Selection of pumps for special applications

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1. Introduction:

Even an expert manufacturer may not be able to produce a pump rendering satisfactory service if the hydraulic parameters specified by him do not meet the conditions required in the system in which the pump is supposed to operate. One of the major reasons for deterioration in such performance is the lack of proper care in system analysis and estimation of flow requirements and more importantly, actual head on pump. Pump performance specifications, if not matched with site operating conditions, lead to consequences that affect safety, reliability, capital costs, operational costs, etc. on actual usage. Entire range of operating conditions and the limitations imposed by the site must be duly considered before concluding on selection. The pump's ability to meet the discharge criteria is related to the pump's performance characteristics and the suction conditions imposed upon it. This paper highlights the critical aspects required to be considered while selecting a pump for a given application, elaborating some typical case studies.

Since success of any engineering project is indicated by the cost-benefit ratio involved in it, a practical approach through experience and expertise is the essence of the discussion here CWPRS has both these qualifications for resolving any pumping system project and has effectively contributed to more than 25 projects in the past two decades.

2. Study of site conditions :

On assessment of site, one may come to a decision about the maximum capacity of a single unit of pumpset and number of stages of pumping required to be adopted. The head on pump may be worked out individually incorporating head losses in pipeline and across each component. End user, however, is only interested in meeting an uninterrupted supply of total flow for maximum working hours of pumping station. To meet the required discharge, the optimum pumping system (with size and number of stages), may constitute a single pipeline or a number of pipelines in parallel or a branched system. While considering a particular quantity of water to be pumped, the following points need to be considered :

1. Selection of source of water
2. Water level conditions and submergence at intake
3. Intake structure required and point of utilisation of water
4. Storage capacity at utility point.

2.1 Selection of source of water:

Depending on the reliable available quantity and quality of water, source of water and location of pump intake are fixed. As in the case of many municipal water supply systems, if the source of water is a lake or a reservoir, sedimentation may not be a big problem for pumping of water through a number of pumps arranged with sufficient spacing. When locating a pump intake near a riverbank, as in the case of most of the lift irrigation schemes, care should be taken to avoid silting and air entrainment (ensuring sufficient submergence). It is conventional to provide openings at various levels to avoid sedimentation. Gates may be manoeuvred to suit the needs like opening the lower gates during lean flows and the upper ones during floods. Practically, it is preferred to locate pump houses slightly away from the riverbed, by cutting a trench in it to reduce siltation and for better maintenance.

2.2 Water level conditions of intake :

The position and location of pump intake generally depend upon the source of water available for pumping and the proximity of the plant to the source of water. In the case of pump intake structures constructed in the source of water (river, lake or sea), the water generally enters the intake structure which is in the form of well, from where water is directly pumped. However, in the case of river intakes, water is pumped continuously from river or stream without any appreciable storage upstream. In the case of pump intake placed away from the source, water is supplied to the intake through an open channel or a closed conduit.

Standard design of pump mainly depends upon rated flow per pump that is to be handled for irrigation, power plant, industrial, domestic or sewerage system. This will, in turn, govern the type and number of pumps required. The following aspects are considered for a good sump design:

1. Even flow distribution
2. Ideal flow condition in each pump bay with respect to swirl vortext or pre-rotation
3. Independent operation
4. Use of screens in pump bays for arresting all trash and floating material
5. Provision of gates to isolate pump bay for maintenance.

Pump sump geometry has large influence on the performance of a pump. Problems of air entrainment and swirl generation at intakes occur because of inadequate design. Theoretical means and design guidelines are available to arrive at a sump geometry, but model tests are the only means to ensure trouble-free operation of sump.

Froudian flow being the citerion for the similitude of pump intake, vortex and swirl phenomena are observed at various levels of water submergence. Operation of the sump with various combinations of pumps are studied to establish satisfactory performance of the pump intake at various submergence conditions. On repeated experiments with velocities exaggerated to twice and thrice Froudian and finally up to equal velocity, one would conclude if the sump configuration is satisfactory that anti-vortex/ anti-swirl devices are required to be incorporated in the prototype with the objective to minimise pre-rotation using expedients such as guide baffles, breast walls, floating rafts, grid walls, anti-swirl cones, splitter vanes, etc. However, efficacy of a suitable device in improving flow conditions can be established only after trial runs on the model and protracted experiments up to equal velocity criterion.

3.0 Selection of off-the-shelf pumps :

Having distributed total head over a number of stages, complete layout of the system is finalised. All components of the system including valves, bends, manifolds, reducers, etc. may be incorporated for evaluating total head for each stage of pumping, summing up static head and friction head. Market survey for various types of pumps and their availability will help to identify costeffective pump for a given site.

Selection of prime mover governs the selection of a pump, whether it is mechanically driven or electrically driven. In the case of electrically driven pumps, directly coupled AC motors up to 100 hp having rated speed up to 2900 rpm, are generally available in the market. As the size of the pump increases, the speed of prime mover reduces because 4-pole motors are used. For 6-pole motors, generally, the speed is around 980 rpm.

3.1 Assessment of capacity and head requirement :

Selection of pump on the basis of discharge capacity required for a given system conditions (head requirement) can often determine the pump type. The greatest number of alternatives are usually available in the smaller capacity ranges (overlapping with different types of pumps). Hence, efficiency, initial cost and running cost may be the primary factors.

Capacity required, together with the total head which the pump must develop, defines the required duty point of a roto-dynamic pump. A suitable size of pumpset can be selected from charts or tables of combined characteristics or from the product catalogues of the manufacturer to exhibit maximum efficiency at the duty point. The head capacity characteristics of a centrifugal pump are dependent on the impeller profile, the diameter (D) and rotational speed (N). The head (H) and discharge capacity (Q) are given by :

$H \propto N^2D^2$

$Q \propto ND^3$

And consequently power, P,

$P \propto N^3D^3$

Specific speed is defined by:

$$Ns = \frac{NQ^{1/2}}{H^{3/4}}$$

In the case of roto-dynamic pumps, for a given Q, the higher the head required, the lower the specific speed of the pump and where the head required is greater, it can be achieved by multistage pumps (with compromise on maximum efficiency at times).

In the case of small submersible pumps specially used in minor irrigation in tube well applications powered by constant speed drives, a range of working heads may be specified much wider than the normal working range of centrifugal pumps. Efficiency will very considerably over the normal working range of a centrifugal pump, the design being a compromise to provide working up to a particular vertical lift. The convenience of continuous operation with associated low running cost, ease of operation and exposure to longer and wider ranges have made submersible pumps very popular in irrigation sector. However, during a centralised selection, reliability of the pump performance may be best guarded by a rigorous test procedure before selection, as enlisted in IS: 8034-1948 and IS:10572-1983.

3.2 Life cycle costs :

Pumping systems often have a life span of 15-20 years. Some cost elements will be incurred at the outset and others at different times during the course of operation. The life cycle cost analysis is concerned with assessments where details of the system design are being reviewed. The cost of one type of pumping system is compared with another. The exercise mainly includes exploring options like configuring selected pump in a wet pit or dry pit arrangement that leads to less excavation cost. Analysis may also cover operational and energy costs with increased size of pipe and different types of material weighed against capital cost. In its entirty,

Live Cycle Cost

(LCC) = $C_c + C_m + C_e + C_o + C_m + C_s + C_{enr} + C_d$

where

C_c : Initial purchase costs (pump, system, pipe, auxiliary services)

C_m : Installation and commissioning cost (initial trials and training)

C_e : Energy costs (predicted cost for system operation)

C_o : Operation costs (including labour costs)

C_m : Maintenance and repair costs (routine/predicted repairs)

C_s : Shutdown costs (loss of revenue)

C_{enr} : Environment costs (to normalise the contamination)

C_d : Decommissioning/disposal costs.

Proper pumping system design being the most important single element in minimising the LCC, one should try to optimise the pumping system. This consists of pump, driver, and piping, operating controls all considered individually. The system design should consider the interaction between the pump and the rest of the system and the calculation of the operating duty point. The characteristics of the piping system must be calculated in order to determine the required pump performance.

4.0 Selection of equipment – Specific applications :

Selection of a particular pump for a given application could done after considering all the costs of components constituting the system. Three case studies detailing such aspects are discussed hereinbelow :

4.1 Case # 1 : City water supply system :

Under the Narmada project, the existing drinking water supply scheme for Indore city catering to 40 mgd (2.08 m^3/s) consists of 5 pump houses at different locations connected in series, which finally deliver water from Narmada river to a distance of 22 km. The static lift is 550 m up to pressure breakdown tank, from where water is further carried by gravity over a distance of 48 km to supply drinking water to Indore city and adjoining towns and villages. Now, it is being proposed by the Public Health Engineering Department to increase the total capacity to 200 mgd (10.4 m^3/s), with installation of 15 (10 working + 5 standby) vertical turbine pumpsets each of 20 mgd capacity to cope with increased demand. To meet this demand, selection of two types of pumps, namely, horizontal split-casing pump and vertical turbine pump was analysed.

Source	:	River
Daily requirement	:	200 mgd
Duration of pumping	:	Continuous / 22 hours per day
Total head available	:	550 m
Anticipated head variation	:	10 m

For the specified duty, one can consider two types of pumps. The horizontal split-casing pumps (HSC) have a slight advantage since they are about 10% cheaper than similar units of vertical turbine (VT) pumps. Cost of the accessories would be common to both the types of pumps; however, HSC pumps would require a valve on the inlet pipe, which would offset a major part of the cost benefit vis-a-vis VT pumpsets.

4.1.1 Civil works:

The width of pump house for installing VT pumps would be about 44.7 m, whereas for an HSC pump, it may be around 65 m to accommodate the, much larger size of base plates. As a result, the cost of pump house for an HSC pump installation will be much higher. In addition, the construction of dry pit for HSC, especially when it will be located in the reservoir after construction of dam at upstream, will be expensive and difficult to maintain in the long run.

4.1.2 Operating costs of pumping equipment :

- The water passages in an HSC pump are smaller; hence it is subjected to greater wear and tear, specially when pumping raw water. This would result in higher maintenance cost and lower reliability and efficiency for long term application.
- Since the efficiencies of the two types of pumps are comparable, there will be only a marginal difference in the costs of electricity for the two types of pumps. The water passages in an HSC pump are very narrow compared to VT pumps, hence it is more prone to erosion and wear, especially when pumping raw water. Hence the maintenance cost for HSC pump would be higher. An additional valve is required on the suction side of pump for maintenance and leakages through such valve and would cause problems for future operations.
- Since the motor of a VT pump is located above water level and the pump impeller can also be removed easily from the top by means of a crane, maintenance of VT pump is easy. On the other hand, for an HSC pump, to remove the impeller requires a valve to be fitted on the inlet side, which becomes a source of leakage of air into the pump. In addition, the walls of the pump house have to be waterproof, hence they require periodic maintenance.
- Impeller of a VT pump is located under the water, whereby very little noise and vibration are transmitted to the pump house as compared to HSC pumps, as per provisions of international standards on vibration and noise.

4.1.3 Sump layout :

Based on the data received from pump manufacturers, regarding column pipe size, bell-mouthed diameter and submergence required for fulfilling the required Net Positive Suction head Required, the configuration of 15 pumps has been divided into 3 compartments and a divider wall is provided to accommodate gates, for isolating the pump compartments and for stopping ingress of floating debris. A silt trip has also been provided to ensure that the water reaching the pumps is free of silt. Provisions were made to make necessary changes to finalise the exact location and orientation of this pump house with respect to water and ground levels and river flow conditions. Thus, a compact intake structure showing 15 VT pumps was finally selected.

4.1.4 Selection of pipe material and pumping stages :

Rigorous analysis was made with an objective of optimising total cost of pumping station. It was found that by considering 5 stages as against 4 stages originally proposed, there was quite a change in the head on pump and associated pumping equipment. The analysis was carried out with pipe material as Glass-Reinforced Plastic as against Mild Steel originally proposed. The proposed pipeline layout suggested a diameter of 1.3 M each for stages I and II; 1.2 M each for stages III, IV and V, as described in Tables 1 and 2. The total cost considering GRP material and five-stage pumping was found to be Rs. 483 lakhs compared to Rs. 522.31 lakhs for MS. Again, this was much less compared to four-stage pumping as originally proposed with MS material with a cost of Rs. 745.25 lakhs.

4.2 **Case # 2 : Irrigation pumps for tube wells :**

The Uttar Pradesh Irrigation Department (UPID), Lucknow invites quotations for supply of submersible pumpsets of varying ranges of head suitable for 300 mm bore wells keeping discharge capacity of 150 m^3 / hr fixed. Based on the water table existing at the Ganga-Yamuna basin, it is assessed that there is a requirement of about 1600 pumpsets of single-stage low head ranging from 15 to 24 m. similarly, towards high Himalayan range, the requirement of pumps of two-stage high head ranging from 27 to 48 m is about 600 Nos. for minor irrigation schemes. The sample pumps are tested at Central Water and Power Research Station (CWPRS) in accordance with the stipulations of IS : 9137 – 1978, IS : 11346 – 1985, IS : 325 – 1978, IS : 8034 – 1989 and IS : 10572 – 1983 (reaffirmed 1993) (all subject to latest amendments) and the specific clauses of the tender documents. To verify the specific performance guarantees quoted by the individual pump manufacturers, a series of tests are undertaken. The main parameters evaluated are tabulated in Table 1. The normal performance tests are carried out precisely at 415 V. The under-voltage and over-voltage tests are carried out at 353 (415-15%)V and 456(415+10%)V correspondingly at duty point.

From Fig 1a (Pump-A), it is observed that for a variation of head from + 10 to – 25% of rated head, the flow varies from 135.0 to 189.0 cum/hr, indicating power variation from 11.5 to 12.0 kW, the corresponding efficiency variation being 64.0 to 57.7%, above 50% stipulated. The rise in temperature of winding is 20.13^{o}C at 20% reserved capacity plus 20% overload, that remains much less than 25^{o}C maximum allowed. The hydraulic performance of the pump does not deviate from the normal voltage condition under the varied voltage conditions, i.e., 456 and 353 V. Thus, pump-A meets the guaranteed duty with a factor of 16.48 and overall efficiency at duty point 64.1%, maximum efficiency being 64.4%, within the range of head variation. The minimum efficiency is at the range of 57.7%, which is reasonably good. This confirms that pump-A is suitable for selection.

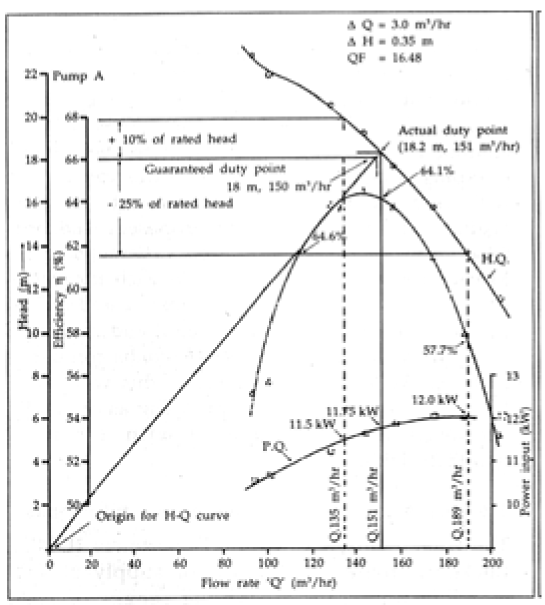


Fig. 1a

From Fig. 1b (Pump-B), it is observed that for a variation of head from +10 to –25% of rated head, the flow varies from 139.0 to 184.0 cum/ hr, indicating power variation from 11.25 to 11.75 kW, the corresponding efficiency variation being 66.8 to 58.0%, above 50% stipulated. The rise in temperature of winding is 22.40°C at 10% reserved capacity plus 20% overload, that remains much less than 25°C maximum allowed. The hydraulic performance of the pump does not deviate from the normal voltage condition, under the varied voltage condition, i.e., 456 and 353 V. Thus, pump B meets the guaranteed duty with a factor of 8.6 and overall efficiency at duty point 65.7%, maximum efficiency being 66.85%, within the range of head variation. This proves that pump-B is suitable for selection, this pump is superior to the previous, considering higher efficiency in the considered range. The minimum efficiency within the range is 58.0%, which is narrow margin from the stipulated value, and temperature rise is 22.4°C, that is less than 25°C.

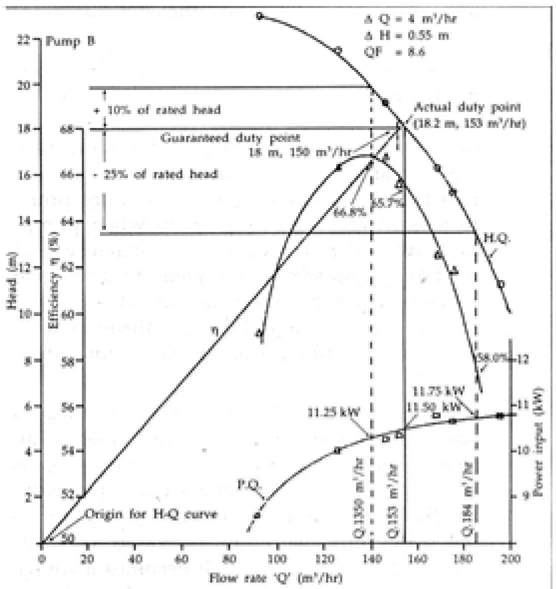
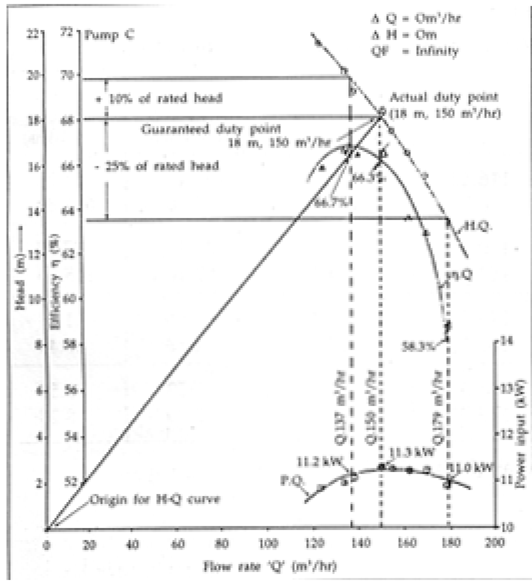


Fig. 1b

From Fig. 1c (Pump-C), it is observed that for a variation of head from +10 to –25% of rated head, the flow varies form 137 to 179.0 cum / hr, indicating power variation from 11.2 to 11.05 kW, the corresponding efficiency variation being 66.7 to 58.3%, above 50% stipulated. Thus, pump-C meets the guaranteed duty with a factor of infinity and overall efficiency at duty point 66.3%, maximum efficiency being 66.71%, within the range of head variation. The rise in temperature of winding is 17.26°C at 10% reserved capacity plus 20% overload, (that remains much less than 25°C maximum allowed), that is also lower in comparison to previous pumps. This proves that pump-C is more suitable for selection and it could be said that it is superior to the previous pumps, considering lower power drawn, and higher minimum efficiency (58.3%) in the considered range.



From Fig. 1d (Pump-D) it is observed that for a variation of head from +10 to –25% of rated head, the flow varies from 107 to 166 cum/hr, indicating power variation from 10.05 to 11.15 kW, the corresponding efficiency variation being 57.75 to 56.0%, above 50% stipulated. However, at the guaranteed duty, the pump is found to exhibit a guarantee factor of only 0.574, with the duty point laying outside the graph, thus the pump is not suitable to be selected, as stipulated by relevant standard. Overall efficiency at duty point is just 60.0%, maximum efficiency being 60.32%, within the range of head variation. This proves that pump-D is not suitable for selection, considerating range of operation of pump. The minimum efficiency at the range is 56.0%. It is worth mentioning that the current drawn at duty point is 18.71 Amp, which is less than the stipulated value. The rise in temperature of winding is 33.61^{o}C at 20% reserved capacity plus 20% overload, that is much higher than the 25^{o}C allowed.

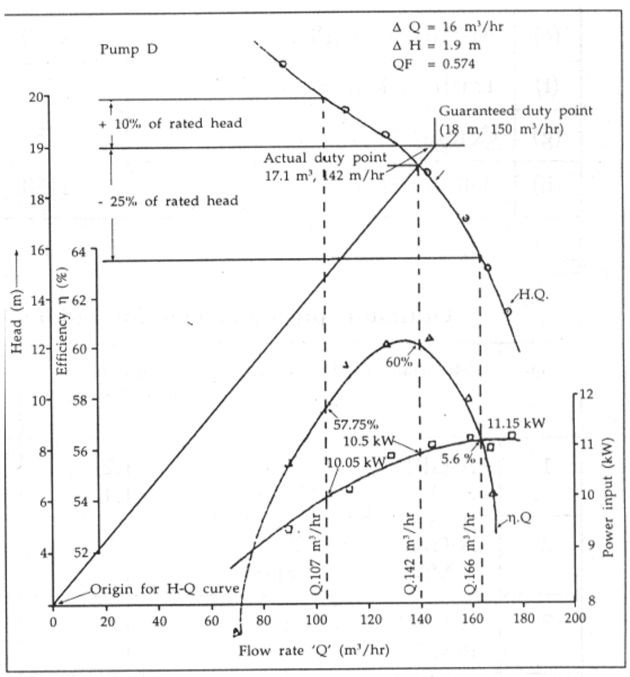


Fig. 1d

5.0 Conclusion :

The two case studies discussed above reveal the necessity to analyse engineering aspects of any pumping system before finalising the equipment. Pumping systems often have a life span of 15-20 years. Since part of the cost elements will be incurred at the outset and others at different times during the course of operating, the life cycle cost analysis is concerned with assessments where details of the system design are being reviewed. The cost of one type of pumping system is compared with another. The exercise mainly includes exploring options like configuring selected pump in a wet pit or dry pit arrangement that leads to less excavation cost. The analysis may also cover operational and energy costs with increased size of pipe and different types of material weighed against capital cost.

TABLE 1

Sr. No.	Sump dimensions in mm	Hyd. Inst. Standards	As per Takari design dimensions	CWPRS recommendations for new sump
(a)	Bottom clearance (C)	370	600	650
(b)	Back wall distance (B)	760	862	950
(c)	Distance between pumps (S)	1800	2775	2500
(d)	Height of water column (H)	2650	4500	3500
(e)	Approach length (Y)	2550	7000	6400
(f)	Trash rack to back wall (A)	4700	6580	6400
(g)	Column pipe dia	750	750	750
(h)	Bell-mouthed dia	1150	1125	1125

TABLE 2

Optimum pipe diameter for Indore Water Supply Project, 4-state pumping

Stage	Material	Length of pipe (Mtr)	Optimum diameter (Mtr)	Total head (MWH)	Annual Capital cost Rs. (lakhs)	Annual energy cost Rs. (lakhs)	Annual total cost Rs. (lakhs)
1	A-GRP B-MS	17000 17000	1.2 1.4	116.13 106.56	337.76 511.63	130.19 90.16	467.95 601.80
2	A-GRP B-MS	2800 2800	1.2 1.2	150.13 152.68	55.63 86.63	21.44 32.10	77.07 118.73
3	A-GRP B-MS	400 400	1.2 1.2	145.73 146.10	7.94 11.91	3.06 4.58	11.01 16.49
4	A-GRP B-MS	200 200	1.2 1.2	145.37 145.55	3.97 5.93	1.53 2.29	5.50 8.23

Total (GRP) : Rs. 561.53 lakhs   Total (MS) : Rs. 745.25 lakhs

TABLE 3

Optimum pipe diameter for Indore Water Supply Project, 5-stage pumping

Stage	Material	Length of pipe (Mtr)	Optimum diameter (Mtr)	Total head (MWH)	Annual Capital cost Rs. (lakhs)	Annual energy cost Rs. (lakhs)	Annual total cost Rs. (lakhs)
1	A-GRP B-MS	8500 8500	1.3 1.5	53.04 53.13	150.97 157.49	44.04 31.93	195.05 189.43
2	A-GRP B-MS	8500 8500	1.3 1.5	53.04 53.13	150.97 157.49	44.08 31.93	195.05 189.43
3	A-GRP B-MS	2800 2800	1.2 1.2	150.13 152.68	55.63 86.63	21.44 32.10	77.07 118.73
4	A-GRP B-MS	400 400	1.2 1.2	145.73 146.10	7.94 11.91	3.06 4.58	11.01 16.49
5	A-GRP B-MS	200 200	1.2 1.2	145.37 145.55	3.97 5.93	1.53 2.29	5.50 8.23

Total (GRP) : Rs. 483.68 lakhs   Total (MS) : Rs. 522.31 lakhs

TABLE 4

Comparative statement on performance evaluation of 18 m head, 150 cum/hr pumpset

Sr.No.	Duty Parameter	Pump A	Pump B	Pump C	Pump D
1	Head, m (against 18 m)	18.2	18.2	18.0	17.1
2	Flow, m3/hr (against 150 m3/hr)	151	153	150	142
3	Guarantee Factor (more than 1.0)	16.48	8.6	Infinity	0.574
4	Efficiency, % (more than 60%)	64.10	65.70	66.30	60.00
5	Power input, kW	11.75	11.50	11.30	10.90
6	Current, A (less than 28.14 A)	18.76	19.02	18.40	18.71
7	Maximum efficiency, %	64.40	66.85	66.71	60.32
8	Flow at max. efficiency, m3/hr	144.04	145.05	134.73	138.00
9	Power factor (more than 0.8)	0.8945	0.8351	0.8356	0.816
10	Min. overall efficiency , % (>50%)	57.70	58.00	58.30	56.00
11	Average efficiency, %	61.93	63.50	63.76	57.91
12	Temperature rise, ^{o}C (<25^{o}C)	20.13	22.40	17.26	33.61
13	Whether fulfils requirement	Yes	Yes	Yes	No

Reference Book:

Indian Pumps
Newsletter of the Indian Pump Manufacturers Association,
June 2005