CHAPTER 5

5.Pumping Station and Machinery

CHAPTER 5: PUMPING STATION AND MACHINERY

5.1 Introduction

Pumping of water serves a variety of functions in water supply systems, such as moving water from a source to a water treatment plant and from the treatment plant to the distribution system. High and low lift pumps are used consistent with the topography of land and location of the water treatment plant, whereas high service pumps are employed to discharge water under pressure to the water distribution system. Booster pumps are used to increase pressure in the water system. Recirculation and transfer pumps are used to transport water through a treatment plant. Vertical turbine (VT) pumps are employed in well pumping.

VT pumps are generally installed in source water intake pumping. Either VT or centrifugal pumps are commonly used for high and low service to lift and transmit water. VT pumps can also be used to move water to treated water transmission and distribution systems. Centrifugal pumps are popular because of their simplicity and compactness, low cost, and ability to operate under a wide variety of conditions. This chapter deals with the design of the pumping station, selection of pumps, their types, and characteristics, electric motors, their types and characteristics, etc.

This Chapter also has important linkage and interdependability with Chapter 9 of Part B dealing with operation and maintenance of pumping station and pumping machinery because designs directly affect the effectiveness of operability and maintainability. Sample calculation for pumping machinery is enclosed in **Annexure 5.1**.

5.2 Requirements of pumping station

The subsections below detail the general requirements of the pumping station comprising intake/sump/other sources, pumps, and allied equipment in the pumping station.

Types of pumping station and source

The pumping stations are for housing pumping machinery powered by energy sources with required equipment and accessories housed in appropriate buildings to pump water at required points of interest such as water treatment plants or treated water to the consumer end. There are other locations also in a water supply system where pumping of water is required to increase pressure in a low-pressure zone or fill water in elevated reservoirs.

Types of sources and pumping stations are as under:

- River intake
- Intake in an impounded reservoir
- Intake in lake
- Piping intake from dam
- Sump and clear water pumping station
- Booster pumping station with sump and pump house
- In-line booster
- Borewell/tube well
- Dug well

Broad classification of pumping station

The size of pumping station depends on the quantity and quality of water and the head to which it has to be pumped. Since all the components are not required in every condition, the pumping station can be broadly classified as small, medium, and large as given in Table 5.1 below.

Table 5.1: Broad classification of pumping station

Sl. No	Size of pumping Station	Quantity of water Pumped in MLD
1	Small	Less than 25 MLD
2	Medium	25 to 125 MLD
3	Large	Above 125 MLD

Components of a Small, Medium, and Large Pumping Station

Sl. No.	Component	Small	Medium	Large
1.	Site and location of pumping station			
a.	Inlet channel	✓	✓	✓
b.	Screen or rose pieces/Drum screen/inlet strainer	✓	✓	✓
c.	Pre-settling tank/silting basin	✓	✓	✓
d.	Sump wells	✓	✓	✓
e.	Pump house	✓	✓	✓
f.	Pumping machinery	✓	✓	✓
g.	Suction and delivery piping system	✓	✓	✓
h.	Water hammer control device	✓	✓	✓
i.	Clear water reservoir			✓
2.	Electric substation and substation building			
a.	Metering panel	✓	✓	✓
b.	Transformers and transformer yard		✓	✓
c.	MCC panels, etc.	✓	✓	✓
d.	D.G. sets	✓	✓	✓
e.	Battery room, charger, and DCDB		✓	✓
f.	Pole-mounted or plinth-mounted transformer	✓	✓	✓
3.	Ventilation (Air supply fans/exhaust fans/combination system -as per requirements)	✓	✓	✓
4.	Instruments - Flow, level, pressure, temperature	✓	✓	✓
5.	Internal and outdoor Lighting	✓	✓	✓
6.	Control room	✓ (Common room)	✓	✓
7.	Operator room		✓	✓
8.	Miscellaneous components			
a.	Security guard room	✓	✓	✓
b.	Boundary wall and gate	✓	✓	✓
c.	Parking lots and roads	✓	✓	✓
d.	Storeroom, office, and toilet block	✓	✓	✓
e.	Thrust block	✓	✓	✓
f.	Lifting arrangement in screen chamber, pump floor, silting basin		✓	✓
g.	Internal water supply, sanitary arrangement, wastewater, storm water, and garbage disposal	✓	✓	✓
h.	Material handling equipment {cranes/hoists/gantry as required (at intake, trash rack, and inside pump house)}	✓	✓	✓
9.	Lightning protection to buildings and substations	✓	✓	✓
10.	Aesthetic and environmental considerations	✓	✓	✓

5.2.1 Site and location of pumping station

The site of the pumping station should be on dry land free from flooding risk. In case the site lies in flood prone area, the pumping station should be protected by constructing a proper embankment along with the river and pump chamber and providing adequate drainage arrangement for the pump house and its adjoining area. The pump/motor floor shall always be kept 1-2 m safety margin above high flood level (HFL) with due consideration of flood risk and should remain approachable by a vehicle even in peak monsoon. The site should have sufficient area to locate all the components of the pumping plant as mentioned and preferably on even ground and adequately above HFL. The tapping from the power grid of the supplier should preferably be as near as possible to the pumping station consistent with the reliability of supply, to avoid the high-cost involvement in obtaining power supply from a distant grid. The pumping station should have easy access for heavy vehicles carrying machines, hoisting equipment, etc. minimum of 3 m clear width (excluding pipe, pipe collar, railing, flowmeter, lighting stand post, cable tray, thrust block/wall, etc.) shall be available in approach road/bridge. Sufficient spaces should be provided for transformer substation, water hammer control device, service roads, parking lots, loading areas, heavy lifting equipment, roadside warning signals, stores, security, toilets, etc.

5.2.2 Dedicated Independent Electric Feeder

In the case of all water works and pumping stations, it is preferable to insist on a dedicated independent electric feeder, as these installations are in operation round the clock, throughout the year. An electric substation is required if the power load is 63/100 kVA or higher. The definition given by Electricity Supplying Authorities regarding independent feeders is given below.

An ‘independent feeder’ would be a feeder in which electricity is supplied only to a single consumer at his own cost relying upon the words “to only that consumer”.

Wherever independent electric feeder is not available, a diesel generator shall be provided as standby power supply.

5.2.3 Inlet Channel for Intake

The inlet channel to the settling tank shall receive water through the outlet conduit emanating from the intake structure. A minimum velocity of 0.8 m/s should be maintained in the channel. The mechanical bar screen is used to retain debris with a travelling rake mechanism to elevate the floating materials like grass, leaves, etc. along the upstream side of the bar screen. The bar screen shall consist of steel bars of suitable depth and thickness generally with a 15-25 mm clear opening

5.2.4 Trash racks and Screen Chamber

A coarse screen may be installed to remove large matter, like floating wood or stones from raw water. A crane for lifting big obstacles and a lifting device for removing accumulated mud or sand from the basin will be installed. Footsteps will be provided for the descent into the basin.

The trash racks may be classified into the following types by their constructional features and the methods of installation:

(i) Type 1 - Removable section racks which are installed by lowering the sections between side guides or grooves provided in the trash rack structure so that the sections may be readily removed by lifting them from guides. These are generally side-bearing types.

(ii) Type 2 - Removable section racks in which the individual sections are not installed between guides in the trash rack structure but are placed adjacent to each other laterally and in an inclined plane to obtain the desired area of flow. Since rack sections may easily be displaced, these have to be secured in place with bolts located above the water line.

(iii) Type 3 - Trash rack sections that are bolted in place below the water line.

Other details shall be as per IS 11388.

Inclination in trash racks is provided to take advantage of an increased section of contact. However, trash racks are also installed without inclination in the vertical grooves of the Intake. These may also be split into panels for ease of handling, i.e., raising/lowering by the lifting beam and hoisting structure provided at deck/pump floor level. A self-grappling/un-grappling type of lifting beam mounted on a manual/electrically operated chain block hoist is provided at the top of the hoist structure.

5.2.5 Pre-Settling tank

Pre-settling tanks, which are plain sedimentation tanks, are useful as a preliminary process to reduce heavy sediments preferably before the intake sump. They may be of quiescent or continuous flow.

Factors that influence sedimentation are:

(i) size, shape, and weight of particle;
(ii) viscosity and temperature of water;
(iii) surface overflow;
(iv) surface area;
(v) velocity of flow;
(vi) inlet and outlet arrangement;
(vii) detention periods; and
(viii) effective depth of basins.

The continuous flow type of sedimentation tank is widely adopted. The aspects of a continuous flow sedimentation tank hydraulic are as follows:

(i) The velocity of flow of water in sedimentation tanks should be sufficient enough to cause hydraulic subsidence of suspended impurities. It should remain uniform throughout the tank.
(ii) Maximum surface loading of 60 m^3/day/m^2 and a hydraulic retention time (HRT) of three to four hours have to be provided.
(iii) Two settling tanks, one working and one stand by should be provided in case of quiescent flow.

Refer to Section 8.2 of Part A of this Manual for further details.

5.2.6 Raw Water intake and sump (raw and clear water)

Raw water intake (popularly also called jack well) is designed keeping in view the period of minimum inflow level, so that the inlets of the suction pipes or bell mouths of pumps as per pump selection always remains submerged with adequate submergence. Please refer section 5.2.7 for details.

Normal practice for all small, medium, and large water supply systems is to design an intake for at least 1.5 times the design flowrate in ultimate stage. Balancing capacity is not an applicable parameter for raw water intake as the inflow rate from the source always matches the outflow/pumping rate. Shape of intake may be circular for small scheme and circular or rectangular for medium scheme. Preferably intake for large scheme shall be rectangular.

Adequate balancing capacity in the raw water/clear water sump is required to overcome variation in discharges of raw water pumps and clear water pumps due to ± tolerances in discharge as per IS and/or substantial increase in discharge of raw water pumps due to lower head consequent to higher water level at source. The balancing capacity of sump shall be referred from Table 2.7 in Chapter 2 Part A. The sump in small and medium scheme may be circular. In case of large scheme, rectangular sump is preferable. Water depth in sump shall be 3-4 metres. Pump/motor floor level of intake and sump shall be at least 0.75-1 m above surrounding/finished ground level or 1-2 m above HFL; whichever is higher.

Spaces for number of working and standby pumps in the ultimate stage shall be planned even though, initially, the number of pumps installed shall be as per planning for immediate/intermediate stage. As regards to intake for large scheme, wherever possible, it is advisable to keep space for additional one pump for contingency during the life of the intake of 50 years as the construction of a new intake is costly and time-consuming.

5.2.7 Intake/Sump Design

5.2.7.1 The objectives of intake/sump design

Detailed consideration needs to be devoted to the intake design to serve various objectives in dry-pit as well as wet pit as follows which are based on IS 1710 and international standards:

(i) to prevent vortex formation;
(ii) to obtain uniform distribution of the inflow to all the operating pumps and to prevent starvation of any pump;
(iii) to maintain sufficient depth of water to avoid air entry during drawdown.

5.2.7.2 Guidelines for Intake/Sump design

Figure 5.1 below illustrates recommended and the not-recommended practices for sump or intake design. The following points are to be noted in this respect:

(i) Avoid mutual interference between two adjoining pumps by maintaining sufficient clearance, the dimension ‘S’ in Figure 5.1 is equal to 2 D to 2.5 D.

(ii) Avoid dead spots by keeping rear clearance, dimension B to a maximum of 0.75 D from the centre line of the pump inlets/bell mouths. A dummy wall may be provided, if necessary, in a clear water sump. The top of the dummy wall shall be a minimum up to low water level (LWL). A dummy wall for rear clearance is not advisable in intake which obstructs silt removal. A cone underneath the bell mouth is an adaptable solution to prevent vortex problems.

(iii) It is not advisable to provide dividing walls/baffles in raw water intake which obstructs silt removal. In the case of a clear water sump, dividing walls may be provided between the adjacent bell mouths ensuring that the front edges of bell mouths and the dividing walls are in line and the ends of dividing walls are ogive.

(iv) Provide tapered walls between the approach channel and the sump. By this, the velocity should reduce gradually to about 0.3 m/s near the pumps. This also helps to avoid sudden changes in the direction of the flow. The angle of tapered walls shall be a maximum of 10 degrees.

(v) Avoid dead spots under the suction bell mouth by maintaining the bottom clearance, dimension ‘C’ between D/4 to D/2, preferably D/3 as shown in Fig. 5.2. It is important that dimension ‘C’ should NOT be less than D/4; otherwise, peripheral approach velocity shall be higher than inlet velocity at bell mouth which can cause flow disturbance at the inlet to bell mouth. It is to be noted that in the case of raw water intake, it is not practicable to adhere to dimension ‘C’ allowable maximum up to D/2 as a margin for silt accumulation of about 500-1,000 mm is required. Thus, actual ‘C’ is excessively higher and shall create vortex disturbance. As a remedial/preventive measure, a Cone or Concrete/Metallic Splitter underneath the bell mouth is necessary and shall be provided, preferably during construction of intake and raw water sump.

(vi) Either splitter or cone shall be provided if a vortex problem occurs as shown in Fig. 5.4 as corrective measure. A splitter or cone is not necessary if ‘C’ is between D/4 to D/2.

(vii) Avoid sudden drops between the approach channel and the pump well/pump pit in intake and sump. A slope of a maximum of 10° is recommended as shown in Fig. 5.2 so as to achieve adequate water depth for submergence parameter. A suction pit as alternative to floor slope is not advisable for water supply system as this causes waterfall effect and unacceptable flow disturbance. (Such suction pit with steep slopes/haunches on sides to prevent deposition of solids, can be, however accepted for sewage pumping system)

(viii) The floor in the approach bay to the pump suction should be flat up to at least 5D.

(ix) V, the velocity of flow in the pump pit, when water is at LWL, shall not exceed 0.3 m/s.

(x) No cross flow greater than 0.5 V is allowed in the pump pit.

(xi) Within 5D on the upstream side from the centre of suction/bell mouth, if any pier/column is positioned, its sides should be rounded off and downstream sides should be tapered. As far as possible, the approaching flow should directly pass to the pumps without any swirl, change in flow direction and without any obstruction in the flow path.

(xii) Follow-up action shall be taken if dimensions and parameters for vortex-free operation are not fulfilled. The recommended actions for large and important pumping stations are either, or both, as follows:

a. Computational Fluid Dynamics (CFD) Analysis should be carried out for medium and large pumping station. Refer to **Annexure 5.2**.
b. Sump model test should be conducted for large pumping station. Refer to **Annexure 5.2**. Remedial measures concluded after CFD analysis and/or sump model test shall be implemented.

(xiii) For small and medium pumping stations, one of the methods indicated in Figure 5.4, as per applicability, can be adopted to eliminate vortex problems in pump pits.

(xiv) Circular sump and pump house

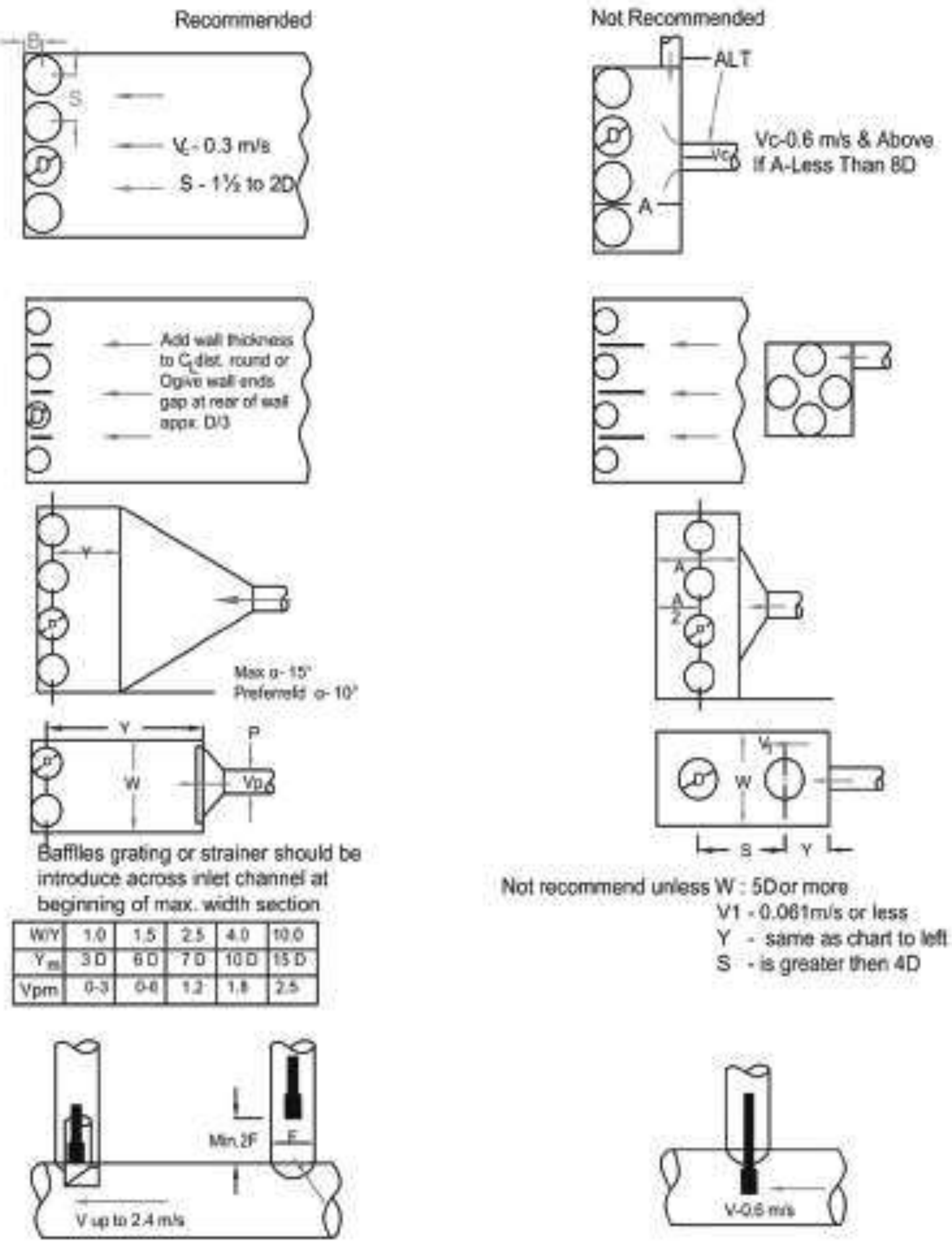
Circular sumps are very popular in India as they are economical in terms of construction costs, easy to construct, and offer compact layout. Figure 5.3 (b) and 5.3 (c) show typical circular sumps for two pumps and three pumps respectively located at centrelines. Important design dimensions and aspects are as follows:

a. Floor clearance (C) between lip of bell mouth and the bottom for clear water sump shall be D/2 where D = diameter of suction bell mouth. In raw water sump, the clearance shall be based on silt margin.
b. Centre to centre spacing between adjoining bell mouths shall be 1.5 D ensuring that the clearance (C_b) between adjoining bell mouths shall not be less than 100 mm or clear gap, i.e., working clearance of minimum 500 mm between two adjoining pumps and motors, whichever is higher.
c. Wall clearance (C_w) shall not be less than D/4 subject to minimum of 100 mm or wall clearance of minimum 400 mm from motor, whichever is higher.
d. The submergence (S_b) above the lip of bell mouth shall be worked as per guideline in (xvi) below.
e. The diameter of sump shall be worked out fulfilling the dimensions stated in ii and iii above.
f. The inflowing pipe shall be at an elevation with partly or fully below LWL to avoid air entrainment and disturbance due to cascading of flow.

(xv) Sump model tests are required to be carried out if the pumping station falls in the following categories:

a. Non-uniform or non-symmetric approach flow to the pump sum exits (e.g., intake from a significant cross flow, use of dual flow or drum screens, or a short radius pipe bend near the pump suction, etc.)
b. Flow greater than 2.52 m^3/s per pump or 6.31 m^3/s per station

c. Circular sump pumps with discharge greater than 0.315 m^3/s



W/Y	1.0	1.5	2.5	4.0	10.0
Y_m	3 D	6 D	7 D	10 D	15 D
Vpm	0-3	0-6	1.2	1.8	2.5

Figure 5.1: Multiple Pump Pit

(xvi) Submergence Sb is to be worked out on the basis of the Froude number, FD using the following two equations.

$$F_D = \frac{V}{\sqrt{gD}}$$

$$Sb = D(1 + 2.3F_D)$$

Where

V = flow velocity, m/s

G = acceleration due to gravity, 9.81 m/s^2

D = bell mouth outside diameter, m

Sb = submergence above the lip of bell mouth

Therefore,

$$H = Sb + C \text{ (actual clearance)}$$

Where H is the minimum depth of water required above the bottom of the sump and C is actual bottom clearance under bell mouth.

Keep adequate submergence of the pump under the LWL as per the dimension H to prevent the entry of air during drawdown and to satisfy NPSHr.

(xvii) Position of trash - rack dimension 'A' is minimum 5D. (Dimension A, however, usually exceeds 5D as Y is also equal to 5D.)
Note: Dimension 'D' is the outside diameter of the suction bell mouth at the inlet which can be derived for dimensions of parameters and hydraulic design of pump bay for vortex-free flow conditions by calculating inside diameter by keeping inlet velocity 1.2 to 1.4 m/s and adding thickness to it.

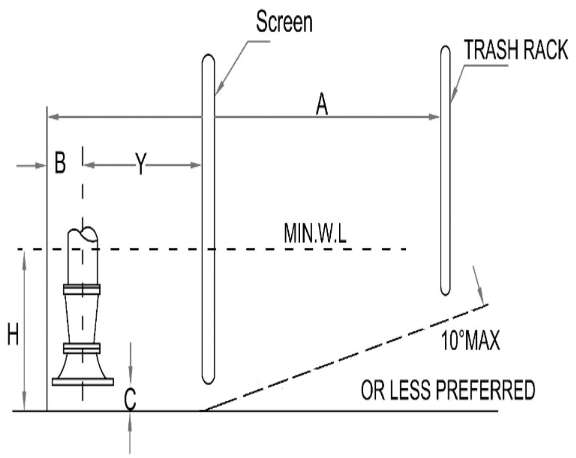


Figure 5.2: Sump dimension elevation view

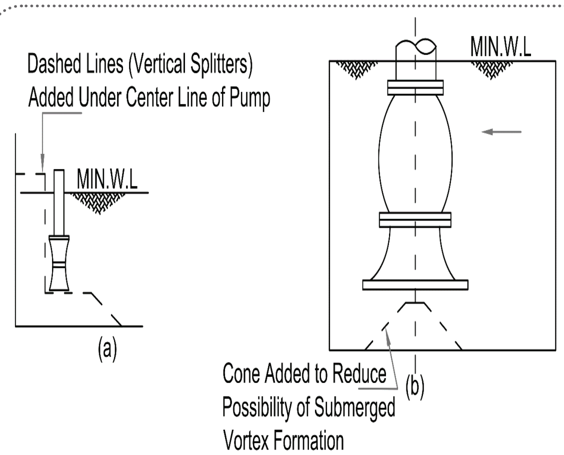
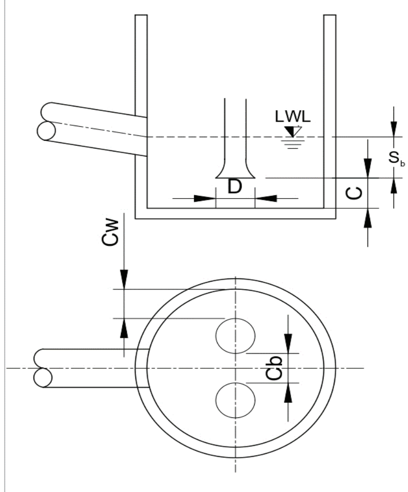
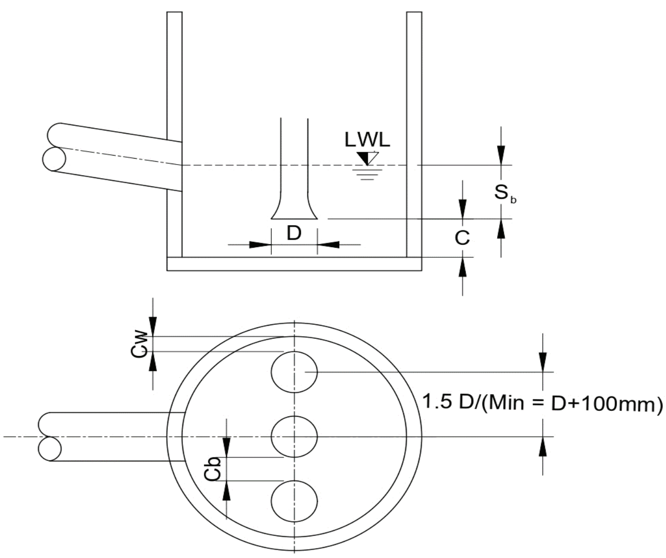


Figure 5.3(a): Vertical Splitters/Cone in the Sump





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D = Bellmouth diameter C(Bottom clearance) = D/2 C_b= D/4/(Min 100mm)
C (Wall clearance) = D/4/(Min 100mm) S_b= Min Submergence

Figure 5.3(b): Two Pumps in Circular Sump **Figure 5.3(c): Three Pumps in Circular Sump**

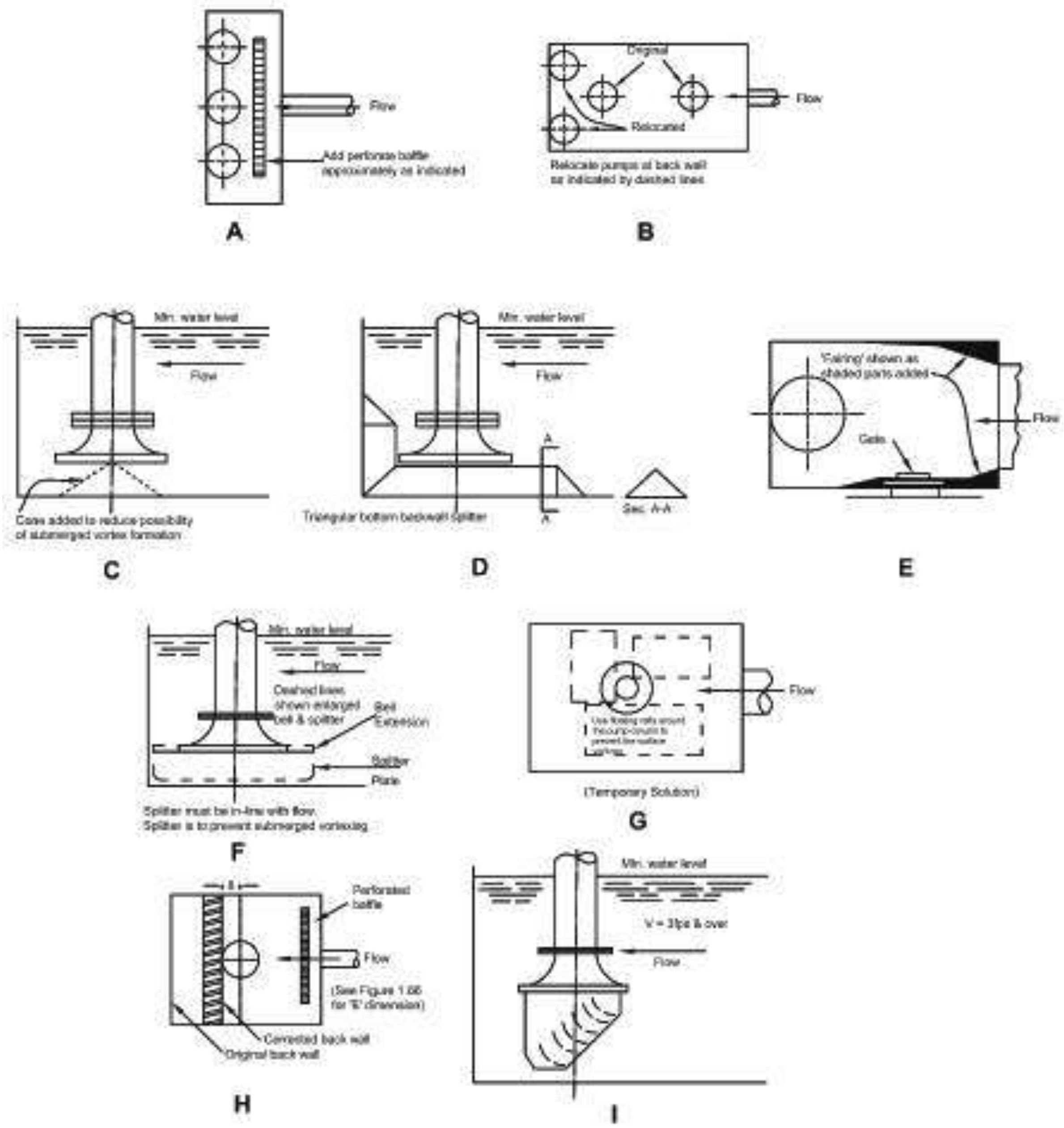


Figure 5.4: Common Methods for Eliminating Vortex in Sumps

Source: Hydraulic Institute ANSI/HI 2000 Edition Pump Standards

5.2.7.3 Piping Intake from Dam

In some impounding reservoirs, where raw water is to supply on downstream of the dam, a pipe outlet is provided from the dam. In such a case, the outlet pipe is extended up to a suitable short distance to locate the raw water pumping station. This outlet pipe is used as piping intake for the pumping station by configuring the outlet pipe as suction manifold for installing (a) barrel type VT pumps or (b) centrifugal pumps as discussed below. Refer to Figure 5.5.

(i) Guiding Criterion

The arrangement is also suitable for connecting the suction manifold to individual suction piping of centrifugal pumps. Criteria as under shall be adhered to:

a. Flow velocity in inlet pipe/suction manifold shall not exceed 2.4 m/s.

b. Velocity in the annular area between barrel and VT pump shall not exceed 1.5 m/s.
c. A 90° long radius bend shall be provided between individual suction/inlet pipe and barrel. Tip of suction bell mouth shall be above the upper tip of 90° bend.
d. LWL in the barrel for VT pump shall be above the lip/tip of bell mouth as per minimum submergence required (based on Froude number) or minimum 1 Db above first stage impeller whichever is higher, where Db is the diameter of the barrel.
e. Velocity in individual suction pipe shall not exceed 1.5 m/s.
f. If individual suction pipes of centrifugal pumps are connected at 90° to the suction manifold. The minimum distance between the individual pump suction nozzle and the centreline of the manifold shall be 8 × Ds where Ds is the individual suction pipe diameter.

(ii) Provision of Surge Control Device on Inlet pipe to Pumping Station

Since inlet pipe/suction manifold is in the continuity of the dam outlet pipe, when all pumps stop on power failure or due to malfunctioning, the flow velocity in the inlet pipe will rapidly decrease causing water hammer overpressure on the inlet pipe and individual suction pipe. A suitable control-free and maintenance-free surge control device is obligatory.

If the elevation difference between FRL in the dam and ground level at the pumping station is less than 25 m, reliable protection can be achieved by providing a MS surge shaft or elevated surge tank as shown in Figure 5.5. The top of the surge shaft/surge tank should be above the FRL of the dam as per the maximum WL rise in the surge shaft/surge tank calculated on the basis of numerical analysis for the surge tank/surge shaft. This is necessary to prevent overflow due to WL rise under surge.

Both the surge shaft and surge tank are ideal and proven devices requiring no control and no maintenance except for re-painting.

If the elevation difference exceeds 25 m, then the air vessel is the only solution. It may be noted that a surge suppressor/surge anticipation valve is not advisable for raw water application as the pilot valve gets clogged due to impurities and floating material in raw water.

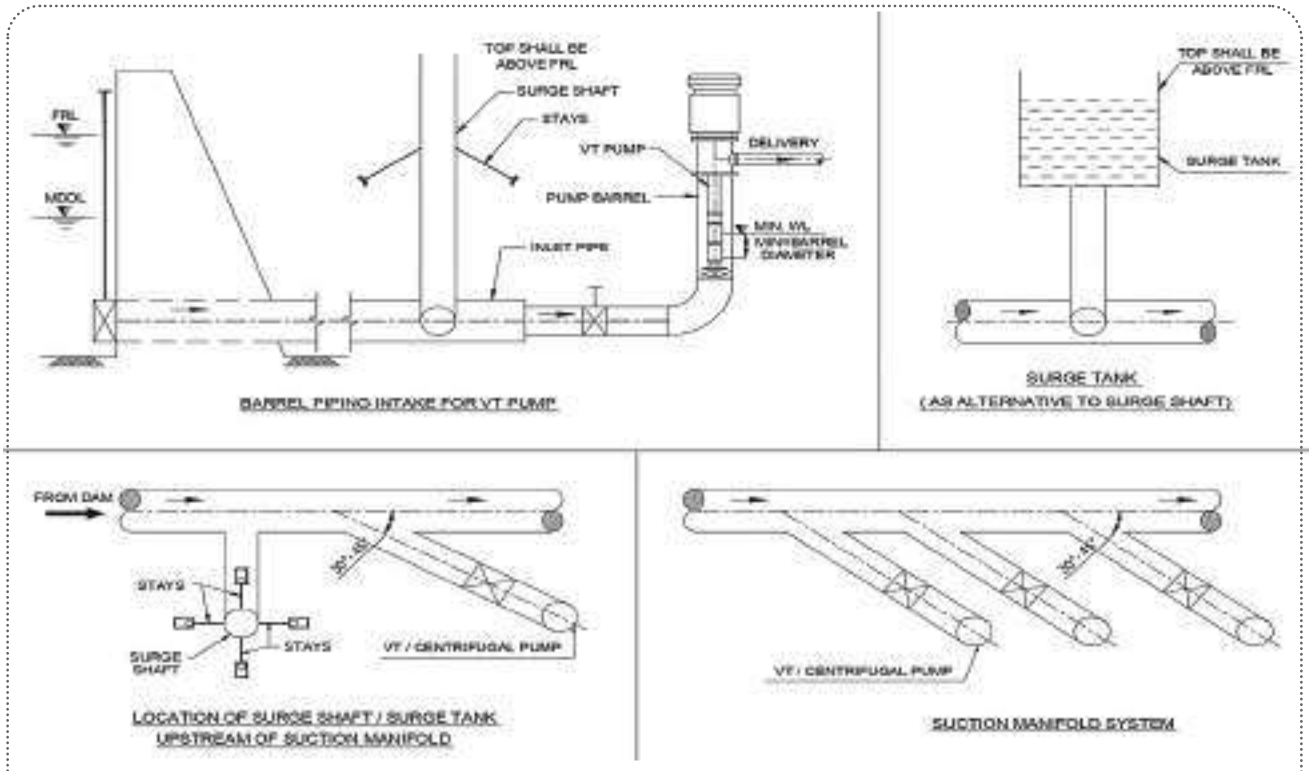


Figure 5.5: Piping Intake, Surge Tank, and Suction Manifold

5.2.8 Pump house

In raw water intake, either vertical turbine pump or an alternatively submerged turbine pump can be selected. In case of sump, positive/flooded suction is commonly arranged for the large/medium pumping station by locating generally double suction horizontal split casing pump or end-suction centrifugal pump in adjoining dry pump room such that top of the volute of centrifugal pump is below minimum water level by magnitude of friction loss on suction piping and a small margin for drawdown level and inaccuracies in installation levels. Alternately, a submerged centrifugal pump can be used. The general arrangement and dimensions of the pump house are determined by the type and number of working (W) plus standby (S) pump sets to be installed in intermediate stage and additions of pumps for ultimate stage, room for storing spares, Motor Control Centre (MCC) and Programmable Logic Controller (PLC) panel, cable trays, etc. The spacing between adjoining pumps depends on the size of the pump-motor set and working clearance, normally kept at 750-1000 mm or minimum spacing required between bell mouths/suction inlets for vortex-free operation in pump pit, whichever is higher. Sufficient ventilation by providing air supply fans and/or exhaust fans and lighting arrangement should be provided in the pump house. Ventilation for large pumping stations, which is usually done by both air supply fans and exhaust fans. Adequate space should be provided for panel boards, working area for maintenance of pump sets, loading/unloading bay, cable ducts, pump foundation, pipe supports, valve supports, and provision for suction and delivery pipe connections. Lifting equipment shall be provided for the handling of pumps, motors, and other accessories. Pump house should have sufficient headroom to operate the EOT/HOT crane. A minimum of 1.5-2 m clearance should be kept between EOT/HOT and the soffit of the roof beam. Dewatering pumps should also be provided to safeguard against emergency flooding of the below-ground pump houses. The pump house should be designed to maintain the noise levels inside the pump house below permissible limits and to absorb vibrations while pumps are in operation.

1. A ramp or a loading and unloading bay should be provided.
2. The lower floor and upper flower are necessary if the diameter of delivery piping is 350 mm and above and the floors should be so planned that all piping and valves can be laid on the lower floor and the upper floor should permit free movement. The headroom between two floors shall be about 2250-2500 mm.
3. Headroom and material handling tackle.
    a. In the case of a vertical pump with hollow shaft motors, the clearance should be adequate to lift the motor clear off the top face of the discharge head and also carry the motor to the service bay without interference with any other motor/apparatus. The clearance should also be adequate to dismantle and lift the longest column assembly and line shaft.
    b. In the case of horizontal pumps (or vertical pumps with solid shaft motors), the headroom should permit transport of the motor above the other apparatus and motor with adequate clearance.
    c. The mounting level of the lifting tackle should be decided based on the construction and repair of the lifting tackle.
    d. The traverse of the lifting tackle should cover all bays and all apparatus.
    e. The rated capacity of the lifting tackle should be adequate for the maximum weight to be handled at any time.
    f. Depending on the magnitude, duty requirements, capacity, and cost aspects, appropriate lifting equipment from the following alternatives shall be selected.

(i) Tripod and chain pulley block

(ii) Monorail (manually operated)

(iii) Monorail (electrically operated)

(iv) Hand operated travelling crane (HOT crane having three motions, i.e., lifting, travelling, and traversing motions)

(v) Electrically operated travelling crane (EOT Crane having three motions similar for HOT crane)

(vi) Cranes of capacity above 3 tonnes shall preferably be electrically operated.

The lifting equipment (i) is for very small borewell/tube well pumping station and (ii), and (iii) are for a small pumping station and (iv), (v) and (vi) are for medium and large pumping stations.

5.2.9 Suction and delivery pumping system

5.2.9.1 Suction Piping (wherever applicable)

a. The suction piping should be as short and straight as possible.

b. Any bends or elbows should be of a long radius (about four times diameter of suction pipe).

c. As a general rule, the size of the suction pipe should be one or two sizes larger than the nominal suction size of the pump. Alternatively, the suction pipe should be of such size that the velocity shall be about 1.5 m/s. Where bell mouth is used, the inlet of the bell mouth should be of such size that the velocity at the bell mouth shall be about 1.2 to 1.7 m/s.

d. Where suction lift is encountered, no part of the suction pipe should be higher than the highest point in the suction side of the pump body.

e. When a reducer is used, it should be of the eccentric type. Irrespective of positive suction or suction lift, the flat side of the eccentric reducer should be on top.

f. The suction strainer should have a net open area, a minimum equal to three times the area of the suction pipe.

5.2.9.2 Suction Manifold

In the installation, where water is abstracted from a dam by outlet piping or separated sump providing positive suction to centrifugal pumps, a suction manifold is provided with suction branches for individual pumps. Refer to Figure 5.5 under piping intake. Criteria for installation are:

(i) Velocity in manifold shall not exceed 2.4 m/s.
(ii) Velocity in individual suction pipe shall not exceed 1.5 m/s.
(iii) Suction pipes shall, preferably be at an angle of 30-45 degrees to the manifold.
(iv) If suction pipes are laid at 90° to the manifold, the straight length from the centre line of the manifold to the suction nozzle of the pump shall be a minimum of eight times the diameter of the suction pipe.

5.2.9.3 Delivery Piping and Common Header

(i) The size of the discharge piping may be selected one size higher than the nominal delivery size of the pump. Alternatively, the delivery pipe should be of such size that the velocity shall generally be 2.0 m/s; in a large pumping station where the cost of valves is very high, the velocity of 2.25 m/s can be considered.

(ii) Delivery piping connected to a common manifold or header should be connected by a radial tee or by a 30° or 45° bend.

(iii) If more than one pump is required to be operated together, a common header should be designed hydraulically, to reduce the head losses.

5.2.9.4 Dismantling Joint

A dismantling joint must be provided adjacent to the valves both in suction and delivery piping. In the case of delivery branches, the design of the dismantling joint should be such that no pull or moment is transmitted to the pump. Stainless steel bellows can be accepted in place of dismantling joints provided that the tie bolts are adequate to withstand pull under maximum pressure encountered and the shear area is adequate.

Bellow type dismantling joint should not be used in delivery piping as incorporation of this type of dismantling joint causes unbalanced thrust on both ends, i.e., pump end and delivery manifold end.

5.2.9.5 Adequacy of Delivery Piping, Header, and Valves for Water Hammer

Even though a surge protection device is provided for the pumping main, it is advisable the same are designed for protecting the pipeline from common header (excluding) to discharging end point, i.e., WTP/MBR/Sump but not for protecting the delivery piping, header, and valves on the pump delivery side. The piping and body of valves should be of proper rating to withstand encountered sub-atmospheric pressure (as applicable) and positive pressure equal to the sum of working pressure plus water hammer pressure in delivery piping without any surge protection devices or shut-off pressure whichever is higher.

5.2.9.6 Valves

(i) Suction Valves

a. When a suction lift is encountered, a foot valve is provided to facilitate priming. The pump can be primed also by a vacuum pump, if the pump is large, usually with a suction pipe larger than DN 300 mm.

   The foot valves are normally available with strainers. The strainer of the foot valve should provide a net area of its openings to be a minimum equal to three times the area of the suction pipe.

b. When there is a positive suction head, a sluice or a butterfly valve is provided on the pump suction, for isolation. The sluice valves should be installed with their axis horizontal to avoid the formation of air pockets in the dome of the sluice valve. In case installation of sluice valve in the horizontal position is not feasible due to space constraints or positioning of electric actuator, sluice valve in a vertical position can be installed.

(ii) Delivery Valves and Reflux valve/Non-Return Valve (NRV)/Dual plate check valve

Near the pump, a non-return (reflux) valve and a delivery valve (sluice or butterfly valve) should be provided. The non-return valve should be between the pump and the delivery valve. The size of the valve should match the size of the piping. A Dual Plate Check valve (DPCV) in place of NRV is acceptable. In an important installation, a manually operated additional sluice valve (SV)/knife gate valve is installed in delivery piping at upstream of the header for attending repairs to the main delivery valve without taking total shutdown.

An electric actuator shall be provided on pump delivery valve if the diameter is 300 mm and above or the pump head is high.

(iii) Isolation valve (IV) and NRV/DPCV on main pipeline Upstream of connecting pipe from Surge Protection Device

One NRV/DPCV along with one isolation valve (SV/BFV) is required to be provided on the main pipeline between the header and the junction point of the connecting pipe from the surge protection device to the pumping main for isolation and improving the effectiveness of surge control device. The surge protection device is designed exclusively for pumping main from common header(excluding) to discharging end.

(iv) Air Valves

Whenever there are distinct high points in the gradient of the pipeline, an air valve should be installed to permit the expulsion of air from the pipeline. If the air is not expelled, it is likely to be compressed by the moving column of water. The compressed air develops high pressures, which can even cause the bursting of the pipeline.

Air valves also permit air to enter the pipeline when the pipeline is being emptied during shut down. If air does not enter during emptying, the pipeline will be subjected to a vacuum inside and the atmospheric pressure outside shall be subjected to undue stresses and, if shell thickness is inadequate, it may collapse. Air valve is also required on downstream of the discharge head elbow for a larger VT pump. One or two air valves are also required on the header. Details on provision and sizing of valves are given in Chapter 11: Pipe and Appurtenances in Part A of this Manual.

An isolation valve (sluice valve) shall be provided for each air valve to facilitate isolation for repairs.

Supports

All valves (including the foot valve, where necessary) and piping should be supported independent of each other and independent of the pump foundation. The supports shall be in RCC construction or fabricated from structural steel or steel plates.

5.2.10 Surge Protection Devices

When starting or stopping a pump (or by operating the regulating valves rapidly) or occurrence of power failure, certain pressure fluctuations are caused, which travel up and down in the pipeline during the transient conditions. This can cause low-pressure zones, particularly at apex points on the pumping main, and subsequently cause very high pressures causing hammer pressures. If such pressure surges exceed the pressure permissible in the pipeline, the pipeline may burst. To prevent such occurrences, the recommended practices are detailed in section 6.12 and 6.16 of Part A of this Manual.

5.2.11 Electric substation and Substation building

Metering panels that draw power from high tension grids either from overhead or underground cables are installed by the electric supply authority. From metering panels power is fed to the vacuum circuit breaker (VCB) panels and further fed to the transformers to step down to the required operating voltage. Electrical power at operating voltage is fed to the power cum motor control centre (PMCC) panel. PMCC panels then feed power to various motor control centre (MCC), main lighting distribution board (MLDB), and auxiliary loads. Automatic power factor control (APFC) panels are also installed to improve the power factor of the entire plant. D.G. sets of appropriate kVA should be provided for emergency operations. Spaces for control panels should be planned as per Indian Electricity rules as given below:

I. A clear space of not less than 915 mm in width shall be provided in front of the switchboard (in practice, a front clearance of about 1.4 metres is required so that a person can move in front of the panel even while the servicing work is in progress).

II. In the case of large panels, a draw-out space for the circuit breakers may exceed 915 mm. In such cases, the recommendations of the manufacturers should be followed.

III. If there are any attachments or bare connections at the back of the switchboard, the space, if any, behind the switchboard shall be either less than 230 mm or more than 750 mm in width measured from the farthest part of any attachment or conductor.

IV. There shall be a passageway of minimum 750 mm width from either end of the switchboard clear to a height of 1830 mm.

V. A service bay should be provided in the station with enough space that the largest equipment can be accommodated for overhauling and repairs. In a large pumping station housing, more than six or seven pumps, preferably two service bays shall be provided, one at each end or one at one end and another in the middle.

VI. Normally an outdoor substation is provided. However, on considerations of public safety and for protection from exposure to environmental pollution, the substation may be indoor.

VII. Following auxiliaries shall be provided:
   i. Lightning arresters.
   ii. Air brake switch/isolator is provided in an outdoor substation. In the indoor substations, circuit breakers are provided. In the case of outdoor substations of capacities 1000 kVA and above, circuit breakers should be provided in addition the to air brake switch/isolator.
   iii. Drop out fuses for small outdoor substations.
   iv. Overhead bus bars and insulators.
   v. Transformer.
   vi. Current transformer and potential transformer for power measurement.
   vii. Current transformers and potential transformers for protections in substations of capacity above 1000 kVA.
   viii. Fencing.
   ix. Earthing.

It shall be ensured that the connection for the pumping station is taken from the nearest 11 kV/22 kV/33 kV/66 kV/110 kV/132 kV HV/EHV networks to ensure a 24×7 power supply.

Note: The 11kV/22kV/33kV networks are normally operated with the neutral point earthed through a resistor to limit earth fault current. However, the 11kV/22kV/33kV networks may also be operated with the neutral isolated from the earth during abnormal conditions. The unearthed 11kV/22kV/33kV equipment shall be suitable for continuous operation with an earth fault on one phase and shall be designed to withstand the overvoltage that may occur due to arcing to earth.

5.2.12 Ventilation System

A separate ventilation system with exhaust fans and/or forced ventilation with air supply fans with or without ventilation ducts and/or a combination of forced ventilation and an exhaust system should be provided. In the motor room, cooling should be provided if required for heat rejection of the motors. The system should be capable of removing heat generated from the motors and panels, to maintain inside temperature within 3 to 5° C above ambient conditions. From the ventilation consideration, a minimum of five to six air changes per hour shall be considered. In case of using self-water cooled submerged/submersible motors, elaborate ventilation in the pump house is not required. The electrical room, MCC, etc. should be ventilated at a rate sufficient to provide five to six complete air changes per hour. Ventilation openings should be screened with fine mesh to prevent the entry of birds, rodents, insects, etc.

Heat Dissipation formula

Heat dissipation is one of the deciding factors in designing heat transfer components. We can calculate heat dissipation for cooling air in pumping station heated due to heat generated from motor windings and other miscellaneous items. Losses from motors (iron loss, copper loss) causes air to be heated. The applicable formula for Q, air flow in m^3/hour is as under:

$$Q = \frac{3.462 x Ks}{t}$$

Where

K_s = heat generated by motors in K_{cal} /hour

t = Permissible temperature rise above outside temperature (generally 3 °C to 5 °C; preferably 5 °C.)

The value of 3.462 cum per hour is for the air flow rate required per Kcal/hour to restrict temperature rise above outside shed temperature by 1 °C.

K_s for motors = kW rating of motor X (1 - motor efficiency) × 860 × M

Where M is number of maximum working motors

It is stated that:

1 kWh = 860 kcal/hour is based on conversions

1 kWh = 3.60 × 10^6 joules (ii) 1 K_{cal} = 4 .19 × 10^3 joules

Hence, 1 kWh = 860 Kcal/hour (rounded)

5.2.13 Lighting

The interior of the pump house should be provided with a sufficient lighting system specially designed to achieve the best illumination suited to the station layout. Energy efficient fluorescent fixtures are preferred. Lighting should be at adequate illumination levels. For routine service, inspections and maintenance activities are as given in Table 5.2.

Table 5.2: Lighting

S. No.	Area	Illumination level in Lux
1	Substation building	200
2	Pump House	200
3	Control room	250/300
4	Transformer room, D.G. set, etc.	200
5	All other indoor areas	100
6	Outdoor plant area	20
7	Roads	10
(Source: IS 3646 and IS SP72 National Lighting code)		

5.2.14 Control Room

The control room for a large pumping station should be equipped with supervisory control and data acquisition (SCADA) control system and be provided with an air conditioner. One number of PLC should be installed in the control room with necessary equipment and switches for operation as required. SCADA system will be comprised with the indication of level in the settling tank, sump, flow of raw water, and turbidity, and pH of raw water.

5.2.15 Operator Room

The officer in charge of the plant sits in this office and keeps a watch on all the activities of the plant for its satisfactory functioning. He maintains the record of workers and employees, their remuneration and salaries, spare parts for operation and maintenance, their proper consumption, etc. A water testing laboratory should be provided for all large and medium waterworks, as described in section 7.7 in Part A of this manual. A telephone should be provided for better control and management of waterworks.

5.2.16 Transformer and Electrical Installation

A supply grid network is generally available in towns and cities for the distribution of power. The elevated tanks are commonly located in such areas. Therefore, it would be economically preferable to opt for transformer substation. Power supply connection to the transformer substation or the pump house can be obtained from the power supply authority after payment of the estimated cost, including additional fees as admissible under their company rules and regulations. Panel spacing and layout in the pump house should be in accordance with Indian electricity rules as described in the preceding section on large pumping stations.

5.2.17 Miscellaneous Components

Security guard room should be located at the entrance and exit of the plant premise. It serves as a checkpoint to monitor and maintain control over men or vehicles entering and leaving the plant premises. Necessary amenities should be provided for the guards.

The plant area should have a boundary wall all around the premises 1 to1.6 m high above ground level preferably having two layers of barbed fencing over top of the wall. Steel gates should be provided wide enough to permit heavy vehicles, cranes, etc.

Proper lighting arrangements should be made for the whole waterworks campus area. Parking lots for large pumping stations are commonly prescribed for five number of light vehicles, heavy vehicles, tall trucks, big cranes, etc. Wide roads for easy and comfortable movements of these vehicles should be provided inside the plant premises.

Proper arrangements for water supply and sanitary installation within the plant should be made with satisfactory disposal of wastewater to a nearby sewerage system. The storm water drainage system for the site shall be provided and all overflows from the plant shall be laid to storm water drainage system. Plant premises should be maintained neat and clean by proper garbage disposal. Dewatering pumps shall also be provided to remove unwanted water that may accumulate due to some leakage from the pump floor.

i. Aesthetic consideration

Typical low-cost measures to enhance visual quality should be employed:

- allowing adequate area of natural and planted vegetation;
- enclosing unsightly objects such as storage tanks, etc.;
- using local building materials that blend in with the surrounding architecture;

- providing underground utilities (power supply, phone lines, etc.).

ii. Environmental consideration

a. Air Quality

Diesel generators or engine-driven pumps are potential air quality polluters that may be replaced by natural gas or purely grid-supplied electrical energy.

b. Noise

Noise attenuation is a necessary concern near residential areas. Noise level shall not exceed 85 dB measured at a 1.2 m distance from the pump-motor set and vibration level for pumps shall conform to the provisions given in IS 14817 (Part 3) or ISO 10816. Wherever practicable, one or more of the following measures may be adopted:

- Use submersible pump.
- Where submersible pumps are not practicable, use an electrically driven motor. If an engine is used, provide mufflers.
- Build pump house from concrete or masonry.
- Sound insulation of the pump house wall may be an option.

iii. Other considerations for a specific situation

a. **Cooling** water system (in case of Closed Air Circuit, Water (CACW) motors and for bearings)

- CACW coolers are excellent for cooling generators and large electrical systems, no matter the environment.
- It circulates the water at a temperature lower than the ambient temperature through an element that cools a generator or motor.

b. Forced water lubricated pumps

- When the pumping media (raw water) is hazardous, dirty, and contains solid and abrasive contents, not suitable for bearings, a forced water lubrication system should be used.
- Before deciding on the feasibility of the system, the pump manufacturer should be consulted with a detailed water chemical analysis report. The pump manufacturer will supply a schematic for the forced water system, as well as the amount of water needed for shaft tube and thrust bearing cooling per pump.
- The time required to start the booster pump before starting the main pumps will also be provided by the pump manufacture.

c. Water-seal arrangement

- For effective operation, many pumping arrangements (like VT, horizontal centrifugal, etc.), including those with packing seals and mechanical seals, rely on seal water. Seal water serves three functions: cooling the seal and shaft, lubricating the seal, and flushing impurities from the system.

d. Vacuum priming pumps

- The centrifugal pumps are unable to pump air, which means that when the pumps are taken off-line for maintenance or some other reason, they need to be completely filled with liquid again for expelling air from the pump before they will operate properly.
- The vacuum priming system is used to initially pump out air from the pump which causes drawl of water from suction sump into the pump. When the pump casing is full of water and water stream coming out from vacuum pump is without any air, priming is considered complete.

5.3 Small pumping station

A small pumping station is built either to fill drinking water in elevated reservoirs for distribution in its command area or to boost water in the certain low-pressure zone of the project area. Components of a small pumping station are listed below:

a) Site and location
b) Suction sump
c) Pump house
d) Pole-mounted transformer or transformer room
e) Ventilation and lighting
f) Water supply, toilet facilities, roads, etc.
g) Aesthetic and environmental considerations

a. Site and location

Pumping stations for filling water into elevated tanks are generally located within premises of elevated tanks preferably when the supply main is not far away. In cases where a suitable site and required land area are not available in densely populated towns and cities, it would be expedient to lay a small branch pipe up to the premises of the elevated tank for the construction of a small pumping station to fill the tank.

b. Suction sump

A suction sump of reinforced concrete should be constructed either circular or rectangular having a balancing capacity of minimum 1.5 hours at the discharge rate of the pump. The top of the sump should be covered with an RCC slab with a manhole of 500 mm diameter having an RCC or W.I. manhole cover. The sump top should be at least 500 mm above ground level.

c. Pump house

A pump house should be constructed in RCC or masonry near the sump keeping the long wall of the pump house parallel to the long wall of the sump. The pump house should have adequate space for 1 (W) and 1 (S), each rated for 100% flowrate or alternatively 2 (W) and 1 (S) with each pump designed for 50% flowrate and empty spaces structurally and hydraulically designed for additional W + S pump sets for ultimate stage, electrical panels, and sufficient working space for operation and maintenance of pump sets and allied equipment. A hand operated monorail or electrically operated monorail of adequate capacity shall be provided in the opposite walls 200 mm below the ceiling with a chain pulley block, slings, motor, etc.

(i) Suction and delivery piping (refer to Subsection 5.2.9)
(ii) Transformer and Electrical Installation (refer to Subsection 5.2.16)
(iii) Ventilation and lighting (refer to Subsection 5.2.12)
(iv) Water supply, toilet facilities, and roads (refer to Subsection 5.3)
(v) Aesthetic consideration (refer to Subsection 5.2.17 (i))
(vi) Environmental Consideration (refer to Subsection 5.2.17 (ii))

5.4 Borewell/Tube well pumping station

A borewell pump station is constructed to house pump sets to draw water from the borewell/tube well. Generally, conventional submersible pump with both pump and motor on common single shaft, installed in borewell/tube well below minimum water level is used. A vertical delivery pipe is connected to pump delivery nozzle to top of the well above ground level. The delivery piping, valves, etc., are installed in the pump house at ground level.

Sometimes if the well is shallow, a vertical turbine pump is selected. The turbine pump assembly is made up of one or more impellers housed in a single or multistage unit known as a bowl assembly. The impellers are suspended on a vertical line shaft that is housed in a pump column which conducts the water to the surface. The individual sections of the pump column are generally manufactured in 2-3 m length. In the course of lowering the column pipe sections inside the well, they are jointed with threaded couplings or flanged fittings. The pump column is attached at the surface to the discharge head which houses a stuffing box around the shaft and an elbow to divert the discharge of water into the above-ground piping system. Components of this type of pumping station are listed below:

(i) Pump house

(ii) Pumping machinery

(iii) Borewell/tube well

(iv) Pole-mounted transformer or transformer room if load exceeds certain kVA

(v) Delivery piping

(vi) Lighting and ventilation

(vii) Water supply, toilet facilities, roads, etc.

(viii) Aesthetic and environmental considerations

Pump house

The pump house is constructed right over the borewell keeping the borewell in the middle of the pump house. Adequate clear space should be kept around the borewell for the installation of a vertical turbine pump set or submersible pump. Sufficient space for locating the delivery piping, valves, electrical panel, starter, switch, circuit breaker, electrical measuring instruments, etc., should be provided. The ceiling of the pump house should be not less than 5-5.5 metres above the floor of the pump house for lowering and extracting column pipe sections. A hand operated monorail of adequate capacity should be provided with a chain pulley, slings, etc., for lifting the pump, motor, column pipe sections, etc. Alternatively, a tripod with chain pulley block can be used for a very small pumping station.

a) Suction and delivery piping (refer to Subsection 5.2.12)
b) Transformer and Electrical Installation (refer Subsection 5.2.19)
c) Ventilation and lighting (refer to Subsection 5.2.15 and 5.2.16)
d) Water supply, toilet facilities, and roads (refer to Subsection 5.3)
e) Aesthetic consideration (refer Subsection 5.2.20 (i))
f) Environmental consideration (refer Subsection 5.2.20 (ii))

5.5 Classes of pumps

All pumps are classified into two major classes:

a. Kinetic energy

- Centrifugal pumps
- Jet pumps

- Airlift pumps

b. Positive displacement

- Rotary pumps
- Peristaltic pumps
- Reciprocating pumps

Of these, the centrifugal pumps and the reciprocating type of positive displacement pumps are more popular. Prominently, the reciprocating pumps are good on high head (high pressure) duties and for metering/dosing requirements. Centrifugal pumps are of mechanically simpler construction and give non-pulsating continuous flow.

The arrow marked on the pump casing is only the direction of rotation and not the direction of flow. The direction of flow has to be found by, i) comparing the suction flange, which is usually larger, than the delivery flange; ii) Pump casing profile.

5.5.1 Pump Types Based on Variable Frequency Drive

A variable frequency drive (VFD) is an electronic controller that adjusts the speed of an electric motor by modulating the power being delivered. Variable frequency drives offer continuous control by matching motor speed to the specific demands of the work being done. However, for intake pumping and clear water pumping, constant speed pumps shall be preferred.

Variable speed pumps are employed when there is a requirement for a change in flow or head due to demand changes over a period. For instance, in a city distribution of water by direct pumping, the terminal head at critical point (at highest elevation node in the operation zone of distribution system) has to be maintained irrespective of demand. During low demand periods, in the case of a constant speed pump, the terminal pressure may become higher as the pump may be discharging lower discharge. In such cases, the pump delivery valves (or the line valves) are throttled to keep the pressure at the required level to avoid excessive pressure. This is detrimental to the pump as it has to work closer to shut-off head, also resulting in a waste of power. Alternatively, if the pumps are run at a lower speed and still maintain the end pressure, the pumps will be working close to their best efficiency point (BEP), and near their rated head (at the reduced speed) and thus is a safer option. Selection of speed control option has to be done keeping in view the entire demand range, static head, and other factors. The use of VFD is beneficial where the system is friction dominant. The use of VFDs for most “24×7 Drink from the Tap” systems would be useful.

To understand how speed variation changes the duty point, the pump and system curves are overlaid. Two systems are considered, one with only friction loss and another where the static head is high in relation to the friction head. It will be seen that the benefits are different. In Figure 5.6, reducing speed in the friction loss system moves the intersection point on the system curve along a line of constant efficiency. The operating point of the pump, relative to its BEP, remains constant and the pump continues to operate in its ideal region. The affinity laws are obeyed which means that there is a substantial power reduction obtained together with the reduction in flow and head, making variable speed the ideal control method for systems with friction loss.

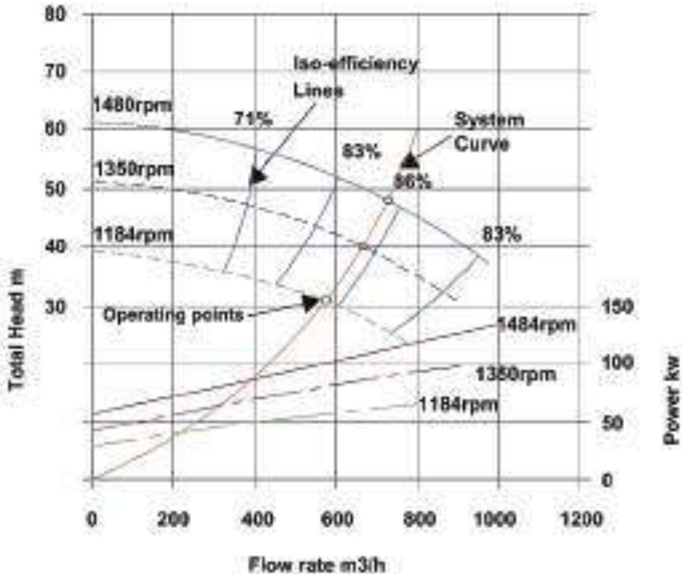


Figure 5.6: Example of the effect of pump speed change in a system with only friction loss

Source: Bureau of Energy Efficiency, "Pumps and Pumping System"

In a system where the static head is high, as illustrated in Figure 5.7, the operating point for the pump moves relative to the lines of constant pump efficiency when the speed is changed. The reduction in flow is no longer proportional to speed. A small turndown in speed could give a big reduction in flow rate and pump efficiency, which could result in the pump operating in a region where it could be damaged if it run for an extended period even at a lower speed. At the lowest speed illustrated (1184 rpm), the pump does not generate sufficient head to pump any liquid into the system, i.e., pump efficiency and flow rate are zero and with energy still being input to the liquid, the pump becomes a water heater and damaging temperatures can quickly be reached.

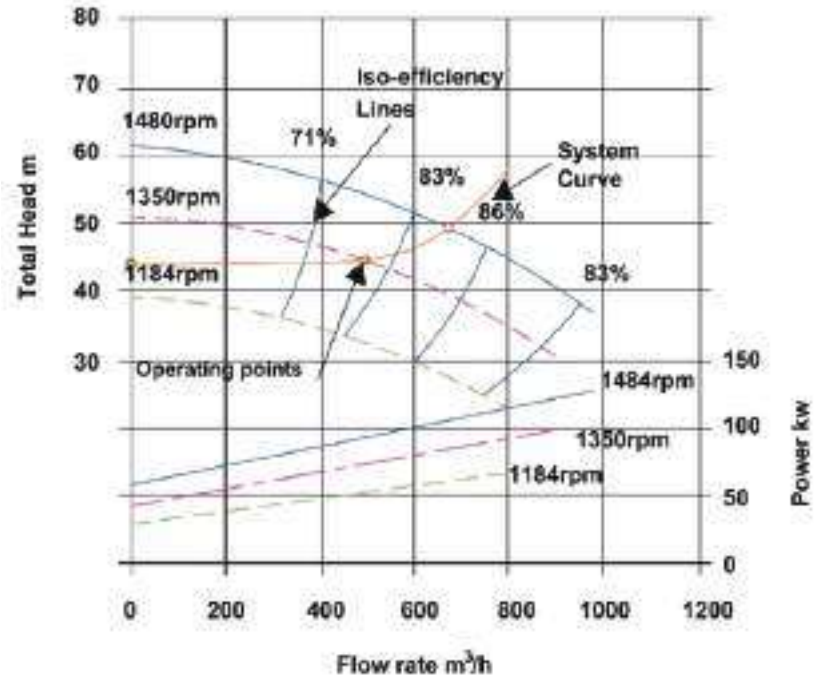


Figure 5.7: Example of the Effect of Pump Speed Change in a System with Static head

Source: Bureau of Energy Efficiency, "Pumps and Pumping System"

The drop in pump efficiency during speed reduction in a system with a static head reduces the economic benefits of variable speed control. There may still be overall benefits, but economics should be examined on a case-by-case basis. Usually, it is advantageous to select the pump such that the system curve intersects the full speed pump curve to the right of best efficiency, in order that the efficiency will first increase as the speed is reduced and then decrease. This can extend the useful range of variable speed operation in a system with a static head. The pump manufacturer should be consulted on the safe operating range of the pump. Further details may be referred at section 5.16.1 of this chapter.

The introduction of VFDs requires additional design and application considerations - additional information can be obtained from pages 12, 13, and 14 of “Variable Speed Pumping - A Guide to Successful Applications” published by Hydraulic Institute Standards, Euro Pump and U.S. Department of Energy.

Motor for VFD system should be VFD Compliant certified by the motor manufacturer.

5.5.2 Pump Types Based on the Method of Coupling the Drive

Some pumps are coupled to the drives, direct through flexible couplings, or are close-coupled or are distantly driven through belt and pulley arrangement, sometimes with gearing arrangement or even with variable speed arrangement.

5.5.3 Pump Types Based on the Position of the Pump Axis

Pumps normally work with their axis horizontal. Vertical turbine pumps, borewell submersible pumps and volute type sump pumps have their axis vertical. Dry-pit pumps are often arranged to work with their axis horizontal.

5.5.4 Pumps of Types Based on Constructional Features

For the purpose of maintenance, pumps are made with axially split casing or with a back pull-out arrangement. Pumps for high heads are built with multi-staging. Pumps to handle solids and sewage are provided with access hand holes for inspection and cleaning the choking and also with the provision for flushing and draining. Submersible pumps to handle raw water should be with mechanical seals. In this manner, a large variety of constructional features are provided in pumps for different purposes in different situations.

Pumps are also made in a variety of materials, to withstand corrosion, erosion, abrasion, and for longer life under wear and tear.

5.6 Design Features of Centrifugal Pumps, Vertical turbines, and Submersible Pumps

5.6.1 Design Types of Pumps

The type of design is given below:

a) Two types based on the type of casing
   - Turbine (diffuser)
   - Volute

b) Three types of designs based on the flow profile of impellers
   - Radial flow
   - Mixed flow
   - Axial flow

   Casing for above three types may be volute or diffuser

c) Three types based on dry or wet pit installations

Centrifugal pump	Both pump and motor dry
Vertical turbine pump	Pump in a wet pit (submerged) and motor dry
Submersible pump/Submerged turbine pump/Submerged centrifugal pump	Both pump and motor in a wet pit (submerged)

5.6.2 Features and Suitability of Various Types of Pumps

This subsection describes features and suitability of various types of pumps

5.6.2.1 Turbine pump

In a turbine pump, the impeller is surrounded by diffuser vanes that provide gradually enlarging passages in which the velocity of water leaving the impeller is reduced, thereby, converting kinetic energy into pressure energy and thus, develops pump head.

VT pump under (5.6.2.6) below and conventional submersible pump under (5.6.2.7) below are examples of turbine pumps.

5.6.2.2 Volute pump

The volute pump differs from the turbine pump in that there are no diffuser vanes, and the impeller is housed in a spiral-shaped case. The velocity of water is reduced upon leaving the impeller, thus transforming velocity to pressure head.

The choice between turbine and volute pumps depends on the condition of use. Ordinarily, the volute design is preferred for large capacity, low/medium head applications whereas turbine design is desirable where high heads are involved.

Centrifugal pump is normally with volute.

5.6.2.3 Radial flow pumps

In radial flow pumps, pressure is developed by centrifugal force. The water normally enters the impeller hub axially and flows radial to the periphery; the impellers may be single or double suction. The impeller may have either straight or double curvature and the pump shaft may be horizontal or vertical.

5.6.2.4 Mixed flow pumps

In mixed flow pumps, the liquid/water enters axially and discharges in partly off radial direction. The head is created by centrifugal force and a lift of the vanes on the water. The casing can be volute or diffuser type. The pump is either single or double volute and may be either single or multistage. These pumps are applicable for medium head application.

5.6.2.5 Axial flow pumps

Axial pumps are also known as propeller pumps and develop the head by the lifting or propelling action of the vanes on the water/liquid. They have a single inlet impeller with flow axially and discharging axially. These pumps are commonly used for large flows and very low head installations such as lift irrigation schemes.

5.6.2.6 Vertical Turbine (VT) pumps

The impellers are mounted on impeller shaft along with diffusers housed in bowl assembly. The impeller shaft is connected to vertical line shaft that is housed in a column assembly which conveys the pumped water to the surface. Individual sections of the column assembly are generally manufactured in 1.5 to 3.0 m length. Generally, column assembly in 1.5 m length which results in practically true rotation of line shaft, reduces critical speed, and also reduces height of installation level of crane, is advisable for all VT pumps, and is essential if length of the column assembly exceeds 12 m. In the course of lowering the column pipe sections inside the well, they are usually with flanged couplings. The top column pipe is attached at the surface to the discharge head which houses a stuffing box around the shaft and an elbow to divert the discharge of water into the above-ground piping system. The impeller shaft is of high tensile steel or stainless steel (SS). The line shafts are of SS for column assembly of any length and essential if length exceeds 12 m, as the diameter of SS shaft being higher, is beneficial for reducing critical speed and true running of line shaft.

The VT pump may be radial flow type as per (5.6.2.3) above or mixed flow type as per (5.6.2.4) or axial flow type as per (5.6.2.5) above.

A flanged motor is installed above the discharge head. If the motor is hollow shaft (generally applicable for motor up 110 kW), the top line shaft is coupled to hollow shaft of the motor. The thrust bearing is provided in the motor to counter total axial thrust as sum of unbalanced hydraulic thrust in the pump and dead load of rotating assembly of the pump (i.e., impellers, impeller shaft, line shafts, and couplings) and the rotor of the motor.

If the motor is solid shaft, a flexible rubber bush coupling in two halves is provided to couple top line shaft and motor shaft and is located in the discharge head. A thrust bearing is housed in the discharge head and is designed to withstand total axial thrust as sum of unbalanced hydraulic thrust of the pump and dead load of rotating assembly of the pump only and it is usually designed for 40,000-50,000 hours of operation, i.e., six to seven years. The thrust bearing in motor counters dead load of the motor rotor.

The discharge head should be mounted on sole plate anchored to foundation. The top of sole plate shall be smooth finished and accurately levelled and permanently anchored in foundation such that levelled sole plate do not need to be disturbed whenever the pump is taken out for repairs. The bottom of the discharge head shall also be smooth finished and contact faces of sole plate and discharge head are blue matched.

Three types of lubrication system are used for vertical turbine pumps depending on raw water turbidity:

i. Self-water lubricated (pumped water lubricated)
ii. Oil lubricated
iii. Forced water lubricated

In all cases, the line shaft shall be of non-corrosive material generally stainless steel.

i) Self-Water Lubricated (Pumped Water Lubricated)

Self-water lubricated pumps are the simplest in constructional features as well as maintenance and should be preferred if raw water turbidity is low in river water and impounded reservoirs (dams) where due to settlement in the reservoir, turbidity of pumped water reduces. In many cases, even if peak turbidity during monsoon is up to 500 NTU which lasts for a few days, self-water lubricated pumps are functioning without any significant problem.

The bearings for the line shaft are generally of cut-less rubber and are provided at each flanged joint of column pipes with a bearing holder.

A water slinger is provided to prevent water from creeping into the motor.

ii) Oil Lubricated Pumps

Oil lubricated pumps shall be selected if turbidity is high. The arrangement comprises a shaft enclosing tube for the line shafts. At each joint of the shaft enclosing tubes, a threaded bronze bearing, commonly called line shaft bearing is held at the joint after tightening screw threads. The shaft enclosing tubes are held in position by spiders, one per tube.

Low viscosity oil is passed under gravity at rate of two to three drops per minute through the shaft enclosing tube to lubricate line shaft bearings.

This arrangement requires maintenance to prevent ingress of raw water into the shaft enclosing tube which results in ineffective oil lubrication. Care should be taken to ensure that oil does not leak into pumped water or else it may pose a public health hazard.

iii) Forced Water Lubricated Pump

This arrangement is applicable if turbidity is very high. It is, however, not very common. The construction feature is similar to an oil lubricated pump with a shaft enclosing tube except that line shaft bearings are of cut-less rubber which are located at flanged joints of column pipes.

Pressurised clear water from an external source at pressure higher than pressure of pumped water is passed through the shaft enclosing tube to lubricate line shaft bearings. A water slinger is provided to prevent water from creeping into the motor.

This arrangement requires maintenance to prevent the ingress of raw water into the shaft enclosing tube.

The VT pumps are suitable for following installations.

a. Constructed intake (river/lake/Impounded reservoir)
b. Sump (raw water/clear water)
c. Piping intake from dam wherein the pump can be used as barrel pump as in 5.2.7.3

5.6.2.7 Centrifugal Pump

The centrifugal pump may be radial flow type, mixed flow type, or axial flow type. This type is with volute casing. Depending on number of stages in the pump, the same are classified as a single stage or multistage. Similarly, on the basis of orientation of pumps, they are classified as horizontal centrifugal as pump axis is usually horizontal. If a pump is with vertical axis, the same is classified as vertical centrifugal pump.

Following types of centrifugal pumps are popularly used.

- Horizontal centrifugal end-suction pump: Suction is at end and in horizontal plane. Delivery nozzle is generally vertical.
- Double suction horizontal split casing pump: This type is the most preferred pump as upper half casing can be removed for attending repairs without taking out pump shaft, impeller, etc. Being double suction, net positive suction head required is lower and axial hydraulic thrust is nearly balanced, thus reducing bearing losses and resulting in higher efficiency.
- Centrifugal pumps are suitable for the following installations.

  a. Dry well above the sump if suction lift capability is adequate
  b. Dry well by the side of wet well with positive suction by extending suction pipes into wet well
  c. In-line booster pumping station
  d. Piping intake from dam

- Important consideration for deciding floor level for centrifugal pump:

Installation of horizontal centrifugal pump on floor below surrounding ground level to the extent possible should be avoided as in the event of burst of any valve or pipe of individual delivery of pump in the pump house, the motor can be damaged due to water logging on the floor.
A good example of centrifugal pump installations is of Bengaluru water supply systems where the pump mounting floor levels are at or above surrounding ground levels, thus, avoiding such risk. Clear water sumps are at higher ground levels, thus rendering positive suction to the pumps.

5.6.2.8 Submersible pump (conventional)

Submersible pumps have bowl assemblies that are similar to those of vertical turbine pumps. The motor, however, is submerged under water and directly connected to and located just below the bowl assembly. Water enters through an inlet strainer between motor and bowl assembly, passes through the stages, and is discharged to the surface via the vertical delivery pipes. Submersible pumps have become a major type of pump used in domestic wells, and increasing numbers of submersible pumps have been installed in large diameter, high-capacity wells. Submersible pumps have several advantages including the following.

- Motor is easily cooled because of complete submergence.
- Noise level transmitted to ground surface is very low or practically eliminated due to submergence and water column.
- The submersible pump has a hermetically sealed motor close-coupled to the pump. The entire assembly is immersed in the fluid being pumped. The pump is just above the motor, and both of these components are suspended in water. Submersible pumps use enclosed impellers and are easy to install and maintain. These pumps run only on electric power and can be used for pumping water from very deep and crooked wells. Moreover, they are unlikely to be struck by lightning and require a constant flow of water across the motor.
- Submersible pumps are suitable for following installations:
    a. tube well/borewell/dug well;
    b. small intake (if raw water turbidity is low);
    c. sump for small schemes.

Single phase (230 V) and three-phase (415 V) submersible pump-motor sets manufactured in India are as follows:

1 phase: Fractional kW to 2.25 kW	Generally used for a very small rural scheme
3 phase: 0.5 kW onwards	Other schemes

5.6.2.9 Submerged turbine and submerged centrifugal pump sets

Submerged turbine pump and centrifugal pump sets wherein both pump and motor are submerged and common shaft provided for pump and motor are manufactured in India and abroad.

The design engineers should arrive at decision after due consideration of merits and demerits. These pumps are, however, very meriting for application where space and time are limited and/or installations where no adequate time is available for construction of civil works. Features of these submerged pump sets, their merits, and demerits including comparison with conventional VT and centrifugal pumps are as follows.

(i) Submerged turbine pump set

This type of pump on detailed consideration of merits and demerits and comparison with conventional VT pump including requirements of civil works may be evaluated as an alternative to the conventional VT pump. The features of submerged turbine pumps are:

- The pump/bowl assembly is on top and the motor is below under submerged condition; as against the bowl assembly of the conventional VT pump, where it is partly or fully under submerged condition;
- However, in both cases, the column assembly, transmission shaft/line shaft, discharge head, and motor are located above the water level and remain dry.

Figure 5.8 (a) illustrate conventional VT pump. Figure 5.8(b) shows submerged turbine pump without a can for motor as per present manufacturing practice in India.

- As seen from the figures, the motor of the submerged turbine pump is below the bowl assembly. The pump is without transmission/line shaft and discharge piping is from delivery nozzle of turbine pump.
- In a submerged turbine pump set, the entire axial thrust, comprising the hydraulic thrust in the bowl assembly/pump and the weight of rotating assemblies of the pump and motor, is taken by the thrust bearing in motor as against separate thrust bearing provided in discharge head in the case of a conventional VT pump with dry motor.
- Merits of the submerged turbine pump:
    - No transmission/line shafting, hence eliminating small power loss and maintenance of line shaft bearings.
    - Due to bearings lubricated by grease and not in contact with pumped water, the same pump is suitable for raw water and clear water application.
    - Design of structure is economical as vibration level transmitted to structure is negligible.
    - Noise level is negligible being submerged.
    - No need of elaborate ventilation at operation floor, as the motor which is the major source for heat emission is submerged.
    - Spacing between pump/bell mouth centres can be reduced as motor is submerged and therefore, working clearance is restricted to spacing requirement from aspect of vortex phenomenon.
- Demerits of the submerged turbine pump
    - A common shaft for pump and motor making the entire set out of service even when either of the pump or the motor fails.
    - Motor of turbine pump set is below the pump. Submergence required for vortex-free hydraulic condition is computed above the lip of bell mouth/inlet and generally bottom clearance equal to half of bell mouth diameter is adopted.
    - However, if a submerged turbine pump is chosen and as a submergence requirement, above pump inlet remains the same, the bottom of the pump well will have to be lowered to accommodate the motor depending on its height. Thus, excess depth of the pump well is required. It therefore follows that if the pump well is designed for a conventional VT pump, a submerged turbine pump set cannot be installed without lowering the bottom of the pump. An important demerit is that if a vortex problem occurs, no remedy is possible in the case of a submerged turbine pump as the motor is near the bottom floor. However, Vortexes can occur with any type of pumps due to poor sump design & hence it is advisable to get sump design checked before installing any type of pump. In a conventional VT pump, remedial measures are always possible as bell mouth is below bowl assembly and near the bottom floor.

- Essential features and improvements required based on the review on international standards, practices, and brochures:
    - A barrel (also called as jacket or shroud) shall be provided enclosing the motor from the bottom of the motor to the pump inlet. The top of the jacket shall be closed, but

not airtight to expel trapped air, if any, in the barrel. Diameter of barrel shall be designed to limit flow velocity in annular space to 1.5 m/s maximum.

- o A well designed and sturdy sole plate arrangement for founding the bend of a vertical discharge piping shall be provided at operating floor. Bottom sole plate shall be levelled and permanently fixed in the foundation. Upper plate shall either be integral with bend or bolted to bottom flange of the bend and shall be fastened to bottom sole plate.

- The pumps are suitable for following installations:

  I. Constructed/Not constructed intake (river/lake/Impounded reservoir)
  II. Sump (raw water/clear water)
  III. Low lying/waterlogged areas at the pumping station prone to floods

(ii) Submerged vertical centrifugal pump rested with auto-coupling

Figure 5.9 (a) illustrates salient features of a pump.

- Merits of the submerged vertical centrifugal pump
  - o Regular pump house can be dispensed with, or smaller pump house is required. However, panel room and lifting equipment are required.
  - o Width of pump well can be reduced as working clearance between motors for heat dissipation is not required being under water.
  - o No need for elaborate ventilation as motor is under submerged condition.
  - o Noise level is negligible.
- Demerit
  - o A common shaft for pump and motor making entire set out of service even if either pump or motor fail.

- The pumps are suitable for following installations:
  I. Intake
  II. Sump (raw water/clear water)
  III. Low lying/waterlogged areas at the pumping station prone to floods.

(iii) Submerged Horizontal centrifugal pump set with portable base frame and submerged vertical centrifugal pump set with portable base frame.

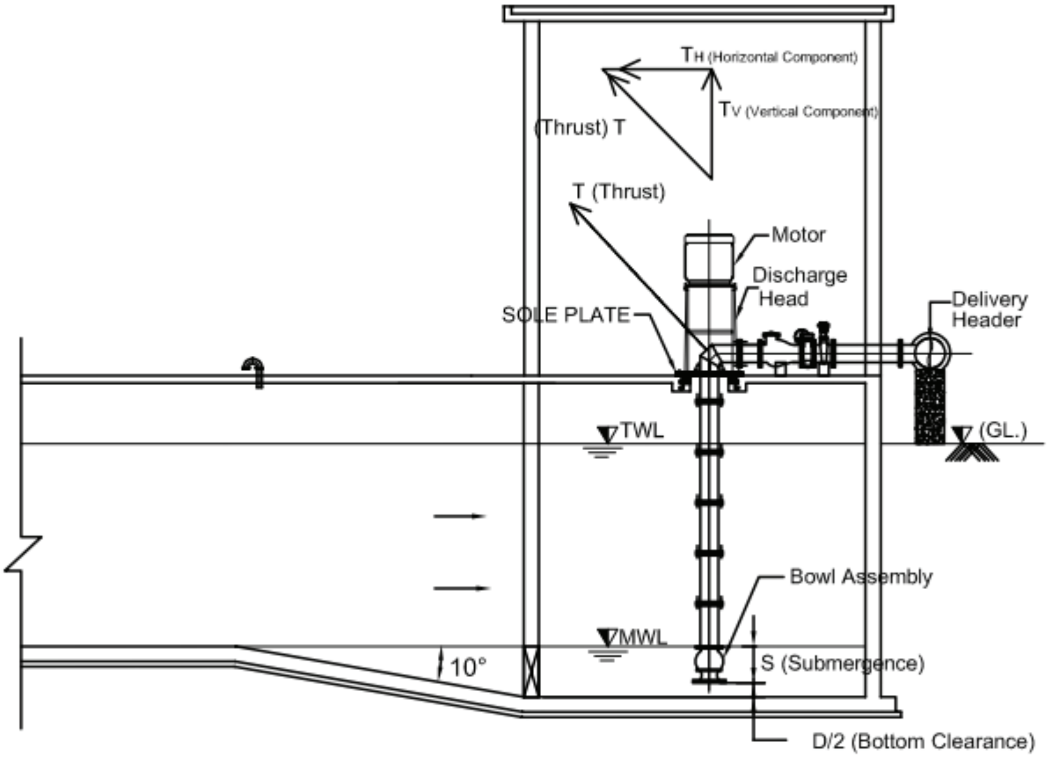
Figure 5.9 (b) illustrates salient features of horizontal centrifugal pump set. The features of vertical centrifugal pump set are similar with motor on top and pump at bottom with end suction and side delivery.

- Merits of the submerged horizontal centrifugal pump
  Merits are same as discussed in (ii) above for submerged centrifugal pump set with auto-coupling.
- Demerits of the submerged horizontal and vertical centrifugal pump:
  - o A common shaft for pump and motor making the entire set out of service even if either of the pump or motor fails.
  - o Whether a portable base frame simply resting at bottom floor without any anchorage can restrain the pump set under dynamic load during normal running is questionable.
  - o Major demerit of installation arrangement of horizontal pump is that the approaching flow passes first to the motor and next to the pump body before reaching to the inlet/suction of the pump. This is contrary to the guideline in the standards for vortex-free design that inflow should approach straight to the suction inlet without swirl or

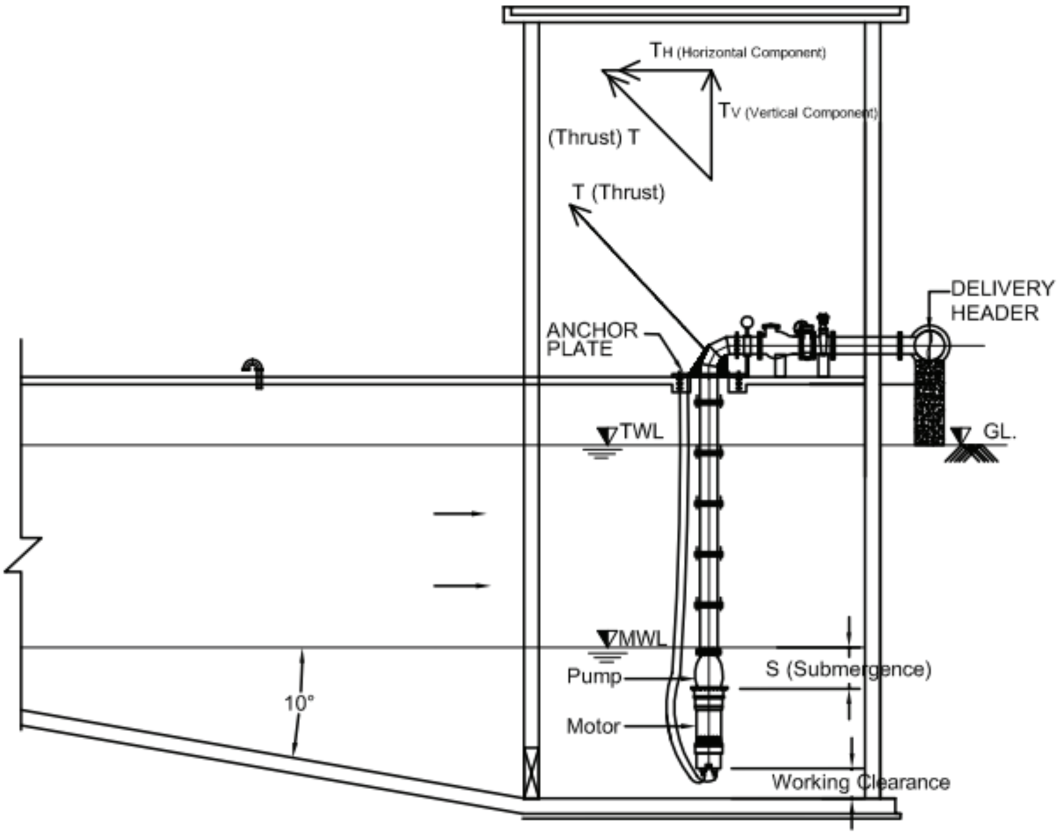
  change in flow direction and without disturbance due to any obstruction in flow passage to pumps.
  - Delivery piping from pump delivery nozzle to operation floor is vertical. Hence, when the pump set is taken for repairs, both the pump set and the vertical piping need to be lifted up. Lifting of such eccentric load can be very cumbersome.
  - For horizontal centrifugal pump set due to being end suction and without suction piping, no remedial measures for vortex prevention can be adopted. Also, it is not possible to maintain bottom suction clearance equal to half of the suction bell/inlet diameter. The portable frame may also cause flow disturbances at the bottom.
  - For vertical centrifugal pump set, the portable frame may cause flow disturbance at bottom.

- Features required for betterment for installation in sump:
  - Orientation of the pump-motor set should be changed such that approaching flow directly passes to the pump.
  - It is advisable to provide proper rigid foundation for the pump-motor set at bottom level subject to feasibility.
  - Frame of vertical centrifugal pump shall be improvised such that the front part of the frame does not cause or minimise obstruction in the flow path to the pump suction.

- The pumps are suitable for the following installations:
  I. Constructed/Unconstructed intake
  II. Sump (raw water/clear water)
  III. Low lying/Waterlogged areas at the pumping station prone to floods

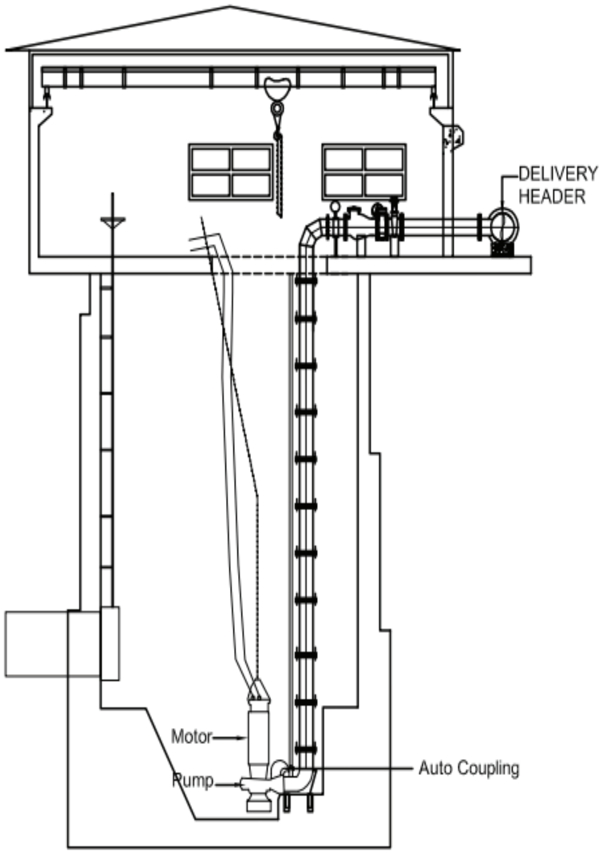


(a) - Conventional VT Pump Installation

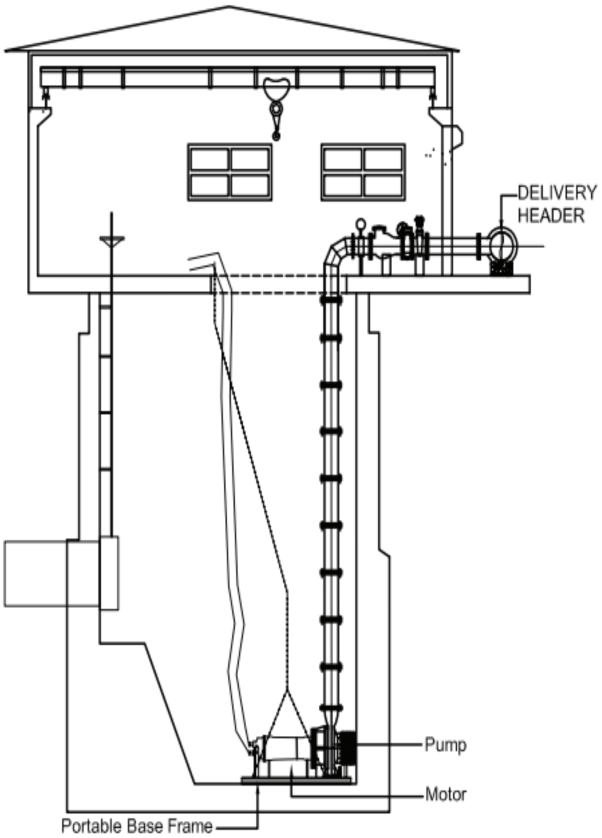


(b) - Submerged Turbine Pump Installation

Figure 5.8: Relative Installation Arrangements of (a) Conventional VT Pump set and (b) Submerged VT Pump sets



(a) Submerged Vertical Centrifugal Pumpset with Auto Coupling



(b) Submerged Horizontal Centrifugal Pumpset

Figure 5.9: Installations (a) Submerged Vertical Centrifugal with auto-coupling and (b) Submerged Horizontal Centrifugal Pump set with Portable Base Frame

5.7 Criteria for Pump Selection

Prior to the selection of a pump for a pumping station, detailed consideration must be given to various aspects, viz.:

a. Nature of liquid may be chemicals or if water, then whether raw or treated
b. Type or duty required, i.e., whether continuous, intermittent, or cyclic
c. Present and projected demand and pattern of change in demand
d. The details of head and flow rate required
e. Type and duration of the availability of the power supply
f. Selecting the operating speed of the pump and suitable drive/driving gear
g. The efficiency of the pump/s and consequent influence on power consumption and the running costs
h. Various options are possible by permuting the parameters of the pumping system, including the capacity and number of pumps including stand by, combining them in series or parallel

5.7.1 Application of Specific Speed in Selection of Speed, Discharge, and Head

Specific speed is a very useful parameter in pump design, selection, determination of efficiency, the shape of H-Q, P-Q, and efficiency-Q characteristics, number of pumps, head per stage, suitability of the pump for required head range, selection of rpm.

These parameters are combined together in the term specific speed of a pump. The pressure and discharge of a pump vary with pump speed. A pump of a given geometrical design is characterised by specific speed N_s. This is the hypothetical speed of a geometrically similar pump with an impeller diameter D such that it will discharge a unit volume of flow against a unit head at maximum efficiency. It is expressed by the following formula:

$N_s = N\, Q^{0.5}/h^{0.75}$

Where

N_s = Pump specific speed

N = rpm

Q = pump discharge m^3/s, (US gpm); irrespective of single suction and double suction pump

h = head per stage, m(ft)

The conversion factor is 1 (SI) = 51.645 USCU.

However, most aspects of the performance characteristics of the different types of pumps can be determined based on their specific speed. Some useful observations are summarised below.

a. Figure 5.10 states values of specific speed versus efficiency. It is also seen that efficiency is higher for higher Q for the same specific speed. It is seen from the figure that better efficiency can be obtained if Ns is between 39 to 68 (SI)/2000 to 3500 (USCS).

b. Variable parameters are Q per pump, head per stage, and N:

- Ns is directly proportional to the square root of Q, i.e., $Q^{0.5}$. The discharge Q per pump can be varied by changing the number of pumps. This indicates that the number of pumps should be minimum for better Ns.
- Ns is inversely proportional to 0.75 power of h (head per stage). Lesser the head per stage, Ns is higher.
- Ns is directly proportional to N (rpm). Thus, higher N renders better Ns.

- The objective should be to aim for Ns in the range 39 to 68 (SI)/2000-3500 USCS by varying the parameters Q, h, and N.
- In a single stage, high head pumps even if Ns is less than 39 (SI)/2000 USCS, there is no choice and lower Ns has to be accepted. However, if Ns is less than 42 (SI)/2170 USCS, the H-Q characteristic is unstable and not suitable for parallel operation.
- Ns above 80 (SI)/4100 USCS should be avoided as shut-off power is higher than the power required at the BEP, necessitating a higher motor rating for the pump. Such a pump cannot be started with the delivery valve closed which is an essential requisite for parallel operation.
- If Ns is less than 39 (SI) 2000 USCS, a head range beyond +7.5% is not probable and should be avoided to prevent heated operation at head higher than duty point/BEP.
- If Ns is less than 58 (SI)/3000 USCU, P-Q characteristics rise at higher Q. Motor for such pump need to be selected considering maximum power required corresponding to lowest head within specified head range.

c. Figure 5.10 illustrates the relationships between the pump efficiency, the shape of the impeller, and the nature of the curves of head (H) versus discharge (Q), power versus Q, and efficiency versus Q as influenced by the specific speed of the pump. The figure also helps in obtaining estimates of pump efficiency, which are useful in planning a pumping plant. This is applicable for all pumps including VT and submersible pumps.

d. Centrifugal pumps are generally with specific speeds above 36.

e. For high discharges, by which specific speed becomes high, the corresponding net positive suction head required also becomes high, the discharge is then shared by two impellers or two sides of an impeller as in a double suction pump.

- For specific speed (Ns), full Q is to be considered even in respect of double suction pump. (This is based on the consideration that discharge collector is single and common for impeller having two/double entries on the suction side).
- For suction specific speed (Nss) however, half Q is to be considered for a double suction pump. (This is based on the consideration that suction lift capability depends only on hydraulic losses on the suction side of the impeller).

f. Similarly, for high heads by which the specific speed becomes low, and hence the attainable efficiency becomes low, it can be arranged that the head is distributed amongst several impellers as in multistage pumps, thus improving the specific speed of each stage and consequently the attainable efficiency.

- The NPSHr characteristic of a pump is parabolic, increasing with flow rate. Pumps of high specific speed have high NPSHr.

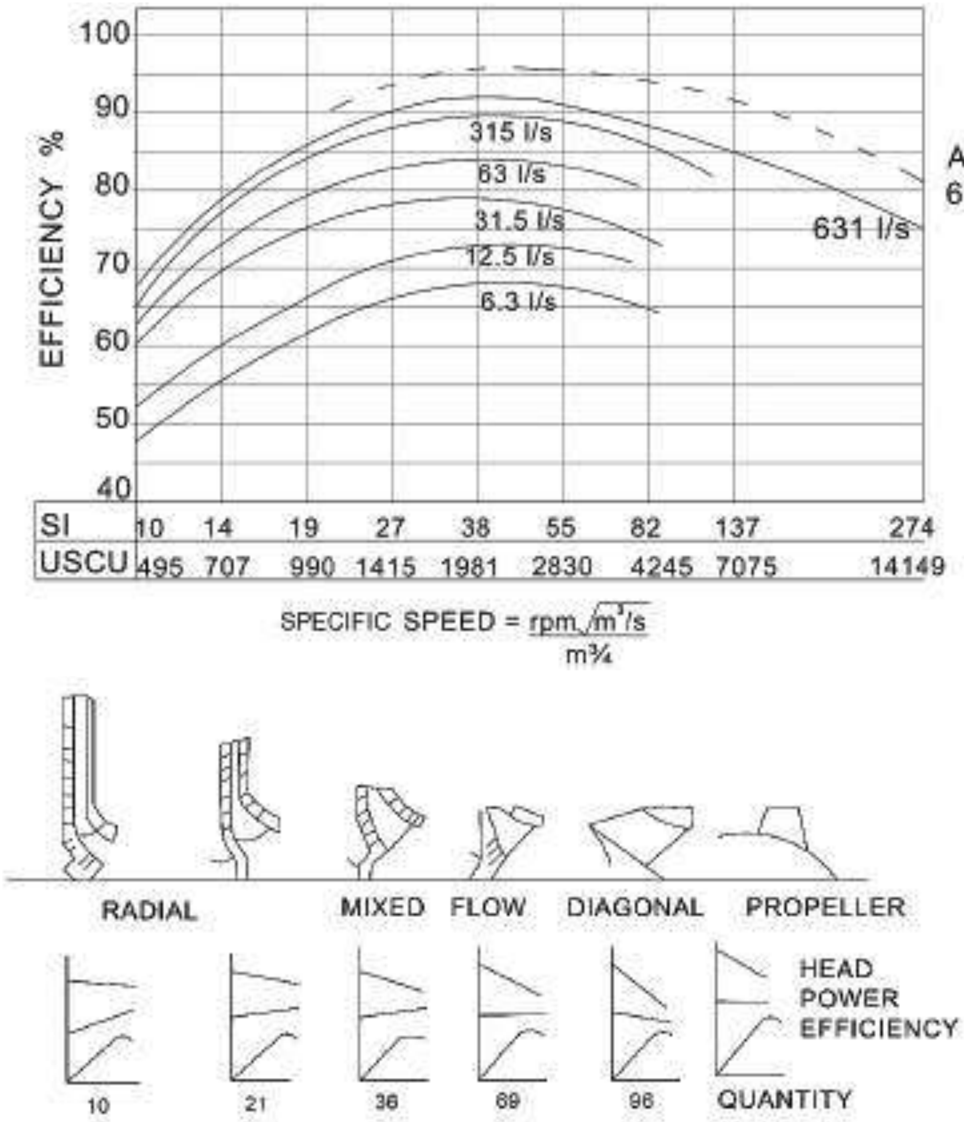


Figure 5.10: Specific Speed and Efficiency Characteristics

5.7.2 Considerations of the System Head Curve in Pump Selection

A pump or a set of pumps has to satisfy the needs of the pumping system. Hence one has to first evaluate the head needed to be developed by the pump for delivering different values of flow rate. A plot of these values is called the system head curve. Each point on the system head curve denotes the head comprised of the following:

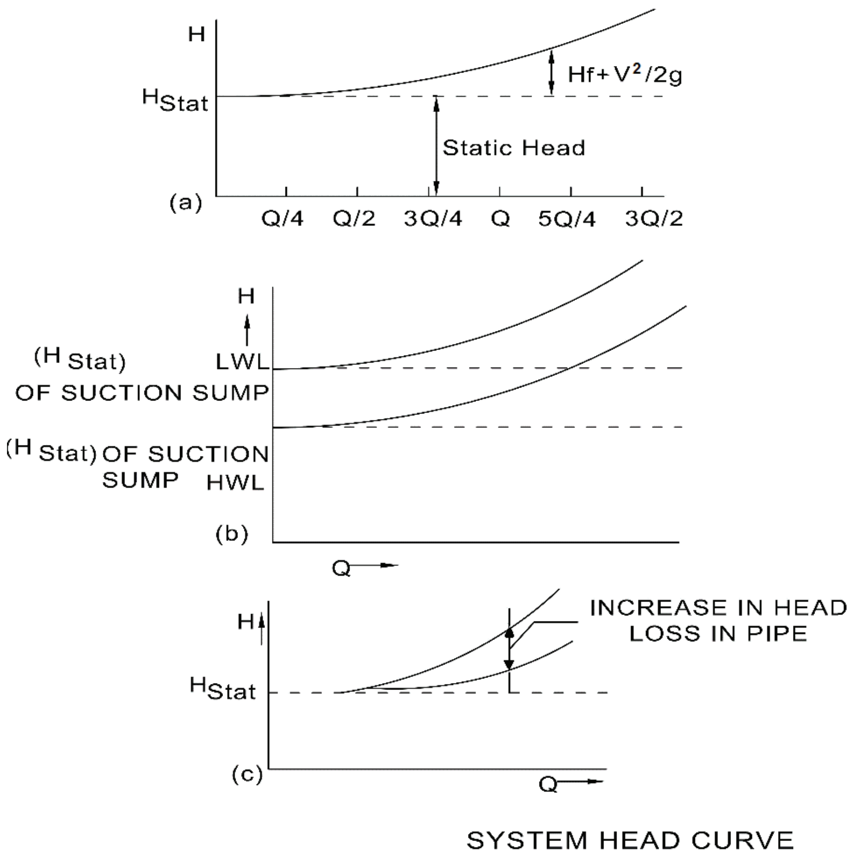


Figure 5.11: System Head Curve

The system head curve will change by any changes made in the system, such as a change in the length or size of the piping, change in size and/or the number of pipe fittings, changes in the size, number, and type of valves by operating the valves semi-open or fully open. These changes can cause the system head curve to be steep or flat as shown in Fig. 5.11 (c).

(i) Static suction lift/suction head

Static suction lift/suction head is the elevation difference from the centre line of the pump to the water level in the suction sump.

(ii) Static Delivery Head

Pump discharge is admitted at TWL/HWL in a tank by terminating the inlet pipe suitably and not at bottom of the tank. The static delivery head is the elevation difference from the centre line of the pump to the top of the exit pipe or TWL/HWL whichever is higher.

(iii) Static Head

This is the difference between the level of the liquid in the suction sump and the level of the highest point on the delivery piping. The static head is more at the low water level (LWL) and less at the high-water level (HWL). It is the sum of static suction lift/suction head and static delivery head.

(iv) Friction Head

This is the sum of the head losses in the entire length of the piping, from the foot valve to the final point of delivery piping, also the losses in all the valves, i.e., the foot valve, the non-return (reflux) valve, scour/wash out valves, air valve and the isolating (generally, sluice or butterfly) valves, and the losses in all pipe fittings such as the bends, tees, elbows, reducers, etc. Friction head also includes exit losses. Minor losses are generally about 10% of straight pipeline losses calculated as per Darcy-Weisbach or Hazen-Williams equations. The friction head varies particularly with the rate of flow. Details for calculating the friction heads are given in Chapter 6: Transmission of Water in Part A of this Manual.

(v) Velocity Head

Velocity head in exit loss is of very small magnitude about 0.05-0.15 m and considered as part of minor losses. At the final point of delivery, the kinetic energy is lost to the atmosphere. To recover part of this loss, a bell mouth/flared outlet is often provided at the final point of delivery. The kinetic energy at the final point of delivery has also to be a part of the velocity head.

(vi) Station Losses

An additional component of the head is station losses on account of losses in foot valve, suction piping, fittings, suction valve, delivery/discharge piping, fitting, NRV/DPCV, SV/BFV, etc., and header. The magnitude of station losses is between 1.0 to 2.0 m. However, it is difficult to show station losses in the system head curve as it is the sum of losses in piping and valves, etc., of only one of the pumps (maximum to be considered) and losses for combined discharge in the header.

(vii) Total pump head

It is the sum of all heads listed above, viz., static head, friction head, velocity head, and station losses.

(viii) Operating Point

It is a point where the system head curve and H-Q curve intersect. Refer to Figure 5.12 and Section 5.9.

5.7.3 Summary View of Application Parameters and Suitability of Pumps

Based on the considerations in section 5.6, a summary view is compiled of the application parameters and suitability of pumps of various types and presented in Table 5.3. However, these are general guidelines. Specific designs may either not satisfy the limits or certain designs may exceed the limits. The stipulation regarding VFD compliance is based on present manufacturing features.

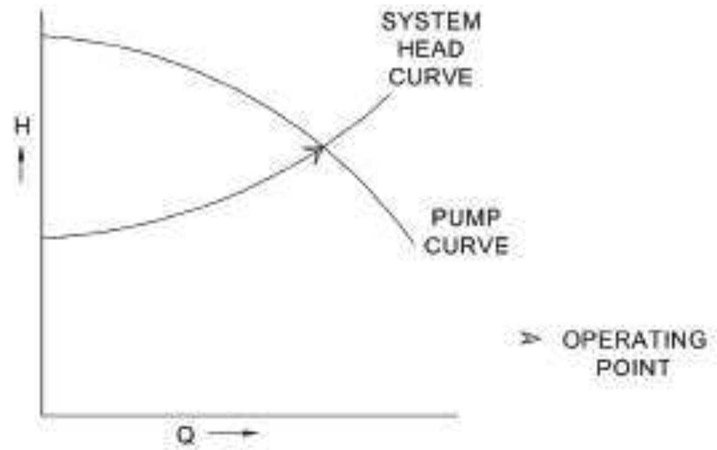


Figure 5.12: Operating Point of the Pump

Table 5.3: Application Parameters and Suitability of Pumps

Pump Type	Suction-Capacity to lift			Head Range			Discharge Range			Application Features							Remarks	
										Compatibility for Speed Control			Intake/Sump — Setting Depth of Pump Centreline from Pump mounting floor/Operation floor				Possibility of Operation despite Flooding pump- motor with electrical room above flood level/nearby safe place	Space Requirement (for Pumping Station)
	Low 3.5m	Medium 6m	High 8.5m	Low Up to 10m	Medium 10 - 40m	High Above 40m	Low Up to 30 l/s (108 m^3/h)	Medium up to 500 l/s (1,800 m^3/h)	High Above 500 l/s (1,800m^3/h)	Fixed Speed	Variable Speed (VFD driven) — Motor portion	Variable Speed (VFD driven) — Pump portion	up to 3.5m deep	Above 3.5 to 7m deep	Above 7 to 12m	beyond 12m deep		
Horizontal centrifugal end suction	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	No	Ok	needs VFD compatible motor	Ok	Ok	Ok subject to checking for safe operation	X	X	No	Large

Pump Type	Suction-Capacity to lift			Head Range			Discharge Range			Application Features							Remarks	
										Compatibility for Speed Control			Intake/Sump Setting Depth of Pump Centreline from Pump mounting floor/Operation floor				Possibility of Operation despite Flooding pump- motor with electrical room above flood level/nearby safe place	Space Requirement (for Pumping Station)
	Low 3.5m	Medium 6m	High 8.5m	Low Up to 10m	Medium 10 - 40m	High Above 40m	Low Up to 30 l/s (108 m^3/h)	Medium up to 500 l/s (1,800 m^3/h)	High Above 500 l/s (1,800m^3/h)	Fixed Speed	Variable Speed (VFD driven) Motor portion	Variable Speed (VFD driven) Pump portion	up to 3.5m deep	Above 3.5 to 7m deep	Above 7 to 12m	beyond 12m deep		
Double suction Horizontal Split Casing	Ok	No	No	Ok	Ok	Ok	No	Ok	Ok	Ok	needs VFD compatible motor	Ok	Ok	Ok subject to checking for safe operation	X	X	No	Large
Horizontal Multistage Centrifugal	Ok	Ok	No	No	Ok	Ok	Ok	Ok	No	Ok	needs VFD compatible motor	Ok	Ok	Ok subject to checking for	X	X	No	Large

<table>
<tr><th rowspan="4">Pump Type</th><th colspan="3">Suction-Capacity to lift</th><th colspan="3">Head Range</th><th colspan="3">Discharge Range</th><th colspan="7">Application Features</th><th colspan="2">Remarks</th></tr>
<tr><td rowspan="3">Low 3.5m</td><td rowspan="3">Medium 6m</td><td rowspan="3">High 8.5m</td><td rowspan="3">Low Up to 10m</td><td rowspan="3">Medium 10 - 40m</td><td rowspan="3">High Above 40m</td><td rowspan="3">Low Up to 30 l/s (108 m^3/h)</td><td rowspan="3">Medium up to 500 l/s (1,800 m^3/h)</td><td rowspan="3">High Above 500 l/s (1,800m^3/h)</td><td colspan="3">Compatibility for Speed Control</td><td colspan="4">Intake/Sump
Setting Depth of Pump Centreline from Pump mounting floor/Operation floor</td><td rowspan="2">Possibility of Operation despite Flooding pump- motor with electrical room above flood level/nearby safe place</td><td rowspan="2">Space Require ment (for Pumping Station)</td></tr>
<tr><td rowspan="2">Fixed Speed</td><td colspan="2">Variable Speed (VFD driven)</td><td>up to 3.5m deep</td><td>Above 3.5 to 7m deep</td><td>Above 7 to 12m</td><td>beyond 12m deep</td></tr>
<tr><td>Motor portion</td><td>Pump portion</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>safe operati on</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Submerged Centrifugal</td><td colspan="3">When suction lift is to be avoided</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Medium</td></tr>
<tr><td>Jet Pump</td><td colspan="3">When Limitations of suction lift are to be overcome</td><td>Ok</td><td>Ok</td><td>No</td><td>Ok</td><td>No</td><td>No</td><td>Ok</td><td>x</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Ok</td><td>Risky</td><td>Small</td></tr>
</table>

Pump Type	Suction-Capacity to lift			Head Range			Discharge Range			Application Features							Remarks	
										Compatibility for Speed Control			Intake/Sump: Setting Depth of Pump Centreline from Pump mounting floor/Operation floor				Possibility of Operation despite Flooding pump- motor with electrical room above flood level/nearby safe place	Space Requirement (for Pumping Station)
	Low 3.5m	Medium 6m	High 8.5m	Low Up to 10m	Medium 10 - 40m	High Above 40m	Low Up to 30 l/s (108 m^3/h)	Medium up to 500 l/s (1,800 m^3/h)	High Above 500 l/s (1,800m^3/h)	Fixed Speed	Variable Speed (VFD driven)		up to 3.5m deep	Above 3.5 to 7m deep	Above 7 to 12m	beyond 12m deep		
											Motor portion	Pump portion						
Vertical Turbine (Conventional)	When suction lift is to be avoided			Ok	Ok	Ok	Ok	Ok	Ok	Ok	needs VFD compatible motor	Ok subject to choking line shaft diameter and bearing spacing for safe critical speed	Ok	Ok	Ok	Ok subject to checking line shaft diameter and bearing spacing for safe	Risky	Medium

Pump Type	Suction-Capacity to lift			Head Range			Discharge Range			Application Features							Remarks	
	Low 3.5m	Medium 6m	High 8.5m	Low Up to 10m	Medium 10 - 40m	High Above 40m	Low Up to 30 l/s (108 m³/h)	Medium up to 500 l/s (1,800 m³/h)	High Above 500 l/s (1,800m³/h)	Compatibility for Speed Control			Intake/Sump: Setting Depth of Pump Centreline from Pump mounting floor/Operation floor				Possibility of Operation despite Flooding pump- motor with electrical room above flood level/nearby safe place	Space Requirement (for Pumping Station)
										Fixed Speed	Variable Speed (VFD driven): Motor portion	Variable Speed (VFD driven): Pump portion	up to 3.5m deep	Above 3.5 to 7m deep	Above 7 to 12m	beyond 12m deep		
																critical speed		
Submerged Turbine	When suction lift is to be avoided			Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Compact
Submersible pump(conventional)-or Polder	When suction lift is to be avoided			Ok	Ok	Ok	Ok	Ok	Ok	Ok	needs VFD compatible motor	Ok	Ok	Ok	Ok	Ok	Ok	Very small

Pump Type	Suction- Capacity to lift			Head Range			Discharge Range			Application Features							Remarks	
										Compatibility for Speed Control			Intake/Sump: Setting Depth of Pump Centreline from Pump mounting floor/Operation floor				Possibility of Operation despite Flooding pump- motor with electrical room above flood level/nearby safe place	Space Require ment (for Pumping Station)
	Low 3.5m	Medium 6m	High 8.5m	Low Up to 10m	Medium 10 - 40m	High Above 40m	Low Up to 30 l/s (108 m^3/h)	Medium up to 500 l/s (1,800 m^3/h)	High Above 500 l/s (1,800m^3/h)	Fixed Speed	Variable Speed (VFD driven): Motor portion	Variable Speed (VFD driven): Pump portion	up to 3.5m deep	Above 3.5 to 7m deep	Above 7 to 12m	beyond 12m deep		
Positive displacement pumps	Normally self-priming			Limited only by the pressure which casing can withstand			Ok	Ok	Ok	Ok	needs VFD compa tible motor	Ok	Ok	X	X	X	No	Medium
							Easy adaptation for dosing or metering			Ok								

5.7.4 Consideration while Selecting Pump for Series or Parallel Operation

(i) When pumps are to run in parallel, to obtain the combined H-Q characteristics, for different values of the head, the values of the flow of individual pumps are to be found and to be added (See Fig. 5.13). The system head curve then intersects the combined H-Q characteristics at higher head and discharge. Each pump ought to be capable of developing such a high head, that too within its zone of stability. Rather, it is always desirable to put into parallel operation only pumps having stable H-Q characteristics.

(ii) A pumping system is often sought to be modified to meet the increasing demand by commissioning additional pumps in parallel. It must be noted however that because the system head curve intersects the combined H-Q curve at a point having the head also higher, an additional pump would not increase the discharge proportionately, i.e., by making two identical pumps work in parallel when one is previously operative, the discharge would not double. (Fig. 5.14)

(iii) Conversely, if a system is to run with many pumps in parallel but is modified to run with only a few of the pumps as in summer, for example, then the duty flow of each pump becomes more than when all the pumps are running. The individual pump would demand higher NPSHr at the higher duty flow. If the NPSHa would not be adequate, the pump/s would cavitate. To prevent such a possibility, individual pumps, which are to be put into parallel operation, would be so selected that the duty flow of combined parallel operation would be to the left of the BEP of the individual pump. By this, when only a few pumps are to run, the duty flow of the individual pump would shift to the higher flow nearer to its BEP (Fig. 5.15)

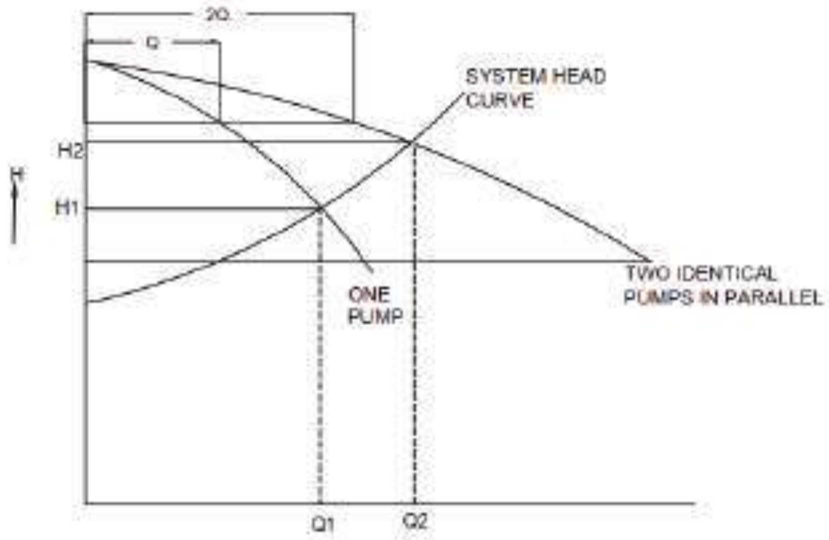
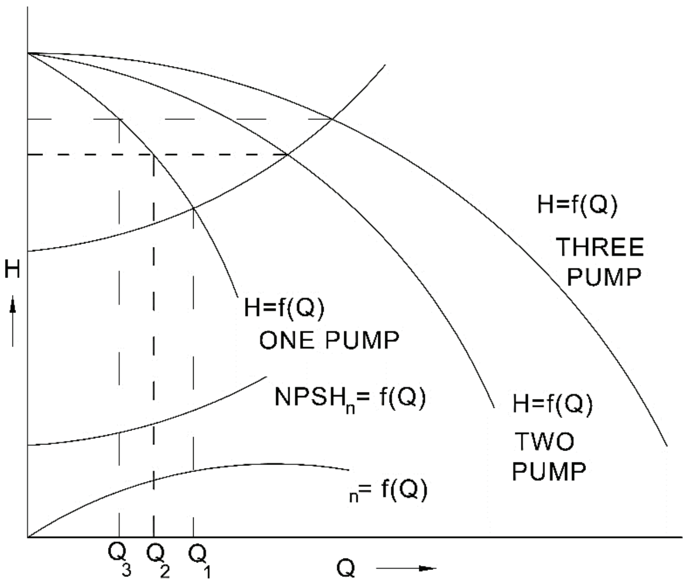


Figure 5.13: Combined Characteristics of Two Pumps in Parallel



NO. OF PUMPS IN OPERN.	FLOW OF EACH PUMP.
1	Q_1
2	Q_2
3	Q_3

Figure 5.14: One Or More Pumps in Parallel

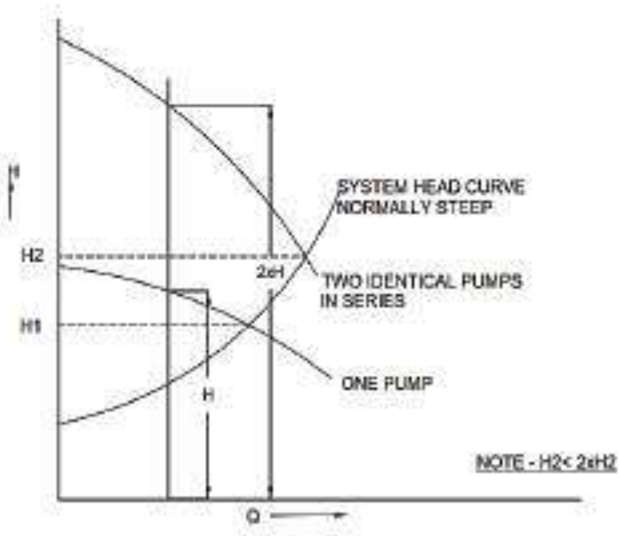


Figure 5.15: Series Operation of Pumps

(iv) Pumps in series are similar to multistage pumps. Rather, multistage pumps are only a compact construction, where series operation is in-built. To obtain the combined H-Q characteristics of pumps in series, for various values of discharge, the values of the head from the H-Q characteristics of individual pumps are to be noted and added. The system head curve would intersect the combined H-Q curve at a point of higher head and discharge (See Fig. 5.15). The individual pumping, in this case, ought to be capable of giving the higher discharge.

(v) If the system head curve comprises a high static head and a flat curve, the intersection at higher discharge on the combined H-Q characteristics may be at such discharge where the NPSHr of the individual pump would be high and the pump/s may cavitate.

(vi) Series operation is most appropriate, where the system head curve is steep. For the pumps to be put in series operation, each pump should be capable of withstanding the highest pressure that is likely to be developed in the system. (Fig. 5.15)

The head towards the potential difference between the centreline of one pump and the suction of the next pump, plus the friction losses in the pipeline between the deliveries of one pump up to the suction of the next pump has to be considered as a part of the total head of the pump giving the delivery. In a series system, the total head of each pump may have to be individually calculated, especially when the features contributing to head calculations are significantly different, as in the case of booster stations along a long conveyance pipeline.

5.7.5 Considerations of the Size of the System and the Number of Pumps

For small pumping systems, generally of capacity less than 25 MLD, two pumps of average daily discharge (one duty and one standby) should be provided. Alternatively, two duty and one standby, each of 50% of average daily water demand may be provided. Although this alternative would need a larger space, it facilitates flexibility in regulating the water supply. Also, in an emergency of two pumps going out of order simultaneously, the third helps to maintain at least partial supply.

The strategy for the number of working and standby pumps is proposed as follows.

i. The number of working pumps shall be decided such that the specific speed (Ns) of pumps is within optimum efficiency range inferred after detailed analysis using the following approach:
   The objective shall be to arrive at optimum Ns by varying parameters Q per pump, speed, and head per stage of the pump as follows:
   a) by varying number of pumps, thus, varying Q per pump
   b) by varying rpm to standard values
   c) by varying number of stages, thus, varying head per stage
   d) Ns is directly proportional to rpm
   e) Ns is proportional to the square root of Q per pump
   f) Ns is inversely proportional to the 0.75 power of the head
   g) rpm is generally, 980, 1480; in some cases, 590, 740, 2900
   h) If rpm increases, wear and tear increase, but pump size and, therefore, pump cost, reduces and vice versa
   i) If the number of stages is reduced, head per stage increases and Ns reduces and vice versa
   j) The number of stages for VT pump should generally not exceed five; in exceptional cases, up to 10
ii. There is no ideal solution. At the most, the best solution is perhaps possible. The solution to be concluded is usually a compromise between conflicting requirements. Even the chosen solution is not free from demerits.
iii. Based on the above, the number of working pumps is decided.
iv. If the number of working pumps is one, then, a combination
   - 1(W) + 1 (S)

   If number of working pumps are two, then,
   - Generally, 2 (W) + 1 (S)
   - Large scheme 2(W) + 2 (S)

This is based on the consideration that one pump may be under major repairs and the 2nd pump is under minor repairs and out of service for a few hours or one or two days. Also, the water supply service level cannot be reduced.

If the number of working pumps is three to five, then, a minimum of two numbers on standby, i.e.,

- 3(W) +2(S);
- 4(W) + 2(S);
- 5(W) + 2(S).

If the number of working pumps is 6 to 10, then, a minimum of three standby pumps shall be provided.

5.7.6 Considerations Regarding Probable Variations of Actual Duties

5.7.6.1 Affinity Laws

The running speed of the electric induction motors is at a slip from its synchronous speed. The running speed of the motor is also influenced by variations in the supply frequency. Since the pump characteristics furnished by the pump manufacturers are at a certain nominal speed, depending upon the actual speed while running, the actual pump performance would be different from the declared characteristics. Estimates of the pump performance in actual running can be worked out from the declared characteristics, by using the following affinity laws.

If

$$\frac{n''}{n'} = k, then\ \frac{Q''}{Q'} = k;$$

$$\frac{H''}{H'} = k^2, and\ \frac{P''}{P'} = k^3;$$

In the above formulas, n denotes the speed of the pump, P denotes the power input to the pump, the superscript “denotes the values at the actual speed and the superscript ' denotes the values at the nominal speed.

Recalculating the pump performance at the actual speed would reveal the following.

(a) If the actual speed is less than the nominal speed, then the values of the discharge, head, and power required to be input to the pump would all be less than the values from the declared characteristics.

(b) Similarly, if the actual speed is more than the nominal, it should be checked that the higher power input required would not overload the motor.

(c) When the actual speed is more because the discharge is also correspondingly more, the NPSHr would also be more, varying approximately as per the following formula.

$$\frac{NPSHr''}{NPSHr'} = k^2$$

5.7.6.2 Scope for Adjusting the Actual Characteristics

To avoid overloading or cavitation, marginal adjustment to the pump performance may be done at the site, either by employing speed-change arrangements or by trimming down the impeller. The modifications in the performance on trimming the impeller can be estimated using the following relations:

If, $\frac{D''}{D'} = k, then\ \frac{Q''}{Q'} = k; \frac{H''}{H'} = k^2, then\ \frac{P''}{P'} = k^3;$

Such modifications are recommended to be done within 5 to 20 per cent of the largest diameter of the impeller. The percentage depends upon the design, size, and shape of the impeller. Generally, a reduction in diameter is allowable within 10 to 20 per cent of the maximum impeller diameter of the pump in radial flow impellers and 5 to 15 per cent in mixed flow and axial flow impellers. The pump manufacturer should be consulted on this reduction.

5.8 Consideration of the Suction Lift Capacity in Pump Selection

5.8.1 Significance of NPSHr

The suction lift capacity of a pump depends upon its NPSHr characteristics. Significance of NPSHr can be explained by considering an installation of a pump working under a suction lift as illustrated in Fig. 5.16.

When a pump, installed as shown is primed and started, it throws away the priming water and has a vacuum developed at its suction. The atmospheric pressure acting on the water in the suction sump then pushes the water through the foot valve, into the suction line, raising it up to the suction of the pump. While reaching up to the suction of the pump, the energy content of the water, which was one atmosphere when it was pushed through the foot valve, would have reduced, partly in overcoming the friction through the foot valve and the piping and the pipe fittings, partly in achieving the kinetic energy appropriate to the velocity in the suction pipe, and partly in rising up the static suction lift. The energy content left over in the water at the suction face of the pump is thus less than one atmosphere until here the flow is fairly streamlined. However, with the impeller rotating at the pump suction, the flow suffers turbulences and shocks and will have to lose more energy in the process. This tax on the energy of the water demanded by the pump, before the pump would impart its energy, is called the NPSHr of the pump.

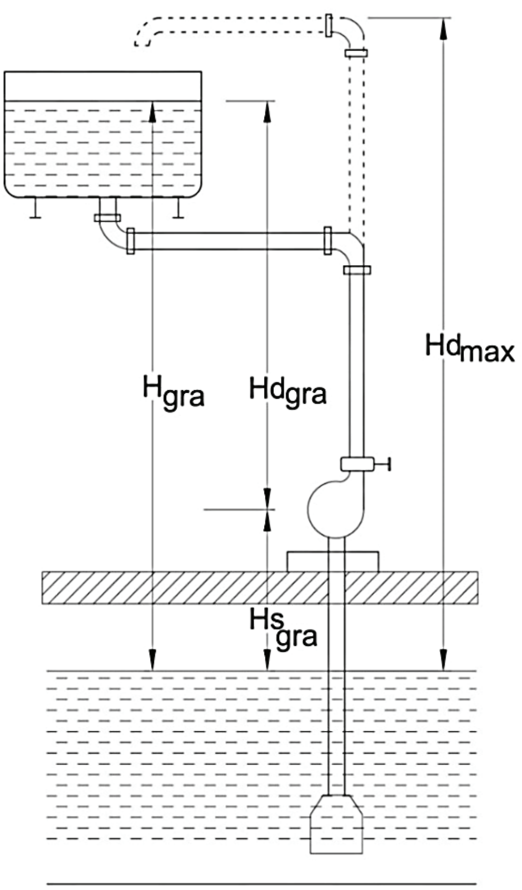


Figure 5.16: Illustration of Suction Lift and Static Delivery Head

5.8.2 Vapour Pressure and Cavitation

The energy of the water at the pump suction, even after deducting the NPSHr, should be more than the vapour pressure Vp corresponding to the pumping temperature. The vapour pressures in metres of water column (mWC) for water at different temperatures in degrees Celsius are given in Table 5.4.

Table 5.4: Vapour Pressure of Water

°C	mWC
0	0.054
5	0.092
10	0.125
15	0.177
20	0.238
25	0.329
30	0.427
35	0.579
40	0.762
45	1.006
50	1.281

If the energy of the water at the pump suction would be less than the vapour pressure, then the water will tend to evaporate. Vapour bubbles so formed will travel entrained in the flow until they collapse. This phenomenon is known as cavitation. In a badly designed pumping systems, cavitation can cause extensive damage to suction side of impeller and suction casing due to erosion, pitting and the vibration and noise associated with the collapsing of the vapour bubbles.

5.8.3 Calculating NPSHa

To insure against cavitation, the pumping system has to be so devised that the water at the pump suction will have adequate energy. Providing for this is called as providing adequate net positive suction head available (NPSHa). The formula for NPSHa, hence becomes as follows:

NPSHa = $P_S - Hf_s - \frac{V_s^2}{2g} - Z_S - V_p$

Where,

P_S = Suction Pressure in the absolute unit.

If the suction tank is open to the atmosphere, Ps = Atmospheric pressure in mWC corresponding to altitude

Hf_s = Frictional Losses across the Foot Valve, Suction Piping, and Fittings

V_s = Velocity head at the suction face

Z_S = The potential energy corresponding to the difference between the levels of the impeller eye centreline and of the water in the suction sump

V_p = The vapour pressure

While calculating NPSHa, the atmospheric pressure at the site should be considered, as the atmospheric pressure is influenced by the altitude of the place from the mean sea level (MSL). Data on the atmospheric pressure in mWC for different altitudes from MSL is given in Table 5.5.

Table 5.5: Atmospheric Pressure in mWC at Different Altitudes above MSL

Altitude above MSL in m	mWC
up to 500	10.3
1,000	9.8
1,500	9.3
2,000	8.8
2,500	8.3
3,000	7.8
3,500	7.3
4,000	6.8

NPSHa is not characteristic of a Pump; it depends on pump installation level with respect to WL in sump/intake, atmospheric pressure, losses in suction piping, and vapour pressure of water at water temperature. NPSHa is an important parameter to calculate suction specific speed which indicates suitability for cavitation-free operation for site suction conditions or otherwise as elaborated in discussions on suction specific speed.

5.8.4 Suction Specific Speed and its application for suitability for Suction head

The formula for suction specific speed (Nsss), is given by,

$$Nsss = \frac{N\sqrt{Q}}{NPSHa^{0.75}}$$

Where

N = rpm

Q = discharge per suction side of impeller (for double suction impeller half Q to be considered); m^3/s (SI)/US gpm (USCU)

NPSHa = Net positive suction head available; m (SI)/feet (USCU)

The method for calculating NPSHa is detailed in subsection 5.8.3 as per which NPSHa depends on site installation, atmospheric pressure at site altitude, and vapour pressure at maximum water temperature at site temperature. Thus, NPSHa for the same pump shall be different for installations at two different sites.

Application of suction specific speed:

Suction specific speed (Nsss) is a very useful parameter for concluding the suitability of pump for prevailing suction conditions at site environments and installation level as elaborated in (a) above.

Nsss should not exceed 145 (SI)/7,500 USCU for pump installation to achieve cavitation-free operation under the site conditions of atmospheric pressure and maximum water temperature.

5.8.5 Guidelines On NPSHr

The NPSHa has to be so provided in the systems that it would be higher than the NPSHr of the pump. The characteristics of the pump's NPSHr are to be obtained from the pump manufacturers. However, some general guidelines for maximum suction lift or min. NPSHa based on the type of a pump and based on the range of head and the specific speed is compiled below:

General Observations

a. In some cases, horizontal centrifugal pumps are installed with a suction lift.

b. For vertical pumps, mainly of the vertical turbine type, and of the borewell submersible type, the suction lift has to be totally avoided. Even for these pumps, when the discharge required is high, they have to be installed providing the minimum submergence. The minimum submergence required may at times demand submerging more than the first stage of the pump. It should also be checked whether the submergence would be adequate for vortex-free operation.

c. Jet centrifugal combinations can work for lifting from depths up to 70 m. However, the efficiency of the pumps is very low.

d. Positive displacement pumps are normally self-priming. However, this should not be confused with the NPSHr. Even if the NPSHa is not adequate, the pump may prime itself and run, but would cavitate.

5.9 Defining the Operating Point or the Operating Range of a Pump

The operating point of a pump is the point of intersection of the system head curve with the H versus Q characteristics of the pump. Shifting of the system. Head curve will cause a change in the operating point of the pump. Hence, the following points are worth noting:

a) If the level of water in the suction sump would deplete during pumping from HWL to LWL the operating point of the pump would vary from a low-head-high discharge point to a high head low-discharge point (Fig. 5.17).

b) If in a pumping system, the throttling of the delivery valve from fully open to close, shifts the system head curve from a flat curve, intersecting the pumps H-Q curve at high flow initially to a steep system head curve intersecting the pumps H-Q curve at the high head (Fig. 5.18).

   Similarly, a pumping system can be with a flat or steep system head curve depending on relative magnitudes of static head and friction losses in pumping mains.

   The most average water level in the suction sump and the most average system head curve for designed number of duty pumps would define the operating point of the pump. For such an operating point of the pump, the pump should have its point of maximum efficiency at or nearest to it. To provide for marginal changes in the operating point, e.g., between HWL and LWL, the nature of the efficiency characteristics of the pump should be as flat as possible in the vicinity of the point of its best efficiency, often called as the BEP.

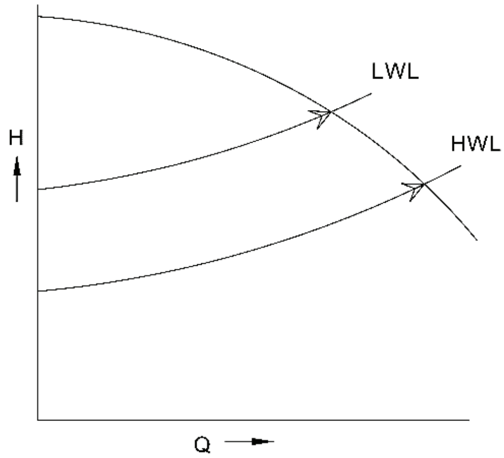


Figure 5.17: Change in Operating Point of Pump with Change in Water Level in Suction Pump

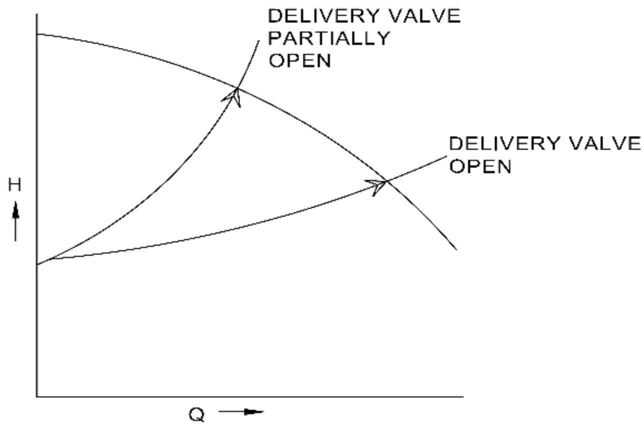


Figure 5.18: Change in Operating Point of Pump due to Throttling of Delivery Valve

c) When specifying the operating point of the pump, margins, and safety factors, especially in specifying the head should be avoided. On providing margins and safety factors, the rated head for the pump would work out high. In actual running, the pump would work at a head less than the rated head and yield high discharge. It would be noted that the power versus Q characteristics of pumps of specific speeds up to 29 (SI)/1500 USCS is with positive gradient, hence, demanding more power at higher discharge. With such higher power demand, the drive may get overloaded.

d) By working at high discharge, the NPSHr demanded by the pump would be higher. If NPSHa is not adequate for this higher NPSHr, the pump may cavitate.

Due to the high discharge included, the pump may vibrate. Sometimes this may result in serious damage to the shaft and bearings.

e) Operating/duty point and operating head range pump parameters are to be specified as under:

i. Duty Point: Q, H, minimum acceptable efficiency, and maximum suction lift as per pump installation levels and LWL.

ii. Head range:

a. VT pumps, submerged VT and submersible pumps:

- +10% and -25% of duty head;
- actual variation in the head from a solo operation to parallel operation up to the maximum number of working pumps and WL variation from LWL to TWL; or
- ±3 m whichever is the highest amongst three bullet values for the maximum head and the lowest for the minimum head.

b. Centrifugal pumps and submerged centrifugal:
   - generally, +10% and -25% of duty head; if shut-off head is within +15%, then +7.5% and -25% of duty head;
   - actual variation in the head from a solo operation to parallel operation up to the maximum number of working pumps and WL variation from LWL to TWL; or
   - ± 3 m whichever is the highest amongst three bullet values for the maximum head and the lowest for the minimum head.

5.10 Stability Of Pump Characteristics

In the H-Q characteristic of the centrifugal pump, the flow reduces as the head increases. If the head increases continuously until zero flow or until full close, i.e., shut-off of the delivery valve, the H-Q characteristic is said to be stable. However, it is also probable that the shut-off head of a pump may be less than the maximum head, as shown in Figure 5.19 which may be realised at some positive flow. Such a characteristic of a pump is called an unstable characteristic. When operating such a pump at any head between the shut-off head and the maximum head, the flow will keep hunting between two values. Because of this, the performance of the pump becomes erratic and unstable.

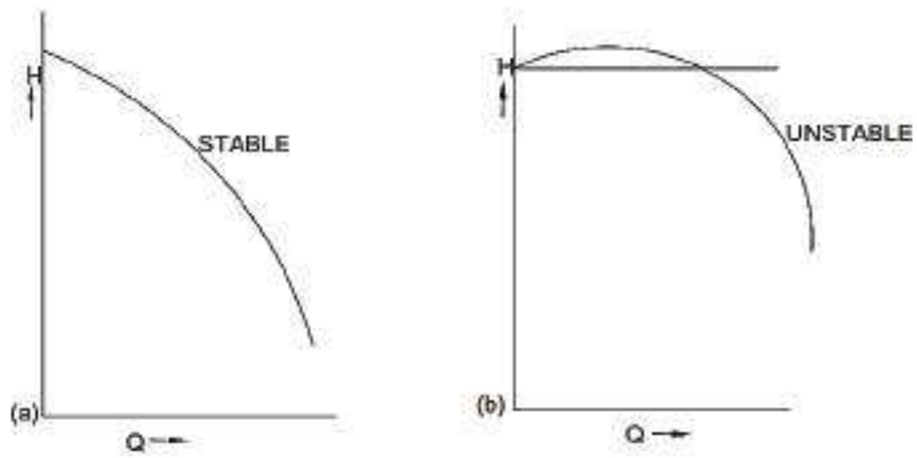


Figure 5.19: Stable and Unstable Characteristics of Pump

While selecting a pump, it ought to be checked that the highest head by the intersection of the system head curve would be less than the shut-off head, in the case of a pump with unstable characteristics. For multiple pumps in parallel, pumps with stable H-Q characteristics should only be selected. If pumps have an unstable characteristic, one pump may operate at a rated discharge, but other pumps shall operate at a lower discharge point or may hunt between two discharge points.

5.11 Important Guidelines for Pump Selection

i. The variable parameters N (rpm), h (head per stage) by varying number of stages, and Q by varying number of working pumps, should be such that the specific speed of pumps is within the range of 38 to 68 (SI) or 2,000 to 3,500 USCU for optimum efficiency. Under no circumstances, specific speed should exceed 80 (SI)/4,100 USCS as shut-off power is higher than BEP power, requiring a higher kW motor for starting the pump.
ii. N should preferably be 980 rpm for large installation. In exceptional cases, 1,480 rpm so as to restrict wear and tear to a minimum and limit noise and vibration levels. 2,900 rpm should be avoided to the possible extent except for borewell type submersible pumps.
iii. In the case of VT or multistage centrifugal pumps, the number of stages should not generally exceed five. However, in exceptional cases, stages up to a maximum of 10 numbers can be accepted.
iv. The centrifugal pump should preferably be a double suction horizontal split casing. End-suction pump should generally be avoided.
v. Submersible pumps for the open well, intake, and sump should generally be avoided as their lifespan is much less than 5-10 years.
vi. In some cases, accept lower rpm, i.e., 740 or 590 or 490 though the cost is much higher.
vii. Use of oil lubricated VT pump should be restricted to river water turbidity higher than 500 NTU.
viii. The diameter of column pipes should be decided by the client as this parameter is not dependent on bowl assembly design and shall be on basis of velocity 1.75 to 2.75 m/s; lower value for low Q and higher value for medium/high value of Q.
ix. The diameter of the bell mouth shall be on basis of 1.2 to 1.4 m/s entrance velocity.
x. The critical speed of the pump/impeller shaft should not be within 75-125% of the rpm of the pump.
xi. Subsurface delivery VT pumps should be avoided as hydraulic thrust is encountered at delivery tee connection vulnerable to column assembly misalignment.
xii. Thrust bearing of conventional VT pump shall be suitable for 40,000-50,000 hours of life.

5.12 Motor Rating

After the operating point of a pump is decided as discussed in 5.9, the efficiency of the pump can be estimated. The rating of the drive should be such that it would not get overloaded when the pump would be delivering the high discharge, as with HWL in the suction sump. Also, the drive rating should be adequate to provide for the negative tolerance on efficiency and the positive tolerance on discharge, applicable for variations in actual pump performance from the rated performance.

The power needed as input to the pump is the power output by the drive, i.e., at the pump shaft. Since most drives are coupled directly to the pump, the power at the pump shaft denotes the brake power of the drive. All drives are rated only as per their brake power capacity, often quoted in brake kilowatts (bkW).

Input to pump and motor is given by the formulas given as under:

i. Pump bkW = $\frac{\mathrm{g\ x\ Q\ x\ H\ x\ Spg}}{effp}$

Where

g = 9.81 m/s^2 (as acceleration due to gravity)

Q = discharge, m^3/s

H = pump head, m

Spg = specific gravity of liquid

effp = pump efficiency

bkW = brake kilowatt input to pump

Specific gravity for water is 1

ii. Input to motor = Pump bkW/effm
Where

effm = motor efficiency

To provide margins over the bkW required at the operating point and maximum bkW required over the required head range, so that the overloading would not happen, the following margins (Table 5.6) are recommended.

Table 5.6: Margins to Decide Motor Rating

bkW required at the operating point	Percentage Margin
Up to 1.5	50%
1.5 to 3.7	40%
3.7 to 7.5	30%
7.5 to 15	20%
15 to 75	15%
above 75	10%

5.13 Pump Testing

The objective of pump testing is to verify that the performance characteristics of the pump are appropriate for the service desired.

The testing is done both at the manufacturers' works and only for preventive maintenance in the field, with the following limitations:

As per IS 9137 for Class C test and IS 10981 for Class B test relating to testing of pumps, the standard arrangements and procedures described are those to be employed for testing a pump individually, without reference to its final installation conditions or the effect upon it of any associated fittings, these being the usual conditions in which a pump is tested at the manufacturer’s works. Acceptance tests can be carried out either at the manufacturer's workplace or at a place to be mutually agreed upon between the manufacturer and the purchaser.

5.13.1 Testing at Manufacturer’s Place

Since the testing at the manufacturers' place is done with water under ambient conditions, the duties desired with service-fluid have to be translated to equivalent duties with water under ambient conditions. Please refer to standards on testing, viz., IS: 9137 or IS: 10981 for permissible tolerances for the variation of test results from guaranteed duties. Out of these two standards, IS: 9137 details Class C code of testing, and IS 10981 details Class B code of testing. The Class B code of testing specifies a narrower band for tolerance, the implicit stringency affects both the cost and the period of delivery. The Class C code of testing is the most widely followed and adequate in most of the cases. However, for a pump above 225 kW, the Class B test is desirable.

The scheme of testing includes taking readings, doing calculations, and plotting:

- the H-Q characteristics;
- the P-Q characteristics; and

- the efficiency versus Q characteristics
- Check for permissible unbalance for pumps above 150 kW which are discussed in the next sub section

The actual speed of the shaft at the time of each reading would be different from the nominal speed. The value of the total head-flow rate and power input are to be converted to the nominal speed, using the affinity laws.

The readings of power input noted during testing are often the values of power input to the motor. Values of power input to the pump have to be derived by multiplying the values of power input to the motor with the appropriate values of motor efficiency.

For the values of motor efficiency, a reference has to be made to the motor characteristics. Often, these are available as motor output to the motor efficiency relationship. Since the readings during the test are for the motor input, the motor characteristics need to be converted into the appropriate motor input to the motor efficiency relationship.

After the performance characteristics are plotted, an assessment has to be made to check whether the plotting reveals variations from the guaranteed duties. The pump can be approved if the variations are within the permissible limits.

It may be noted that the limits specified in IS: 9137 and IS: 10981 are both for positive and negative variances.

Only occasionally the testing is extended to cover testing the NPSHr characteristics of the pump. Care is always to be taken to provide NPSHa such that it has an adequate margin over NPSHr at all flow rates in the operating range. Hence the data of NPSHr provided by the manufacturer need not be verified by an actual test. This is so advocated considering that:

- Conducting test for NPSHr requires elaborate and often special arrangements on the test bed and becomes costly and time-consuming.
- Even on readily available test rigs, the actual conducting of the test itself becomes time-consuming, exerting and with a cost element.
- The variations from the declared data are mostly on the safer side.

However, if the site plan is laden with such constraints that NPSHa cannot have adequate margins over NPSHr, then testing for NPSHr may be stipulated very clearly in the purchase specifications. Unless stipulated, routine testing of a pump does not include the test for NPSHr in the scope,

5.13.2 Balancing test for Impeller or rotating assembly

The pump impeller balancing is performed based on ISO 1940-1 for pumps above 150 kW. During carrying out the test at the manufacturer's place, the inspector shall verify the approved balancing test procedure and identify the following information:

- Speed (RPM)
- Acceptance Criteria (permissible unbalance)

Permissible residual unbalance

The permissible residual unbalance U_{per} can be derived based on a selected balance quality grade G by the following equation:

$$U_{per} = 1000 \frac{\left(e_{per} \; X \; \Omega \right) X \; m}{\Omega}$$

Where

U_{per} is the numerical value of the permissible residual unbalance, expressed in gram millimetres (g·mm);

$(e_{per} X \Omega)$ is the numerical value of the selected balance quality grade, expressed in millimetres per second (mm/s); this is as per Table 1 of ISO 1940-1 (balance quality grades) 6.3 mm/s for pumps

m is the numerical value of the rotor mass, expressed in kilograms (kg);

Ω is the numerical value of the angular velocity of the service speed, expressed in radians per second (rad/s), with $\Omega = \frac{\pi \times n}{30} \approx \frac{n}{10}$ and the service speed n in revolutions per minute (r/min).

For example, if you have a 2 kg impeller with a 3,000-rpm rotor, the permissible unbalance is as follows:

$$\text{Permissible residual Unbalance} = U_{per} = 1000\frac{(2.5)\,X\,2}{314.2} = 15.91\ \text{g.mm}$$

The 2.5 is the ISO 1940-1 “grade of balance”. $(e_{per} X \Omega)$

Ω = Divide 3,000 RPM to 30/π to obtain speed in rad/s = 314.2

5.13.3 Testing at Site

At the site, the testing is done soon after installation to assess whether any adjustments are required to the pump characteristics. Further testing is done at the site, mostly once in a year to assess whether there is any deterioration in the performance of the pump due to wear and tear.

The objective of the field test is to serve as a timely caution for preventive maintenance and not one of obtaining very elaborate details of the pump characteristics.

During the testing at the site, it is often impractical to provide adequate instrumentation of an appropriate class of accuracy. Setting up the instrumentation may disrupt the online operation of the pump. Apart from the disruption, certain temporary modifications may be needed to introduce flow-measuring devices like the orifice plates, etc., in the line. A field test has to be scheduled considering when the disruption of the online operation can be tolerated.

5.14 Installation of Pumps

The procedure of installation depends upon whether the pump is to be mounted horizontal or vertical. Most pumps to be mounted horizontally are supplied by the manufacturers as a wholesome, fully assembled unit. However, pumps to be mounted vertically are supplied as sub-assemblies. For the installation of these pumps, the proper sequence of assembly has to be clearly understood from the manufacturer's drawings.

The installation of a pump should proceed through five stages in the following order:

i. Preparing the foundation and locating the foundation bolts.
ii. Locating the pump on the foundation bolts, however, resting on levelling wedges, which permits not only easy levelling but also space for filling in the grout later on.
iii. Levelling the pump.
iv. Applying grouting.
v. Performing alignment.

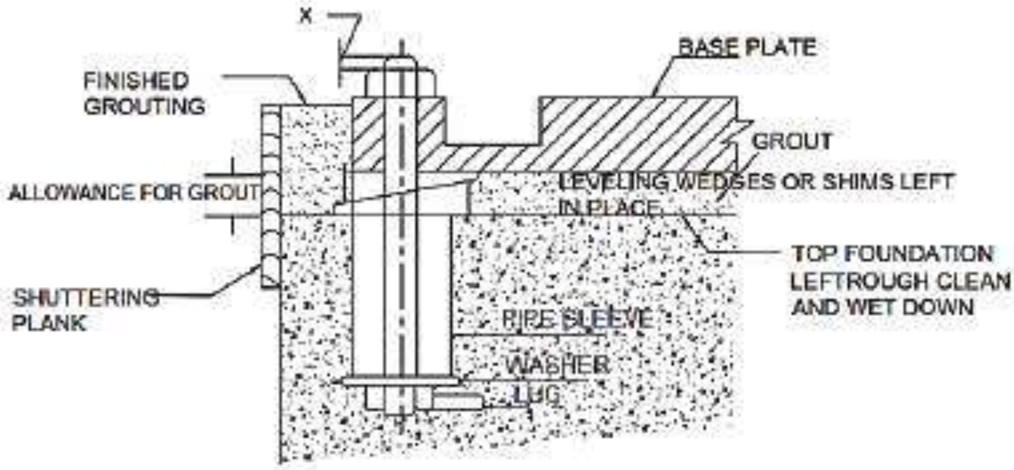


Figure 5.20: Typical Foundation Design

The following points should be taken care while installation:

(a) The foundation should be sufficiently substantial to absorb vibrations and form a permanent rigid support for the base plate. A typical foundation is illustrated in Fig. 5.20.

(b) The capacity of the soil or the supporting structure should be adequate to withstand the entire load of the foundation and the dynamic load of the machinery. As mentioned in clauses 6.2.2 and 6.2.3 of IS: 2974 (Part IV), the total load of the pump and the foundation should include the following:

- constructional loads;
- three times the weight of the pump;
- two times the total weight of the motor;
- weight of water in the column pipe;
- half of the weight of the unsupported pipe connected to the pump flanges.

(c) If the pumps are mounted on steel structures, the location of the pump should be as near as possible to the main members (i.e., beams or walls). The sections of structures should also have corrosion allowance.

(d) A curb ring or sole plate with a machined top should be used as a bearing surface for the support flange of a vertical turbine pump. The mounting face should be machined because the curb ring or sole plate is used to align the pump. Fig. 5.21 shows a typical arrangement with a curb ring and with a sole plate. A curb ring or sole plate is highly desirable for the VT pump. The sole plate is preferred and permanently installed after blue matching sole plate top surface with discharge head and need not be removed when the pump is lifted for repairs.

(e) Pumps kept in storage for a long time should be thoroughly cleaned and bearings checked, before installation.

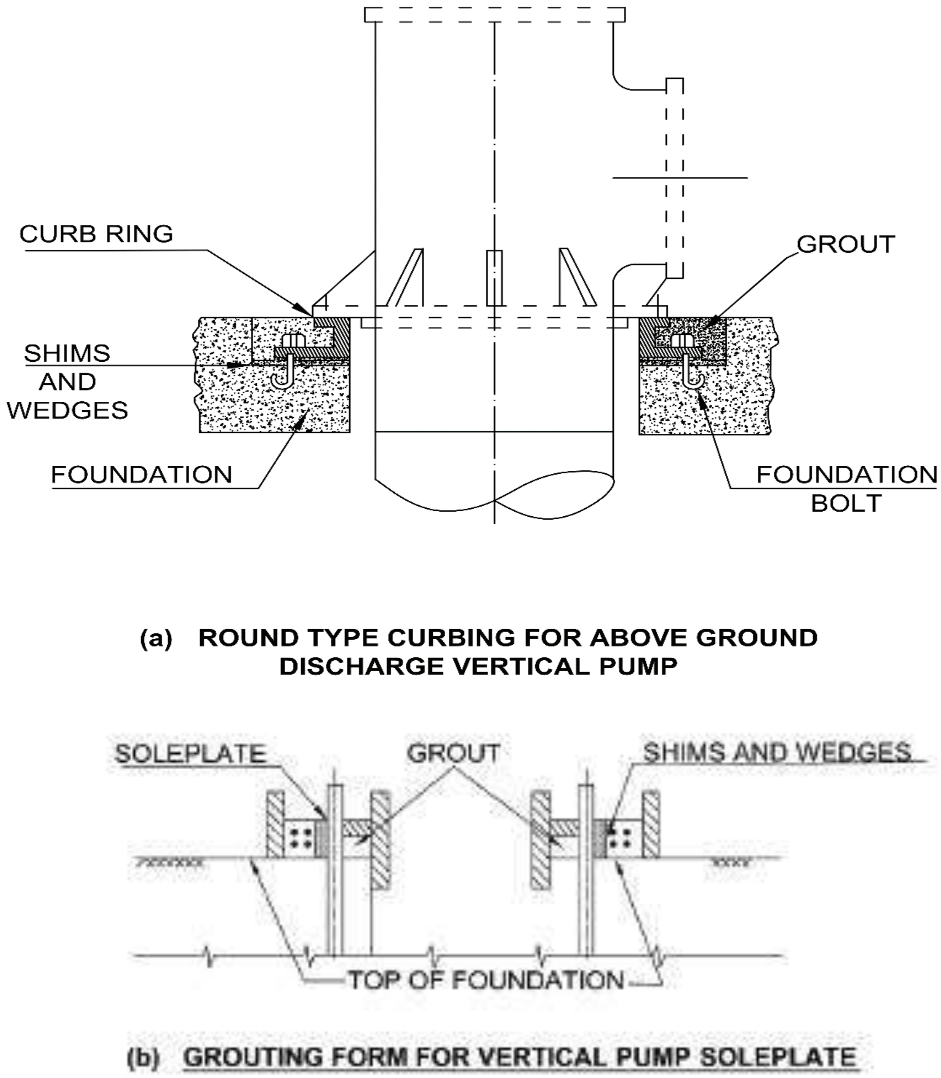


Figure 5.21: Foundation for Vertical Pump

(f) Submersible pumps with wet-type motors should be filled with water and the opening should be properly plugged after filling the water.

(g) Alignment of the pump sets should be checked even if they are received aligned by the manufacturers. The alignment should be proper both for parallelism (by filler gauge) and for co-axiality (by straight edge or by dial gauge).

During all alignment checks, both the halves should be pressed hard over to one side while taking the reading.

Alignment should also be checked after fastening the piping and thereafter, periodically during operation.

5.15 Pump Inertia

Normally I, Motor Inertia, is available from motor manufacturers directly and I, Pump Impeller Inertia is available from pump manufacturers. Both of these information can sometimes be obtained from the pump vendor. In case motor and pump inertia are not available, these can be estimated separately and then summed up using an empirical relationship developed by Thorley as given below:

$$I_{pump} = 1.5 \times 10^7 \times \left(\frac{P}{N^3}\right)^{0.9556} \text{ kg m}^2$$

$$I_{motor} = 118 \times \left(\frac{P}{N}\right)^{1.48} \text{ kg m}^2$$

Where

P is the power in kilowatts at the BEP

N is the rotational speed in rpm

5.16 Energy efficiency in Pumps by Flow Control Strategies

5.16.1 Pump control by varying speed

As can be seen from the above laws, doubling the speed of the centrifugal pump will increase the power consumption by eight times. Conversely, a small reduction in speed will result in a drastic reduction in power consumption. This forms the basis for energy conservation in centrifugal pumps with varying flow requirements.

Small increases in the speed of a pump significantly increase power absorbed, shaft stress, and bearing loads. It should be remembered that the pump and motor must be sized for the maximum speed at which the pump set will operate. At higher speed, the noise and vibration from both pump and motor will increase, although for small increases, the change will be small. If the liquid contains abrasive particles, increasing speed will give a corresponding increase in surface wear in the pump and pipework.

Flow control by speed regulation is always more efficient than by control valve. In addition to energy savings, there could be other benefits of lower speed. The hydraulic forces on the impeller, created by the pressure profile inside the pump casing, reduce approximately with the square of speed. These forces are carried by the pump bearings and so reducing speed increases bearing life. It can be shown that for a centrifugal pump, bearing life is inversely proportional to the 7^{th} power of speed. In addition, vibration and noise are reduced and seal life is increased, provided the duty point remains within the allowable operating range.

5.16.2 Pumps in parallel switched to meet demand

Another energy efficient method of flow control, particularly for systems where the static head is a high proportion of the total, is to install two or more pumps to operate in parallel. Variation of flow rate is achieved by switching on and off additional pumps to meet demand. The combined pump curve is obtained by adding the flow rates at a specific head.

The system curve is not affected by the number of pumps that are running. For a system with a combination of static and friction head loss, it is seen that the operating point of the pumps on their performance curves moves to a higher head and, hence, a lower flow rate per pump, as more pumps are started. It is also apparent that the flow rate with two pumps running is not double that of a single pump. If the system head were only static, then the flow rate would be proportional to the number of pumps operating.

It is possible to run pumps of different sizes in parallel if the operating head in parallel operation is less than shut-off heads of all pumps and individual discharges of pumps are above the minimum discharge values of the individual models. By arranging different combinations of pumps running together, a larger number of different flow rates can be provided into the system.

Care must be taken when running pumps in parallel to ensure that the operating point of the pump is controlled within the region deemed as acceptable by the manufacturer. It can be seen that if one or two pumps were stopped, then the remaining pump(s) would operate well out along the curve where NPSH is higher and vibration level increased, giving an increased risk of operating problems. While drafting specification, care must be taken to stipulate that the pumps shall be suitable over a specified head range due to varying operating conditions, from a solo operation to a parallel operation, up to a specified maximum number of pumps and WL variation from LWL to TWL. All variations in related parameters, i.e., discharge, head, the power drawn and NPSHr should be within design limits and noise and vibration should be within applicable limits.

5.16.3 Stop/Start control

In this control method, the flow is controlled by switching pumps on or off. It is necessary to have a storage capacity in the system, e.g., a wet well, an elevated tank, or an accumulator-type pressure vessel. The storage can provide a steady flow to the system with an intermittent operating pump. When the pump runs, it does so at the chosen (presumably optimum) duty point, and when it is off, there is no energy consumption. If intermittent flow, stop/start operation, and storage facility are acceptable, this is an effective approach to minimise energy consumption.

The stop/start operation causes additional loads on the power transmission components and increased heating in the motor. The frequency of the stop/start cycle should be within the motor design criteria and checked with the pump manufacturer.

It may also be used to benefit from “off-peak” energy tariffs by arranging the run times during the low tariff periods.

5.16.4 Flow control valve

With this control method, the pump runs continuously and a valve in the pump discharge line is opened or closed to adjust the flow to the required value.

To understand how the flow rate is controlled, see Figures 5.18 and 5.22. With the valve fully open, the pump operates at a higher flow. When the valve is partially closed it introduces an additional friction loss in the system, which is proportional to square of the flow rate. The new system curve cuts the pump curve at lower flow, which is the new operating point. The head difference between the two curves is the pressure drop across the valve.

It is a usual practice with valve control to have the valve 10% shut even at maximum flow. Energy is therefore wasted, overcoming the resistance through the valve at all flow conditions. There is some reduction in pump power absorbed at the lower flow rate, but the flow multiplied by the head drop across the valve is wasted energy. It should also be noted that, while the pump will accommodate changes in its operating point as far as it is able within its performance range, it can be forced to operate high on the curve, where its efficiency is low, and its reliability is affected.

The maintenance cost of control valves can be high, particularly on corrosive and solids-containing liquids. Therefore, the lifetime cost could be unnecessarily high.

5.16.5 Variable Speed Drives (VSDs)/Variable Frequency Drives (VFDs)

Pump speed adjustments provide the most efficient means of controlling pump flow. By reducing pump speed, less energy is imparted to the fluid and less energy needs to be throttled or bypassed. There are two primary methods of reducing pump speed: multiple-speed pump motors and variable speed drives (VSDs).

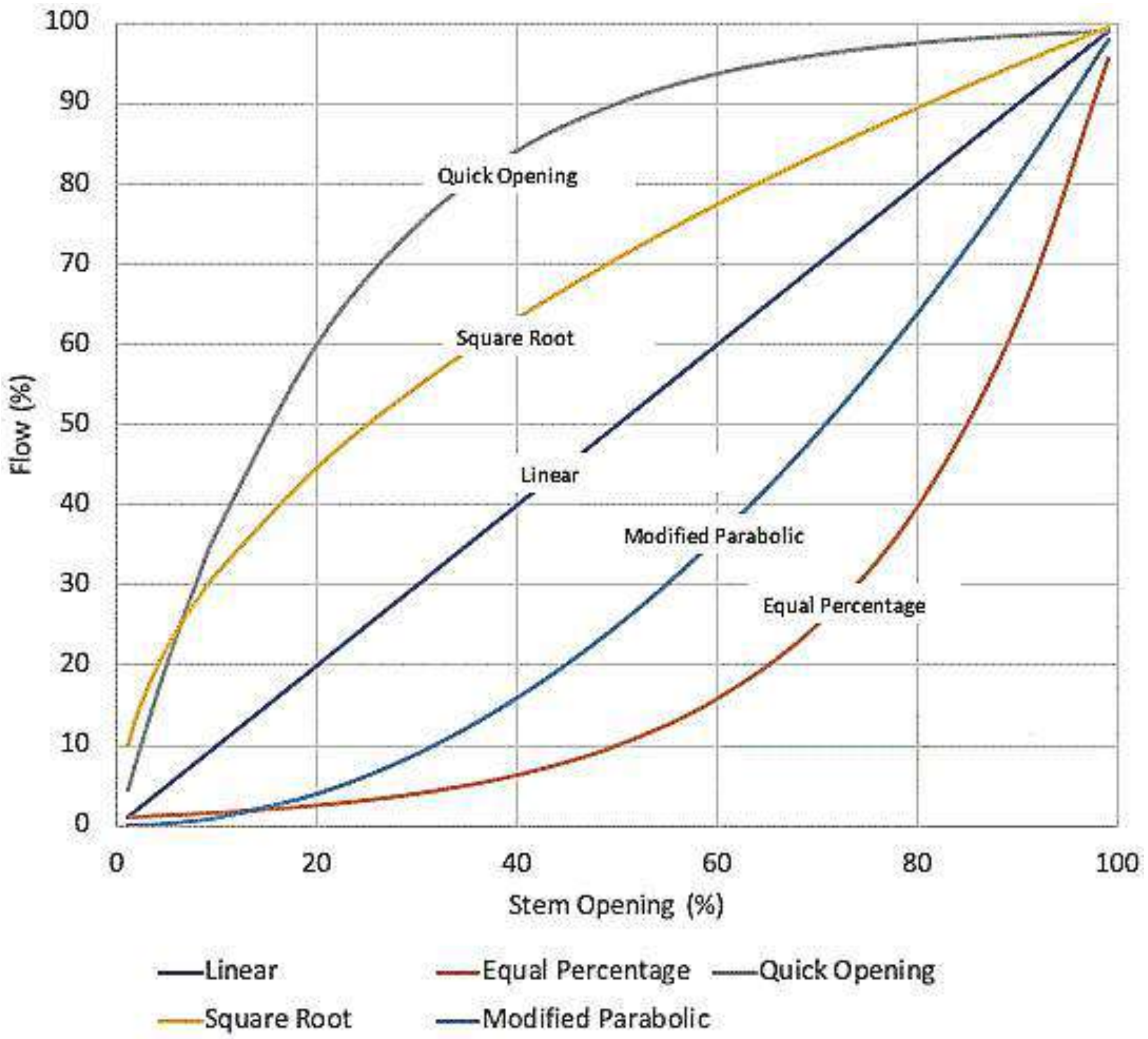


Figure 5.22: Flow Control Valve Characteristics

Although both direct control pump output, multiple-speed motors, and VSDs serve entirely separate applications. Multiple-speed motors contain a different set of windings for each motor speed; consequently, they are more expensive and less efficient than single-speed motors. Multiple-speed motors also lack subtle speed-changing capabilities within discrete speeds.

VSDs allow pump speed adjustments over a continuous range, avoiding the need to jump from speed to speed as with multiple-speed pumps. VSDs control pump speeds using several different types of mechanical and electrical systems. Mechanical VSDs include hydraulic clutches, fluid couplings, and adjustable belts and pulleys. Electrical VSDs include eddy current clutches, wound rotor motor controllers, and variable frequency drives (VFDs). VFDs adjust the electrical frequency of the power supplied to a motor to change the motor's rotational speed. VFDs are by far the most popular type of VSD.

However, pump speed adjustment is not appropriate for all systems. In applications with a high static head, slowing a pump risk inducing vibrations and creating performance problems that are similar to those found when a pump operates against its shut-off head. For systems in which the static head represents a large portion of the total head, caution should be used in deciding whether to use VFDs. VFD manufacturers have to be consulted to avoid the damage that can result when a pump operates too slowly against a high static head. For many systems, VFDs offer a means to improve pump operating efficiency despite changes in operating conditions. When a VFD slows a pump, its head-flow and brake kilowatt curves typically shift downward and to the left, and its efficiency curve shifts to the left. This efficiency response provides an essential cost advantage; by keeping the operating efficiency as high as possible across variations in the system's flow demand, the energy and maintenance costs of the pump can be significantly reduced.

VFDs may offer operating cost reductions by allowing higher pump operating efficiency, but the principal savings derive from the reduction in frictional or bypass flow losses. Using a system perspective to identify areas in which fluid energy is dissipated in non-useful work often reveals opportunities for operating cost reductions.

For example, in many systems, increasing flow through bypass lines does not noticeably impact the back pressure on a pump. Consequently, in these applications, pump efficiency does not necessarily decline during periods of low flow demand. By analysing the entire system, however, the energy lost in pushing fluid through bypass lines and across throttle valves can be identified.

Another system benefit of VFDs is a soft start capability. During start-up, most motors experience in-rush currents that are five to six times higher than normal operating currents. These high currents fade when the motor spins up to normal speed. VFDs allow the motor to be started with a lower start-up current (usually only about 1.5 times the normal operating current). This reduces wear on the motor and its controller.

In most 24×7 distribution systems, VFDs will offer benefits and should be considered at design stage itself.

5.17 Solar Pumps

The solar pump shall conform to specifications prescribed in the notification of the Ministry of New and Renewable Energy, Government of India, New Delhi vide its letter 32/5/2021 - SPV Division dated 08 June 2021.

These specifications cover design qualifications and performance specifications for centrifugal/submersible Solar Photo Voltaic (SPV) water pumping systems from 0.75kW/1 HP up to 11.25kW/15 HP to be installed on a suitable borewell, open well, water reservoir, water stream, etc., and specifies the minimum standards to be followed.in addition to IS 5120 and IEC 62253. These pumps are suitable for emergency use such as power failure on account of floods, cyclones, fires, etc.

Two types of pumps exist, viz., submersible pumps and surface (centrifugal) pumps. Which type of pump is ideal depends on the water source. In the case of a well, the pump needs to be placed underwater. Surface pumps can be placed at the side of a lake or, in the case of a floating pump, on top of the water. Surface pumps are less expensive than submersible pumps, but they are not well suited for suction and can only draw water from about 6.5 metres depth. Surface pumps are excellent for pushing water over long distances.

Solar pumps are powered by solar energy. Solar pumps are inexpensive, long-lasting, simple to install, and require little maintenance. The components of the solar pump are as below:

(a) Solar Panels
(b) Electric motor
(c) Pumps
(d) Inverter
(e) Converter
(f) With battery/Without battery

a) Solar panel

A solar panel consists of photovoltaic modules that generate direct current electricity when exposed to sunlight (Figure 5.23). These panels are hoisted under the open sky supported over steel or masonry structure or over the roof of a building if available. The panels should be installed in shadow free area.

Figure 5.23: Solar Panels

Source: https://www.climateaction.org/news/solar-irrigation-can-improve-prosperity-and-food-security-says-un-agency

b) Electric Motor

The motor is driven by electricity produced by the solar panels exposed to sunlight. The motor may either direct current or alternating current as required.

c) Pump

A pump of required capacity is used either for surface pumping or submersible pumping from borewells.

d) Inverter

An inverter is used to convert direct current electricity into alternating current for use in D.C. or A.C. motors as required.

e) Converter

A converter is an instrument that converts alternating current to direct current, or adjusts the voltage, current, or frequency to help smooth the running of motors.

f) Battery

A battery with 24 hr. storage capacity is provided to sustain the power supply when the panels are rendered ineffective during clouded sky or rains. Now, submersible pumps are available even without a battery.

5.17.1 Utility of Solar Pump

Solar pumps are useful for providing water supply to small communities in villages located in remote areas where electricity is not available. It may also be useful in gardening of small strips of garden or crop fields.

5.18 High-pressure pumps used in desalination plant

The high-pressure pump is critical to the overall system because it provides the energy required to overcome osmotic pressure in membrane desalination. The high-pressure pump is mainly divided into two categories such as centrifugal pumps and piston pumps. In general, a multistage centrifugal pump is mainly suitable for large-sized desalination plants. A piston pump is mainly suitable for small sized desalination plants. The desalination high-pressure pumps can significantly reduce engineering costs and are widely used in desalination projects.

5.19 Positive Displacement Pumps

Positive displacement pumps operate by trapping a fixed volume of fluid, usually in a cavity, and then forcing that trapped fluid into the discharge pipe. A centrifugal pump transfers the kinetic energy of the motor to the liquid by a spinning impeller. As the impeller rotates, it draws in the fluid causing increased velocity that moves the fluid to the discharge point.

The main differences between centrifugal (rotodynamic) and positive displacement pumps are highlighted in Table 5.7.

Table 5.7: Performance differences between centrifugal (rotodynamic) pumps and positive displacement pumps

Aspects	Centrifugal	Positive Displacement
Working Principle	Impellers pass on velocity from the motor to the liquid which helps move the fluid to the discharge port (produces flow by creating pressure).	Captures a limited volumes of liquid from the suction and forces to the discharge port (produces pressure by creating flow).
Flow Rate vs Pressure	The flow rate changes as the pressure changes.	With a change in pressure, the flow rate remains constant.
Viscosity	Due to frictional losses inside the pump, flow rate rapidly falls with increasing viscosity, even at moderate thickness.	High viscosities are easily managed owing to the internal clearances.
Efficiency	Efficiency peaks at a specific pressure; any variations decrease efficiency dramatically. When run far from the centre of the curve, it does not perform properly and can cause damage and cavitation.	Efficiency is less affected by pressure, but if anything tends to increase as pressure increases. Can be run at any point along their curve without causing harm or reducing efficiency.
Suction Lift	Suction lift is not achievable with standard models; however, self-priming variants are available, and a manometric suction lift is possible with a non-return valve on the suction line.	Create a vacuum on the inlet side, making them capable of creating a suction lift.

Positive displacement pumps are chosen for their ability to handle high viscosity fluids at high pressures and low flows because pressure does not affect their efficiency. While centrifugal pumps are the most common type of pump installed due to their simplicity, positive displacement pumps can handle difficult conditions where centrifugal pumps may fail due to their ability to run at any point on their curve.

Positive displacement pumps are either reciprocating or rotary.

Since positive displacement pumps do not have a shut-off head like centrifugal pumps, they must not be operated against a closed valve on the discharge side of the pump. When operating against a closed discharge valve, a positive displacement pump will continuously produce flow and build-up pressure till the line bursts or the pump is severely damaged, or both. As a result, a relief or safety valve on the positive displacement pump's discharge side is necessary. The relief valve might be internal or external. Internal relief or safety valves are usually supplied by the pump manufacturer. It is recommended that an external relief valve be installed in the discharge line, with a return line connected back to the suction line or supply tank.

5.20 Selection of Prime Movers

5.20.1 General

With the universal adoption of the alternating current system of electric energy for light and power, the field of application of A.C. motors as prime movers for all drives either in industries or water supply systems are widely used on account of their economy, compactness, ease in operation/maintenance, etc. In the water supply system, Asynchronous A.C. motors are commonly used as a prime mover for the water pumps but the use of synchronous A.C. motors and D.C. motors under circumstances may not be ruled out.

- Asynchronous A.C. motors
- Synchronous A.C. motors
- D.C. motors

Synchronous motors have two types.

a) Induction motors

b) Commutator motors

Induction motors are mostly used in the water supply system. It consists primarily of two major components: (a) rotor and (b) stator. The stator carries a three-phase winding from a three-phase power supply. The rotors of induction motors are of two types (a) squirrel cage rotor and (b) phase wound rotor. The induction motor having a phase wound rotor is known as a slip ring motor. Generally, either squirrel cage motors or slip ring motors are used as a prime mover for pump drive as per the requirement of the load. The squirrel cage motor is used up to 2500 kW load, whereas for higher loads above that, slip ring motors are used.

Synchronous motors merit consideration when large HP, low-speed motors are required. D.C. motors are used occasionally for pumps where only direct current is available as in ships, railways, etc.

5.20.2 Selection Criteria

The type of motor has to be selected considering various criteria such as the constructional features desired, environment conditions, type of duty, etc. Generally, energy efficient motors which are of the highest standard manufactured in India amongst IE2, IE3, and IE4 shall be selected. Improvement in motor efficiency as per IE criteria is continuing. Design and practicing engineers are advised to update about the availability of motors conforming to the highest IE standard and select motors suitably.

5.20.3 Energy Efficient motors

Energy efficiency and sustainability are becoming important topics for all stakeholders globally. Bureau of Indian Standards (BIS) in the IS 12615-2018 for “Line operated three-phase A.C. Motors (IE Code) Efficiency class and Performance specification” clearly mentions the need for the use of energy efficient motors and their impact. The Standard defines three levels of efficiencies for low-voltage motors - IE2, IE3, and IE4 - IE4 being the highest efficiency and provide values of performance characteristics and comparison of energy efficient induction motors. In India, IE2 is the mandatory minimum efficiency. However, the standards, Bureau of Energy Efficiency (BEE), and various industry and government entities encourage the use of higher efficiency motors.

Though IS 12615 follows IEC60034-30-1, additional performances are defined in IS 12615 and clearly mentioned so. These include locked rotor torque, locked rotor current, higher variation in voltage and frequency considering Indian grid conditions, etc.

The European Union and many countries all over the world have LV motors with IE3 guaranteed efficiencies which are mandatory and for variable frequency drives, IE2 is minimum. EU's latest Eco-design Regulation (EU) 2019/1781 also stipulates that from July 2023, motors sold in the range of 75kW to 200kW would have to meet IE4 efficiency requirements.

The Return on Investment (ROI) benefits are better when higher efficiency motors are used in a green field project. The life of motors is high at 15 to 30 years and hence, the intermediate replacement of low-efficiency motors with higher efficiency has relatively lower ROI. In lieu of the benefits of using energy efficiency motors on the running cost as well as the lower impact on the environment, it is recommended that motors above 11KW to 200KW be IE4 and smaller motors where the volumes are higher and envisage more manufacturers to participate, a minimum of IE3 efficiency be specified. Typical example and comparison of efficiencies of IE2 to IE4 follows below:

Examples of efficiencies:

KW	Pole	IE2	IE3	IE4
22	4	91.6	93	94 .5
30	4	92.3	93.6	94 .9
37	4	92.7	93.9	95.2
11	6	88.7	90.3	92.3
37	6	92.2	93.3	94 .5
22	2	91.3	92.7	94
55	4	93.5	94 .6	95.7

5.20.4 Constructional Features of Induction Motors

Squirrel cage motors are most commonly used. Normally, the starting torque requirement of centrifugal pumps is quite low and squirrel cage motors are therefore suitable.

Slip ring or wound rotor motor to be used where required starting torque is high as in positive displacement pumps or for centrifugal pumps handling sludge.

Slip ring motors are also used when the starting current has to be very low, such as 1.25 times the full load current; such regulatory limits being specified by the power supply authorities.

In addition, the type of mounting is also an important construction feature. Horizontal pumps like split-case centrifugal pumps, end-suction pumps, etc., require horizontal, foot mounted motors which are covered in IS 1231:1974. Vertical turbine pumps which are underwater and have the column pipe and shaft extending to the top require vertical flange-mounted motors, covered under IS 2223:1983. Further details of different types of mountings of rotating electrical machines are available in IS 2253:1974, or its latest edition.

5.20.5 Voltage Ratings

Table 5.8 gives general guidance on the standards voltages and corresponding range of motor ratings.

For motors of ratings 225 KW and above, where high tension (HT) voltages of 3.3 kV, 6.6 KV, and 11 kV can be chosen, the choice could be made by working out relative economics of investment and running costs, taking into consideration the costs of the transformer, motor, switchgear, cables, etc.

Table 5.8: Selection of Motors Based on Supply Voltages

Supply	Voltage	Range of Motor rating in KW	
		Min.	**Max.**
Single phase A.C.	230 V	0.3	2.5
Three-phase A.C.	415 V	-	250
	3.3 kV	225	750
	6.6 kV	400	-
	11 kV	600	-
D.C	230V	-	150

N.B. When no minimum is given, very small motors are feasible. When no maximum is given very large motors are feasible.

5.20.6 Type of Enclosures:

Table 5.9 gives guidance on the type of enclosures and the place where it is used.

Table 5.9: Types of Enclosures

Type	Environment Code as per IS	Where used
Screen protected drip proof (SPDP)	IP.23	Indoor, clean (dust-free) environment
Totally enclosed fan cooled (TEFC, IC4A1A1)	IP.44	Indoor, dust-prone areas
	IP.54	Normal outdoor
	IP.55	Outdoor at places of heavy rainfall
Totally Enclosed, Self-Water Cooled (TESWC, IC4A0W0)	IP68	Directly submerged under Water (to be pumped)

For motors above 225 kW, HT motors are used for which higher grade of cooling and enclosure protection are required. The types, as under, are stated in increased order of cost and effective cooling:

i) Totally Enclosed, Self-Water Cooled (TESWC)
ii) Totally Enclosed Tube Ventilated (TETV)
iii) Closed Air Circuit Air Cooled (CACA)
iv) Closed Air Circuit Water Cooled (CACW)

HT motor of appropriate enclosure and cooling arrangement from the above three categories shall be selected and further details of enclosure and application are available in IS 13555:1993.

5.21 Class of duty and number of starts

i. All motors should be suitable for continuous duty, i.e., Class S1 as specified IS: 325

ii. Allowable number of starts are as follows:
   - Two consecutive starts from cold condition with second start only after the motor stops fully;
   - One hot restart under high steady state temperature;
   - Permissible number of starts depends on the kW rating, speed, moment of inertia, and stoppage intervals. Generally, for lower kW, higher number of starts per hour are permissible and vice versa. Similarly, the lesser the speed, the greater the number of starts per hour are permissible.

For practical application, the minimum number of starts, as under, can be followed.

Synchronous RPM	Number of starts per hour	Minimum rest (minutes)
3,000	2	20
1,500	3	15
1,000	4	10

5.22 Insulation

Class B insulation is generally satisfactory since it permits temperature rise up to 80 °C. In cool places having ambient up to 30 °C, motors with Class E insulation can also be considered. In hot places having ambient above 40 °C, motors with Class F insulation should be considered. Generally, for hot places, even if Class F insulation is selected, the temperature rise limit is specified as applicable for Class B insulation. If altitude at installation exceeds 1,000 m above mean sea level, the temperature rise limit is reduced to 1 °C per 100 m.

5.23 Starters

5.23.1 Types

Starters are of different types, viz., direct online (DOL), star delta, autotransformer, and stator rotor. Of these, the last one is used with slip ring motors. The other three are used with squirrel cage motors.

5.23.2 Starters for Squirrel Cage Motors

Starters draw starting current, which is considered as a multiple of the full load current (FLC) of the motor. Different types of starters help control the starting current required. General guidelines are given in Table 5.10.

Table 5.10 Guidelines for Starters for Squirrel Cage Motors

Type of Starter	Percentage of voltage reduction	Starting Current	The ratio of starting torque to locked rotor torques, %
DOL	Nil	6 X FLC	100
Star delta	58%	2 X FLC	33
Autotransformer	Tap 50%	1.68 X FLC	25
	Tap 65%	2.7 X FLC	42
	Tap 80%	4 X FLC	64

Note: As per the torque speed characteristics of the motor, the torque of the motor at the chosen percentage of reduced voltage should be adequate to accelerate the pump to the full speed.

5.23.3 Method of Starting

Squirrel cage motors when started directly online (with DOL, starter) draw starting current about six times the full load (FL) current. If the starting current has to be within the regulatory limits specified by the power supply authorities, the squirrel cage motors should be provided with the star delta starter or autotransformer starter.

5.23.4 Selection of the Tapping of Autotransformer type Starter

The torque available from the motor is generally much higher than the starting torque required by the pump, as the starting torque required by the pump is also regulated by starting the pump with the delivery valve closed or open, depending upon the nature of the power versus Q characteristics of the pump.

The torque available from the motor being more than the starting torque required by the pump draws an unnecessary excessive current. This can be controlled by the torque available from the motor, the voltage to be applied to the motor can be reduced by selecting the appropriate percentage by tapping on the autotransformer starter. The value of the percentage for the tapping position can be decided by the following formula.

$$\text{Tapping \%} = 100 \times \sqrt{\frac{Torque\ for\ pump}{Torque\ for\ motor}}$$

Where

Torque for the pump is the torque required to the pump at its rated speed and at its maximum power demand; and

Torque from the motor is the torque available from the motor at its full load capacity and its rated speed at rated voltage.

Based on the above calculation, the nearest higher available position of tapping should be selected.

5.23.5 Reactance Based Starters or Soft Starters:

In the normal start-up of the induction motor, more torque is developed, which causes the stress to be transferred to the mechanical transmission system resulting in excessive wear and failure of the mechanical parts. Soft start offers a dependable and cost-effective solution to these issues by providing a controlled release of power to the motor, resulting in smooth, stepless acceleration and deceleration. Winding and bearing damage are reduced, resulting in a longer motor life. A soft starter is a low-voltage starter for A.C. induction motors.

Soft starters are used on high tension motors due to the following benefits:

i. Smooth starting through torque control for a gradual acceleration of the drive system, preventing jerks and extending mechanical component life.
ii. Reducing starting current to achieve breakaway and holding back current during acceleration to prevent mechanical, electrical, and thermal weakening of electrical equipment such as motors, cables, transformers, and switch gear.
iii. Improved motor starting duty by lowering temperature rise in stator windings and supply transformer.
iv. The microprocessor version of the soft starter has a software-controlled response at full speed that saves energy regardless of load. Because of the tendency to over specify the motor-rated power, this feature has benefits for most installations, not only those where the load is variable.
v. The power factor improvement is a self-monitoring in-built feature. When the motor is running at less than full load, the comparative reactive component of the current drawn by the motor is unnecessarily high due to magnetising and associated losses. As a result of the load proportional active current component, voltage-dependent losses are minimised, and the power factor improves concurrently.
vi. Autotransformer starters provide a lower starting current but take up a lot of switchboard space.
vii. Soft starting and soft stopping minimise the water hammer effect.

The starting performance of the squirrel cage induction motors using soft starters provides valuable economics of electrical energy. Optimum benefits are gained when a motor duty involves frequent start or stop cycles but is still likely to be worthwhile in systems that are in continuous operation.

The disadvantage of soft starter technology over frequency converter technology is that it cannot control speed and is therefore is unsuitable for applications that require speed control. The advantage of soft starter technology is that it does not consume power when the motor is in running (unlike a VFD which will always consume power) and does not generate harmonics that may disturb SCADA systems and state electricity grid. It is suitable for constant pumping flow×head applications. It is easily applicable when starting loads with high inertial torque and must be selected at a higher power level.

5.24 Panels

5.24.1 Regulations

The regulations, as per Indian Electricity (IE) Rules for receiving the supply - circuit breaker or switch and fuse units:

(i) For distribution - bus bar, switch fuse units, circuit breakers.

(ii) For controls - starters: level-control, if needed: time-delay relays.

(iii) As protections - under voltage relay, over-current relay, earth fault relay, and single phasing preventer.

(iv) For indications and readings - phasing lamps, voltmeters, ammeter, frequency metre, power factor metre, temperature scanners, indications for the state of the relay, indications for levels indications of valve positions, if valves are power actuated.

The scope and extent of provisions to be made on the panel would depend upon the size and importance of the pumping stations.

5.24.2 Improvement of Power Factor

Power factor is the ratio of KW to kVA drawn by an electrical load, where KW is the actual load power and kVA is the apparent load power. For improvement of power factor, appropriate capacities, operations, and maintenance of the power capacitors are compiled in the following paragraphs. The power factor shall be improved to unity; this shall conform to IS 7752 guides for improvement of power factor.

5.25 Selection of Capacitors

It is generally advisable that capacitors be installed across individual machines. However, in the case of intermittently running machines, it is advisable to select the capacitor of rating appropriate to the average active load for a group of such machines, installing the capacitor across the mains through a fuse switch. A rationalised combination of individual machine mounting of capacitors and a mains installation of capacitors, for a group of machines running intermittently, can also be made in order to maintain a power factor yielding optimum economy. Recommended capacitor ratings are given in Table 5.11.

To have a flexible arrangement for maintaining the power factor within some limits would require an automatic power factor correction panel, monitoring a bank of capacitors for direct connection to induction motors.

Table 5.11: Recommended Capacitor Rating for Direct

Capacitor rating in kVAR when motor speed is							Capacitor rating in kVAR when motor speed is						
Motor kW	3,000 rpm	1,500 rpm	1,000 rpm	750 rpm	600 rpm	500 rpm	Motor kW	3,000 rpm	1,500 rpm	1,000 rpm	750 rpm	600 rpm	500 rpm
2.5	1	1	1.5	2	2.5	2.5	78.3	22	24	27	29	36	41
3.7	2	2	2.5	3.5	4	4	82	23	25	28	30	38	43
5.7	2.5	3	3.5	3.5	5	5.5	85.8	24	26	29	31	39	44
7.5	3	4	4 .5	5.5	6	6.5	89.5	25	27	30	32	40	46
9.3	3.5	4 .5	5	6.5	7.5	8	93.2	26	28	31	33	41	47
11.2	4	5	6	7.5	8.5	9	98	27	29	32	34	43	49
13	4.5	5.5	6.5	8	10	10.5	100.7	28	30	33	35	44	50
15	5	6	7	9	11	12	104.4	29	31	34	36	46	52
16.8	5.5	6.5	8	10	12	13	108	30	32	35	37	47	54
18.7	6	7	9	10.5	13	14.5	112	31	33	36	38	48	55
20.5	6.5	7.5	9.5	11.5	14	16	115.5	32	34	37	39	49	56
22.8	7	8	10	12	15	17	119.3	33	35	38	40	50	57
24.2	7.5	8.5	11	13	16	18	123	34	36	39	41	51	59
26	8	9	11.5	13.5	17	19	126.8	35	37	40	42	53	60
28	8.5	9.5	12	14	18	20	130.5	36	38	41	43	54	61
29.8	9	10	13	15	19	21	134	37	39	42	44	55	62
31.7	9.5	11	14	16	20	22	138	38	40	43	45	56	63
33.6	10	11.5	14.5	16.5	21	23	141.7	38	40	43	45	58	65
35.5	10.5	12	15	17	22	24	145.4	39	41	44	46	59	66
37	11	12.5	16	18	23	25	149.2	40	42	45	47	60	67
41	12	13.5	17	19	24	26	152.9	41	43	46	48	61	68
44.7	13	14.5	18	20	26	28	156.6	42	44	47	49	61	69
48.5	14	15.5	19	21	27	29	160.3	42	44	47	49	62	70
52.2	15	16.5	20	22	28	31	164	43	45	48	50	63	71
57	16	17	21	23	29	32	167.8	44	46	49	51	64	72
59.7	17	19	22	24	30	34	171.5	45	47	50	52	65	73
63.4	18	20	23	25	31	35	175.2	46	48	51	53	65	74
67	19	21	24	26	33	37	180	46	48	51	53	66	75
70.9	20	22	25	27	34	38	182.7	47	49	52	54	67	75
75	21	23	26	28	35	40	185	48	50	53	55	68	76

Connection to Induction Motors (To improve power factor to 0.95 or better)

Note: The recommended capacitor rating given in above Table 5.11 is only for guide purposes. (The capacitor rating should approximately correspond to the apparent power of the motor when it is operating under no-load conditions).

5.25.1 Installation of Capacitors

While installing a capacitor, ensure the following:

(a) A capacitor should be firmly fixed to a base.
(b) Cable lugs of appropriate size should be used.

(c) Two spanners should be used to fasten or loosen capacitor terminals. The lower nut should be held by one spanner and the upper nut should be held by the other to avoid damage to or breakage of terminal bushings and leakage of oil.

(d) To avoid damage to the bushings, a cable gland should always be used, and it should be firmly fixed to the cable entry hole.

(e) The capacitor should always be earthed appropriately at the earthing terminal to avoid accidental leakage of the charge.

(f) There should be a clearance of at least 75 mm on all sides for every capacitor unit to enable cooler running and maximum thermal stability. Ensure good ventilation and avoid proximity to any heat source.

(g) While making a bank, the bus bar connecting the capacitors should never be mounted directly on the capacitor terminals. It should be indirectly connected through flexible leads so that capacitor bushings do not get unduly stressed. This may otherwise result in oil leakage and/or porcelain breakage.

(h) Ensure that the cables, fuses, and switchgear are of adequate rating.

5.25.2 Automatic Power Factor Controller

An APFC panel is used to improve the power factor, whenever needed, by automatically turning on and off the requisite capacitor bank units based on the compensation required in an electrical system.

Power factor is defined as the ratio of active power to apparent power and is an important factor in power conservation.

The power factor controller (PFC) is the command-and-control unit of a capacitor bank system. It switches capacitors to achieve a user-specified target cos ϕ. It is possible to optimise processes, accelerate troubleshooting, and lower the costs of supervised systems by incorporating a PFC.

The aim is to find the amount of reactive power (Qc (kVAR)) that must be installed in order to improve the power factor (cos φ) and decrease the apparent power (S). Qc can be determined from the formula:

$Qc = P (\tan \varphi - \tan \varphi')$.

Where

Qc = power of the capacitor bank in kVAR

P = active power of the load in kW

$\tan \varphi$ = tangent of phase shift angle before compensation

$\tan \varphi'$ = tangent of phase shift angle after compensation

5.26 Transformer

5.26.1 Essential Features

If power requirement exceeds maximum limit of kVA, as per criteria of power supply authority, power supply to the pumping station or any electrical installation is drawn from the power suppliers' grid at a standard grid voltage of 11,000, 33,000, 66,000 volts, etc., depending on the grid voltage. However, the electrical equipment of the consumer will be working at lower voltages like 415 volts, 3,300 volts, or 6,600 volts, depending on the equipment size. This is called consumer side voltage. Transmission of power at such lower voltages will not be economical for the power supplier as this would result in more power losses and necessitate larger conductors for transmission. Hence, the supply voltage is always higher, and the consumer voltage is lower. The power received at the higher voltage is 'stepped down' to a lower voltage by using a power transformer. While the power supply company may supply at a higher voltage and install billing meters at that voltage itself (HT Metering), the consumer or the water utility installs the power transformer to step it down to the required voltage for its use.

The transformer shall conform to IS 2026-2011 of three-phase, copper wound, conventional outdoor type, as per IEC-60076 and IS-1180, with all subsidiary materials like cables, channels, nuts and bolts, air brake switch, etc., as per relevant IS specifications. The transformer shall have complete internal self-protection features (HV fuse, inside HV bushing). A duplicate transformer may be provided, where installation so demands. For a large pumping station and important installation, 1 (Working) + 1 (Standby) transformers shall be provided.

The transformer should be equipped with tap changer to take care of ±10% voltage variation on incoming feeder. Transformer up to 1,000 kVA shall be with manual tap changer in steps of ±2.5% and transformers above 1,000 kVA shall be with on-load tap changer (OLTC) in steps of ±1.25%.

Two types of transformer substations are in use.

- Outdoor substation, where sufficient space is available and generally, majority of substations are outdoor type. Cost of installation is comparatively much less.
- Indoor substation, where problem of space constraint is encountered, or substation is near residential locality. Cost of installation is very high.

5.26.2 Outdoor Substation

a) Pole-mounted transformer, generally for small load up to 63/100 kVA with lightning arrester, air break switch, drop out fuses, insulators, and HT meter.

b) Plinth-mounted transformer substation with insulators, air brake switches, lightning arrestor, bus bar, and HT meter.

5.26.3 Indoor Substations

Indoor substations and UG cabling are provided for ensuring service with minimum breakdowns to overcome the disadvantages of outdoor substations as:

i. Outdoor substations are subject to dust, rain, storm, extreme heat, and theft leading to breakdowns and higher maintenance. During winds, cyclones, and storms, the entire distribution system, including poles and conductors, collapse, taking a long time to restore the power supply.
ii. The indoor substations (Figure 5.24 & 5.25) work at a much lower ambient, say at 28 °C, when the outside temperature may be above 40 °C. Similarly, the UG cable of power distribution is far superior to the overhead system.

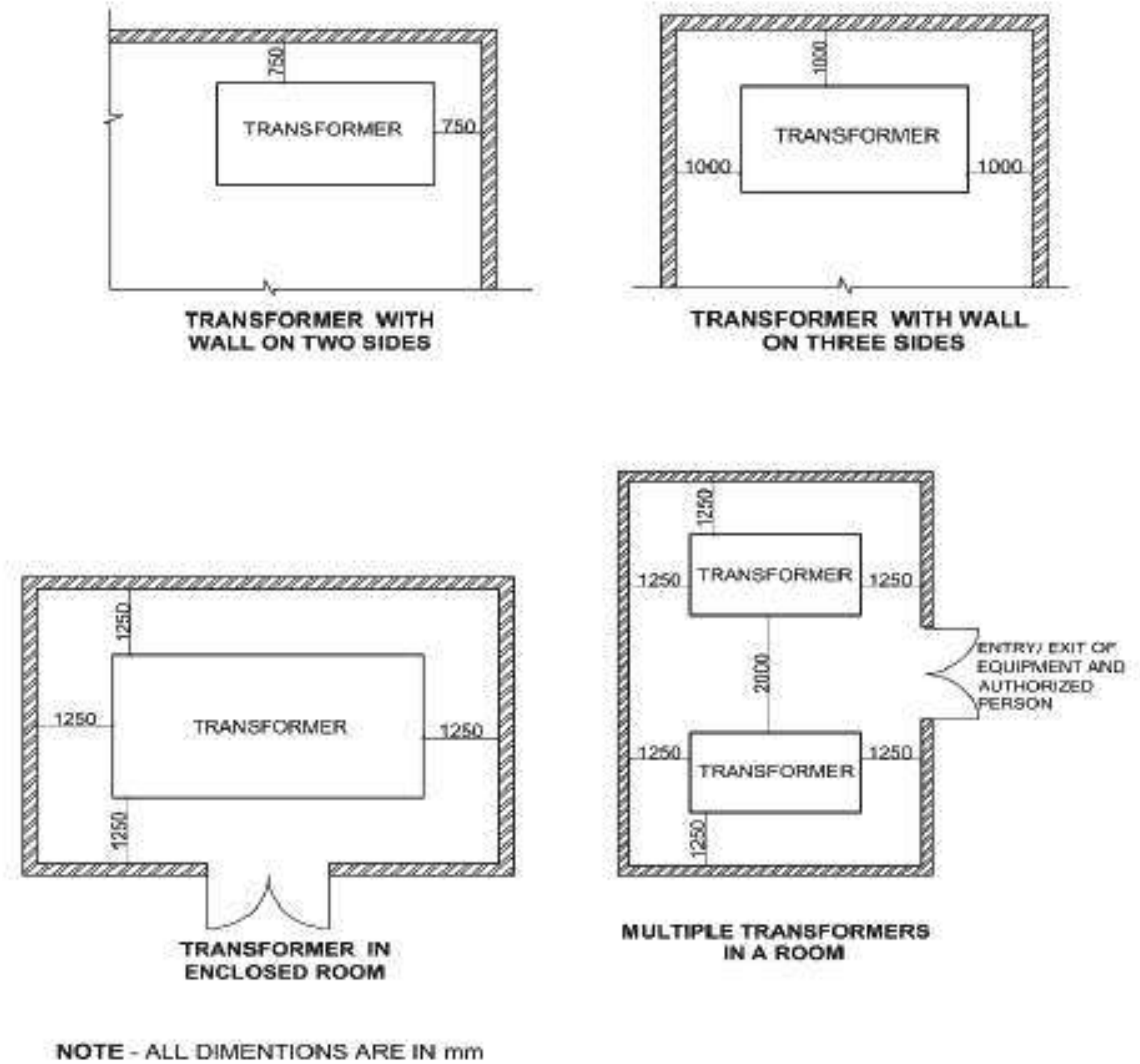


Figure 5.24: Minimum Recommended Spacing between the Transformer Peripheries and Walls

Source: *National Building Code*

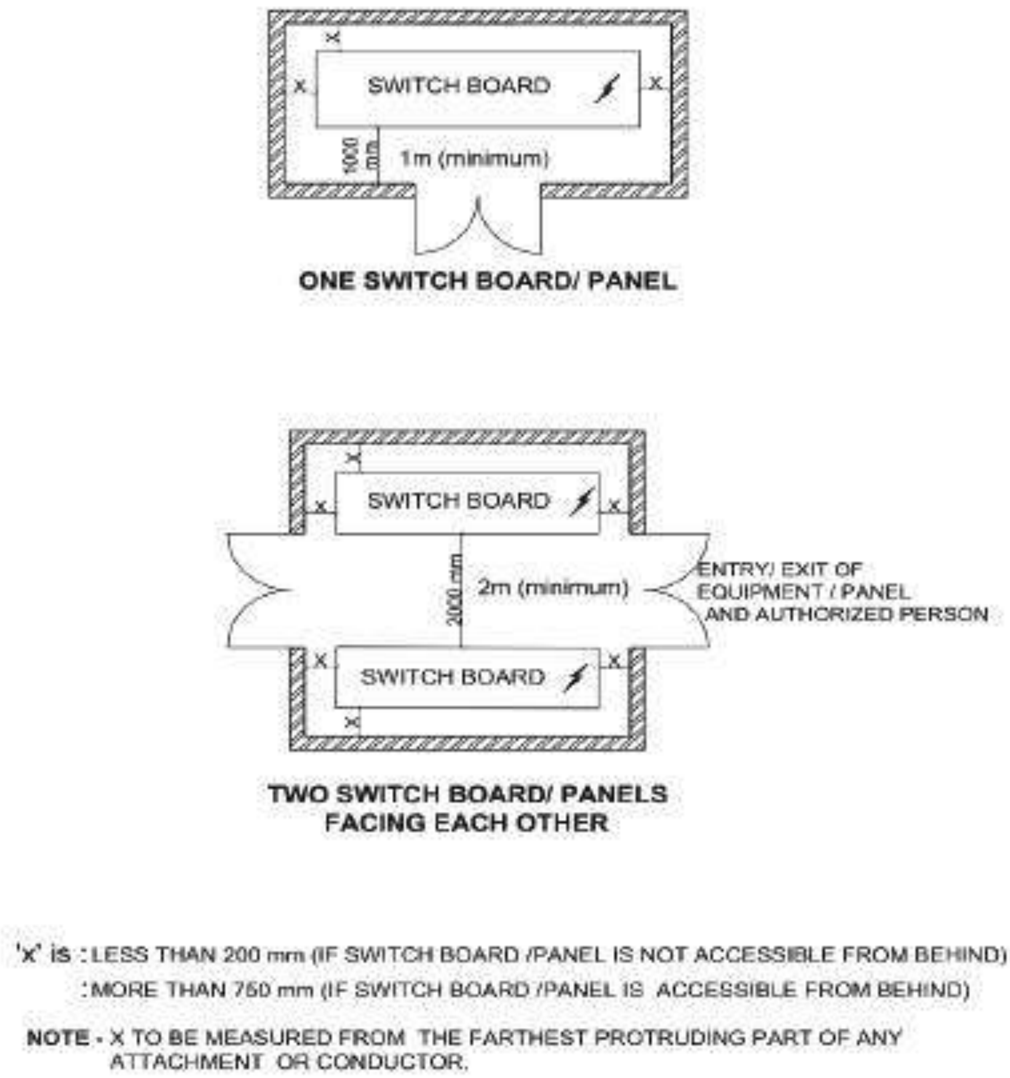


Figure 5.25: Minimum Recommended Spacing of Switch Board/Panels from Walls

Source: *National Building Code*

5.26.4 Transformer rating

The total power consumption of the pump station should be calculated as below.

a. Power consumption in kW for working motors
b. Power consumption in kW for control equipment
c. Power consumption in cooling, ventilation, lighting, etc.
d. Power factor (PF) 0.85/0.9 to be considered for design purposes
e. Misc. consumption: add 10% of the total a + b + c
f. The total installed capacity shall be at least 15% to 20% higher than the anticipated maximum demand
g. All working pumps except last pump are running and the last pump started. Starting kVA to be considered Momentary kVA under last pump motor starting should not exceed 1.5 times rated kVA of the transformer
h. A margin for a minimum of one pump motor for future expansion/augmentation is advisable

5.26.5 Other design consideration

a. With a growing emphasis on energy conservation, the system design is made for both extremes of loading. During the periods of lowest load in the system, it would be desirable to operate only one transformer and to subsequently switch on the additional transformer as the load increases during the day.

b. Total transformer capacity is generally based on present load and possible future load.

c. The selection of the maximum size (capacity) of the transformer is guided by the short circuit making and breaking capacity of the switchgear used in the medium voltage distribution system. Maximum size limit is important from the aspect of feed to the downstream fault.

d. Where two or more transformers are to be installed in a substation to supply a medium voltage distribution system, the distribution system shall be divided into separate sections, each of which shall be normally fed from one transformer.

e. Provisions may, however, be made to interconnect separate sections through a bus coupler in the event of failure or disconnection of one transformer.

5.26.6 Location and Other Requirements

- The substation should preferably be located as near to the load (main pumping station) as possible except for operational clearances. In case of jack well pumping stations, the substation shall be located on the mainland, at a safe height above maximum flood levels, with suitable approaches. In case of an indoor substation, it shall be in a separate building well-ventilated and with natural light, and may be adjacent to the D.G. room, for ease of interconnection.
- All equipment in the substation shall be protected with lightning protection, earthed as per relevant rules and the entire area illuminated at night. The substation should be accessible by vehicle carrying the largest equipment in the station (mostly power transformer). It is also preferable if the substation is visible from the pumping station, as the same operator generally will be manning the substation and pumping station.
- In case there is only one basement in a building, the substation /switch room shall not be provided in the basement. Also, the floor level of the substation shall not be the lowest point of the basement.
- Oil-filled installation - Substations with oil-filled equipment require great consideration for fire detection, protection, and suppression.
- Substations with oil-filled equipment/apparatus (transformers and high voltage panels) shall either be located in an open or in a utility building. They shall not be located on any floor other than the ground floor or the first basement of a utility building. They shall have direct access from outside the building for the operation and maintenance of the equipment.
- Dry-type installation - In case an electric substation has to be located within the main multi-storied building itself for unavoidable reasons, it shall be a dry-type installation with very little combustible material. Such substations shall be located on the ground floor or in the first basement and shall have direct access from the outside of the building for the operation and maintenance of the equipment.
- In the case of two transformers (dry type or transformers with oil quantity less than 2,000 litres) located next to each other without an intermittent wall, the distance between the two shall be a minimum of 1,500 mm for 11 kV, minimum 2,000 mm for 22 kV and minimum 2,500 mm for 33 kV. Beyond 33 kV, two transformers shall be separated by a baffle wall with a 4-hour fire rating.
- The minimum height of the substation/HV switch room/MV switch room shall be arrived at considering the 1,200 mm clearance requirement from the top of the equipment to the bottom of the soffit of the beam.

5.26.7 Generating set

The generator set shall be CPCB-approved, silent type, air cooled, with acoustic enclosures, anti-vibration mountings, foundation, etc., and shall have a standard control panel. The generating set shall be robust in construction, factory tested, and assembled to ensure perfect alignment of engine and alternator on a common base frame. The equipment shall be suitable for operating in a hot humid and saline atmosphere at an ambient temperature of up to 45°C. It should be a multi-cylinder, vertical, four-stroke, direct injection, air/water-cooled type capable of developing the rated horsepower at a speed of 1,500 rpm. The engine shall be with an hour metre to record the hours of operation. The engine shall be started by a completely enclosed axial electric starter suitable for 12 volts D.C. The cooling system shall be adequate for the total requirements of the engine when running on continuous full load and on 10% overload for one hour. The exhaust piping system shall be with a residential silencer. The generating set shall have a tank of minimum capacity of 120 litres to enable running of the generator set for 12 hours of continuous run. The base of the genset shall be kept at a minimum of 0.6 m above the ground level so that the oil/fuel can be drained out easily. The insulation shall be Class H. The alternator shall be provided with single bearing or two sleeves to ensure perfect alignment under all conditions. To regulate the generated voltage, a rapid response voltage regulator must be provided. The overall regulations from no load to full load, including cold to hot variation and load power factor of 0.746 lag to unity shall be within 2% of the normal voltage. The sound level shall have less than 75 dB (A) at a distance of 1 metre. The measurement of noise shall be as per ISO 3744/ISO 8528 (Part 10) standard. Typical indoor generator installation in shown in figure 5.26.

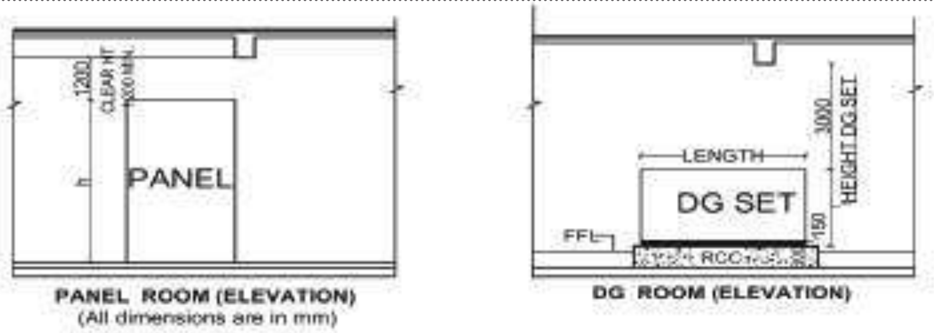


Figure 5.26: Typical indoor generator installation

Source: National Building Code

5.26.8 Generating set rating

The total power consumption of the pump station should be calculated as given below:

a. Power consumption in kW for working motors just before start of last motor

b. Power consumption in kW for control equipment

c. Power consumption in cooling, ventilation, lighting, etc.

d. Misc. consumption - add 10% of the total a + b + c

e. kVA required when last pump set is started considering starting current

f. Generating set kVA = Total kW (a + b + c + d) × Load diversity factor/Power factor × efficiency with last but one pump running + kVA at time of starting

5.26.8.1 Storage for Diesel

Adequate facilities for storage of diesel and decanting barrels shall be provided.

5.26.8.2 Low Tension Power Supply (415 Volts)

Where power requirement is less than certain kW, power is taken generally at 415 volts (3 phase) and for very small installation at 230 volts (1 phase). Thus, no transformer is required. In such cases, a voltage stabiliser (1 phase or 3 phase) is provided to correct low or high voltage in incoming power line. The voltage stabiliser shall be of kVA of maximum power load. Setting should be available to improve voltage from 375 volts to 415 volts.

5.27 Cables

Table 5.12 gives guidelines for the types of cables to be used for different voltages.

Table 5.12: Types of Cables for Different Voltages

Sl. No.	Range of Voltage	Type of cable to be used	Reference
1	10-230 V or 30-415 V	PVC insulated; PVC sheathed	IS 1554
2	up to 6.6 kV	PVC insulated; PVC sheathed	IS 1554
		Paper insulated, lead sheathed	IS 692
		XLPE, cross-linked, polyethylene insulated, PVC sheathed	IS 7098
3	11 kV	Paper insulated, lead sheathed, XLPE	IS 692, IS 7098

The size of the cable should be so selected that the total drop in voltage, when calculated as the product of current and the resistance of the cable shall not exceed 3%. Values of the resistance of the cable are available from the cable manufacturers.

In selecting the size of the cable, the following points should be considered:

i. The current carrying capacity should be appropriate for the lowest voltage, the lowest power factor, and the worst condition of installation, i.e., duct condition.

ii. The cable should also be suitable for carrying the short circuit current for the duration of the fault.

iii. The duration of the fault should preferably be restricted to 0.1 second by a proper relay setting.

iv. Appropriate care for the fault should be applied when cables are laid in a group (paralleled) and/or laid below ground.

v. For laying cables, suitable trenches or racks should be provided.

The three different parameters of cable sizing are as follows:

- Current carrying capacity
- Voltage regulation
- Short circuit rating

5.27.1 Derating Factors

Cable derating ensures all factors which can increase the temperature experienced by the installation are properly accounted for when selecting cables to prevent cable insulation damage and reduce system losses. The derating factor is used to lower the cable's current carrying capacity, e.g., if an X-90 cable could carry 40A at 90 °C temperature, additional factors may necessitate derating the cable so that it only carries 30A at 90°C in the installation.

Heat is the main reason why cables need to be derated. Heat is produced as a result of the electrical resistance of the cable as current flows through it. Multiple circuits operating in close proximity can raise the temperature of the conductors due to electromagnetic and physical proximity effects. When cables are arranged close to each other, cables have limited ability to dissipate heat and reach a hotter operating temperature. Linear resistance, or the resistance of the cable per metre, is very small, but it accumulates over a long cable run and causes voltage drop. As the temperature of the cable rises, so does the linear resistance, resulting in increased voltage drop and reduced system output.

5.27.2 Distribution of Water by Direct pumping

Bigger cities require a large number of operational zones and hence, a large number of service tanks. It is a common observation that land is not available for the construction of tanks and hence, in some the cities like Ahmedabad and Chennai, water is distributed by direct pumping.

Smart Pumps

Another reason is that, generally, residual nodal pressures in the existing distribution system are less than 12 m or 17 m as the case may be. In such a situation, direct pumping is proposed. Direct pumping can be through smart pumps. The characteristics of the smart pumps are as follows:

1) Demand-based pumping using smart pumps may be designed for an efficient water distribution network.
2) At the pumping station, the controller should control the pump speed based on the actual flow rate and pressure. To optimise the proportional-pressure curve used by the controller, remote sensors should be installed at critical points in the distribution network, i.e., where a stable pressure is required.
3) The remote sensors should log the pressure throughout the day and send the logged data to the controller as text messages once every 24 hours. Every day the controllers should automatically adapt their proportional-pressure curve, ensuring a stable pressure at the critical points. When the water demand is low, the controller lowers the discharge pressure at the pumping station to save energy and reduce leakages and wear of the pipes.
4) The automatic adoption function should automatically optimise the proportional-pressure curve using the logged pressure data from remote sensors and ensures water is available at a constant pressure at consumers or critical points. The pressure at the pumping station will change depending on the usage at the critical points.

Components - The components may be:

a) The control system should include the pump with variable frequency drive, and other related hardware for 24×7 water distribution. The controller should be of suitable rating, with Modbus RTU on RS485 for SCADA integration.
b) 24×7 system controller must be designed specifically for controlling two to six pumps in water supply pumping stations. The controller can also be integrated into most SCADA systems via a range of different communication protocols embedded in the control hardware. This can also be connected with digital twin technology.

Measures to be taken: Following measures are suggested:

- The cities in which the present water supply is by pumping should prepare GIS maps of the entire pipe network. Condition assessment of the pipes and appurtenances should be shown on GIS maps.
- GIS-based hydraulic model should be prepared.
- Pumps to be used should be of variable frequency drive.
- Exercise for maximum negative pressure (cavitation) of metallic pipes should be made.

5.27.3 Erection and Commissioning

It should be ensured that the direction of the motor agrees with the arrow on the pump. A specimen test should be conducted to derive the system head curve and to understand the actual operating point/range of the pump and the variation, if any, from the original estimated duties. In the case of variations, some analysis may be done to explore any feasible modifications of the system to bring it nearer to the original estimates or to generally improve the system so that it can work better and work trouble-free for long.

Saving Energy in Pumping Stations and Pumping Machinery - A Case Study

Implementation Agency - Oswego Water Department, New York

The City of Oswego Water Department provides potable water to approximately 29,000 customers. The city's conventional water treatment plant has a capacity of 20 million gallons per day (MGD) and an average flow rate of 5-10 MGD. The water system consists of a raw water pumping station, a water treatment plant with a finished water pumping station, three booster pump stations, and water storage tanks with a combined capacity of 11 million gallons.

The city hired an energy performance contractor to provide energy evaluations, energy grant services, and design, bidding, and construction services for the rehabilitation of the raw and finished water pumping stations and booster pump stations. Based on contractor recommendations, the following improvements were made:

- rebuilt two 450 horsepower (hp) finished water vertical turbine pumps;
- rebuilt one 350 hp finished water vertical turbine pump;
- replaced motors and variable speed drives at the finished water and raw water pump stations (seven motors from 125-450 HP);
- installed VFDs to modulate pump speeds to maximise energy efficiency;
- installed a SCADA system with remote telemetry;
- upgraded the filter valve actuators;
- upgraded the coagulant chemical feed system; and
- replaced the lighting system.

While adopting improvements, the city obtained financial benefit energy incentives through various NYSERDA programmes. The improvements reduced the peak-electric demand at the facility by 1,463 kW and resulted in an annual electric savings of 1,474,664 kWh.

(Source: US EPA Strategies for Saving Energy at Public Water Systems)