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Turbine Pump Selection for Agricultural Applications in Saudi Arabia

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ABSTRACT. A thorough hydraulic analysis is used to evaluate turbine pump selection for agricultural purposes in Al-Qassim Province of Saudi Arabia. In this study, 18 real-world cases are considered. Complexity of irrigation systems for these cases ranges from a single turbine pump supplying a single sprinkler system to multiple turbine pumps supplying a complex irrigation network. For each case, the existing pump in operation is evaluated; then, competitive pumps are checked for suitability for the same application. Since operational costs dominate other factors for pump selection, this study considers the pump that requires less input power as a better selection for a given application. In most cases, it is found that the pump in operation is not the best pump. In addition, in most of these cases, the pump driver is found to have excessive power more than the minimum required input power to operate the pump.

Introduction

In the past two decades, more than 22 billion Saudi Riyals (SR) (5.87 billion U.S. dollars) were distributed as governmental loans to farmers in Saudi Arabia[1]. About 19% of this figure, *i.e.*, 4.13 billion SR (1.1 billion U.S. dollars), were spent on turbine pumps and diesel engines. The agricultural machinery market grew very rapidly, attracting even unqualified dealers, sales persons, and technicians to make use of this unique business opportunity. This, of course, was at the expense of the quality of service. Combined with unawareness of customers (farmers), this led to the equipment selection being imprecise or even erroneous. Due to the high operational and initial cost of this type of machinery, a wrong or imprecise selection of equipment can be very costly.

A turbine pump is part of most irrigation systems in Saudi Arabia. The water suitable for irrigation is mostly in confined aquifers that are 300 to 1200 meters (984 - 3937 ft) deep. Three decades ago, artesian wells were common in most of these aquifers. The great withdrawal of water for agricultural purposes caused the water level in wells of these aquifers to drop by 100 to 200 meters (328 - 656 ft) below the ground surface. Vertical turbine pumps are used to pump water from these levels to the irrigation systems. These pumps are usually operated either by a diesel engine or by an electric motor. With the driver being above ground a gear is used to transmit the power (revolution) from the driver to the pump via a vertical shaft. Figure 1 shows a schematic diagram for a typical irrigation system in its simplest form.

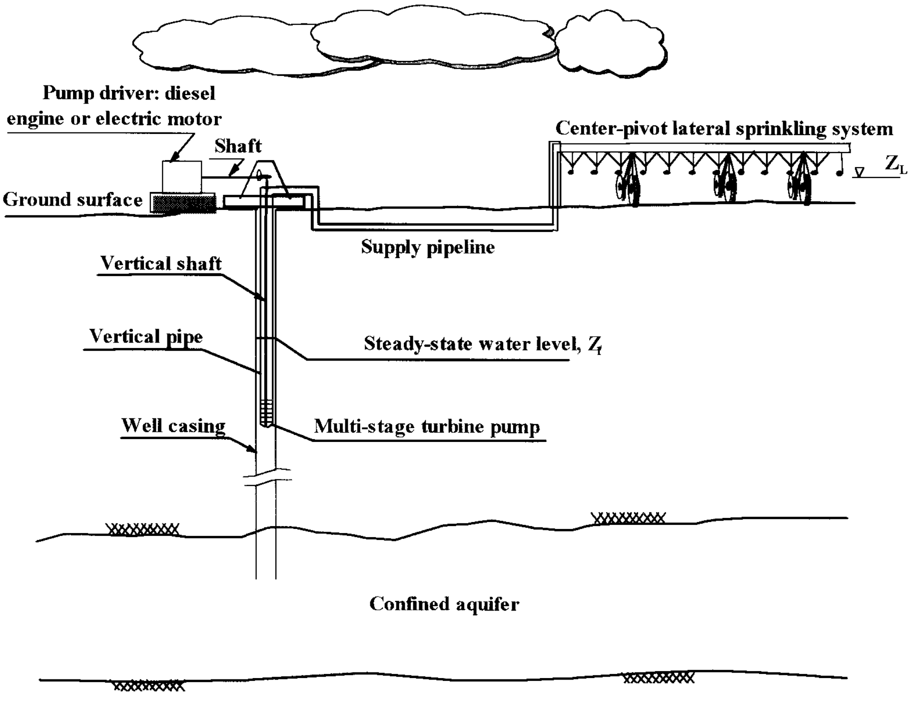

FIG. 1. Schematic diagram for a simple typical irrigation system.

Pump Selection Criteria

Pump selection has been covered in the literature[2,3,4,5,6,7]. To ensure an accurate pump selection, competitive pumps are analyzed against selection criteria. Optimum pump selection should lead to a lower expenditure and maximum productivity over the service life of the pump. The following selection criteria[8] form a sound basis for reliable selection:

1. Performance: the ability of the pump to provide the required head and discharge.
2. Operational cost: the cost of energy required to operate the pump.
3. Maintenance cost: this includes, part cost, service rates, and the amount of revenue lost during each quarterhour of downtime.
4. Vendor service quality: this includes delivery time, level of customer support, and warranty policy.

The literature has been dealing primarily with pump selection optimization for water distribution networks. Pump selection for agricultural water distribution networks has been receiving a much less attention. Due to the varying water demand with time, pump selection for municipal water distribution network involves a range of operational conditions. This paper shows that pump selection for agricultural pipe networks in Saudi Arabia should consider a single operational point for two reasons. Firstly, flow at demand points usually does not change with time as center-pivot lateral irrigation systems are mostly used, and secondly, pump operational cost is very high that deviation from the point of maximum efficiency can be costly. In the Kingdom of Saudi Arabia, operational costs are much greater than initial costs for turbine pumps. Three examples for three different pumps are shown in Figures 2, 3, and 4. Knowing that most turbine pumps operate at least 50% of the time, the three figures prove that operational cost exceeds initial cost in less than two years. Initial costs in these examples are based on actual quotations provided by the pump suppliers to the Saudi Ministry of Agriculture and Water. The operational cost is based on a survey made by the author. The survey revealed that the cost per each 0.75 kW (1.0 horsepower) per month is 40 Saudi Riyals ($10.57) during summer season. This applies for both diesel engine- and electric motor-driven pumps. These figures emphasize the importance of avoiding long-term plans for agricultural activities with regard to pump and pump driver selection as they may imply operating the machinery off the optimum efficiency, leading to much higher costs. Thus, this study considers only a single operational point, which is the point at which the total required discharge is pumped into the network to satisfy the flow and head requirements at each demand point (*e.g.,* at each lateral). It is most probable that if future expansions/alteration of the agricultural activities would not take place in five years, it would be more beneficial to design for a single operational point for the current conditions regardless of future plans. Then, once this expansion/alteration takes place, the machinery may be replaced by more suitable ones.

With the initial and part cost being small as compared to the operational cost, criterion 3 is omitted from consideration. Furthermore, since all pumps approved by the Saudi Ministry of Agriculture and Water (MAW) being from ma-

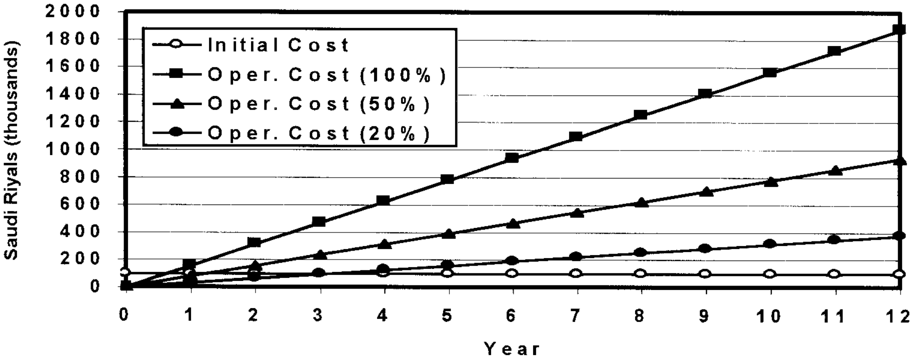

FIG. 2. Initial cost versus operational cost for Verti-Line Pump, Model 12-RH, series 1110, 19 stages, operating at 1770 rpm and 295.23 m^3/hr (1300 GPM).

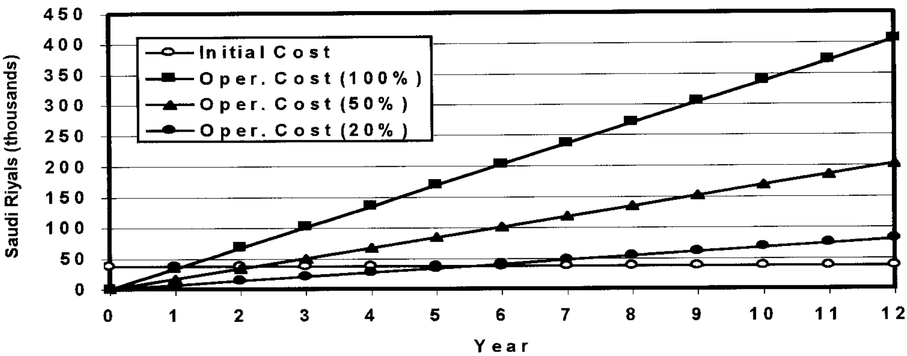

FIG. 3. Initial cost versus operational cost for Torrent Pump, Model 10NMH, 8 stages, operating at 1770 rpm and 181.68 m^3/hr (800 GPM).

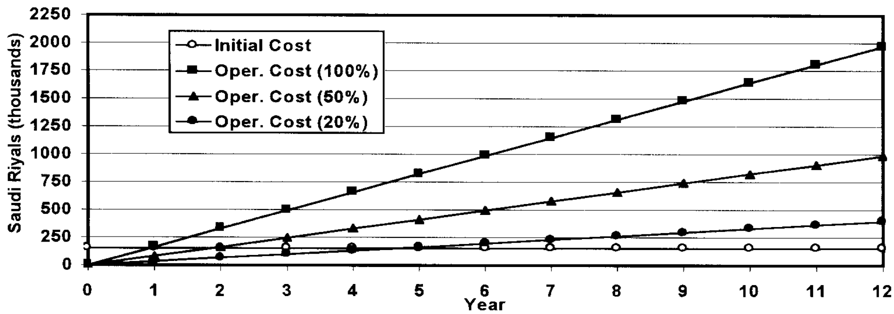

FIG. 4. Initial cost versus operational cost for Simmons Pump, Model 11 PAH, 19 stages, operating at 1770 rpm and 227.1 m^3/hr (1000 GPM).

jor pump companies, criterion 4 is also omitted from consideration. In this study, the first criterion is satisfied automatically since no pump is considered for comparison unless it satisfies the required discharge and head. Additional head or/and discharge above the required quantities are not considered credits for a pump since this implies higher operational costs. Thus, the only factor considered for pump comparison herein is the operational cost. Therefore, the pump that requires less input power is considered a better selection. The turbine pumps considered in this study include the brands: Verti-Line (Aurora), Byron Jackson, Al–Gammas*, Jacuzzi, Johnson, National, Peerless, Simmons, Torrent, and Western Pumps.

Data Collection and Associated Difficulties

There were some unavoidable difficulties that a researcher in this area may encounter. The lack of literature on equipment selection for agricultural networks with sprinkling systems was a major concern. This could be attributed to the fact that this type of irrigation is not among the common means of irrigation in other areas of the world. Furthermore, the data necessary to accomplish this study were difficult to obtain. A long time was spent to gather the minimum data to do the analysis. This applies for both published pump literature (*e.g.*, performance curves) and field parameters. The other aspect of difficulty is due to the fact that these turbine pumps are actually buried underground. With the owners (farmers) being among the least educated class, getting the right information is difficult. In this study, only the cases with reliable information are considered. Sometimes it was necessary to confirm the information provided by the farmer on his pump such as the number of stages, the model, etc., from the dealers or from the Saudi Agricultural Bank.

Analysis Procedure

The analysis for each of the 18 real-world cases studied herein involves the following steps in order to determine which pump is the best for the application:

1. Estimation of the required discharge.
2. Computation of the required pump head.
3. Trying a pump that seems to satisfy the discharge and head requirements.
4. Determining the required number of stages for the pump being tried.
5. Establishing the system demand curve for the network and overlapping it with the pump characteristic curve.
6. Finding the pump design head, design discharge, design input power and the design efficiency.

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*A locally manufactured pump.

7. Repeating Steps 4-6 for other competitive pumps.
8. The pump that requires the minimum input power is considered the best pump.
9. The pump already serving in the field (the actual pump) is analyzed (the number of stages in this case is already known) and its design head, design discharge and design input power are determined by carrying out Steps 5 and 6. The design head and design discharge are then compared to the corresponding required quantities.
10. The actual pump is analyzed again but after hypothetically modifying the number of stages so that it just delivers the required discharge and head, and its design head, discharge, and input power are found.
11. The obtained input power for competitive pumps are compared against each other as well as against that of the pump already installed in the field (the actual pump).

Center-pivot lateral irrigation system is the most widely used irrigation method in Saudi Arabia. All the 18 cases studied here involve this kind of irrigation. As Figure 1 reveals, the lateral consists of a series of spray nozzles (*i.e.,* small orifices). These nozzles can be treated as a single giant orifice[9], which is the case in this study. In order to ensure optimum lateral operation, a minimum lateral inlet head must be maintained during normal operation. Table 1 lists the

Table 1. The minimum lateral inlet head suggested by the Saudi Ministry of Agriculture and Water[11].

Lateral length (L)	< 200 m (<656 ft)	200 - 350 m (656 - 1148 ft)	351 - 400 m (1149 - 1312 ft)	401 - 450 m (1313 - 1476 ft)	451 - 500 (1478 - 1640 ft)	> 500 m (> 1640 ft)
Lateral inlet head (H_{in})	21 m (70 ft)	24 m (80 ft)	28 m (92 ft)	35 m (115 ft)	43 m (140 ft)	56 m (185 ft)

minimum lateral inlet head suggested by the Saudi Ministry of Agriculture and Water (MAW) and is a function of the lateral length. This table is also considered in this study. The lateral inlet head would simply be the head loss across the lateral (*i.e.,* the giant orifice), from which the orifice constant is obtained. To impose the required discharge through each lateral once the total required discharge is pumped into the network, control valves are considered upstream of each water demand point (*e.g.,* lateral). Coefficients for these valves are adjusted until obtaining the required discharge through each lateral during normal operation. The control valve coefficient and the orifice constant allow one to simulate the actual network behavior by running network analysis for different discharges and finding the pump head corresponding to each discharge value. Thus, the system demand curve is obtained. The equation for the head on the pump can be established using either the Hazen-Williams Equation or the Darcy-Weisbach Equation for frictional head loss. Neglecting the velocity head, the head on the pump is obtained by starting from any point of known hydraulic gradeline. The difference in elevation between this point and the pump plus the total head loss between the two points gives the head on the pump. When, using the Hazen-Williams Equation for frictional head loss, the equation for the head on the pump has the form[10].

$$H_P = Z_L - Z_1 + \Sigma K_{mi} Q_i^2 + \Sigma C_{fi} Q_i^{1.852} \qquad (1)$$

in which

Z_L = elevation of water demand point (*e.g.,* elevation of a representative lateral sprinkler outlet);

Z_1 = elevation of steady-state water level at the well when pumping at the required discharge;

$$K_{mi} = K_{fi} + K_{vi} + K_{oi}\ ; \qquad (2)$$

K_{mi} = total minor losses coefficient for pipe *i*;

K_{fi} = coefficient of head loss (for pipe *i*) associated with different fittings (*e.g.,* elbows, bends, etc.), excluding control valves;

K_{oi} = coefficient of the head loss across the single giant orifice that simulates the lateral at the end of pipe *i*;

K_{vi} = coefficient of the head loss across the control valve along pipe *i* and is used along with other control valves to impose the required discharges through each demand point;

C_{fi} = frictional loss coefficient for pipe *i*;

$\Sigma K_{mi} Q_i^2$ = total minor losses along the path from the selected point of known hydraulic gradeline to the pump;

$\Sigma C_{fi} Q_i^{2.852}$ = total Hazen-Williams frictional losses along the path from the selected point of known hydraulic gradeline to the pump; and

Q_i = discharge through pipe *i.*

The pump design head, design discharge and the design input power are found by overlapping the system demand curve obtained with the pump discharge-head characteristic curve. Comparison of input power values for different turbine pumps allows selection of the pump with the least input power. Figure 5 shows a sketch for a typical system demand curve intersecting pump discharge-head curve. It is shown on the figure how the pump design discharge

(Q_D), design head (H_D), design efficiency (η_D) and design input power $(W_P)_D$ are read at the point of intersection of the two curves.

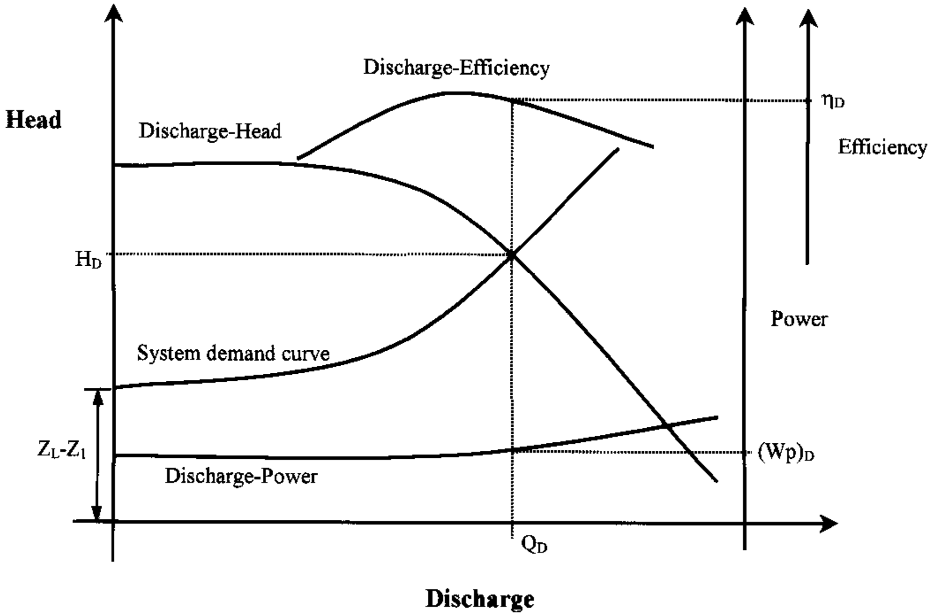

FIG. 5. A typical system demand curve intersecting a pump discharge-head curve.

Case Study

Following the procedure explained above, 18 real-world installed turbine pumps were considered for analysis. Table 2 shows some details on these cases, including the required pump discharge $(Q)_r$, required pump head $(H)_r$, installed pump brand, number of stages and number of laterals for each case. Figure 6 shows the irrigation network layout for Case 18 along with pipe information, initial assumed flow rates as well as lateral and well information. For each case in the analysis, design pump head, design pump discharge and design pump input power are computed for the following situations:

1. The actual pump with the actual number of stages.
2. The actual pump with the hypothetically modified number of stages to meet the flow and head requirements.
3. The best pump, which is the pump that requires the least input power to operate.

The best pump is found by considering all competitive pumps that can serve in the field and supply the flow and head requirements. The pump which deliv-

TABLE 2. Some information on the 18-real world cases considered in this study.

Case	Qr, m^3/hr (GPM)	Hr, m (ft)	Installed pump brand / model	Number of stages	Installed pump input power, kW (hp)	Pump driver	Depth to water, m (ft)	Number of laterals
1	363.8 (1602)	212.4 (696.7)	Aurora, 12-RH	12	206.6 (276.9)	DE*	100.0 (328.1)	1
2	156.0 (687)	118.1 (387.6)	Simmons, 10PAH	10	132.7 (99.0)	DE	70.0 (230.0)	1
3	112.0 (493)	127.5 (418.4)	Al-Ghammas, 8GP	17	65.6 (48.9)	DE	80.0 (263.0)	1
4	112.0 (493)	127.5 (418.4)	Aurora, 8-RH	20	79.2 (59.1)	DE	80.0 (262.5)	1
5	363.8 (1602)	212.4 (696.7)	Aurora, 12RH	12	276.9 (206.6)	DE	100.0 (328.0)	1
6	363.8 (1602)	212.4 (696.7)	Aurora, 12RH	12	276.9 (206.6)	DE	100.0 (328.0)	1
7	253.0 (1114)	121.1 (397.2)	National, H12HC	7	167.3 (124.8)	EM**	65.0 (213.3)	1
8	197.6 (870)	100.9 (331.2)	Turkish, 8HQH	22	88.0 (65.6)	DE	80.0 (262.5)	0
9	695.6 (3063)	163.3 (535.6)	Bayron Jackson, 11MQH	9	360.0 (268.6)	DE	60.0 (197.0)	2
10	123.8 (545)	140.4 (460.7)	Torrent, 8KMM	25	95.0 (70.9)	DE	100.0 (328.0)	2
11	123.8 (545)	140.4 (460.7)	Torrent, 8KMM	25	95.0 (70.9)	DE	100.0 (328.0)	2
12	267.5 (1178)	163.3 (553.6)	Bayron Jackson, 11MQH	11	185.1 (138.1)	DE	90.0 (296.0)	2
13	323.6 (1425)	141.4 (464.0)	Aurora, 12RH	15	272.3 (203.1)	DE	70.0 (230.0)	2
14	278.2 (1225)	107.0 (351.2)	Jacuzzi, 12HC	8	176.4 (131.6)	DE	65.0 (213.3)	2
15	452.8 (1994)	177.0 (580.7)	Aurora, 12FHH	14	222.0 (165.6)	DE	120.0 (393.7)	0
16	300.7 (1324)	125.9 (413.0)	Torrent, 12HNM	8	109.8 (81.9)	DE	40.0 (132.0)	2
17	256.9 (1131)	118.9 (390.1)	National, H12HC	7	168.0 (125.3)	EM	71.0 (233.2)	3
18	367.7 (1619)	176.2 (578.0)	Al-Ghammas, 8GPH	12	432.0 (322.3)	DE	126.0 (414.0)	3

*Diesel engine
**Electric motor

ers the head and flow requirements with the least input power is considered the best pump for a given application. The output power of the pump driver is compared to the pump input power for each of the three situations. To avoid overloading, it is a common practice to multiply the pump input power by 1.25 if the pump driver is a diesel engine and by 1.15 if the pump driver is an electric motor. The pump driver is then selected so that it delivers this resulting input power.

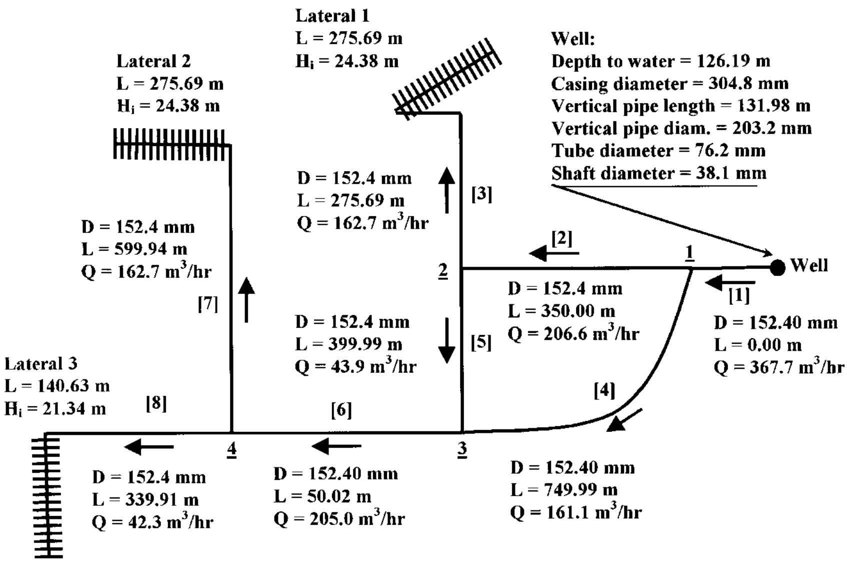

FIG. 6. Schematic diagram for the irrigation network for one of the cases (Case 18).

Discussion of Results

The results of the analysis are shown and discussed in the following paragraphs. The discussion includes comparison of different competitive pumps to each other with respect to design head, design discharge, design input power and efficiency for all the 18 real-world cases considered in this study.

Discharge and Head Requirements

The pump design discharge and design head for the three situations mentioned earlier are compared to the required quantities. Figure 7 depicts the design discharge versus Case number for the 18 cases studied. It is clear that the design discharge for the actual pump with the actual number of stages $(Q_D)_a$ is less than the total required discharge through the pump $(Q)_r$ in 10 cases. In other words, the already installed pump is not capable of providing the required discharge in these 10 cases. One may note the close match between the required discharge $(Q)_r$, the design discharge for the actual pump with the hypothetically modified number of stages $(Q_D)_s$ and the design discharge for the best pump $(Q_D)_b$. This close match assures that competitive pumps and the suggested number of stages for the actual pump are considered so that they just satisfy the minimum discharge requirements.

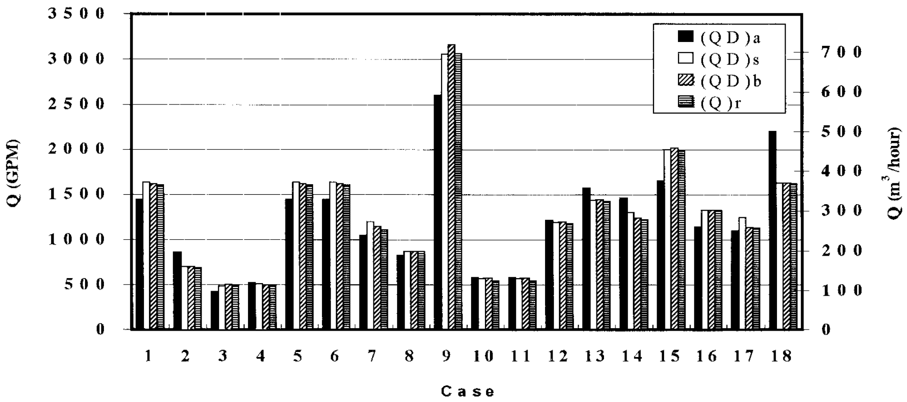

FIG. 7. Design discharge as obtained from the analysis of the 18 cases.

Figure 8 shows that out of the 18 cases, the design head delivered by the actual pump is less than the minimum required head [*i.e.,* $(H_D)_a < (H)_r$] in 9 cases. Again, there is a close match between the design head for the actual pump with the hypothetically modified (suggested) number of stages $(H_D)_s$, the design head for the best pump $(H_D)_b$ and the required pump head $(H)_r$. This is attributed to the fact that competitive pumps are selected so that they just deliver the required head and discharge quantities.

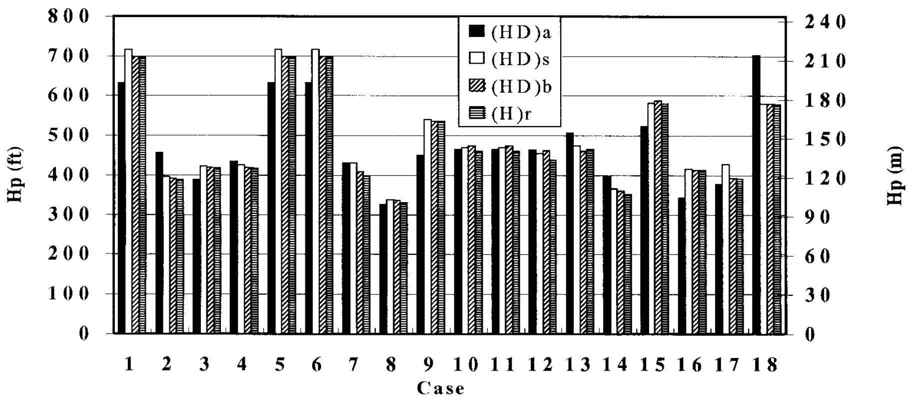

FIG. 8. Design pump head as obtained from the analyses of the 18 cases.

Pump and Pump Driver Power

Figure 9 shows the pump input power versus the case number for the 18 cases under consideration. When comparing the factored input power for the actual pump (with the actual number of stages) [*i.e.,* $(W_p)_a$] to the driver output power, one may notice that in 10 cases, there is a considerable excessive driving power beyond the minimum required values to operate the pump. There is a close match between these two quantities in 5 cases. However, the driver output power is less than the required pump input power [*i.e.,* driver power $(W_p)_a$] in 3 cases. The pump driver in the latter 3 cases is not considered overloaded since the power required by the pump is already multiplied by a factor of safety to obtain the $(W_p)_a$. Overloading may occur when the unfactored pump input power exceeds the driver output power.

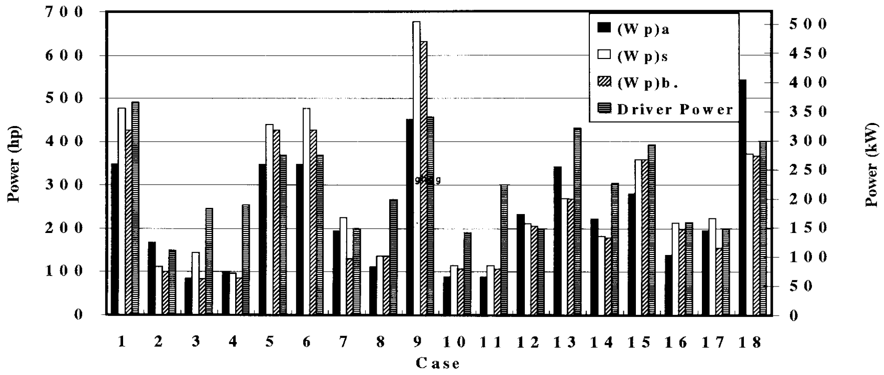

FIG. 9. Pump input power versus case number for the 18 cases.

Comparison of the $(W_p)_a$ to the input power of other competitive pumps is invalid since the actual number of stages for the actual pump was not necessarily considered so that it just delivers the required discharge and head quantities. To compare the existing pump to other pumps from other companies, the factored input power for the actual pump with the hypothetically modified number of stages $(W_p)_s$ is compared to the input power for the best pump $(W_p)_b$. In other words, the actual pump with the number of stages being hypothetically modified to handle the discharge and head requirements is compared to the best pump, which is the pump that requires the least input power. In this case, the number of stages for both pumps is considered so that they just deliver the minimum head and discharge. Figure 9 shows that in 16 cases out of the 18 cases under consideration $(W_p)_b$ is less than $(W_p)_s$. That means in all of these 16 cases, the actual pump is not the best with respect to its input power requirements.

In only two cases (Cases 8 and 15), the actual pump is the best pump. The worst case is Case 3 where the input power for the best pump is about 46 kW (62 hp) less than that of the actual pump.

Figure 10 shows the difference between the driver output power and the pump input power. When subtracting the input power for the actual pump with the actual number of stages $(W_p)_a$ from the driver output power, one obtains what can be called the Unused Power, and in this study denoted by UUP_a. It is clear that there is more than 75 kW (100 hp) wasted (or unused) power in 7 cases. Again, the negative value indicates that the driver output power is less than the factored pump input power, but it may not be less than the unfactored pump input power.

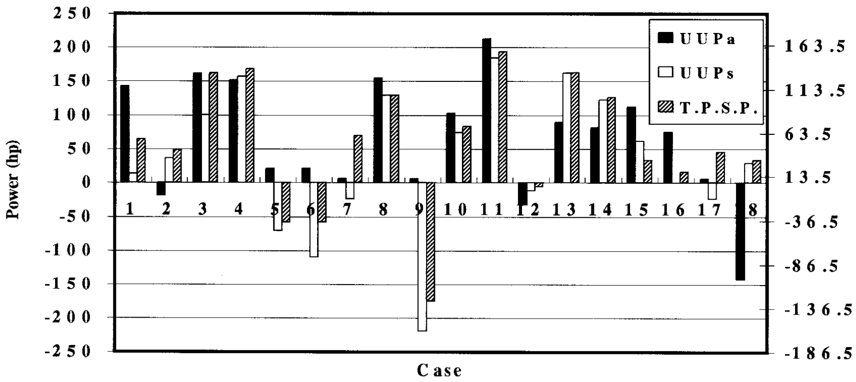

FIG. 10. Unused (wasted) power for the 18 cases.

When subtracting the pump input power after hypothetically modifying its number of stages $(W_p)_a$ from the driver output power, the unused power in this case is denoted by UUP_s . Figure 10 depicts that in 11 cases out of the 18 considered cases the value of UUP_s is positive. This reveals that in these cases it is possible to modify the number of stages to that which will allow delivery of the head and discharge requirements without the need to replace the driver. Furthermore, let's assume that the actual pump in the field was replaced by the best pump (obtained from analysis) and the pump driver was replaced by a one that delivers the minimum power required by this pump. Then, the difference between the existing driver output power and that of the newly suggested one would be the total possible saving in power (or T.P.S.P). Figure 10 reveals that out of the 18 cases under consideration the total possible power saving is positive in 14 cases. Moreover, the value of T.P.S.P. is greater than 75 kW (100 hp) in 6 cases and greater than 37 kW (50 hp) in 9 cases.

Efficiency

Figure 11 shows that the efficiency of the actual pump (η_a) is less than that of the best pump (η_b) in 14 cases. However, the efficiency of the actual pump with the suggested number of stages (η_s) is less than η_b in 15 cases. Note that the average values of η_a, η_s, and η_b are 71.4%, 75.7% and 80.6%, respectively. This means that, on average, there is a 10% loss in efficiency due to improper pump selection. This also suggests that if the number of stages for the actual pumps were modified to satisfy the head and flow requirements, there would be about 5% gain in pump efficiency.

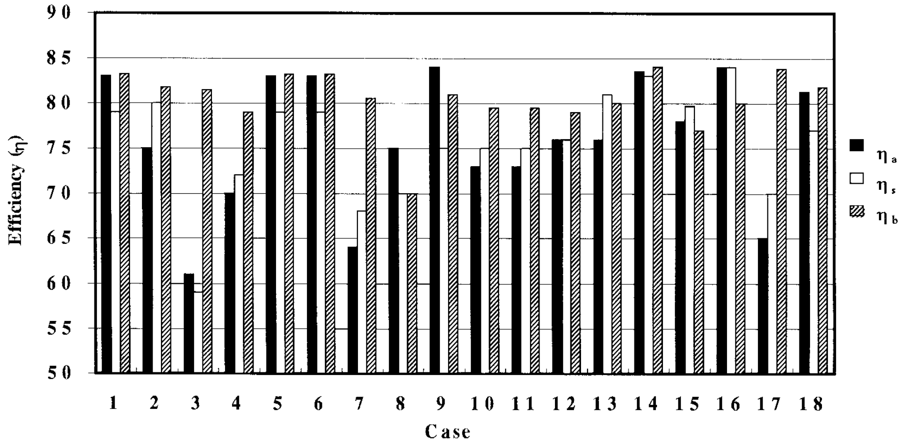

FIG. 11. Efficiency values for the 18 cases.

The above discussion provides clear evidences about the poor selection of turbine pump and its driver in most of the considered cases. Finally, one may want to have an idea about the extent of variation in suitability of the different competitive pump brands considered in this study for agricultural applications with similar parameters. Table 3 indicates that some pump brands should not be ignored when deciding to select a turbine pump for agricultural applications. The frequency of appearance as the best pump for the ten pump brands is listed in Table 3 without any particular order.

TABLE 3. Cases at which each pump was the best (had the least input power) among other competitive pumps as percent of the total cases studied.

Brand 1	Brand 2	Brand 3	Brand 4	Brand 5	Brand 6	Brand 7	Brand 8	Brand 9	Brand 10
47%	17%	12%	6%	6%	6%	6%	0%	0%	0%

Conclusions and Recommendations

Conclusions

Selected 18 real-world cases of turbine pump selection are considered in this study to evaluate turbine pump selection for agricultural applications in Saudi Arabia. It is found that turbine pumps were poorly selected in the sense i) they do not supply the required head and discharge, and ii) they are not among the most economical pumps for the applications they have been used for. The number of stages for these pumps can be increased to increase the discharge and head to the desired quantities without the need to upgrade the driver. Pump drivers were highly oversized in most of the cases, which causes operational costs to be high.

Recommendations

1. Since operational costs are much greater than other costs, it is important to select the pump and the pump driver so that they just deliver the required head and discharges at best efficiency. In other words the pump and pump driver should be selected without consideration of future expansions, especially if these expansions will not take place in about 5 years.
2. All major pump brands should be considered in the selection as efficiencies and point of maximum efficiency of pumps vary from one pump to another.
3. The Ministry of Agriculture and Water should consider creating consultation offices at each of its branches to provide consultation to farmers who need it. This office can be run by qualified engineers who may consider all competitive pumps to provide farmers with a reliable recommendation of pump and pump driver that best fit their applications.
4. The consultation office suggested above should be provided with a computer facility and suitable pump selection software so as to offer prompt help for farmers.

Acknowledgments

The author would like to thank the Saudi Ministry of Agriculture and Water for their willingness to support this kind of study. Thanks also extend to all pump dealers who provided information on their pumps as well as to farmers who allowed and facilitated inclusion of their machinery selection in this study.

Nomenclature

C_{fi} = frictional loss coefficient for pipe i;

$(HD)_a$ or $(H_D)_a$ = design head for the actual pump with the actual number of stages;

(HD) or $(H_D)_b$ = design head for the best pump (the best pump is the pump that can deliver the required discharge and head with the least input power);

$(HD)s$ or $(H_D)_s$ = design head for the actual pump with the hypothetically modified (suggested) number of stages;

H_{in} = lateral inlet head;

hp = horsepower

H_p = total dynamic (or steady-state) head on the pump;

$(H)_r$ or $(H)r$ = the required pump head;

H_r = the required head to be delivered by the pump when delivering Q_r;

K_{fi} = coefficient of head loss (for pipe i) associated with different fittings (*e.g.,* elbows, bends, etc.), excluding control valves;

K_{mi} = total minor losses coefficient for pipe i;

K_{oi} = coefficient of the head loss across the single giant orifice that simulates the lateral at the end of pipe i;

K_{vi} = coefficient of the head loss across the control valve along pipe i and is used along with other control valves to impose the required discharges through each demand point;

kW = kilowatt;

L = lateral length (*i.e.,* the radius of the circular area which the lateral irrigates);

$(QD)a$ or $(Q_D)_a$ = design discharge for the actual pump with the actual number of stages;

$(QD)b$ or $(Q_D)_b$ = design discharge for the best pump (the best pump is the pump that can deliver the required discharge and head with the least input power);

$(QD)s$ or $(Q_D)_s$ = design discharge for the actual pump with the hypothetically modified (suggested) number of stages;

Q_i = the discharge through pipe i;

$(Q)r$ or $(Q)_r$ = the total required discharge through the pump;

Q_r = the total required discharge through a lateral;

T.P.S.P. = total possible saving in power; it reflects the difference between the driver output power and the input power required by the best pump suitable for the application;

$UUPa$ or UUP_a = unused power or the difference between the driver output power and input power for the actual pump with the actual number of stages;

$UUPs$ or UUP_s = unused power or the difference between the driver input power and input power for the actual pump after hypothetically modifying its number of stages so that it just delivers the required head and discharge;

(W_p) = pump input power;

$(W_p)_a$ = design input power for the actual pump with the actual number of stages;

$(W_p)_b$ = design input power for the best pump (the best pump is the pump that can deliver the required discharge and head with the least input power);

$(W_p)_s$ = design input power for the actual pump with the hypothetically modified (suggested) number of stages;

Z_L = elevation of water demand point (*e.g.,* elevation of a representative lateral sprinkler outlet);

Z_1 = elevation of steady-state water level at the well when pumping at the required discharge;

η_a = design efficiency for the actual pump with the actual number of stages;

η_b = design efficiency for the best pump (the best pump is the pump that can deliver the required discharge and head with the least input power); and

η_s = design efficiency for the actual pump with the hypothetically modified (suggested) number of stages.

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اختيار المضخات للأغراض الزراعية في المملكة العربية السعودية

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المستخلص . يقدم هذا البحث تقييمًا مفصلاً لاختيار المضخات التربينية للأغراض الزراعية بالمملكة العربية السعودية . تشتمل هذه الدراسة على عرض لـ ١٨ حالة في منطقة القصيم من المملكة . يتراوح تعقيد أنظمة الري لهذه الحالات بين مضخة واحدة تغذي رشاشًا محوريًا واحدًا إلى عدة مضخات تغذي شبكة ري معقدة . في كل حالة ، يتم تقييم المضخة المستخدمة ومقارنتها بالمضخات الأخرى التي يمكن استعمالها لنفس الغرض . وحيث إن تكلفة التشغيل تفوق بكثير أي عنصر آخر من عناصر اختيار المضخة ، فإن المضخة التي تستهلك طاقة أقل تعتبر – في هذه الدراسة – هي الأفضل . تبين في معظم الحالات أن المضخة المستخدمة فعلا ليست الأفضل بين منافساتها من شركات أخرى . كما تبين أيضًا أن طاقة محرك المضخة المستخدم تفوق الطاقة اللازمة لتشغيل المضخة بمقادير متفاوتة .