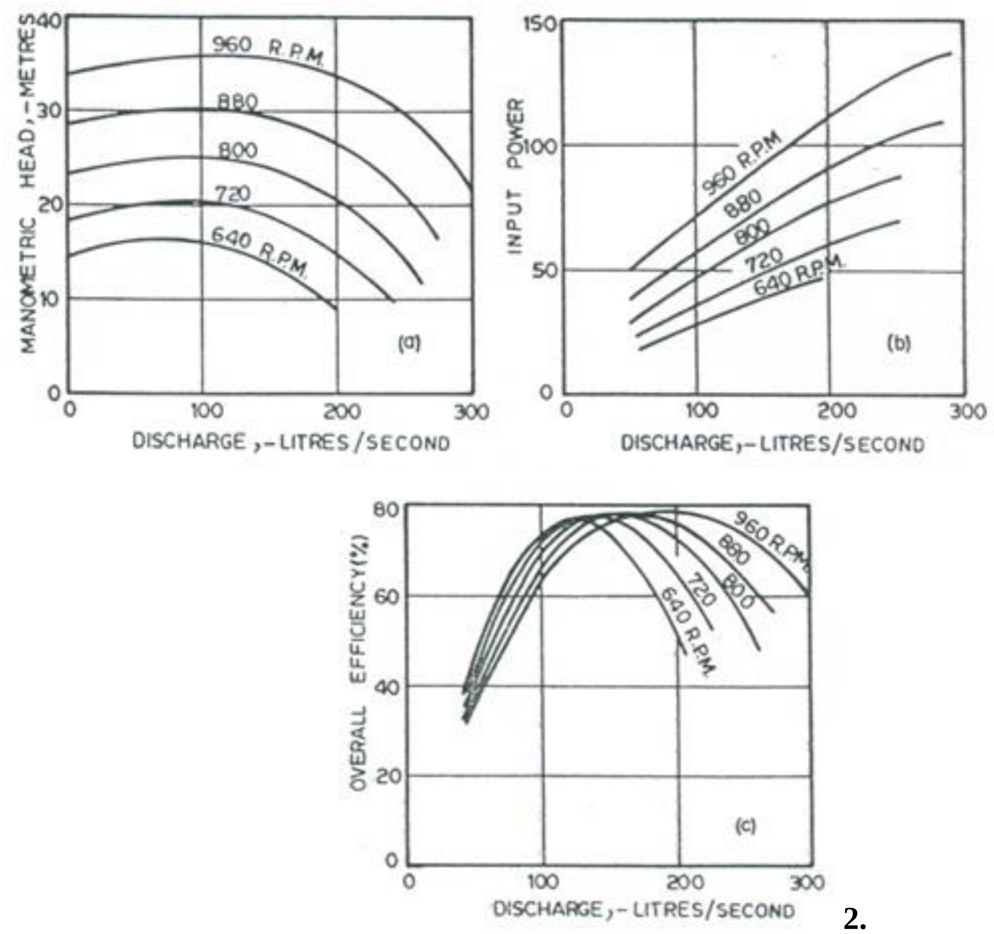


2.

2. Operating Characteristic Curves

During operation of a pump, the pump must run constantly with the speed of the prime mover; this constant speed is usually the design speed. The set of main characteristics curves which corresponds to the design speed is mostly used in pump operation, and hence such curves are known as the operating characteristics curves. A typical set of such characteristics of a centrifugal pump is shown in Fig., which consists of four curves at a constant speed viz., head versus discharge (H_m vs Q) curve, efficiency versus discharge (h_o vs Q) curve, power versus discharge (BP or SP vs Q) curve, and net positive suction head (NPSH) versus discharge (NPSH vs Q) curve.

From these characteristic curves, it is possible to determine whether the pump will handle the necessary quantity of liquid against the desired head and what will happen if the head is increased or decreased. In addition, these characteristic curves illustrate what size motor will be required to operate the pump at the required conditions and whether or not the motor will be overloaded under any other operating conditions.

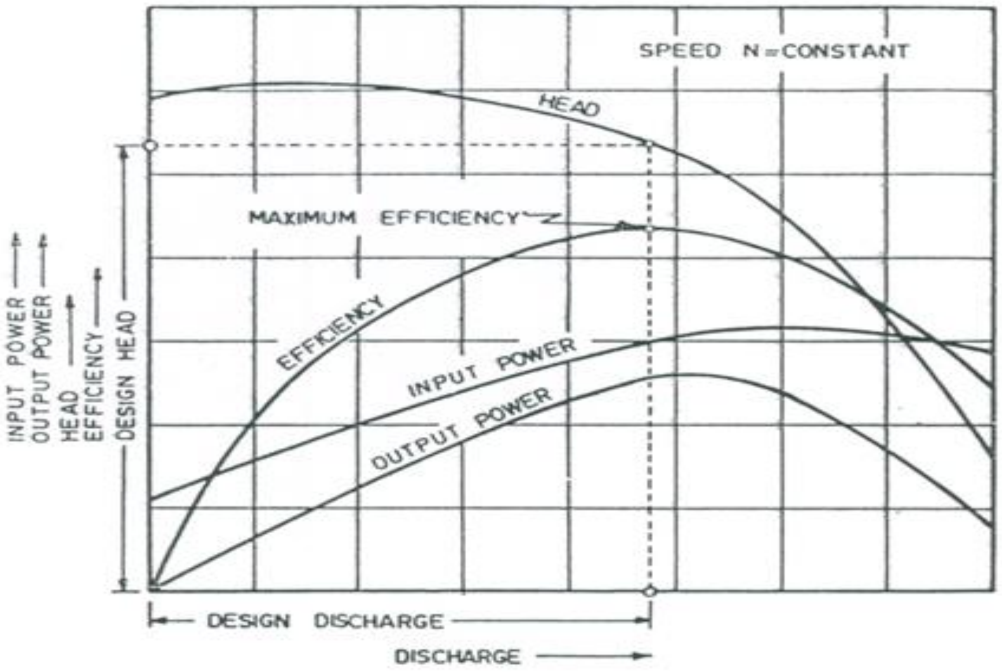


Fig. 28.2. Operating characteristic curves of a centrifugal pump.

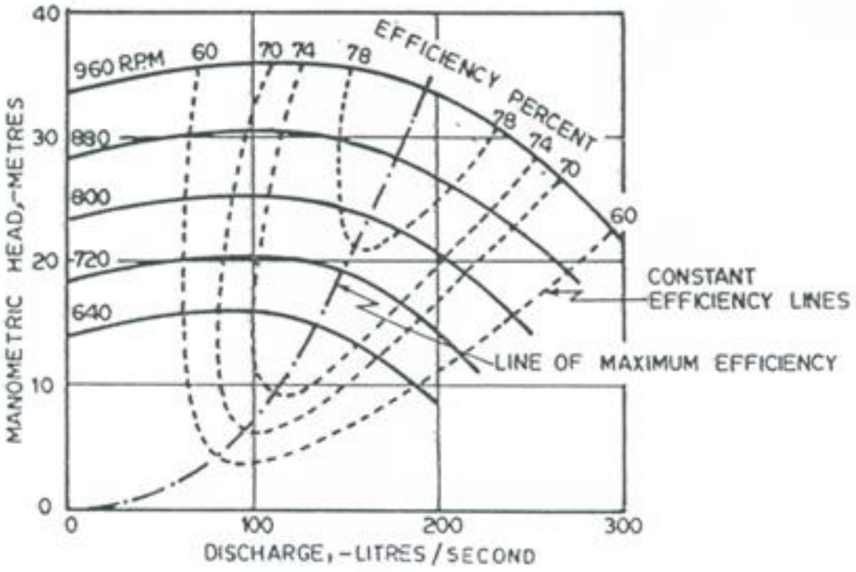


Fig. Constant efficiency curves of a centrifugal pump.

3. Constant efficiency curves

The constant efficiency curves (Fig.) help determine the range of pump operation for a particular efficiency. As shown in Fig., the constant or iso-efficiency curves may be obtained from H_m vs Q and h_o vs Q curve of main characteristic curves. In order to plot the iso-efficiency curves, horizontal lines representing constant efficiencies are drawn on the h_o vs Q curves. The points at which these lines cut the efficiency curves at various speeds are transferred to the corresponding H_m vs Q curves. The points corresponding to the same efficiency are then joined by smooth curves, which represent the iso-efficiency curves. From these curves, the line of maximum efficiency can be obtained (Fig.).

Thus, the constant efficiency (Muschel curves) facilitates the job of a salesman and enables the prospective customer to see directly the range of pump operation for a given efficiency. These curves further serve as a suitable basis for the comparison of pumps, especially from a commercial viewpoint.

4. Constant Head and Constant Discharge Curves

It is quite possible that a pump may be required to deliver water at a certain height, wherein head (H) is fixed. If for some reason, the pump speed (N) varies, the discharge of the pump will also be affected. In order to predetermine the performance of the pump under such conditions, it is necessary to draw a constant head curve by plotting Q versus N (Fig.). The constant head curve can be used to determine the speeds required to discharge varying amounts of water at a constant pressure head. Similarly, to determine the speeds required to discharge a certain quantity of water at different heads or to find variation of head with N, it is convenient to draw constant discharge curves by plotting H versus N (Fig.).

The constant head curves and the constant discharge curves are also useful for determining the performance of a variable speed pump having constantly varying speed.

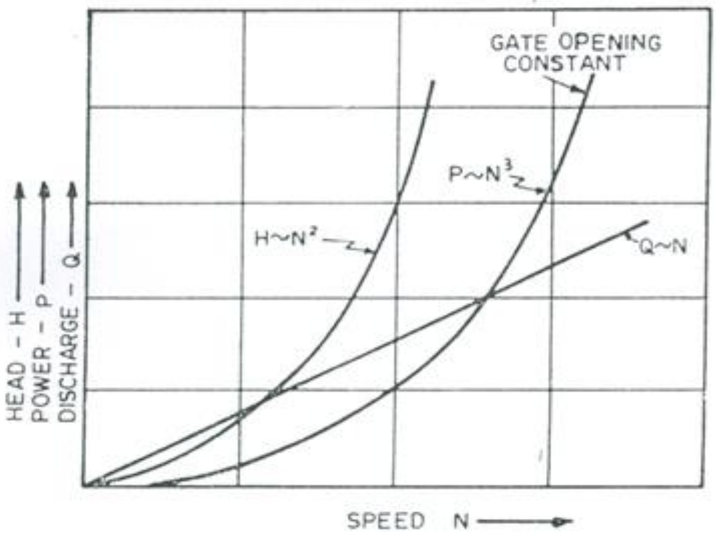


Fig. Q versus N, H_m versus N, and P versus N curves of a centrifugal pump. (Source: Modi and Seth, 1998)

Operating Point of a Pump

A system characteristic between the head required (H) and the discharge (Q) to be maintained is generally expressed as a parabolic equation as follows,

$$SH = K_1 + K_2Q^2$$

Where, K_1 and K_2 are constants for the system. His equation is graphically illustrated in Fig.

A centrifugal pump usually operates at different combinations of head and discharge given by its head-discharge (H-Q) characteristic curve. The particular H-Q combination at which a pump operates is known as the 'pump's operating point'. A system head curve and the H-Q characteristic curve of the pump are used to determine the operating point. The point of intersection of the pump's H-Q characteristic curve and the system characteristic (H-Q) curve locates the actual operating point of a pump when it will be installed in a given system (Fig. 31.2). At the operating point, the head and discharge (H-Q) requirements of a system are equal to the head and discharge (H-Q) generated by the pump.

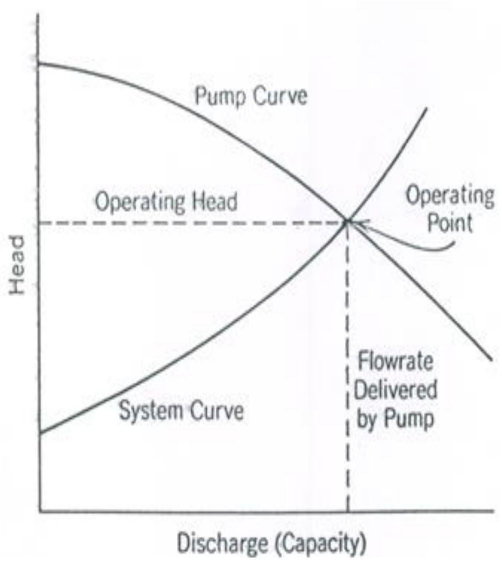


Fig. Superposition of 'system head curve' and 'pump head-discharge curve' for determining operating point

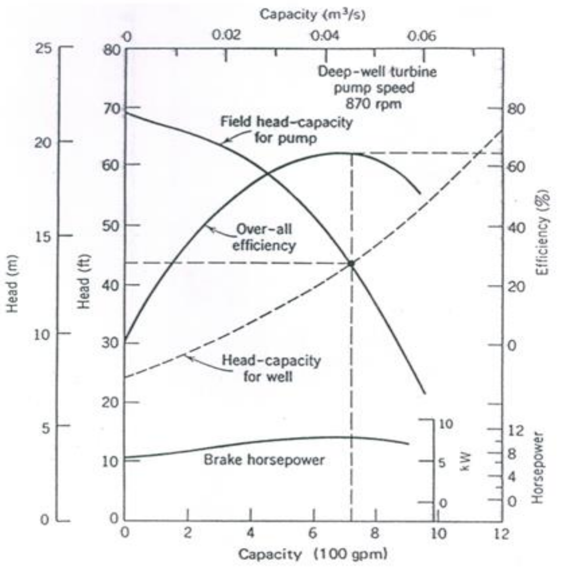


Fig. Typical system and pump head-capacity curves.

Once the operating point of a pump is determined, the power, overall efficiency, and NPSH (net positive suction head) for the pump can be obtained.

ROTODYNAMIC PUMPS FOR SPECIAL PURPOSES

Where high heads are needed, the primary means to achieve this with a single impeller centrifugal pump are either to increase the impeller speed or to increase impeller diameter. However, there are practical limits to this way of increasing head. Therefore, in practice either single impeller pumps are connected in series or a more practical solution is to use a specially designed pump wherein multiple (two or more) impellers mounted on the same shaft such that the output from one impeller feeds directly through suitable passages in the casing to the next impeller. Such pumps are: vertical turbine pumps, submersible pumps, propeller pumps, mixed-flow pumps and jet pumps.

1. Vertical Turbine Pump

Vertical turbine pumps are most widely used for large deep tube wells. A vertical turbine pump is a vertical axis centrifugal or mixed flow type pump comprising stages which accommodate rotating impellers and stationary bowl possessing vanes. The bowl-assembly (containing impellers) is placed below the lowest pumping water level, but *the prime mover (electric motor or diesel engine) is placed on the ground surface* and is connected by a long shaft (Fig.). Usually deep-well turbine pumps are used for fairly high flows under high heads. The overall efficiency of vertical turbine pumps ranges from 50 to 80 %.

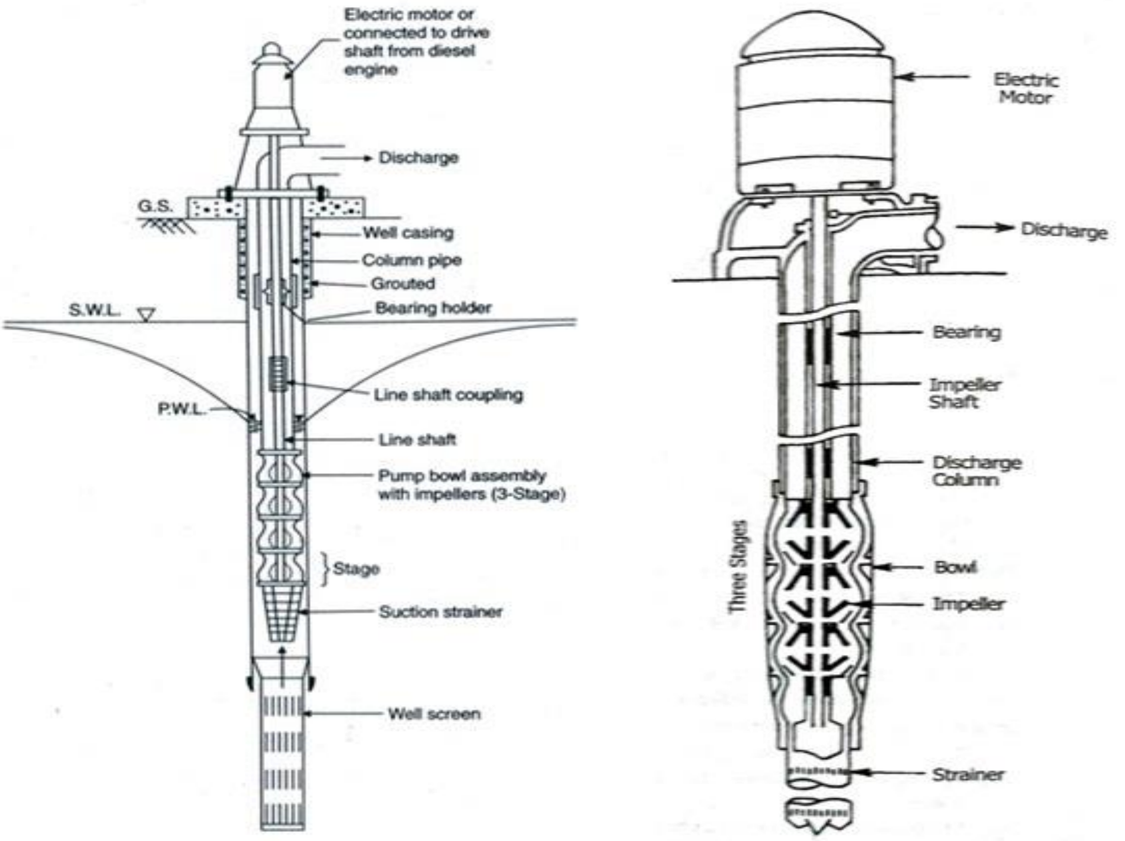


Fig. Schematic diagram of a vertical turbine pump.

Principles of operation

The impeller of the turbine pump operates on a modified radial flow centrifugal principle. Water enters the impeller near its centre and is whirled out towards the periphery at a high velocity by virtue of centrifugal force. The bowl has stationary guide vanes surrounding the impeller. As the water leaves the impeller, the gradually enlarging vanes direct it upwards, through velocity head partly converted into pressure. As with all centrifugal pump, the pressure head developed in a turbine pump bowl assembly depends on the diameter of the impeller and the speed at which it is rotated.

Advantages of Turbine Pump

1. Vertical turbine pumps have the advantages of high efficiency, high head pumping capability and excellent serviceability.
2. It is sturdier than a submersible pump.
3. It provides less wear and tear.

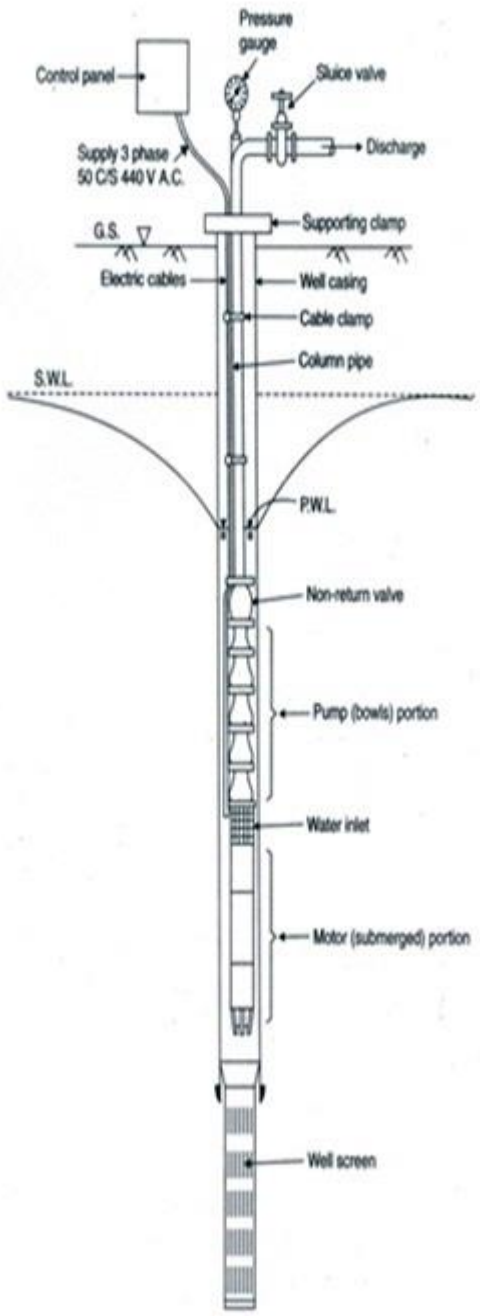
Disadvantages of Turbine Pump

1. High initial cost
2. They require sufficiently straight and plumb well for installation and proper operation and
3. They are subjected to abrasion by sand.
4. The maintenance problem becomes severe when they are pumping corrosive water unless the pump, column pipe, line shaft and other components are made of non-corrosive materials.
5. Lubrication and vertical alignment of line shaft is critical.

2. Submersible Pump

A vertical turbine pump *close-coupled to a small diameter submersible electric motor* is termed as submersible pump. The motor is fixed directly below the intake of pump. The pump element and the motor operate while entirely submerged. Such an installation *eliminates the long vertical shaft and column pipe*. The performance characteristics of the submersible pump are similar to those of the vertical turbine pump. The efficiency of the pump is increased by the direct coupling of the motor and its effective cooling by submergence in water.

Submersible pumps have the motor and the bowl assembly as a unit submerged below the lowest pumping water level (Fig.). A water-proof cable supplies power to the motor. Submersible pumps to fit inside 10, 15, 20 and 25 cm bore wells are available in India. They can be used for discharges varying from 40 to 3000 L/min and heads varying from 15 to 150 m.



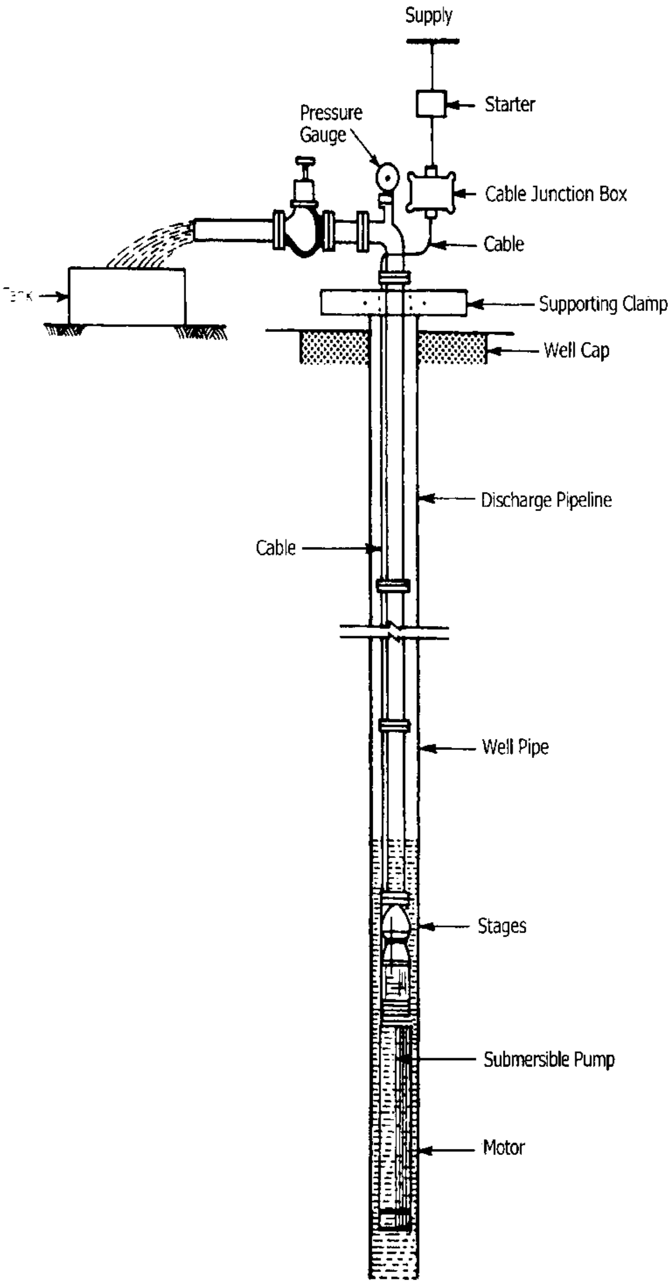


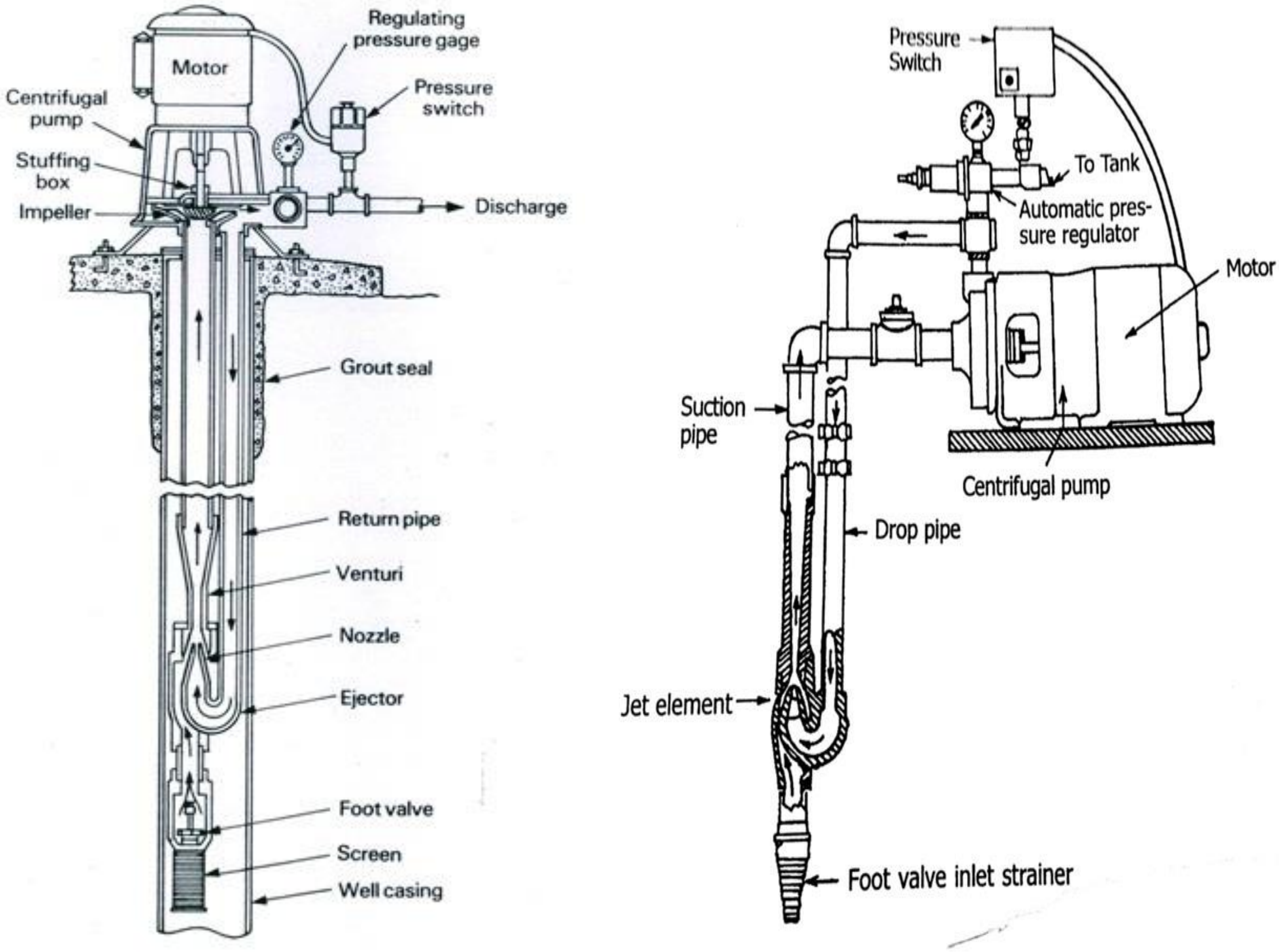
Fig. 10.20. Submersible pump.

Fig. Schematic diagram of a submersible pump.

Submersible pumps have the advantage that they can be installed in the localities where there is little or no floor space to install a pump unit as well as in the localities where noise or theft is a serious issue. They can be either water or oil lubricated. The new types of voltage regulated starters have solved the problem of overloading. Although the initial costs of submersible pumps are lower than those of vertical turbine pumps, their repair and maintenance costs are higher.

3. Jet Pump

A jet pump consists of a centrifugal pump and a jet assembly (Fig.) and it is essentially a self-priming centrifugal pump which is *based on the fact that if water is accelerated through a jet, it causes a drop in pressure.* In the jet pump, the pump is fitted into a secondary casing which contains water at the discharge pressure. A proportion of the water from this chamber is *bled back to a nozzle fitted into the suction end* of the pump casing and directed into the eye of the impeller (Fig.). If the pump has been used once (having been manually primed initially), it remains full of water so that on start up, *the water is re-circulated from the delivery side of the pump to the bottom of the suction pipe and is injected through a nozzle to impart additional kinetic energy.* Thus, the jet causes low pressure in the suction line and thereby increases suction considerably compared to the effect of impeller on its own, which in turn *provides additional suction lift*. Initially, the entrapped air is gradually drawn up the suction line.



Schematic diagram of a borehole jet pump

As soon as all the air is removed from the system, most of the discharge goes up the discharge line and *a small proportion is fed back into the nozzle*. In this way, *the jet pump not* *only creates a higher suction lift than normal but also it can reliably run on 'snore'* (i.e., sucking a mixture of air and water without losing its prime). This makes it useful in situations where shallow water is to be pumped under suction and it is difficult to obtain sufficient submergence of the foot valve, or where a water source may occasionally be pumped dry. The provision of a jet assembly allows a *surface-mounted pump and motor* to 'suck' water from depths of about 10 to 20 m; the diffuser after the jet raises the pressure in the rising main and avoids cavitation (FAO, 1986).

Jet pumps are often viable for pumping fairly small discharges (40-90 L/min instead of 40 to 3000 L/min in case of submersible pump) under low heads (15 to 45 m) *when the water level is more than **7.6 m** from the ground surface* (Raghunath, 2007). Their capacity reduces as the lift increases. They are generally used for residential buildings and hotels.

Jet pumps are of two types: twin type for the bore wells of 15 cm diameter and larger, and packer type (duplex) for the bore wells of less than 15 cm diameter (Raghunath, 2007). Although the jet circuit usually needs 1.5 to 2 times the flow being delivered (discharge), and therefore is a source of significant power loss, the jet pumps are sometimes useful for lifting sandy or muddy water as they are not so easily clogged as an ordinary submerged pump. In such cases, however, a settling tank is provided on the ground surface between the pump suction and the jet pump discharge to allow the pump to draw clear water.

Moreover, jet pumps have two main disadvantages:

i) Greater complexity and hence higher cost, and

ii) Reduced efficiency because power is used in pumping water through the jet, though some of this power is recovered by the pumping effect of the jet.

Considering these disadvantages of jet pumps, it is better to use a conventional centrifugal pump in the situations where there is little or no suction lift. However, in the situations where suction pumping is essential, a jet pump can offer a successful solution.

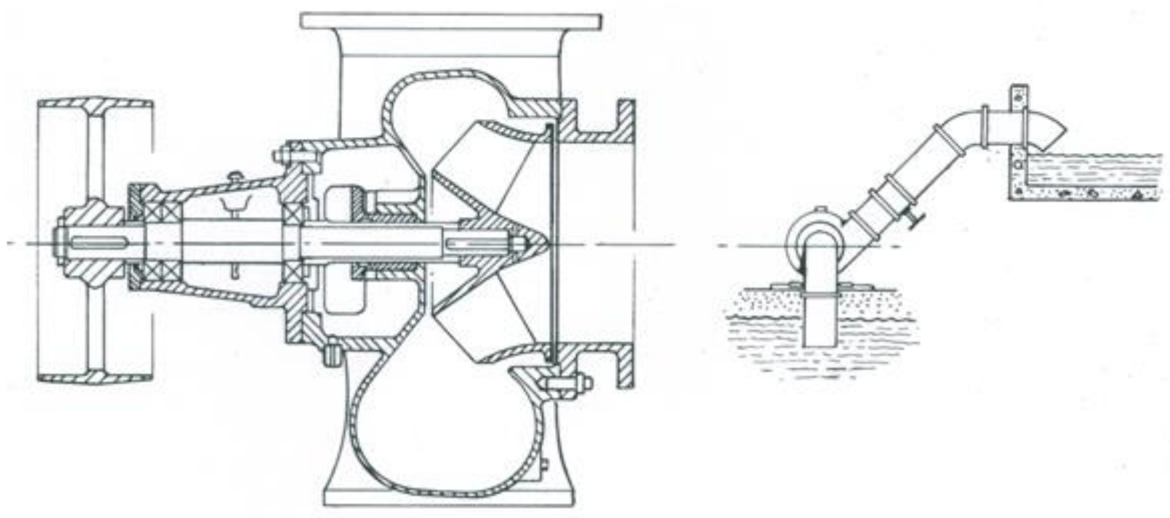
[Axial Pump: Fluid particles, in course of their flow through the pump, do not change their radial locations since the change in radius at the entry (called 'suction') and the exit (called 'discharge') of the pump is very small. Hence the name "axial" pump.]

4. Mixed-Flow Pump

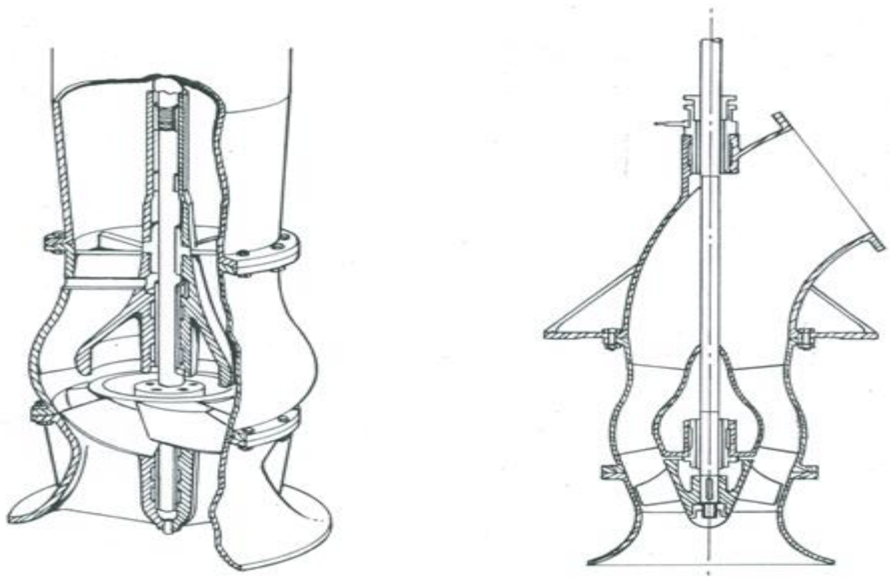
The mixed-flow pump, as its name suggests, involves something of both axial and centrifugal pumps. In a mixed flow pump, the head is developed partly by centrifugal force and partly by the lift of the vanes on the liquid. The flow enters axially and discharges in an axial and radial direction. Hence the name is mixed flow pump.

When the prime mover drives the impeller to rotate, the action of the liquid is both centrifugal force and axial thrust, which is integrated with the centrifugal pump and axial flow pump, and the liquid is inclined to flow out of the impeller. So it is a kind of pump between the centrifugal pump and axial flow pump. Mixed flow pump than the speed higher than the centrifugal pump, lower than the axial flow pump, generally between 300-500. Its head is higher than the axial flow pump, but the flow rate is smaller than the axial flow pump, larger than the centrifugal pump.

Mixed flow pump performance is also between centrifugal pump and axial pump, when comparing with centrifugal pump, head is lower, and flow is larger; compared with axial pump, head is higher, flow is lower. This supply us a selection of adjust measures to local conditions to our vast, complex terrain. It is applicable for high discharge medium head conditions. The head usually varies from 3 to 10 m. Mixed flow pumps are extensively used for drainage pumping and in pumping from canals, rivers and streams. Mixed flow pumps have medium specific speeds. The specific speed varies from 90 to 160.



1. Surface mounted mixed-flow pump



2. Submerged mixed-flow pump

Basic Difference

- In axial flow pumps, the entry and exit is *parallel* to the axis of the impeller.

- In radial flow pumps, the exit is _perpendicular_ to the flow at the inlet.
- In mixed flow pumps, the flow at the exit of the impeller is _at an angle_ to the axis of impeller.

Hydraulic Ram / Hydram

Hydraulic ram (or is a special type of pump, which utilizes the energy of a large quantity of water falling through a small height to lift a small quantity of this water to a much greater height. Therefore, _no external power is required to operate this pump_. Thus, hydram can be employed when some natural source of water like a spring or a stream is available at some altitude (e.g., in hilly regions). It can be used wherever a stream of water flows with a minimum of about 1 m fall in altitude.

It can also be used for water supply to countryside and remote areas where a water source having a large quantity of water at some height is available, but the power is scarce or not available so that other types of pumps cannot be used. The simplicity of construction and the automatic operation of the hydram make it particularly suitable _for remote rural areas in a hilly region_ which often suffer from non-availability of commercial power sources (e.g., electricity or diesel) and lack of skilled technicians for the repair and maintenance of pumps and prime movers.

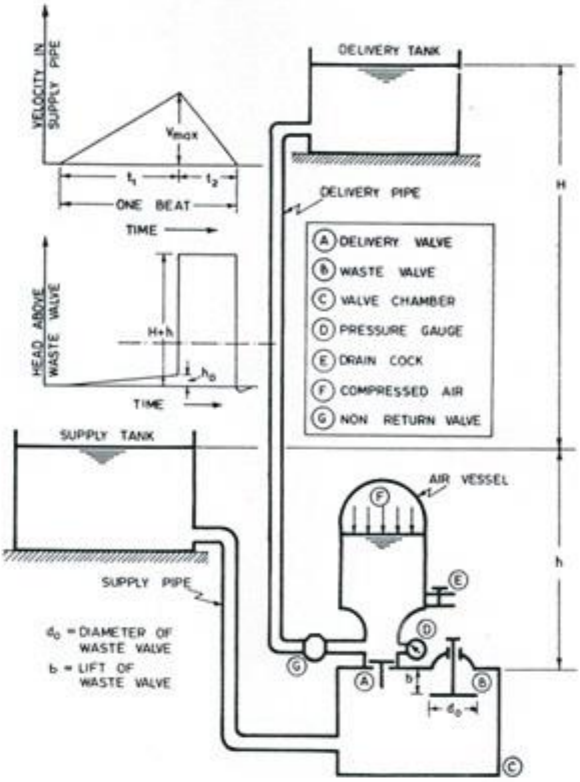
The hydram can be used for various purposes such as irrigation in sloping lands, domestic water supply in villages, water supply to small industries and fish ponds in hilly areas, supplying water to a high-level field channel in undulating hills, and boosting the discharge of lift irrigation schemes in hilly areas by taking part of the pump discharge to higher elevations for irrigation.

Main Components of Hydram

A hydraulic ram consists of a valve chamber (also called 'hydram chamber' or 'hydram body') having a waste valve and a delivery valve (Fig. 23.1). The waste valve opens into a waste water channel and the delivery valve opens into an air vessel to which a delivery pipe is connected which carries water to a water storage tank located at a higher elevation. The valve chamber is connected to a water supply tank through a supply pipe. _The supply pipe is fitted with a gate valve to operate the hydraulic ram_. Figures 23.2(a, b) illustrate two typical designs of a hydraulic ram.

Working Principle of Hydram

The hydram works on the principle of water hammer or inertia pressure developed in the supply pipe. Thus, in principle, it is an impulse pump. The *momentum of a long column of water flowing through the supply pipe is made to force a part of the water to a height greater than that of the supply source itself*. _In order to develop maximum impulse, the supply pipe should be as long as possible_. _Installation of a hydram too close to the source of supply will reduce the impulse, and hence the delivery head._



Components and operating principle of a hydraulic ram

Operation of Hydram

Initially, the water is at rest and the delivery valve and waste valve are closed. The hydram is started by opening the gate valve of the supply pipe, thereby setting the water in motion. The water in the inlet pipe starts to flow under the force of gravity and picks up speed and kinetic energy . The column of water in the supply pipe rebounds a short distance creating partial vacuum in the valve chamber (hydram chamber). It causes the waste valve to open due to its own weight. Thus, water begins to escape through the waste valve into a waste water channel. As discharge through the waste valve increases, the flow of water in the supply pipe accelerates (i.e., velocity of flow increases). The acceleration of the water column in the supply pipe causes inertial pressure due to which pressure in the valve chamber increases (An inertial force is a force that resists a change in velocity of an object. It is equal to—and in the opposite direction of—an applied force, as well as a resistive force.). The pressure in the valve chamber rapidly increases to such an extent at which the dynamic thrust acting on the lower face of the waste valve is greater than the weight of the waste valve. Consequently, the waste valve closes rapidly which produces water hammer in the supply pipe. A very high pressure is momentarily produced in the valve chamber. The momentum of the water flow in the inlet pipe against the now closed waste valve causes a water hammer that raises the pressure in the pump, opens the delivery valve, and forces some water to flow into the delivery pipe. The water then flows from the supply tank through the delivery valve into the air vessel and the delivery pipe. Thus, some of the water flowing through the delivery valve is directly supplied to the water storage tank and some of it is stored in the air vessel. The water flowing into the air vessel compresses the air inside it, which pushes a part of the water in the delivery pipe even when the delivery valve is closed. Thus, an air vessel of a hydram helps provide a continuous delivery of water at a more or less uniform rate.

As the pressure gradually rises in the air chamber, inflowing water is brought to rest and the delivery valve then closes and the waste valve opens due to the reduced pressure in the valve chamber, which again causes the water to flow from the supply tank to the waste water channel. This constitutes one cycle of operation or one beat of the hydram (Fig. 23.1). The same cycle is then repeated until the water supply is stopped. The operation of the hydraulic ram can be stopped by closing the gate valve fitted to the supply pipe.

A hydraulic ram pump is powered by a body of water flowing downhill with a height difference. A general rule of thumb is that the water can be pumped 30 times as high as the available drive head (the height difference of the water driving the pump). So a head of 1 m can be used to pump up water to ~30m, while a 7 m head can pump water up to 210 m. The capacity of a hydraulic ram depends on the scale of the pump, which is often measured in the diameter of the tube delivering the water to the pump. Pumps exist in the range 1" up to 5".

It should be noted that the operation of a hydram depends on the successful creation and destruction of velocity of flow in the supply pipe. The waste valve must close suddenly to enable kinetic energy to be utilized to a maximum extent. Theoretically, the pumping head remains constant during the operation.

MAINTENANCE AND TROUBLESHOOTING OF CENTRIFUGAL PUMPS

Introduction

Proper maintenance of a centrifugal pump is very important in order to ensure its trouble-free operation and long service life. The major causes of deteriorating pump performance can be summarized as follows (Roscoe Moss Company, 1990):

1. Improper pump installation. For example, leakage from the column pipe and power losses due to crooked shafts and improper tightening.
2. Changes in system conditions that force the pump to operate inefficiently.
3. Insufficient line-shaft lubrication that causes power loss and pre-mature wear of line-shaft bearings.
4. Motor overloading and/or overheating that decreases efficiency and breakdown insulation.
5. Improper pump adjustment causing increased wear and power losses.
6. Cavitation either from entrapped air or from insufficient NPSH.
7. Abrasion from sand and/or silt produced from the well.
8. Wear from rubbing mechanical parts. This can be normal wear expected over time or abnormal wear caused by deformed or bent parts.
9. Corrosion and incrustation of pump components.
10. Mechanical plugging of the impellers or the pump suction.

Therefore, a good maintenance program should be implemented. A well-planned maintenance program maintains high pump efficiency, helps reduce power costs, improves dependability of the equipment, reduces operating costs and provides extended service life of the pump.

The maintenance operations of a centrifugal pump can be classified into two groups: (a) preventive/routine maintenance, and (b) overhaul or repair operations.