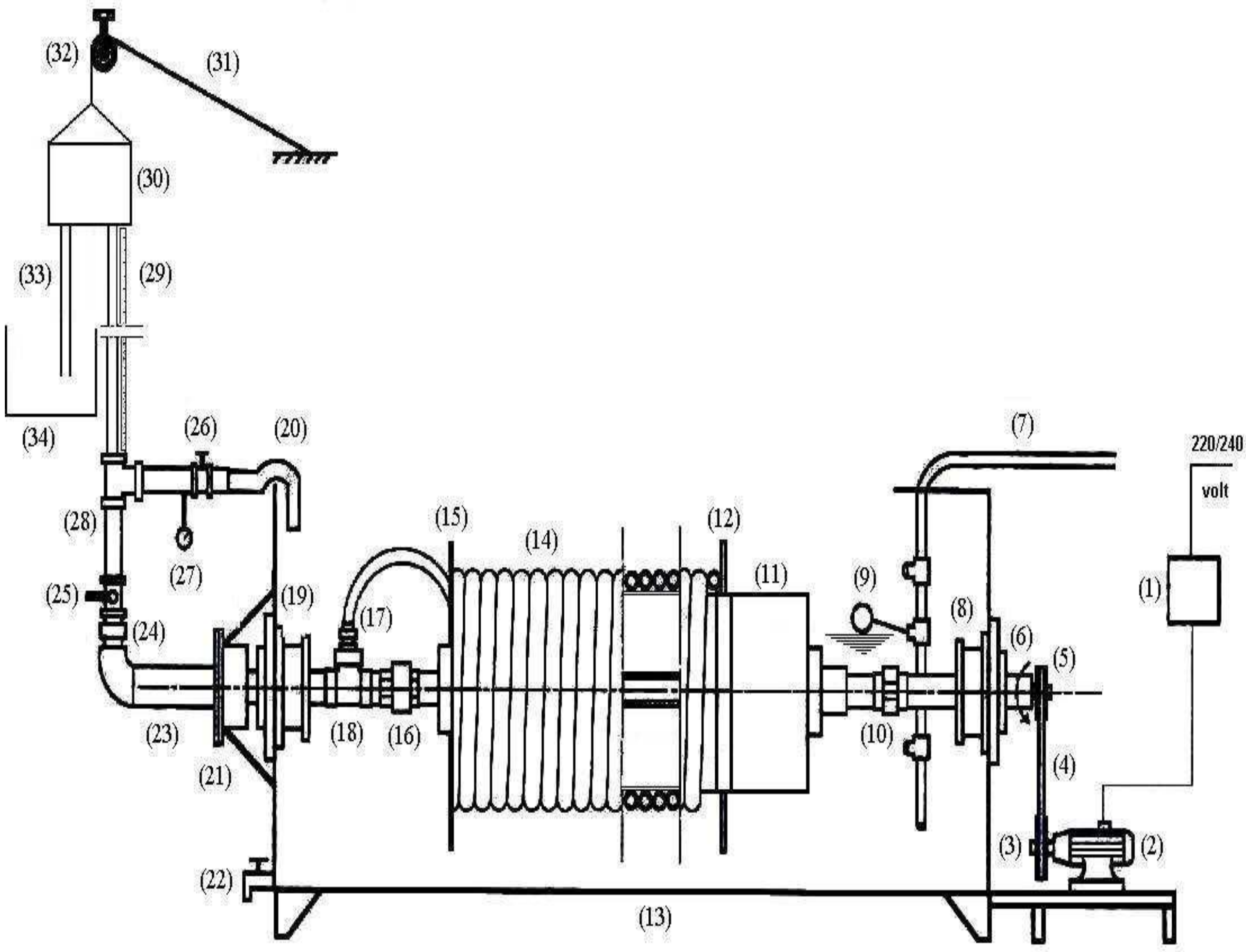


Figure 1 Schematic drawing of the experimental setup

(1): Frequency converter.
(2): A.C. geared motor.
(3): Pulley of motor shaft.
(4): V-belt.
(5): Pulley of pump shaft.
(6): Rotating hollow shaft.
(7): Water supply.
(8): Bearing and packing housing.
(9): Float control valve.
(10): Quick coupling.
(11): PVC drum.
(12): PVC movable screen.
(13): Water tank.
(14): Flexible hose.
(15): Steel fixed screen.
(16): Non-return valve.
(17): Non-return valve.
(18): Tee-connector.
(19): Bearing and packing housing.
(20): By-pass pipe.
(21): Rotary joint.
(22): Manual drain valve.
(23): Fixed hollow pipe.
(24): Non-return valve.
(25): Manual valve.
(26): Manual valve.
(27): Pressure gauge.
(28): vertical delivery pipe.
(29): Scale.
(30): Collecting tank.
(31): Rope.
(32): Single-fixed pulley.
(33): Final delivery pipe.
(34): Measuring tank.

The hollow shaft is divided into four sections, as schematically shown in Fig. 2.a, for easy mounting and dismounting of the drum, and to allow studying the effect of changing the type and size of the drum on the pump performance. The first section is connected to the pump drive of a geared A.C. motor (8). The rotational speed of the motor is regulated through a variable frequency converter (1). In this way, it was possible to simulate the real situation of using the coil pump at different currents or water stream velocities. The rotational power is transmitted from the geared motor to the pump through the V-belt (4) and two pulleys; one of them is on the pump shaft (5) and the other is on the geared motor shaft (3). The other end of the first section of the hollow shaft is joined with the second section by a quick-disconnect coupling (10). The second section is fixed with the drum by two flanges; one of them is welded with the shaft and fixed to the drum by bolts and the other is fixed with the drum by bolts and has a hub which is fixed with the hollow shaft by a set of radially three stop screws for ease of disconnecting the drum. The coil on the drum is bounded by two screens; one of them is a steel fixed screen (15) and the other is a movable PVC screen (14). The second screen is easy to be slide on the drum to allow studying the effect of increasing and decreasing the number of layers and coil-turns of the flexible hose wound on the drum and to allow the change of winding length.

The third section is joined with the second section by a nonreturn valve (16) and with the fourth section by the Tee connector. The second end of the fourth section of the shaft is passed through a designed rotary joint (21), which is shown in details in Fig. 2.b. The stationary part of the rotary joint is connected to a vertical flexible delivery pipe (28) which is connected to an aluminum cylindrical collecting tank (30), hung by a single-fixed pulley (32).

The shaft is supported by two symmetrically designed bearings and packing housing supports (8) and (19) shown in details in Fig. 2.c. The supports have two flanges fixed with the tank walls. The outlet of the rotating hollow shaft (6) passes through a fixed hollow pipe (23) connected to a nonreturn valve (24) and a manual valve (25) to a vertical delivery pipe (28). Water is collected in the collecting tank (29) then delivered to a calibrated plexi-glass collecting tank (34). A calibrated pressure gauge (27) is placed on the delivery pipe. A by-pass pipe (20) is connected to the delivery pipe and controlled by the manual valve (26). Vertical delivery pipes (28) of different lengths and heights from the pump center line are used to allow collecting water at different heights. Water is drained from the main water tank (13) through a manual drain valve (22) which is fixed at the tank bottom side.

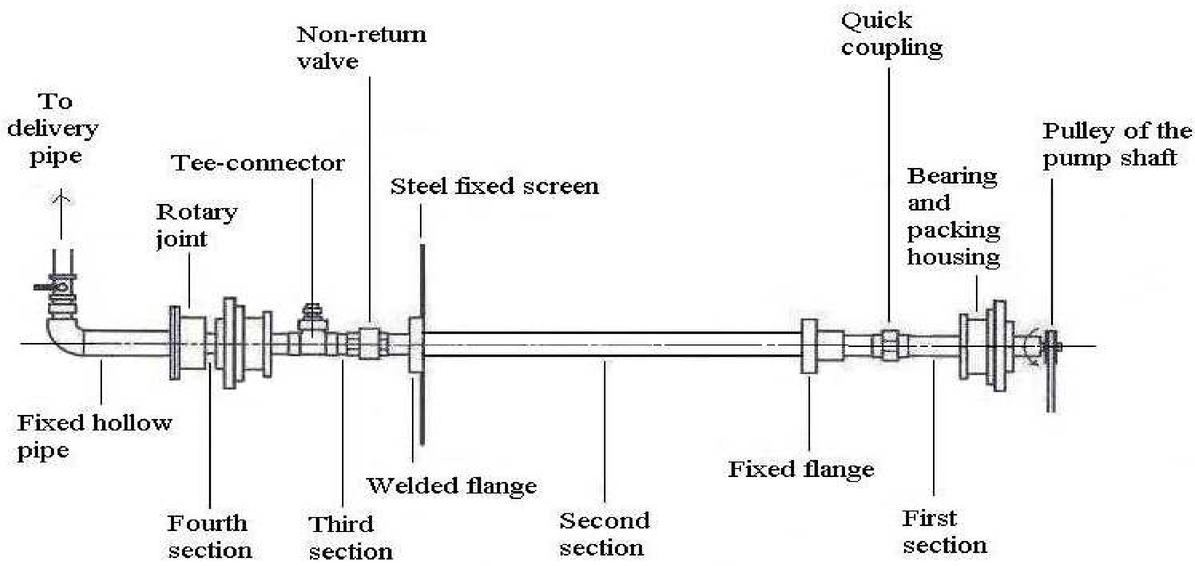


Figure 2.a Schematic drawing of the pump hollow shaft and its connections

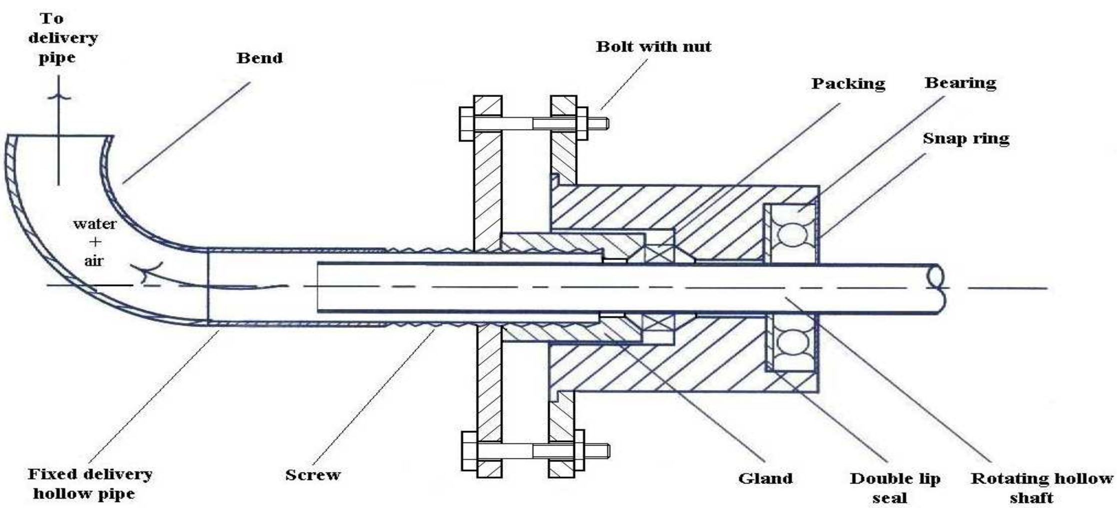


Figure 2.b Details of the rotary joint

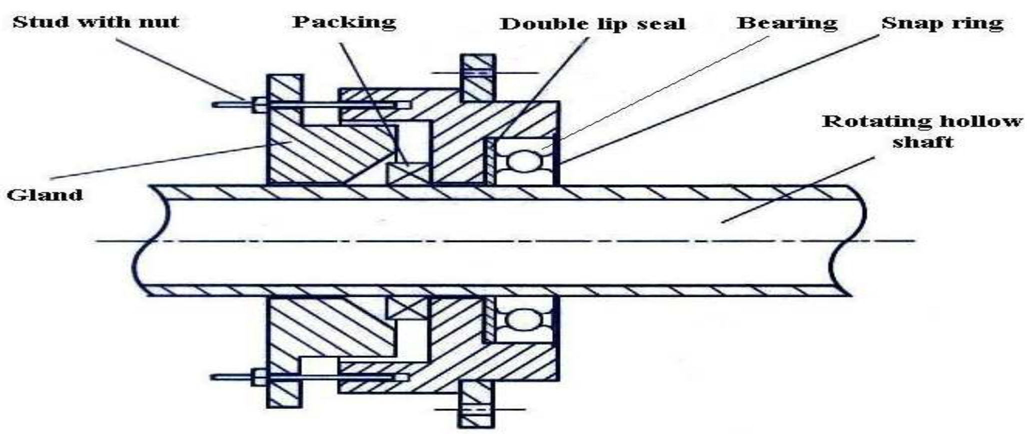


Figure 2.c Details of the bearing and packing housing

In order to investigate the coil pump performance under the variation of different parameters, series of experiments were carried out. Experiments are planed as follows:

1- One layer of 29.5 coil-turns of flexible hose of inner diameter 19 mm (3/4 in) wrapped uniformly around a cylindrical drum of outer diameter 204 mm (8 in) and 750 mm length for winding is used for the case of one layer study.

2- Reforming the single layer of 29.5 turns, at the same conditions as above, into two layers (lower: first layer of 14 turns, upper: second layer of 13 turns). The drum length for winding is 340 mm. Then, transforming it to three layers (lower: first layer of 9 turns, intermediate: second layer of 8.5 turns, upper: third layer of 8 turns). The drum length for winding is 220 mm, as shown in Fig.3.a, to study the effect of forming multi-layers of the coiled hose on the pump performance (head and flow rate) without changing the hose length.

3- Changing the inlet and outlet positions of the previous two and three layers of the pump, as shown in Fig.3.b, to investigate the effect of these positions on the pump performance. So, the effect of changing the pump inlet position from the upper, second or third, layer to the lower first layer could be investigated.

4- Flexible hose inner diameter is changed (1/2, 3/4, 1 and 1 1/2 inch) to estimate the effect of changing of the inner diameter of the wound hose on pump performance.

5- Drum outer diameter is changed (8, 10, 12 and 16 inch), to investigate the effects of the drum size on the pump performance.

RESULTS AND DISCUSSION

1. Effect of the number of coil layers on pump performance

The effect of the submergence ratio on a single layer coil pump performance was established by Kassab et al. (2005). In the present study, all the experimental work is done with the optimum submergence ratio 50% obtained by Kassab et al. (2005). The whole length of hose used in studying the performance of one layer coil pump is reformed into two layers and three layers, Fig. 3.a. The pump inlet for the two cases of two and three layers was made through the upper layer and the coiled hose outlet to the central hollow pipe was fixed at the lower first layer.

Figure 4 shows that, the flow rate of the pump in the case of two layers is higher than the flow rate in the case of one layer. Also, the flow rate in the case of three layers is higher than that of two layers pump at all rotational speeds. Meanwhile, Fig. 5 shows the performance curves for one, two and three layer pump at constant rotational speed (N = 29.8 rpm) and submergence ratio of 50%. The curves shift upward when the number of layers increases results in an improvement in the coil pump performance.

Figures 4 and 5 show that, when using multi-layers instead of single layer, both pump flow rate and static head increase. This may be due to the position of the coil inlet at outer layer, i.e. the inlet at a larger diameter which gives the chance for more air and water to discharge to the pump and improves the pumping action and consequently increases the pump discharge and the pump head.

More details for the pump performance curves were obtained for one, two and three layers for the same submergence ratio and different rotational speeds and presented in Fig. 6. The same trend was obtained as explained before, Fig. 5, and the three layers pump has the best performance at all values of rotational speed.

2. Effect of changing the inlet and outlet positions

The previous study for the effect of the transformation of one layer pump to both two and three layers pump was studied when the pump inlet through the upper second layer for two layers and through the upper third layer for three layers while the pump outlet was from the lower first layer for both cases. In order to investigate the effect on the pump performance when exchanging the pump inlet and outlet positions for the multi layers pumps, the inlet and outlet positions were reversed, Fig. 3.b. The pump inlet for two and three layers were made through the lower first layer and the outlet from the upper second layer for the case of two layers pump and from the upper third layer for the case of three layers pump. These new two cases of two and three layers were tested in a series of experiments at the same conditions of submergence ratio and rotational speeds.

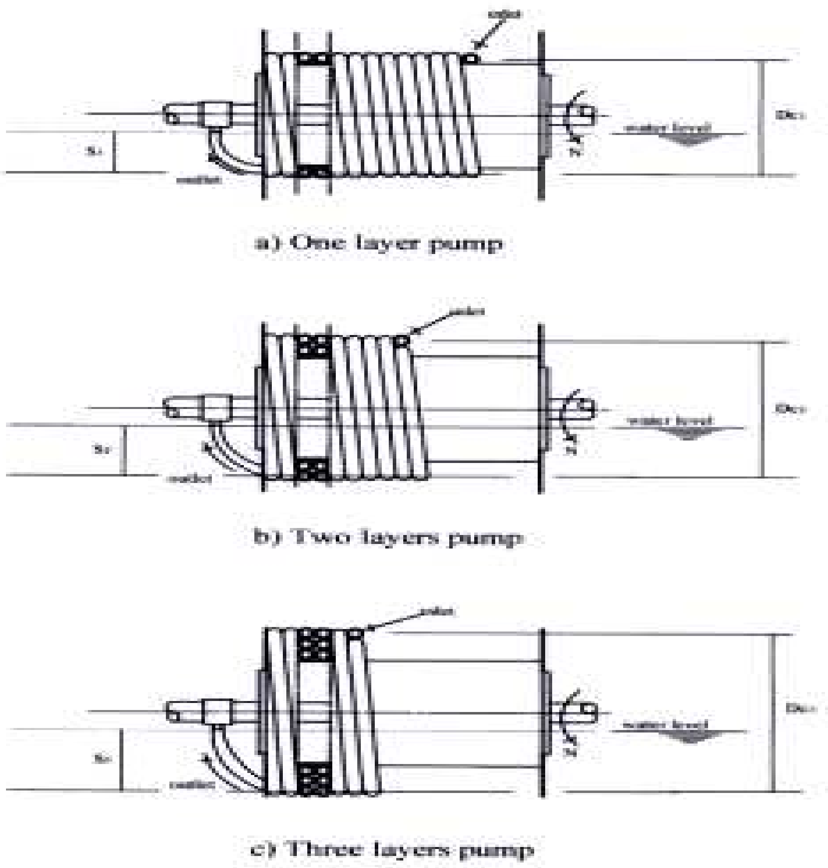


Figure 3.a Schematic drawing for one, two and three layers coil pump

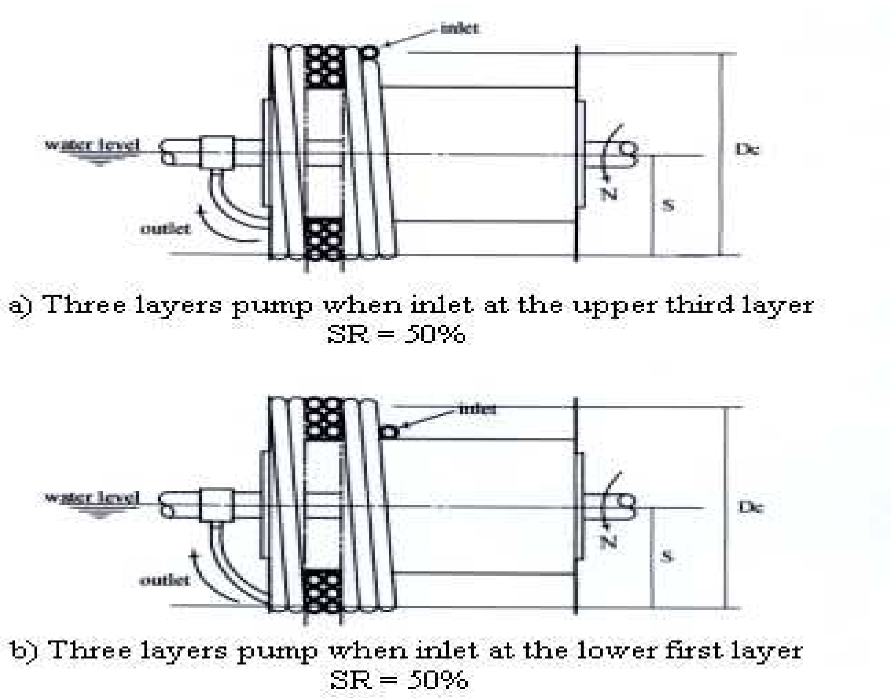


Figure 3.b Schematic drawing for three layers pump at different inlet positions

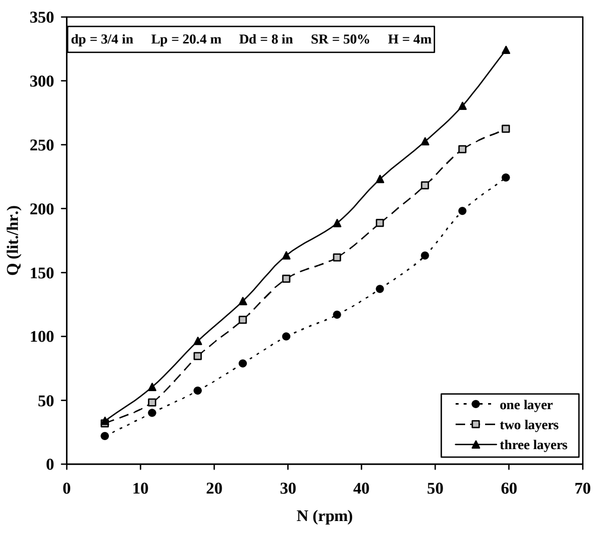


Figure 4 Variation of the pump flow rate with the number of layers at different rotational speeds

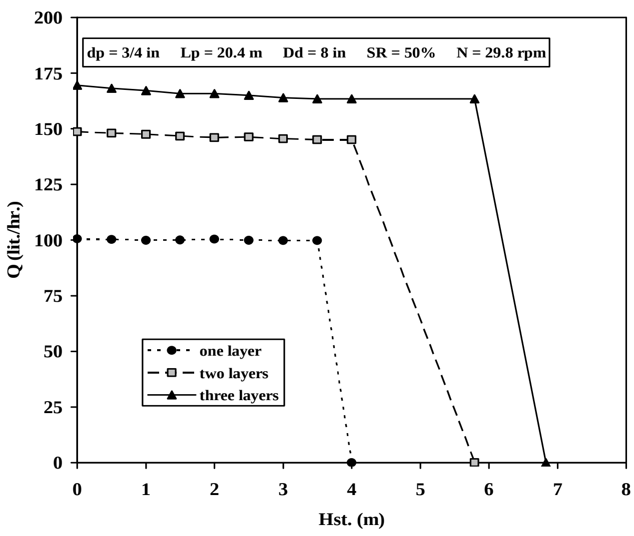


Figure 5 Variation of the pump performance with the number of layers

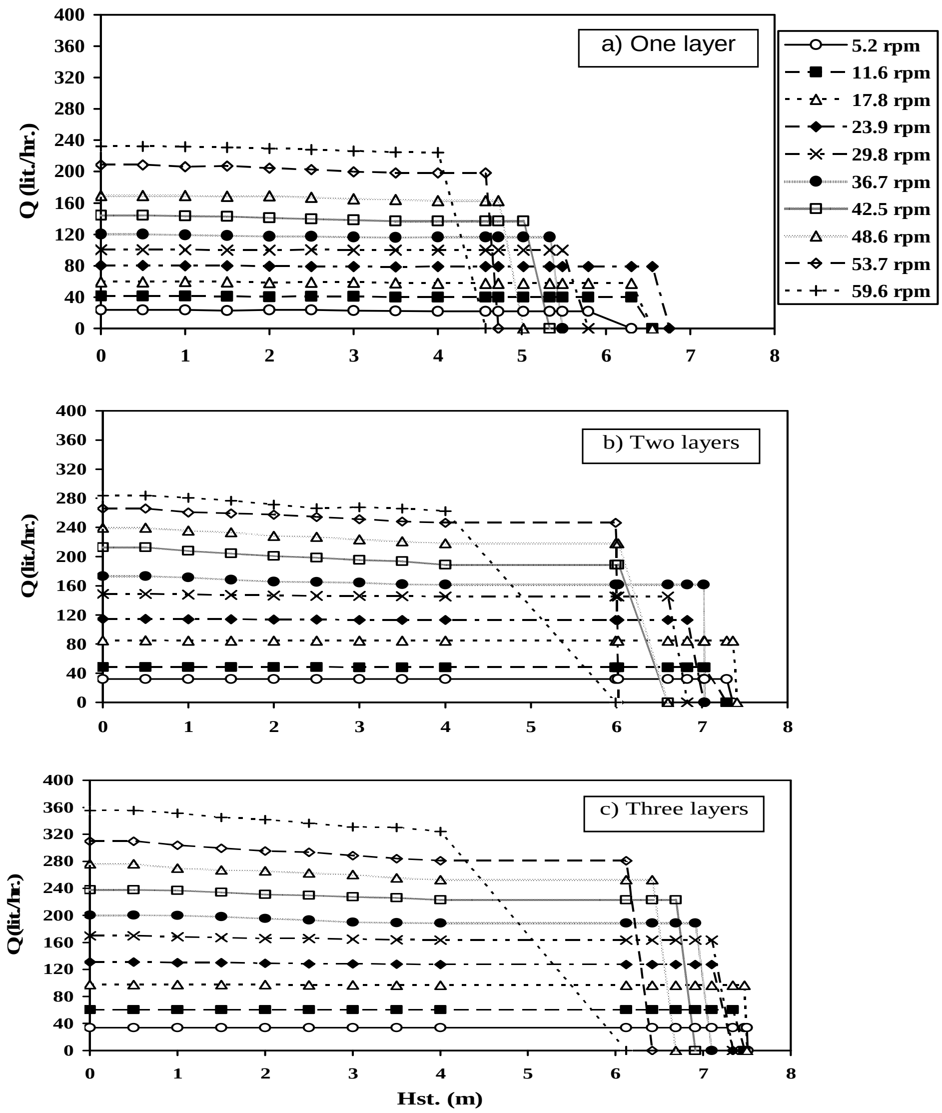


Figure 6 Performance of the multi-layers coil pump at different rotational speeds

Figures 7 shows the effect of changing the inlet and outlet positions on the coil pump performance, at constant rotational speed (N = 29.8 rpm), for the cases of two and three layer pumps at submergence ratio of 50%. The results reveal that, for multi-layer coil pump, it is preferable to let the air and water inter from outer layer than from the lower one to obtain a better performance. Head, H, versus discharge results, at different rotational speeds and after reversing the inlet and outlet positions for the two cases, are presented in Fig. 8. The explanation related to the results presented in Figs. 4 and 5 is also valid for the obtained results in Figs. 7 and 8. Moreover, comparing the results shown in Fig. 8 with the results presented in Fig. 6 confirms the conclusion drawn from Fig. 7 regarding better coil pump performance when pump inlet placed at the top end in the case of multi-layer pump.

3. Effect of the coiled hose inner diameter

Figure 9 shows that for a certain hose diameter, as the rotational speed increases the discharge Q, linearly increases. In addition, for a certain rotational speed, N, as the hose inner diameter increases, the pump flow rate increases. Moreover, Fig. 9 shows that the rate of increasing of the flow rate increases with the increase of the inner coil diameter. Therefore, the flow rate increases due to increases in rotational speed and/or the hose diameter.

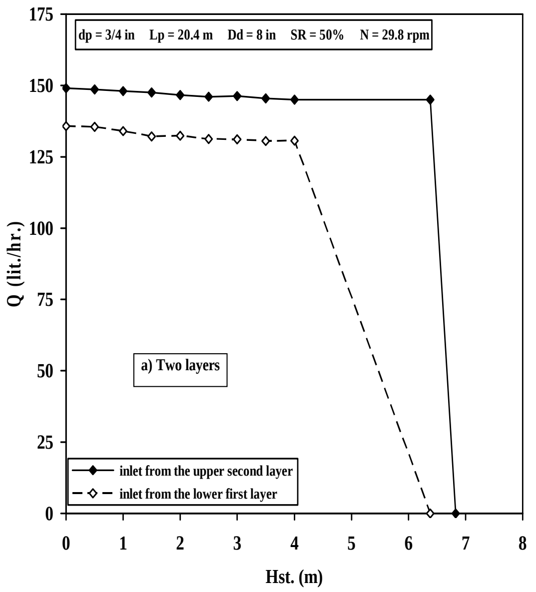
Figure 10 presents the performance (H - Q) curve of the coil tube pump at constant rotational speed of 36.7 rpm for different tube diameters. It is shown that, increasing the hose inner diameter increases the pump flow rate which is collected at different heights. For small values of hose diameter, changes in pump discharge and head are small relative to those obtained in the case of 1 1/2 inch hose diameter. Therefore, the use of a larger size hose is one of the major important design parameters for coil pump.

Figure 11 shows (H - Q) curves for each pipe inner diameter at different rotational speeds. In Fig. 11.a, the maximum flow rate in the case of 1/2 inch pipe is 125 lit./hr, occurs at 59.6 rpm. While, for the pipe inner diameter, dp = 1 1/2 inch, Fig. 11.d shows that the maximum pump flow rate is 1500 lit./hr which also occurs at 59.6 rpm.

Figures 9 to 11 show an improvement in the coil pump performance with the increase of the coil hose inner diameter. This behavior can be attributed to two effects: First, increasing the inner diameter of the coil tube results in a reduction in the friction loss within the hose and leads to a better pump performance. Second, increasing the inner diameter of the coil increases the pump inlet area as well as the mean pump outer diameter. This leads to an increase in the amount of air and water inter to the pump which leads to improve the pump performance as shown in the previous figures.

4. Effect of the drum outer diameter

Figure 12 presents the obtained results of the discharge, Q, versus the drum outer diameter. This figure shows that, the flow rate linearly increases as the drum outer diameter increases for all rotational speeds. Meanwhile, Fig. 13 expresses the variation occurred in the (H - Q) curve at constant rotational speed (N = 53.7 rpm). It is clearly seen that, increasing the drum outer diameter leads to increasing both the flow rate, Q and static head, H, of the pump. These results can be explained as follows: as the drum outer diameter increases, for a certain pump rotational speed and for the same number of turns, the amount of air and water entering the coil increases. Consequently the pumping effect increases.



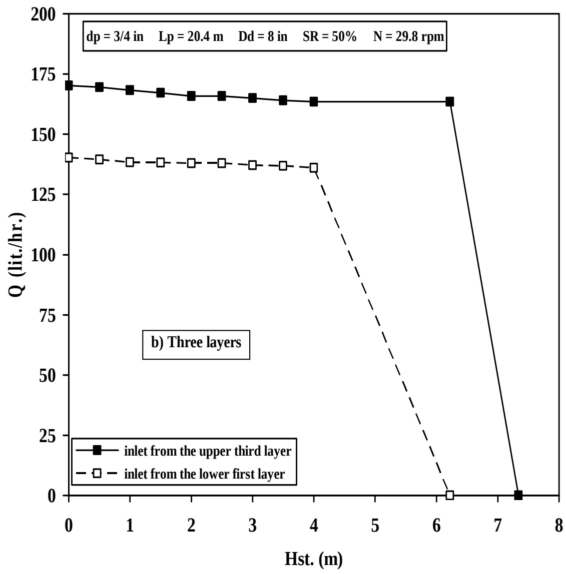
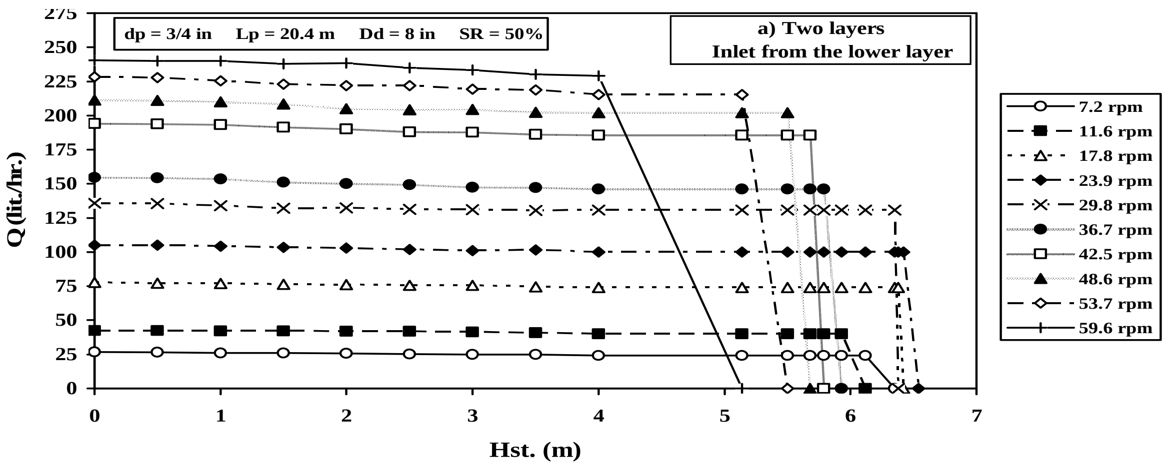


Figure 7 Effect of changing the inlet and outlet positions on the multi-layers coil pump performance



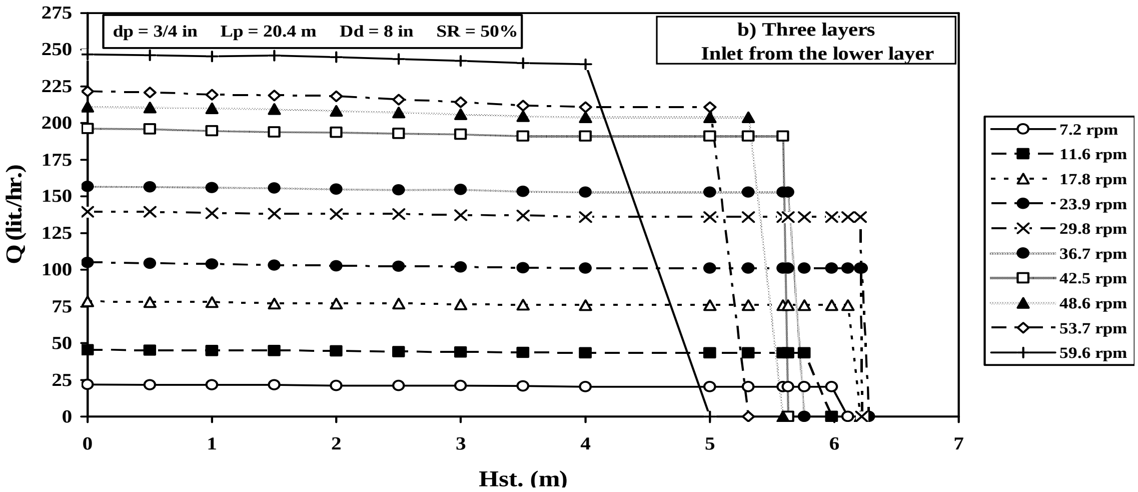


Figure 8 Performance curves for the multi-layers coil pump at different rotational speeds when the pump inlet from lower first layer

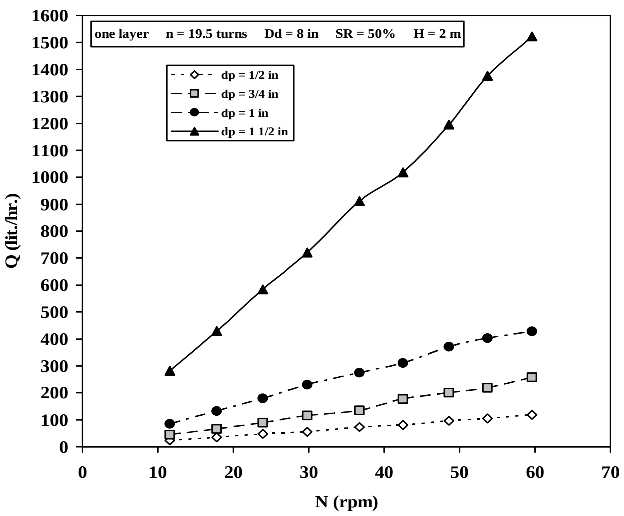


Figure 9 Variation of the pump flow rate with rotational speed for different hose inner diameters

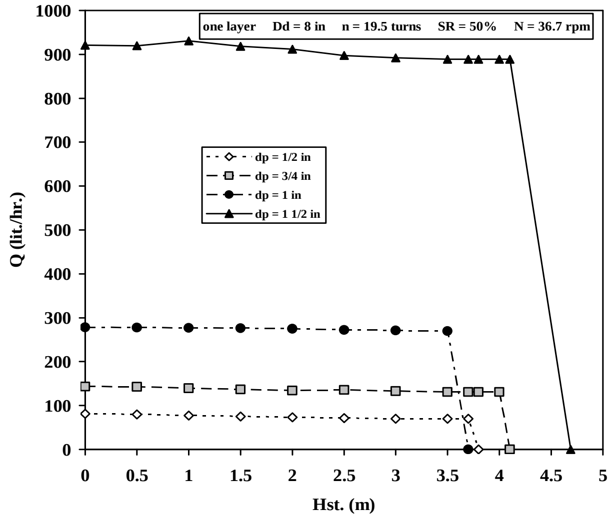


Figure 10 Variation of the coil pump performance with the hose inner diameter

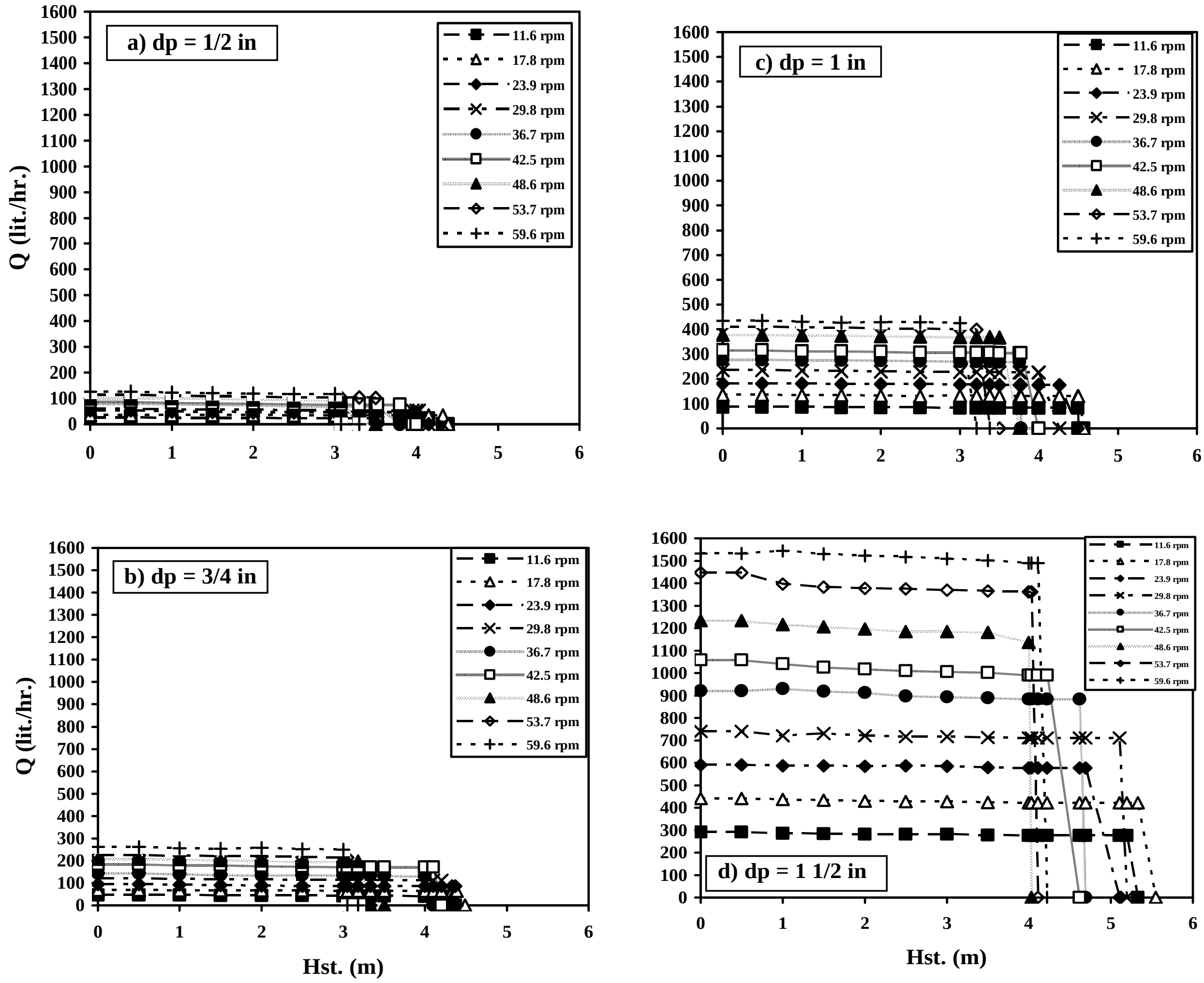


Figure 11 Performance curves for coil pump at different hose inner diameters. (One layer, n = 19.5 turns, SR = 50%, D_d = 8 in.)

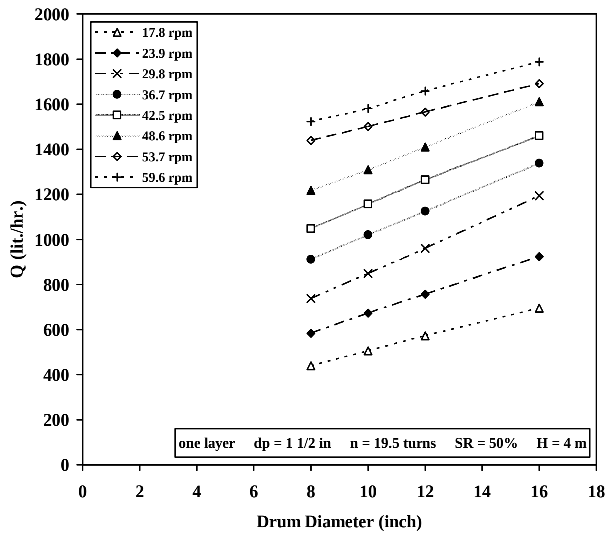


Figure 12 Variation of the flow rate with the drum outer diameter for different rotational speeds

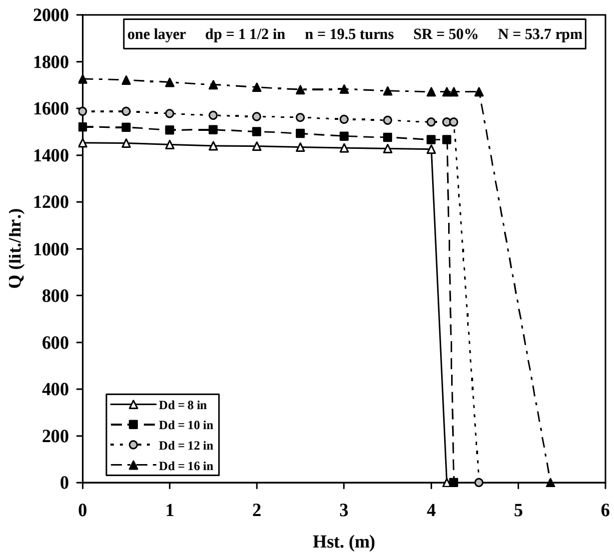


Figure 13 Effect of changing the drum outer diameter on the pump performance

Figure 14 shows an individual (H - Q) curve for each outer diameter of the drum at different rotational speeds. Comparing the results shown in this figure, at the same speed, supports the drawn conclusion from the results presented in Fig. 13 regarding the improvement of the coil pump performance due to the increase of the drum outer diameter. For example, the maximum flow rate in case of 8 inch drum diameter is 1550 lit./hr and is occurred at the speed of 59.6 rpm, Fig. 14.a. When the drum outer diameter increases to 16 inch, Fig. 14.d, the maximum flow rate is approximately 1800 lit./hr, occurring at the same speed of 59.6 rpm.

Finally, one can connects the outcomes from the present study as follows: using multi-layers coil pump with the pump intake placed at the top end of the upper layer improves the pump performance. This effect is the same as increasing the drum outer diameter of the case of only one layer. In both cases the circumferential distance of the pump inlet increases due to the increase of the pump outer diameter. Consequently, the period for both air and water intake increases which has a positive improvement in the coil pump performance. The increase in the air intake results in an increase in the effective motive pumping power, and consequently the pressure head. While increasing the amount of water intake results in an increase in the flow rate. Both effects add to each other and produce better pump performance. In addition, it is important to point out that the effect of increasing the coil inner diameter has the same effect as the other two previously mentioned parameters and due to the same reasons in addition to the effect of reduced friction to the flow within the coil.

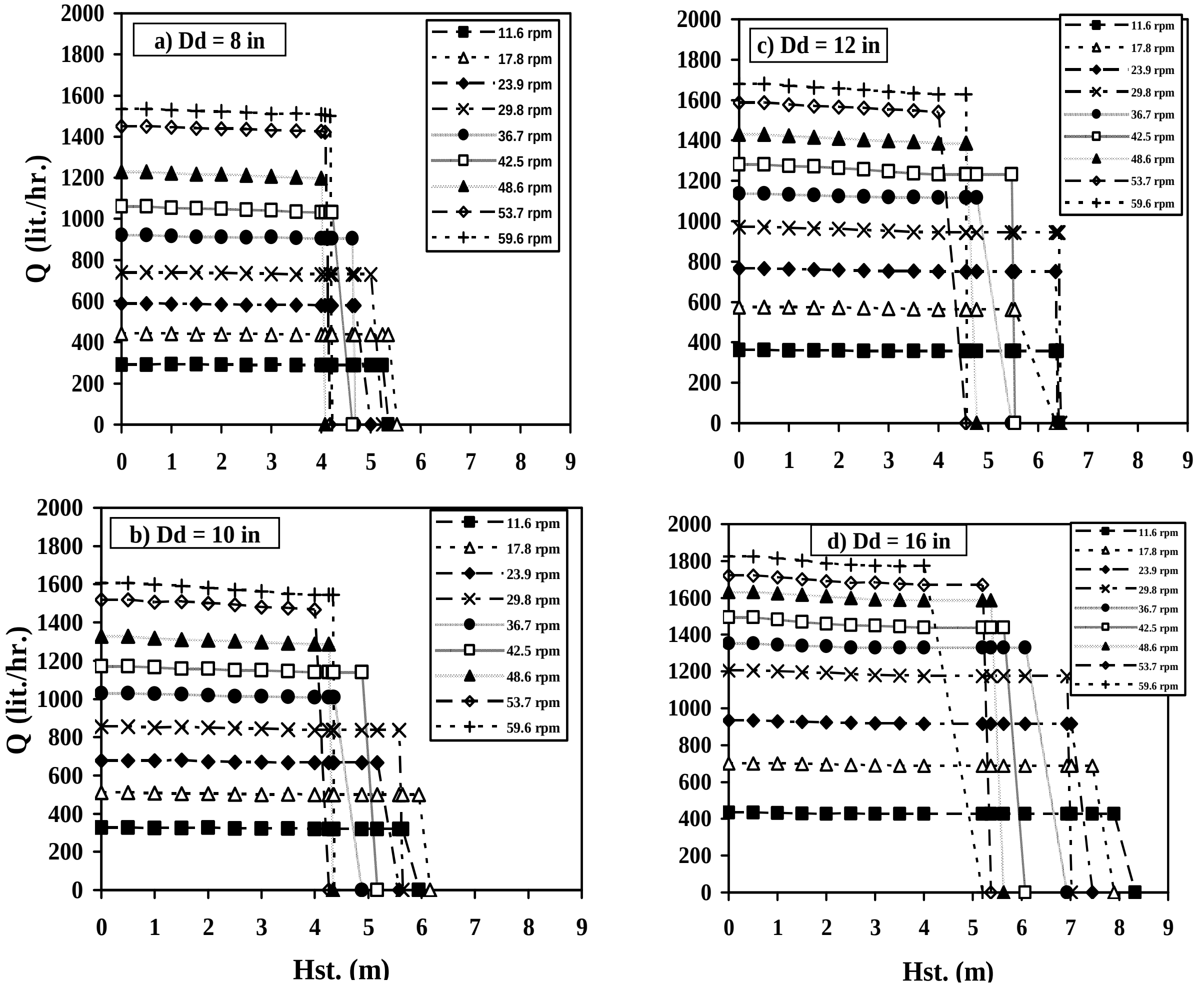


Figure 14 Performance (H-Q) curve for single layer pump for different drum diameters (One layer, n = 19.5 turns, SR = 50%, dp = 1 1/2 in.)

CONCLUDING REMARKS

From the presented results and related discussions the following concluding remarks are deduced:

1. Using multi-layer coil pump improves the pump performance (head and discharge).
2. For multi-layer coil pump, water inlet from the upper layer gives higher discharge, higher static head and better pump performance.
3. Increasing hose diameter leads to better coil pump performance.
4. Increasing drum diameter leads to better coil pump performance.

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