بسم الله الرحمن الرحيم

Pumps & Pumping Stations-3rd Class(المضخات ومحطات الضخ)

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Dictionary:
Impeller = الدفاعة, suction= سحب أو أمتصاص , centrifugal = تنابذي, rotary= دوارة , Piston = Plunger = مكبس,Progressing = تقدم , Screw = لولب, Gear = ترس, Submersible = غاطس,Mounted = مركب على حامل, Pneumatic = هوائي,hub=محور, Positive displacement = الازاحة الايجابية ,Line shaft = عمود مناولة علوي, Ejector = قاذف, Regenerative = أسترجاع, Multistage = متعدد المراحل, Vessel = وعاء, Lobe = نتوء مستدير, affinity laws = قوانين التقارب,angular =زاوي,specific speed = السرعة النوعية,booster = تقوية,

Pumps are needed for:

1. Lift water from a lake, reservoir or river to WTP.
2. After WTP to force the water into the mains & elevated storage.
3. In the system booster pumps is required at certain points to keep the required pressure.
4. Raise the water from wells into a collecting basin (C.B.). Then from the C.B. into the main pipe.

River → L.L.P. → W.T.P. → H.L.P. → Distr. System (booster P.)
(1) (2) (3)

Wells → Pumps → C.B.→ Pumps → Distr. System
(4) (4)

Classification of Pumps(تصنيف المضخات)

1. Kinetic Pumps

Kinetic pumps impart velocity and pressure to the fluid as it moves past or through the pump impeller and, subsequently, convert some of that velocity into additional pressure.

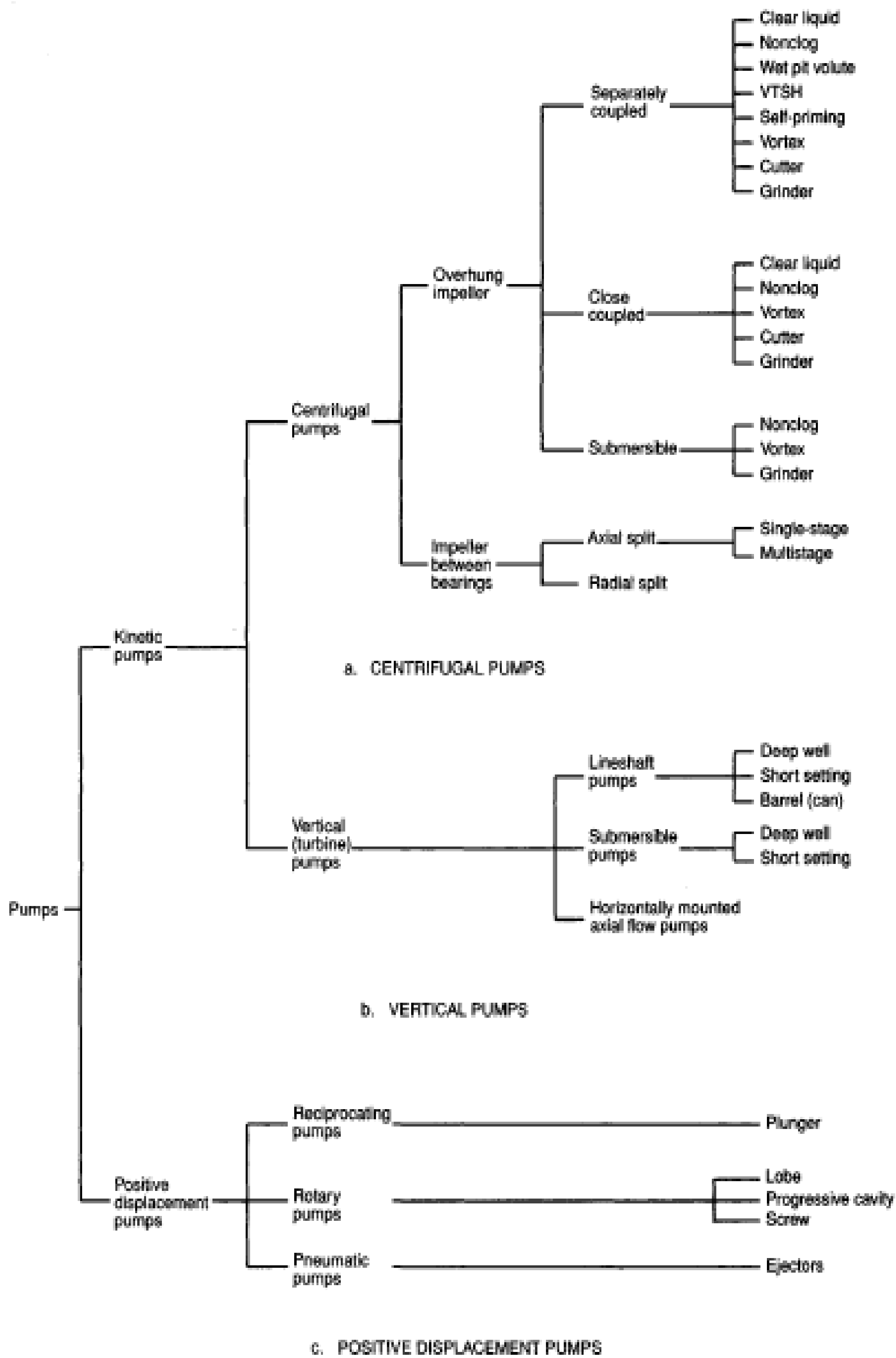


Fig.(1) Classification of pumps. Hydraulic Institute [2].

1.1 Centrifugal Pumps (Fig.2):

All centrifugal pumps have one common feature: they are equipped with a volute or casing. The function of the volute is to collect the liquid discharged by the impeller and to convert some of the kinetic (velocity) energy into pressure energy. It gives high head.

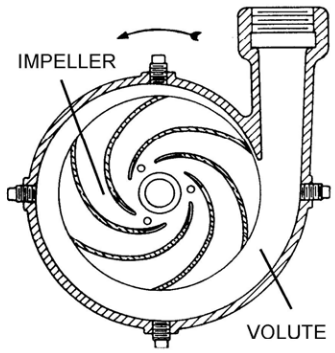


Fig. (2) centrifugal pump

1.2 Vertical Pumps

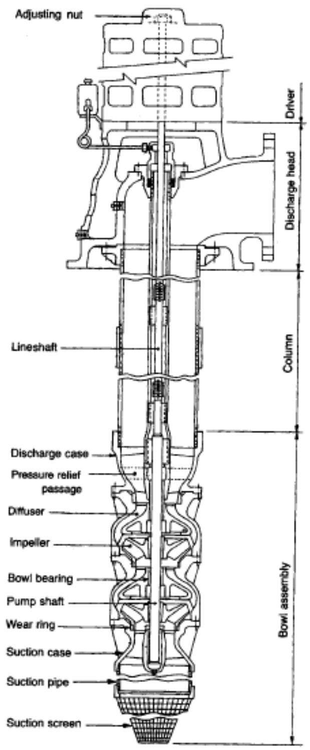
They are equipped with an axial diffuser (or discharge bowl) rather than a volute. The diffuser performs the same basic functions as the volute.

Classification of Vertical Pumps

Vertical pumps were originally developed for well pumping. The bore size of the well limits the outside diameter of the pump and so controls the overall pump design.

1.2.1 Lineshaft Pump

In lineshaft pump, the driver is mounted on the discharge head.
A typical lineshaft-driven, deep well pump is shown in Fig. (3). The bowl assembly of the pump may contain as many as 60 stages, depending on the well setting and on the discharge pressure requirements.



Figure(3) A lineshaft-driven vertical turbine pump. Hydraulic Institute [2].

1.2.2 Submersible Pump

It (Fig. 4) is driven by a submersible motor. The motor is mounted below the bowl assembly and is directly coupled to the pump rotor shaft.
Deep well submersible pumps, particularly useful for very deep (more than 180 m or 600 ft).
Short-setting submersible pumps, used for pumping shallow wells and sumps or where the noise of a motor would be objectionable.

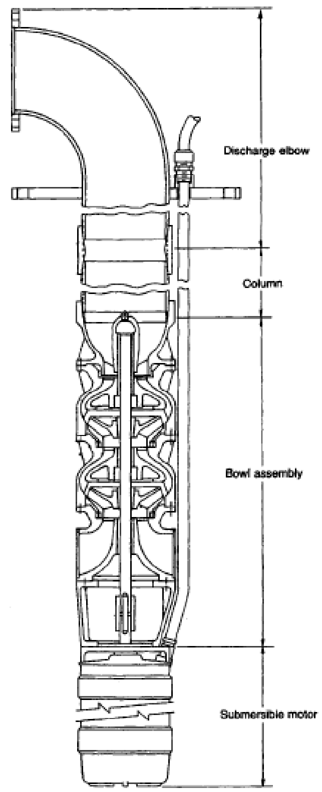


Figure (4) A vertical turbine pump driven by a submersible motor, Hydraulic Institute [2].

1.2.3 Horizontally Mounted, Axial-Flow Pumps

They are high-capacity pumps and are typically used for flood control and similar applications.

Horizontally mounted, axial-flow pumps are typically low-head pumps, and larger sizes can have very high capacity—up to 30 m^3/s (500,000 gal/min) or more. Smaller pumps frequently have a bearing frame (Fig. 5) High-capacity pumps operating with suction lift and located above the high-water level may have a center hub that is equipped with water shaft seals and is accessed through a manhole. The hub is never flooded with water.

Submersible, motor-driven, axial-propeller pumps are used in Europe for flood-control applications.

The motor of these pumps may be filled with water and the bearings lubricated with water. The pump and motor are inherently flood resistant. Such pumping stations are compact, low in cost, and require no pump house.

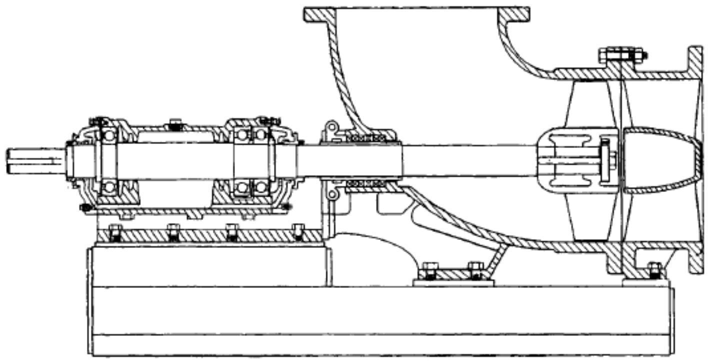


Figure (5) Horizontally mounted axial-flow pumps, Bearing frame, Hydraulics Institute [2]

2. Positive Displacement Pumps

When compared with kinetic pumps, positive-displacement pumps are inherently low-capacity, high discharge- pressure pumps. Although they are used to pump a great variety of liquids, they are also capable of pumping slurries in small volumes or in consistencies that cannot be handled by centrifugal pumps— the basic reason for using positive-displacement pumps in water and wastewater pumping and treatment stations.

In positive displacement pumps, the moving element (piston, plunger, rotor, lobe, or gear) displaces the liquid from the pump casing (or cylinder) and, at the same time, raises the pressure of the liquid. The three major groups of positive displacement pumps are

(1) reciprocating pumps,

(2) rotary pumps, and

(3) pneumatic pumps.

2.1 Reciprocating Pumps

It operates via pistons, plungers, or diaphragms. The energy is added to the pumped fluid periodically.

Operation: A piston draws water into a cylinder on the intake stroke & then forces it out on the discharge stroke.

Such pumps can develop very high pressures.

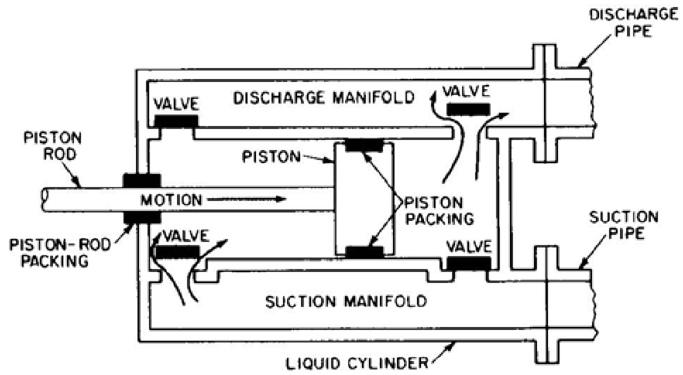


Fig. (6) piston type

Plunger Pumps

A representative plunger pump is shown in Fig. (7). It can be used for all types of wastewater, sludge, scum, slurries, and clarifier and thickener underflow. It can be applied for transfer and for metering service. Such pumps are available in single and multicylinder models. The plunger contains the crosshead, driven by a camshaft arrangement.

A plunger pump is equipped with single or dual ball lift check valves. The dual design contains two ball check valves in series for each plunger on both the suction and the discharge side. Two valves rarely hang up on foreign matter at the same time, so if one valve is unseated the other continues to operate properly until the foreign matter is flushed through without affecting the pump operation.

The pump bodies and plunger housings are separate components, and the plunger can be removed for replacement without disturbing the shaft assembly, pump body, or piping. As with all positive displacement pumps, plunger pump capacity is not altered by a changing discharge head. The positive pressure exerted by the plunger clears plugged lines.

The pumps are, therefore, well suited for metering applications.

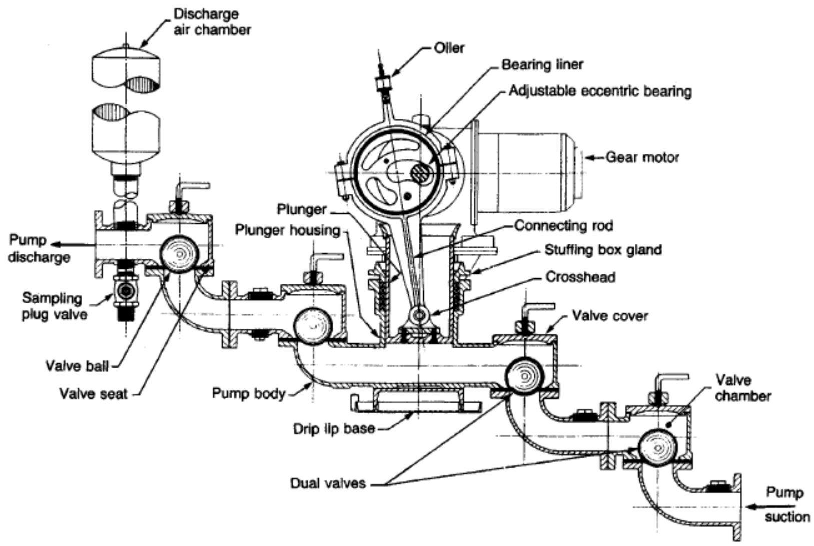


Figure (7) A plunger pump, G.M. Jones [3].

2.2 Rotary Pumps:

It is positive displacement pump use gears, lobes, screws, vanes. The energy is added to the pumped fluid continuously.

Operation: It contains two rotating gears draw water into chamber & forces it into discharge pipe.

2.2.1 Rotary Lobe Pumps

It contains two elastomer-coated rotors that are driven by an integral gear box and synchronized by timing gears. The rotors run without touching each other or the casing. The liquid is drawn through the inlet port into the pockets between the lobes and chamber walls. Because liquid cannot escape between the two rotors, it discharges in the direction of rotation of the outer lobes through the discharge nozzle.

Because of the "twisted" lobes, the pump discharges at a continuous and smooth flow rate and is relatively nonagitating and nonshearing. The pump is self-priming and can be run dry without damage from blocked or starved suction inlets. It is suited for handling a wide range of sludge viscosities and types. No check valves are required (provided the gearing prevents backward rotation), and the pumping is not susceptible to rag buildup. Elastomeric coatings for the lobes have been developed to pass hard solids up to 120 mm (4 in.) in diameter, and the coating has good wearing life in mildly abrasive duty. Where there is a high content of debris, an automatic reverse mechanism can be provided to reduce operator attention.

At the head of the treatment plant (where sludges contain a low percentage of solids but high grit content), urethane-coated rotors are recommended and the pumps should be run at reduced speeds. Otherwise,
Buna N-coated rotors are used. The pumps are used for pumping sludge with as much as 6% solids.
In summary, the initial cost is relatively high, but the advantages of
(1) quick, easy, inexpensive replacement of moving parts;
(2) compactness and space saving;
(3) high tolerance for rags and large solids;
(4) long life at low speeds; and
(5) self-priming make the overall life cycle cost attractive.

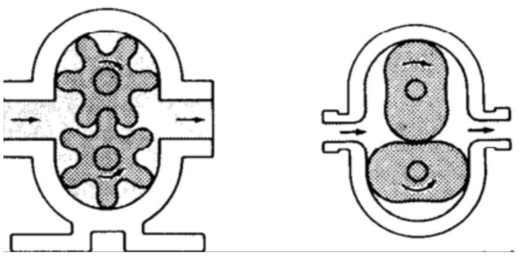


Fig.(8) Lobe pumps

2.2.2 Progressing Cavity Pumps

A progressing cavity pump is designed specifically to transfer abrasive and viscous fluids with a high solid, fiber, and air content. A hard steel screw rotor rotates and orbits within an elastomer stator. The pitch of the stator is two times the pitch of the rotor. As the rotor turns, it contacts the stator along a continuous sealing line, creating a series of sealed cavities that progress to the discharge end.
The cavity fills with liquid as it gradually opens and expands at the suction end of the rotor. The trapped liquid is transported to the discharge end and is then gradually discharged in an axial direction. Multistage pumps of up to four stages are available for reduced wear from abrasives.
Progressing cavity pumps are used in wastewater treatment plants for transferring all types of slurries and sludge, and they can pass solids with a sphere diameter of up to 50 mm (2 in.). A "bridge breaker" can be added at the front end of the pump to reduce the size of large solids. These pumps are self-priming up to lifts of 8.5 m (28 ft), but they cannot be operated dry.

The flow is even and the shear is low. The pump is relatively easy to service, but sufficient clear floor space must be available for dismantling and for access to the rotor and the Cardan shaft.
Progressing cavity pumps are relatively low in cost, but stators and rotors may have to be replaced frequently, especially if grit is present in the fluid. To reduce wear, pump speed should be low (no more than 400 rev/min) when pumping sludge or raw wastewater.

2.2.3 Screw Pumps

In an Archimedes screw "pump" (a water lifter, really), a helical screw rotates slowly and conveys water at atmospheric pressure trapped between the flights of the screw up a trough or a pipe.
Screw pumps are high volume, nonclog, atmospheric-head devices that can pump a variety of solids and debris in raw wastewater without screening. There are two general types:
(1) the open screw, which rotates in a trough (Fig. 9-a), and
(2) the enclosed screw, in which both the screw and an enclosing cylinder rotate (Fig. 9-b).

A major advantage of these pumps is variable pumping at constant speed, because the output (up to design capacity) is controlled by the sump level and equals the influent flow rate. The disadvantages are the inducement of turbulence, the release of odors and other volatile substances in wastewater, and the relatively high initial cost. But when comparing costs with those of other types of pumps, consider the cost of the total system, including all piping, wet or dry wells, screens, fittings, valves, variable-speed controls, and other accessories as well as operating and maintenance costs. Note that operators like screw pumps because the good ones, when properly installed, are so trouble-free.

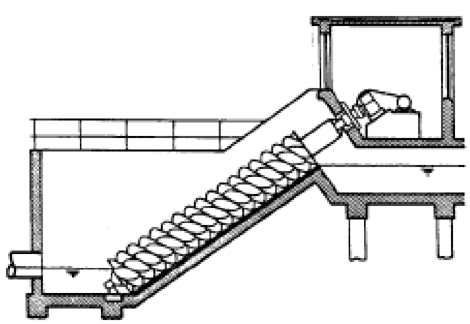


Fig. (9-a) An open screw pump

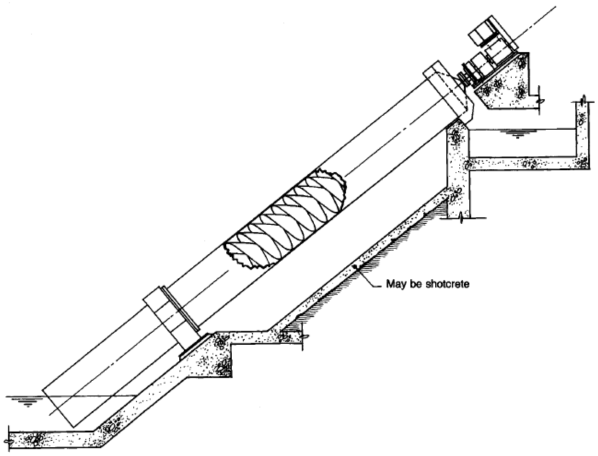


Fig. (9-b) An enclosed screw pump, G.M. Jones [3].

2.2.3.1 Open Screw Pump

It (often called Archimedes screw) consists of a torque tube to which spiral flightsare attached, a lower submerged bearing, an upper radial and thrust bearing, a gear reducer (typically driven by an electric motor), and a trough in which the screw rotates at a constant speed. The limiting speed ranges from 20 rev/min in large pumps to 75 rev/min in small ones and cannot be exceeded without water spilling over the top of the screw.

2.2.3.2 Enclosed Screw Pump

Except for the following differences, the enclosed screw pump is similar to the open type:

• Because the flights are welded to the outer cylinder, there is no slippage (backflow). If the pump is stopped, the water is retained between the flights. The lower bearing (a self-aligning set of rollers mounted above the high-water level) is easily accessible.
The rollers carry most of the radial load.

• Because there is no slippage, the efficiency of the pump is very high and stays high even at low discharge.

• A massive concrete structure is not needed.

2.2.3.3 Screw-Centrifugal Pump

It has a deep, cone-shaped impeller with a demonstrated superior ability to pass stringy material combined with low shear pumping action. These pumps have been applied successfully in wastewater pumping stations with heavy rag loads and variable speed drives, in treatment processes with a need to preserve flocculated material, and in situations requiring fish friendly operation.

2.3 Pneumatic Pump

Compressed air is used to move the liquid in pneumatic pumps. In pneumatic ejectors, compressed air displaces the liquid from a gravity-fed pressure vessel through a check valve into the discharge line (Fig. 10) in a series of surges spaced by the time required for the tank or receiver to fill again.

The reduced density of a column of an air-liquid mixture is used to raise the liquid in an air lift pump (Fig. 11). But because the water is not pressurized, it is not really a pump. It is therefore not included in Fig. (1), and it should be called a "water-lifting device."

Air Lift Pump (water-lifting device)

It consists of a simple tube immersed in the sump or wet well with a high volume of low-pressure compressed air admitted at the bottom of the tube. The reduced-density air-liquid mixture in the tube is raised by the static head in the wet well, and it overflows into the open discharge channel (Fig.11). The pump is extremely simple and can be constructed in the field. It is suitable for raw wastewater, sludge, and sandy or dirty water.

The hydraulic efficiency is very low and rarely reaches 35%. For all except very low heads, the pump requires large submergence.

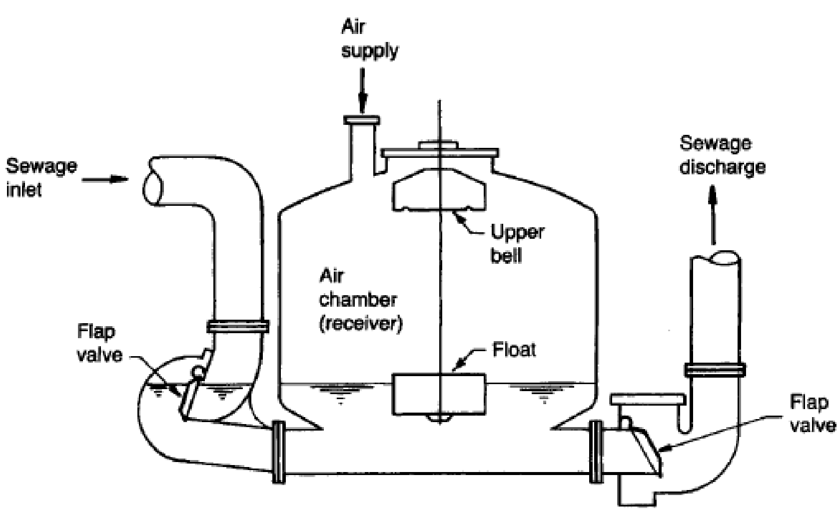


Fig. (10) A pneumatic ejector, G.M. Jones [3].

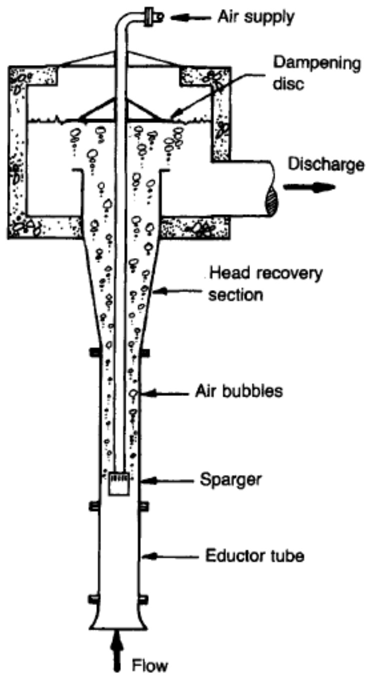


Fig. (11) An air lift pump, G.M. Jones [3].

Pneumatic Ejector

It is used for pumping low flow rates of wastewater at high heads (flow rates to 140m^3/h [600gal/min] at heads to 90 m [300 ft]), especially if the flow rates are highly variable. The pump consists of a pressure vessel that is allowed to fill by gravity until a predetermined level is reached (Fig. 10). Controls are then operated to admit compressed air to the vessel. The high pressure moves the liquid into the force main. When the chamber has been emptied, the controls close the air supply valve and vent the air in the tank to the atmosphere, which allows the next cycle to begin. The compressed air may be supplied from a plant air system or from compressors installed on location. Air receivers of adequate capacity for several cycles are sometimes installed to provide for limited continuing operation of the system during power outages.

Regenerative Turbine Pumps (special pumps)

They have long been recognized for efficiently producing low flows at pressures much higher than those of centrifugal pumps of comparable size. The liquid circulates in and out of the impeller buckets many times on its way from the inlet to the outlet of the pump. Both centrifugal and shearing action combine to impart additional energy to the liquid each time it passes through the buckets. Pressure from the inlet in Fig. (12-a) increases linearly

to the discharge. The impeller runs at very close axial clearances with the pump channel rings to minimize the recirculation losses, so these pumps can only be used with clean liquids.
Pumps are made with capacities ranging from 0.13 L/s to more than 4.4 L/s (2 gal/min to more than 70 gal/min) at heads ranging from 3 m to more than 120 m (10 ft to more than 400 ft).

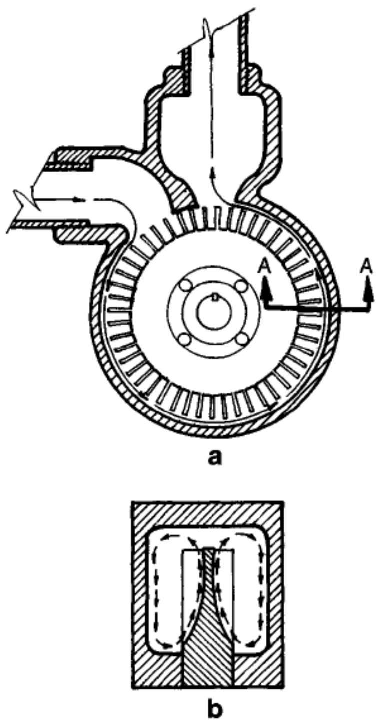


Fig. (12) A regenerative turbine pump, (a) Impeller; (b) Section A-A. G.M. Jones [3].

Multistage Centrifugal Pumps

Sizes are available for pumping from 0.08 to over 22 L/s (1.2 to over 350 gal/min) at corresponding heads of 150 to 260 m (350 to 600 ft). An advantage of the multistage configuration is that pressures do not change very much with a change in flow rate.

Summary of Typical Pump Applications

The principal uses of the pumps shown in Fig. (1) are given in Table (1). No distinction is made in Table (1) between clean water and dirty water (with gritty material such as sand in suspension) because a clean water pump can be made satisfactory for dirty water if it is constructed of abrasion-resistant materials and if it is equipped with, for example, the appropriate kinds of seals.

Table 1 Application of Pumps, G.M. Jones [3]. **(For information)**

Type of pump (see Figure 11-1)	Capacity m/h	Capacity gal/ml	Service
Overhung impeller			
Clear-liquid	to 2300	to 100,000	Water
Nonclog	9–2300	40–100,000	Wastewater
Wet pit valute	50–9000	250–40,000	Water
VTSH®	450–5000	2000–22,000	Wastewater
Self-priming	23–910	100–4000	Wastewater, water
Vortex	10–230	50–1000	Sludge, wastewater
Cutter	11–230	50–1000	Wastewater
Grinder	<23	<100	Wastewater
Submersible nonclog	9–11,000	40–50,000	Wastewater
Submersible vortex	11–60	50–250	Sludge, wastewater
Submersible grinder	<23	<100	Wastewater
Impeller-between-bearings			
Axial-split, single-stage	23–23,000	100–100,000	Water
Axial-split, multistage	23–460	100–2000	Water
Vertical (turbine) lineshaft			
Deep well	9–2300	40–10,000	Water
Short-setting	9–23,000	40–100,000	Water
Barrel pumps	9–9100	40–40,000	Water

Type of pump (see Figure 11-1)	Capacity m/h	Capacity gal/ml	Service
Vertical (turbine) submersible			
Deep well	23–460	100–2000	Water
Short setting	23–1000	100–8000	Water
Horizontally mounted			
Axial-flow	9–110,000	40–500,000	Storm water
Positive-displacement			
Plunger	0–120	0–540	Sludge
Lobe	<450	<2000	Sludge
Progressive cavity	<100	<480	Sludge
Screw (open)	2300–14,000	10,000–60,000	Wastewater, storm water
Screw (enclosed)	110–8000	500–35,000	Wastewater, storm water
Ejector	0.5–140	2–600	Wastewater
Other (omitted in Figure 11-1)			
Air lift	11–570	50–2500	Water, activated sludge

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Ejector	0.5–140	2–600	Wastewater
Other (omitted in Figure 11-1)			
Air lift	11–570	50–2500	Water, activated sludge

Work & Efficiency of Pumps(الشغل والكفاءة)

Head, $h = p/\gamma$

If $h = 1ft \rightarrow p = \gamma\, h = 62.4Lb/ft^3 \times 1ft \times (1ft^2/144in^2)$

$= 0.433psi$

$h = 1m \rightarrow p \quad = 9.8kN/m^3 \times 1m$

$= 9.8kN/m^2 = 9.8kPa$

Pressure → absolute pressure (AP)

→ gage pressure

1bar = 10m = 100kPa

Atmospheric pressure & Absolute Pressure relationship:

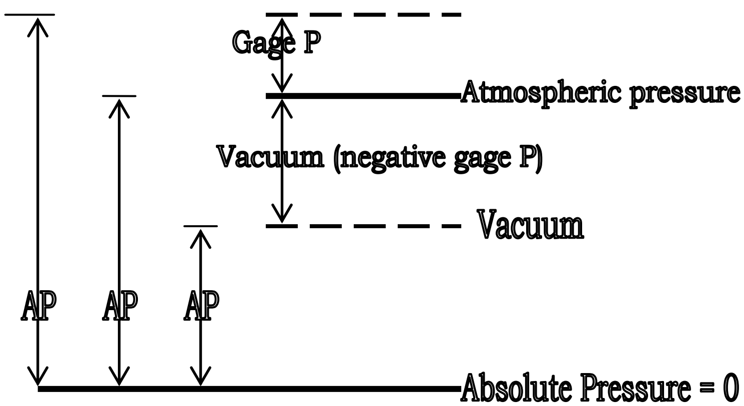


Fig.(13)

Total dynamic head (TDH) of a pump (total pumping head)

= static suction lift + static discharge head + friction head + velocity head (negligible)

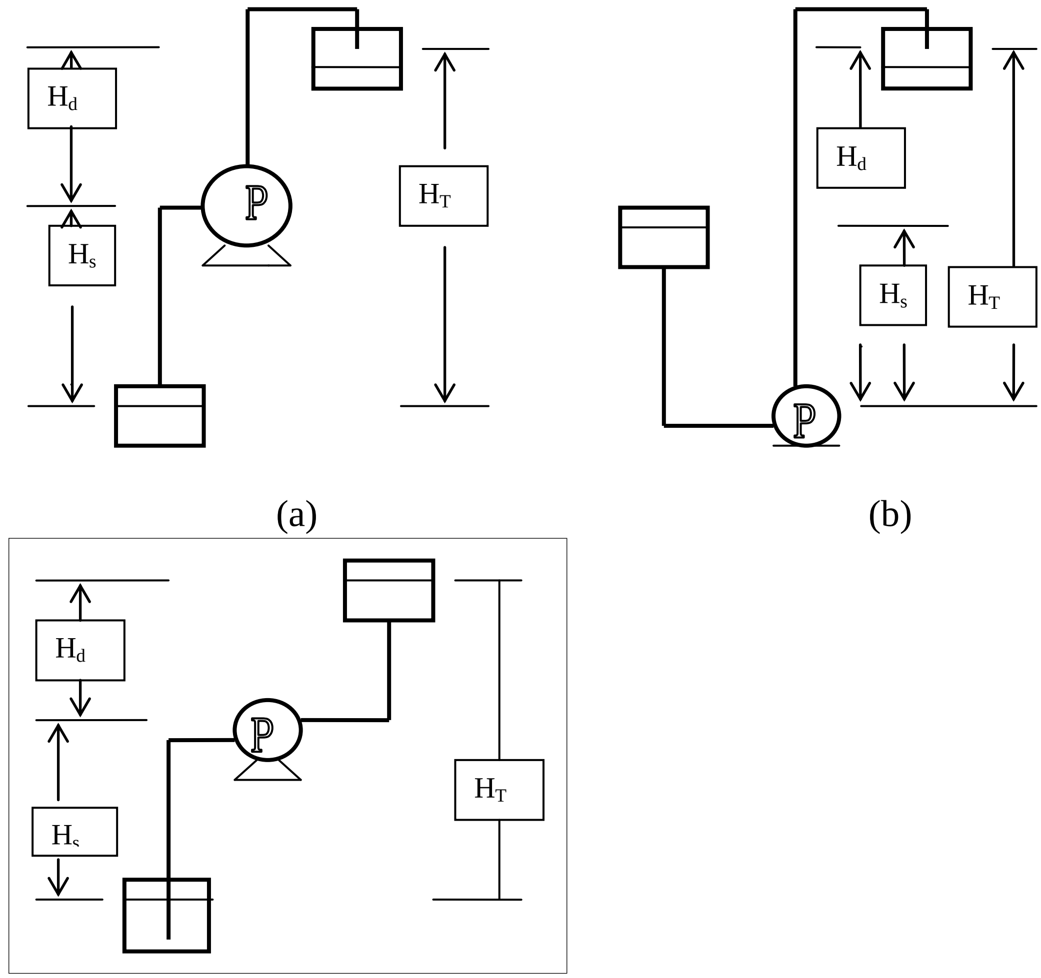
$= H_s + H_d + H_L$

Fig.(14) Head terms used in pumping

(a) & (c). Total static head = static suction lift + static discharge head

(b) Submerged pump inlet (positive head upon intake)

Total static head (TSH) = static discharge head – static suction lift



(c)

Fig.(14) Head terms used in pumping

Where:

H_T = total static head

H_s = static suction lift

= difference in elevation between pump centerline & low level of supply

H_d = static discharge head

= difference in elevation between the pump & point of discharge

H_L = headloss due to friction & fittings in discharge pipe

Friction head = $h_f + h_L$

$h_f \rightarrow$ Darcy-Weisbach eq. or Hazen William eq.

$h_L = K(V^2/2g)$

$K = f$ (1/dia. of fittings) $\rightarrow$ Table (2)

Many types of fittings $\rightarrow$ Table (3)

f (equivalent length of straight pipe) $\rightarrow$ Table (4)

Table (2) Minor loss coefficient

Type of minor loss	*K* coefficient
Pipe fitting	
90° elbow, regular	0.21–0.30
90° elbow, long radius	0.14–0.23
45° elbow, regular	0.2
Return bend, regular	0.4
Return bend, long radius	0.3
AWWA tee, flow through side outlet	0.5–1.8
AWWA tee, flow through run	0.1–0.6
AWWA tee, flow split side inlet to run	0.5–1.8
Valves (fully open except as noted)	
Gate valves (4 to 12 in) fully open	0.07–0.14
¼ closed	0.47–0.55
½ closed	2.2–2.6
¾ closed	12–16
Angle	1.8–2.9
Ball	0.04
Gate	
Double disc	0.1–0.2
Resilient seat	0.3
Check valves	
Swing gate	0.6–2.5
Double door (8 in or smaller)	2.5
Double door (10 to 16 in)	1.2
Foot (hinged disc)	1–1.4
Foot (poppet)	5–14
Slanting disc	1.1

Sources: From Sanks et al. (1998) and Velon and Johnson (1993).

Table (3) Energy Loss Coefficients for Flanged Pipe Fittings

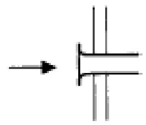
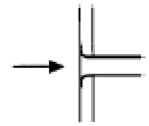
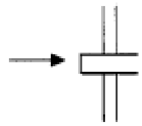
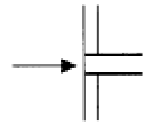
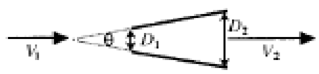
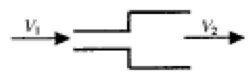
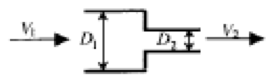
Fitting	K	Fitting	K
Bell mouthed entrance 	0.05	Rounded entrance 	0.25
Sharp edged entrance 	0.5	Projecting entrance 	0.8
Conical increaser $h = K(1 - (D_1/D_2)^2)(V_2^2/2g)$ $K = 3.5(\tan\theta)^{1.22}$ 		Sudden expansion $h = (V_1^2 - V_2^2)/2g$ 	
Conical reducer $H = KV_2^2/2g$ $K = 0.03 +/- 0.01$ 		Sudden contraction $h = ½[1 - (D_1/D_2)^2]V_2^2/2g$ 	

Table (4) Approximate resistance of common Fittings, in equivalent feet of straight pipe

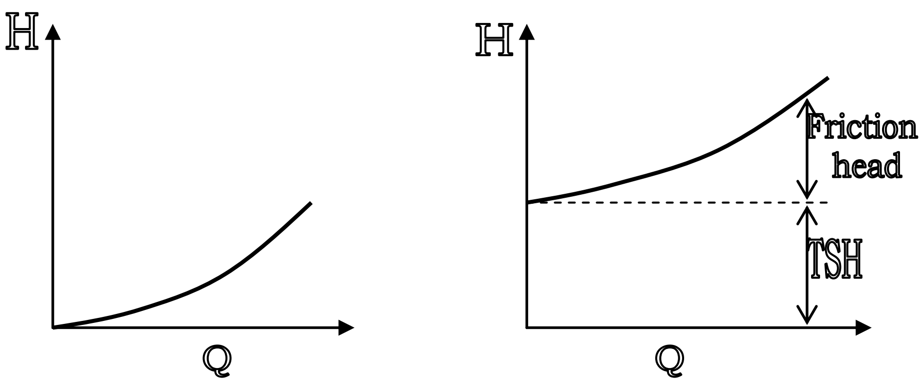
Table 2-7 Approximate Resistance of Common Fittings to Water Flow, in Equivalent Feet of Straight Pipe

Nominal Diameter, In.	*Standard L*	*Medium L*	*Long Sweep L*	*45° L*	*Gate Valve, Open*	*Globe Valve, Open*
1/2	1.0	0.9	0.7	0.6	0.23	5.0
3/4	1.51	1.3	1.0	0.80	0.40	10.0
1	1.8	1.5	1.3	1.0	0.55	13.0
1 1/4	2.7	2.4	2.1	1.5	0.80	18.0
1 1/2	3.0	2.6	2.3	1.6	0.90	20.0
2	4.1	3.5	3.0	2.3	1.3	29.0
2 1/2	5.5	4.8	3.8	2.8	1.4	35.0
3	7.0	6.0	4.6	3.5	1.9	45.0
4	10.0	8.5	6.6	5.0	2.6	60.0
6	16.0	14.0	12.0	8.0	4.5	110.0
8	21.0	18.0	15.0	12.0	6.0	150.0
10	26.0	22.0	18.0	15.0	8.0	200.0
14	40.0	35.0	31.0	23.0	12.0	280.0
18	55.0	45.0	40.0	30.0	16.0	380.0
20	60.0	55.0	42.0	34.0	17.0	420.0

$H_L = f$ (dia., length, material, material condition, no. and type of fittings).
$H_L = f$ (D, L, f)
Fig. (15-a) System headloss curve, H_L-Q.

$Q_1 \rightarrow H_{L1}$ from Darcy eq.
$Q_2 \rightarrow H_{L2}$
$\downarrow$

At $Q = 0 \rightarrow H = 0$
H-Q parabolic $\rightarrow H = f(V^2) = f(Q^2)$.
Fig. (15-b) System Head Curve, H-Q
$TDH = H = H_L + TSH$
At $Q = 0 \rightarrow H = TSH$
Note: No relation between TSH & Q, Why?



(a) System headloss curve (b) System head curve
Fig.(15) Head curves

Water Power(قدرة الماء) :

$$P_w = KQH \qquad \text{--- (1)}$$

Where:
P_w = output power,
Q = flow,
H = total head,
K = constant = f (γ & units).
For water at 20^{o}C
$K = 2.525 \times 10^{-4}$ (h_p, gpm, ft)
= 0.163 (kW, m^3/min, m)

Power input to pump, $\mathbf{P_p = P_w/e}$ --- (2)

e =pump efficiency = f (pump design, fluid, & operation) < 1
range (40 - 90%)

Power input to motor, $\mathbf{P_m = P_p/e_1}$

Where: e_1 = motor efficiency < 1
For design purpose use e = 0.75 & e_1 = 0.95.

$P_m \rightarrow$ $\boxed{\text{Motor}}$ $\rightarrow P_p \rightarrow$ $\boxed{\text{Pump}}$ $\rightarrow P_w$
motor input — motor output / pump input — pump output

Example (1):
Determine the water power, pump power, & motor load (power) for a pump system designed to deliver 1.89 m^3/min (500 gpm) against a total system head of 50 m (164 ft).assume the efficiency of both pump & motor is 80%.

Solution:
$\gamma QH = (kN/m^3).(m^3/s).m = kN.m/s = kW$
$P_w = KQH$
$= 0.163 \times 1.89 \times 50 = \underline{15.4}$kw
$= 2.525 \times 10^{-4} \times 500 \times 164 = 20.7$hp (1hp = 0.746kw)
$P_p = P_w/e$
$= 15.4/0.8 = \underline{19.25}$ kw
$P_m = P_p/e_1$
$= 19.25/0.8 = \underline{24.06}$ kw (32.3hp).
****

The Centrifugal Pump

Action of the Centrifugal pump (Fig.16)(مبدأ العمل):
Water in a rotating vessel(وعاء)

$$\mathbf{h = s^2/2g} \qquad \text{------- (3)}$$

Where:
h = height above level at center,
s = linear speed at point where h is measured.
Increase h with s indicates that these pumps produce high head.

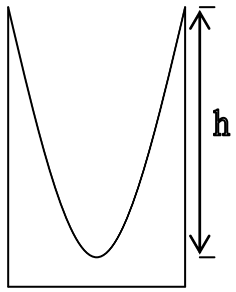


Fig.(16) Water in a rotating vessel

Operation:

Water enters at casing center accelerated by rotating impeller through radial & tangential velocity. The water leaving the impeller is slowed by the casing & the flow velocity converted to pressure. The conversion is by casing (volute pump).

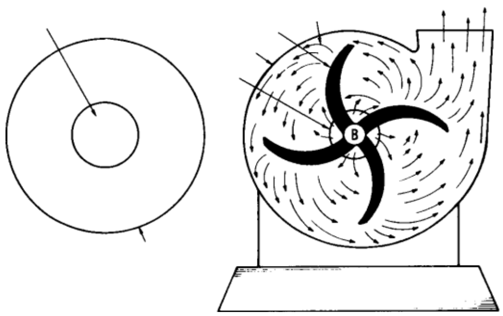


Fig.(17) operation

Basic parts of a centrifugal pump showing cover (left) and section of a centrifugal pump, commonly termed a volute pump because of the shape of its housing.

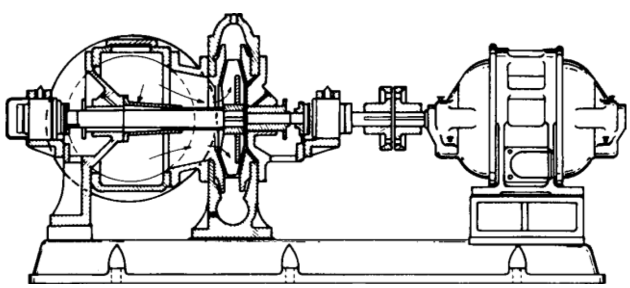


Fig.(18) Basic parts

Effect of Varying Speed(تأثير تغيير السرعة)

D = impeller diameter

ω = angular velocity

$Q = f\,(\omega)$

$h = f\,(\omega^2)$

$P_w = f\,(\omega^3)$

For a pump (affinity laws):

$Q_1/(\ \omega_1\ D_1^3) = Q_2/(\ \omega_2\ D_2^3) = ---$ ---- (4)

$h_1/(\ \omega_1^2\ D_1^2) = h_2/(\ \omega_2^2\ D_2^2) = ---$ ----(5)

$P_{w1}/(\ \omega_1^3\ D_1^5) = P_{w2}/(\ \omega_2^3\ D_2^5) = ---$

Specific speed, ω_s: the speed at which a pump in series will discharge a unit flow under a unit head at max. efficiency. Q, h at e_{max}

$$\boldsymbol{\omega_s = (\omega Q^{1/2})/h^{3/4}} \qquad \text{--- (6)}$$

Where:

Q –gpm, h –ft, ω –rpm

$$\boldsymbol{\omega_s = 6.67\ (\omega Q^{1/2})/h^{3/4}} \qquad \text{--- (7)}$$

Where:

Q –m^3/min, h –m, ω –rpm

High ω_s more efficient than low ω_s

For max. efficiency;

ω_s = 1000- 4000 → centrifugal pump (radial p.)

4000- 7000 → mixed pump (radial & axial p.)

> 7000 → axial pump

Why we call a centrifugal pump, radial pump?

For a particular pump, the value of specific speed will vary from zero at zero discharge to ∞ at zero head.

<u>Characteristics of Centrifugal Pumps(خواص المضخة النابذة)</u>

$Q = f\,(\omega, h)$

Fig. (19) **Characteristic curves** (H α 1/Q), ω = constant

h, P_w, η, vs. Q

e.g.: at e_{max} → Q =   gpm, h =   ft, P_w =   hp

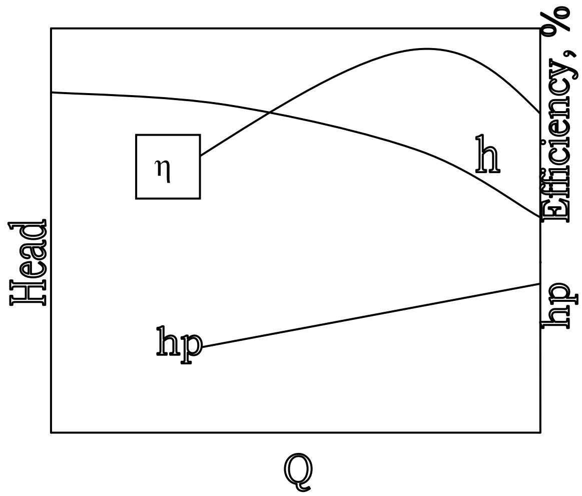


Fig. (19) Characteristic curves of a centrifugal pump, ω = constant

Fig. (20) Pump Series Characteristic Curves, submitted by manufacturers.
For each pump, h, Q, P_w, e, D, & NPSH.

Ex.: If D = 12″, η = 72%, h = 108ft, Q =   gpm, P_w =   hp, & NPSH =

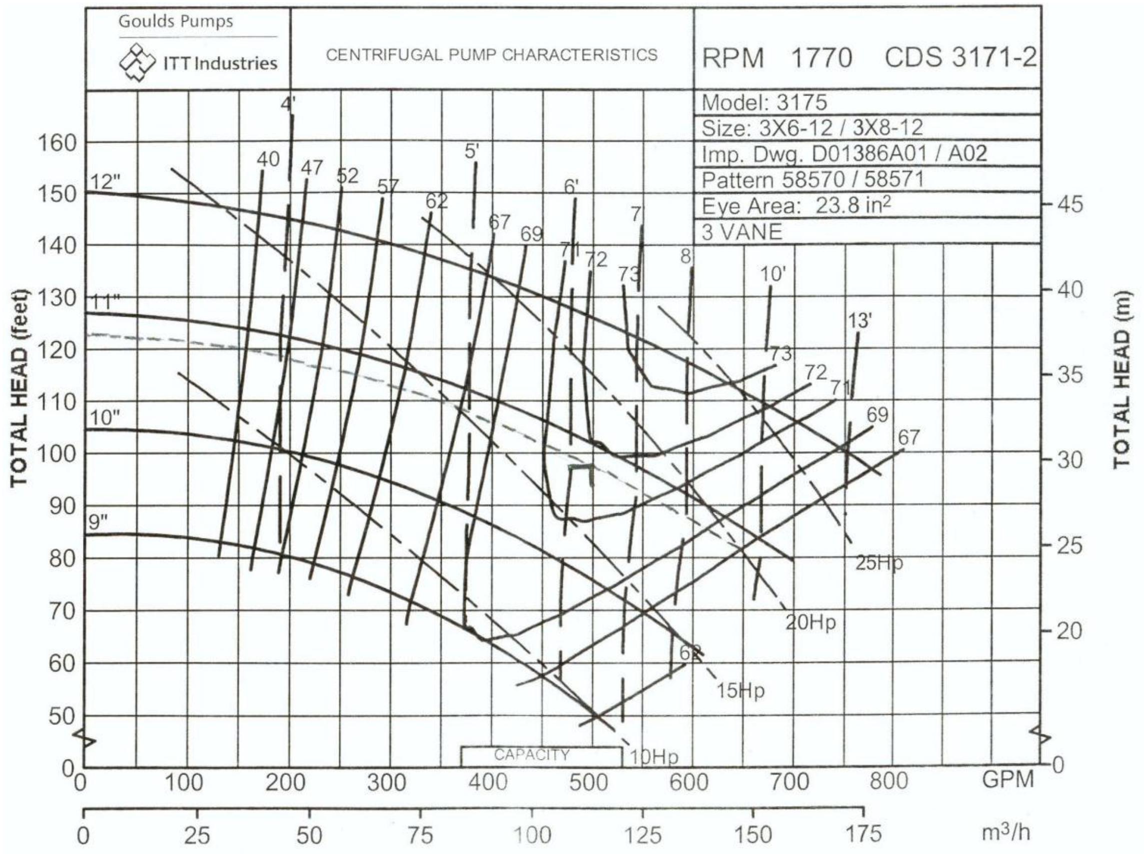


Fig. (20) Pump Series Characteristic Curves.

One casing → several impeller sizes.
→ expansion of an existing system.

Note: Cost of installation & alignment of large pumps may equal or exceed that of pump itself.

The conditions that can alter pump performance:

a. Changes in impeller or casing geometry,
b. Increased internal pumping losses caused by wear, &
c. Variation of liquid properties.

Classification of characteristic (Fig.21)

1. drooping head: rise to a max. h at an intermediate Q, then drop to a lower shutoff,
2. rising head: rise to shutoff as Q decreases.
3. flat head: low variation in h with Q.
4. steep head: high variation in h with Q.

Moderately steep curve is preferable.

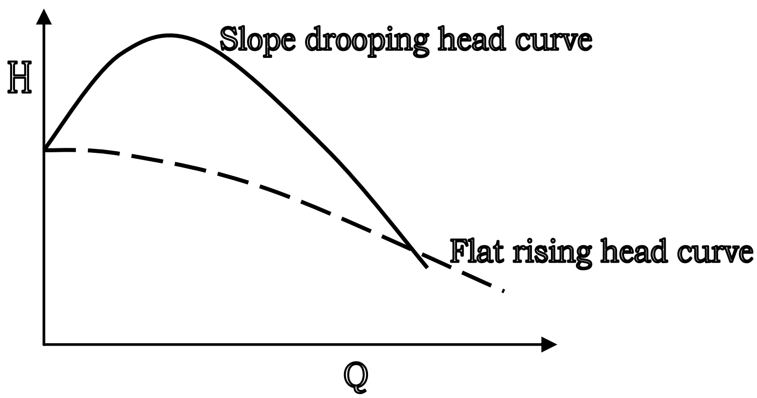


Fig.(21) Characteristic Curves.

Suction Lift

It is a force available to drive flow into pump.

Net positive suction head, NPSH = f (system design)
= f (pipe sizes, suction lift, Q, etc.)

Required NPSH = f (pump design) → Fig.(20)

Available NPSH = barometric pressure + static head –losses in pipe & fitting - vapor pressure of water(p_v).

$$= P_b + P_s - \text{losses} - P_v$$

Use min. barometric pressure → Table (5)

Table (5) Barometric pressure vs. altitude

Altitude m	ft	Pressure kPa	ft, H_2O
0	0	101	33.9
305	1 000	98	32.9
457	1 500	96	32.1
610	2 000	94	31.5
1220	4 000	88	29.2
1830	6 000	81	27.2
2439	8 000	75	25.2
3049	10 000	70	23.4
4573	15 000	57	19.2

Note: Barometric pressure in Table (5) should be reduced by 1.2ft of water (3.5kPa) due to storm activity.

Use max. vapor pressure → Table (6)

Table (6) Vapor pressure of water vs. temperature

Temperature ^oC	^oF	Pressure kPa	ft, H_2O
0	32	0.61	0.204
4.4	40	0.84	0.281
10	50	1.23	0.411
15.6	60	1.76	0.591
21.1	70	2.5	0.838
26.7	80	3.5	1.17
32.2	90	4.81	1.61
37.8	100	6.54	2.19
43.3	110	8.81	2.95
48.9	120	11.7	3.91
54.4	130	15.3	5.13
60	140	19.9	6.67

<u>Example (2)</u>:

Assume that a water pumping station at 500 m elevation uses pumps which require 30 kPa positive suction pressure (NPSH) when delivering water at 30^oC. What is the allowable suction lift of these pumps if the entrance & friction losses are 15 kPa?

<u>Solution</u>:

$NPSH = P_b + P_s - \text{losses} - P_v$

Table (5): parametric pressure

457m 96kPa

500m → → 95.45kPa

610m 94kPa

43 x

153 2 → x = 43 × 2/153 = 0.55kPa → 96 – 0.55 = 95.45kPa

Storm activity: P_b = 95.4 – 3.5 =91.9kPa

Table (6): vapor pressure

$$30^{o}C \rightarrow \begin{matrix} 26.7 & 3.50 \\ 32.2 & 4.81 \end{matrix} \rightarrow P_v = 4.3kPa$$

$x = 2.2 \times 1.31/5.5 = 0.52kPa \rightarrow 4.81 - 0.52 = 4.3kPa$

$NPSH_{available} = 91.9 - 15 - 4.3 + (-P_s) = 72.6 - P_s$
$NPSH_{required} = 30 = 72.6 - P_s$
$P_s = \underline{42.6}$ kPa (4.35m).

****

For greater lift:

1. added another pump
2. entrance modification

<u>Cavitations</u>

If **$NPSH_{actual}$ below $NPSH_{required}$** $\rightarrow$ Pressure below P_v $\rightarrow$ Water vaporize
(available) (required) ↓

Impeller damage ← Collapse ← Bubbles ← Gas in pump

To avoid cavitations, use h & Q at max. η.

<u>Pump Selection(أختيار المضخة)</u>

$P_w = KQH$
Pump requirements = f (Q, H)
Pump selection = f (pump curve, system curve)

<u>Fig. (22)</u>:
Actual design (in site) - point 1
Engineering design (in office) – 2
Available pump – 3
Pump no.1 → appropriate selection, but
Pump no.3 available → point 4 actual operating
Point 4 actual operating → $Q_1 = Q_4$, losses in H & η ($H_4 > H_1$)

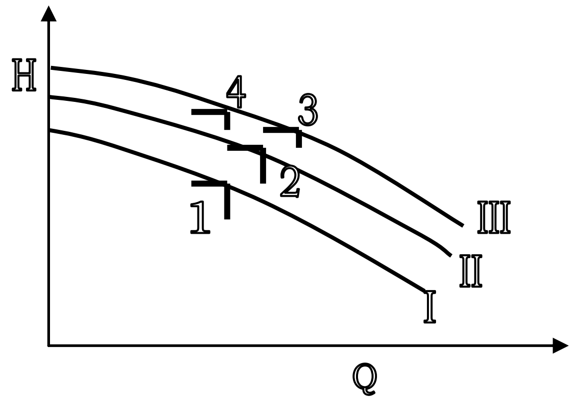


Fig.(22) Effects of Pump selection.

General Requirements for Pump Selection:

1. Capacity: satisfy the required discharge
2. Operation reliability: easy to start, sure of service in working, & does not fail suddenly or cause trouble.
3. Efficiency: high efficiency
4. Power: low required power
5. Cost: cheap in initial cost, operation & maintenance cost, & long life.

<u>System-Pump Curves</u>

Cases:

1. both curves flat (Fig. 23a)
2. flat system-steep pump (Fig. 23b)
3. steep system-flat pump (Fig. 23c)
4. both curves steep (Fig. 23d)

Note: Case (3) is preferable: Q not varies much with H.

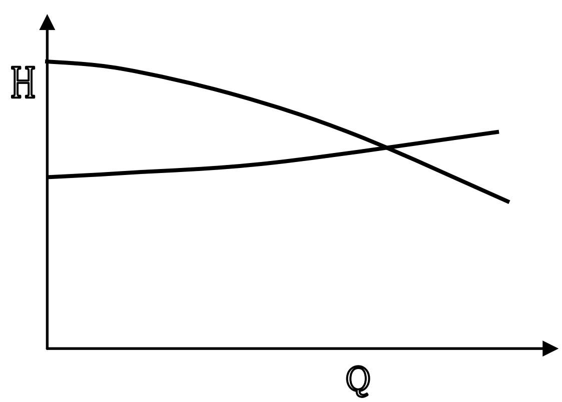


Fig.(23a) Both curves flat

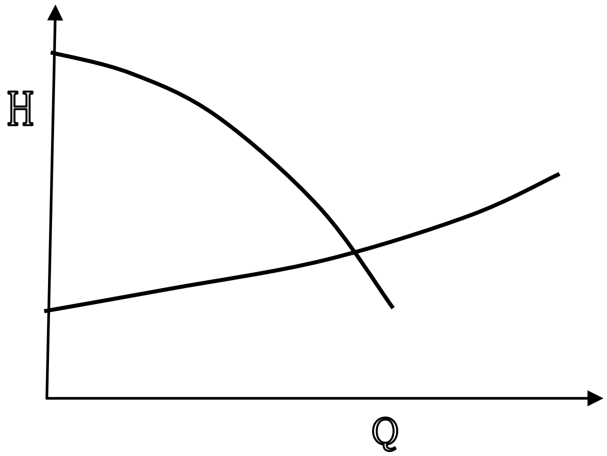


Fig. (23b) flat system-steep pump

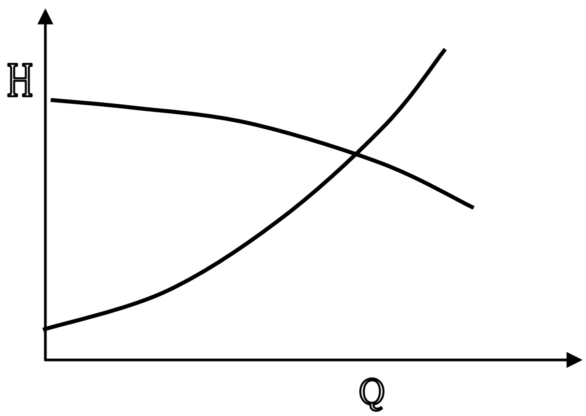


Fig. (23c) steep system-flat pump

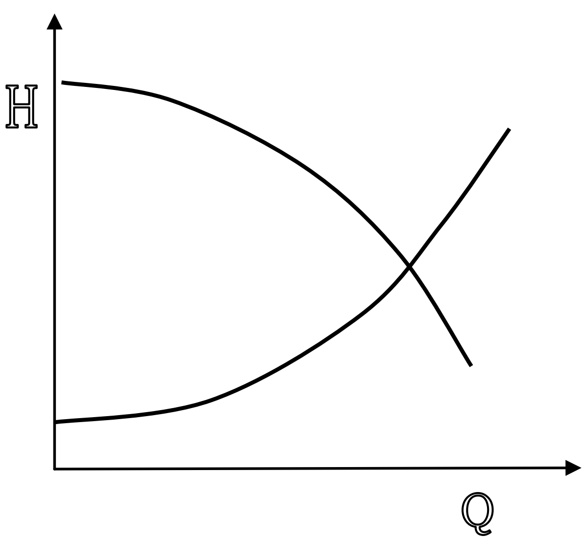
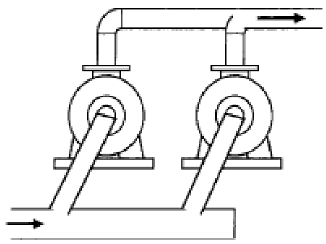


Fig. (23d) both curves steep

<u>Variation in Capacity(التغيّر فى السعة)</u>

Variable demand required variable pump capacity. Choose pump with max. demand & let throttling to min. demand.

<u>Pumps in Parallel</u>

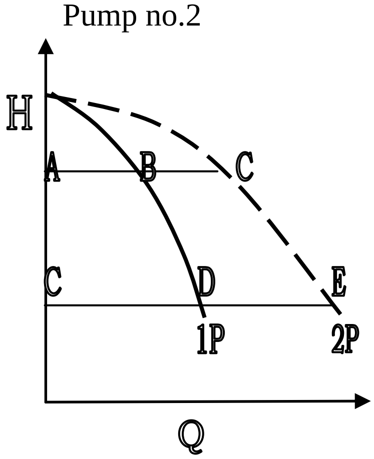


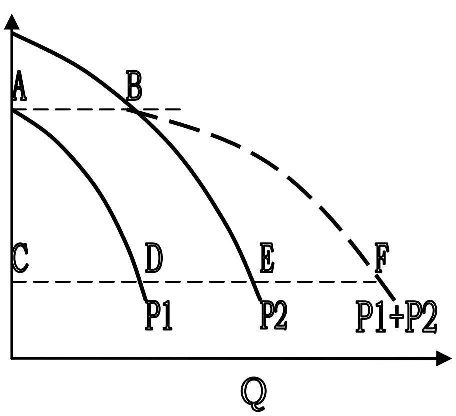
(Fig.24)

To increase capacity, Q.
This done by addition of characteristic curve:
Addition discharges of pumps at each head.

a. identical pumps ($Q = 2Q_1$): AC = 2AB, CE = 2CD
b. dissimilar pumps($Q = Q_1 + Q_2$): CF = CD + CE
   At H > A:
   Pump no. 1 dose not discharge, why?
   Pump no. 2 discharge only.
   For low Q use pump no.1
   If pump no.2 used, pump no.1 never start due to high head, otherwise use check valve.
   At H ≤ A:

Pump no.1	can be used for low Q
Pump no.2	medium Q
Pump no.1 & no.2	high Q
Pump no.1	low H
Pump no.2	high H





(a) Identical pumps. (b) Dissimilar pumps.

Fig. (25) Combined characteristic curves.

Multiple pumps & system curve:
More than two pumps (Fig. 26)

Pump no.1,	% of max. design Q in the system
2	%
3 or (1+2)	%
1 + 3	%
2 + 3	%
1 + 2 + 3	%

Intermediate Q → throttling, or pressure increases (system curve).

One selects a pump whose design point is close to operating point & that it can be operate efficiently & economically over the required range.

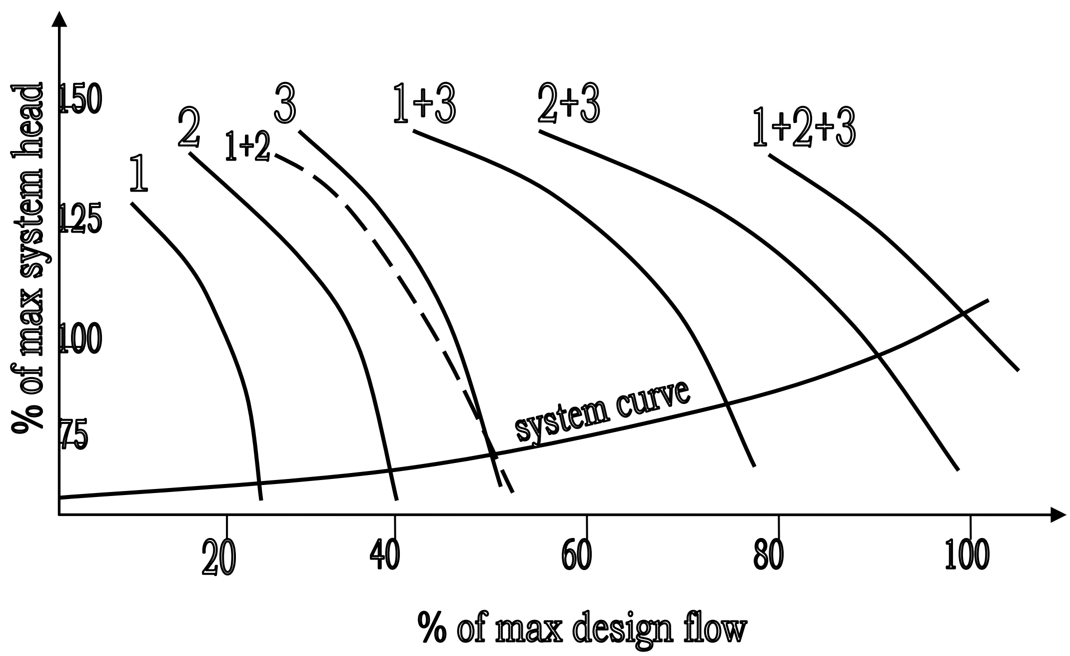


Fig. (26) Combined characteristic curves for multiple pump installation.

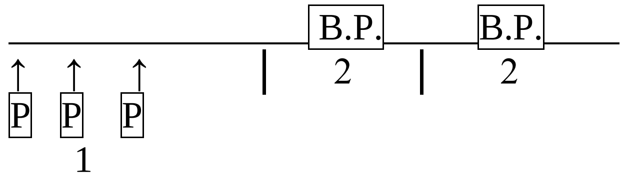
Water Distribution Pumping (مضخات التوزيع)

High-lift pumps move treated water from water treatment plant into distribution system.

Different sets of pumps may be needed against unequal pressures.

1. Source pumps: they located at the upstream end of the pipeline. They draw water from reservoirs, tanks, & wells.

2. Booster pumps(مضخات تقوية) , B.P.: they are located at some intermediate point in the pipeline. They are used for high elevations, & away areas.



Pumps in series: used in booster pumps to increase head

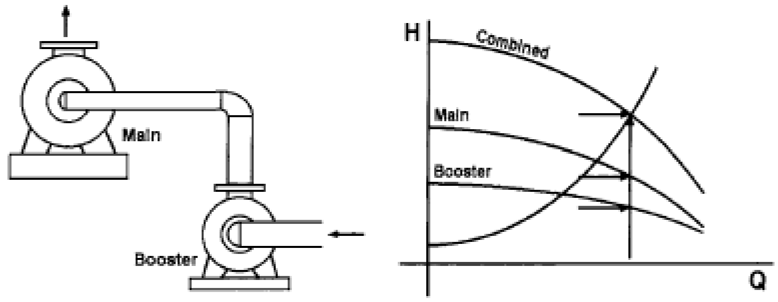


Fig.(27) Pumps in series

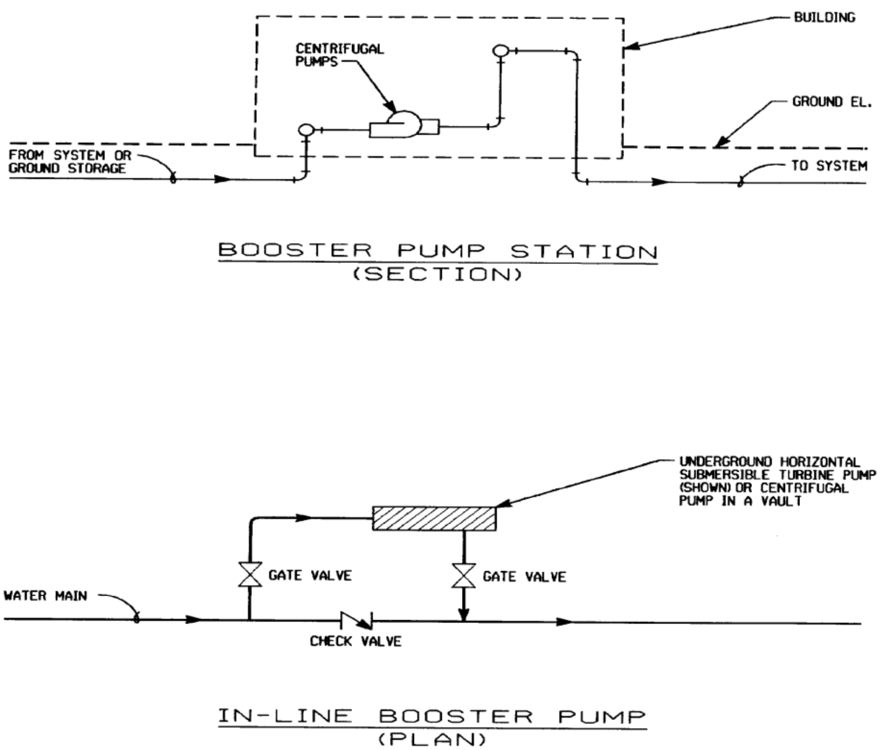


Figure 3–1. Booster Pump Stations

Fig. (28) Connection of booster pump, US DEP. OF THE ARMY [3]

Well Pumps(مضخات البئر)

<u>Shallow wells</u>

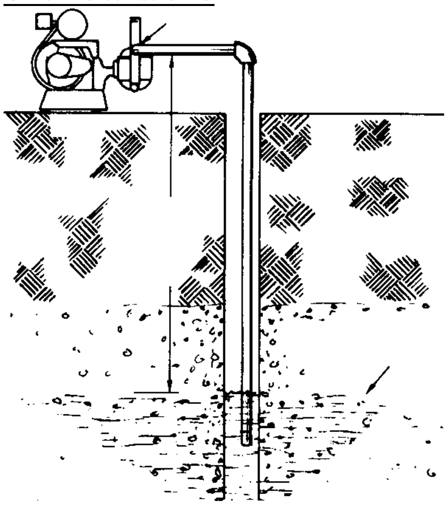


Fig.(29) Shallow-well pump installation, R. Miller, et al [4].

<u>Deep wells</u>

They use vertical turbine pumps.
Multistage diffuser centrifugal pumps:
Series of small impellers.

Multistage pump chara. Curves (Fig.30)
It is same as pumps in series.
Each stage related to impeller.
Dia. 100mm – 750mm
H up to 5,000kPa (1,500ft water)
Q up to 100m^3/min (30,000gpm)

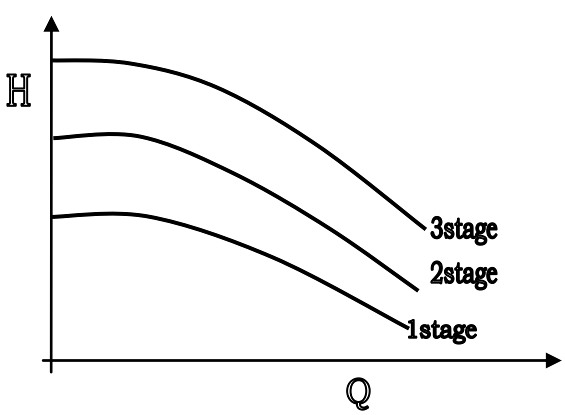


Fig.(30) Series combination of pump stages.

Power for Pumping(قدرة الضخ)

Choice of prime Mover(أختيار المحرك)
Electricity motor is used to drive pumps & there are many other movers.

Steam Engines(مكائن بخارية)
Steam engines can be used in large plants & with cheap fuel.

Steam Turbines(عنفات بخارية)
Impulse turbines are operated by the velocity of moving jet steam. They use velocity & expansive force of steam.
Combined steam turbine & centrifugal pump advantages:
Small space, light foundations, simplicity, reliability & automatic oiling.
η for turbine 64 - 74%
with reducing gears 97.5 – 99%.

Diesel Engines(مكائن ديزل)
High first cost, large space, need skilled operators, noisy in operation, cheap fuel, & gearing is necessary.

Gasoline Engines(مكائن بنزين)
High fuel cost, but low first cost, therefore can be used for standby or emergency service.
No gearing need. Wear in valves.

Electric Motors(محركات كهربائية)
Cheap, & available

Pumping Stations

Location
Central location gives pressure uniformity in distribution system.
Small city: station on one side of high use area & storage tank on the other side.
Large city: main station at central & substations or booster stations at such points.

Figs. 31, 32, & 33 show layout of pump stations.

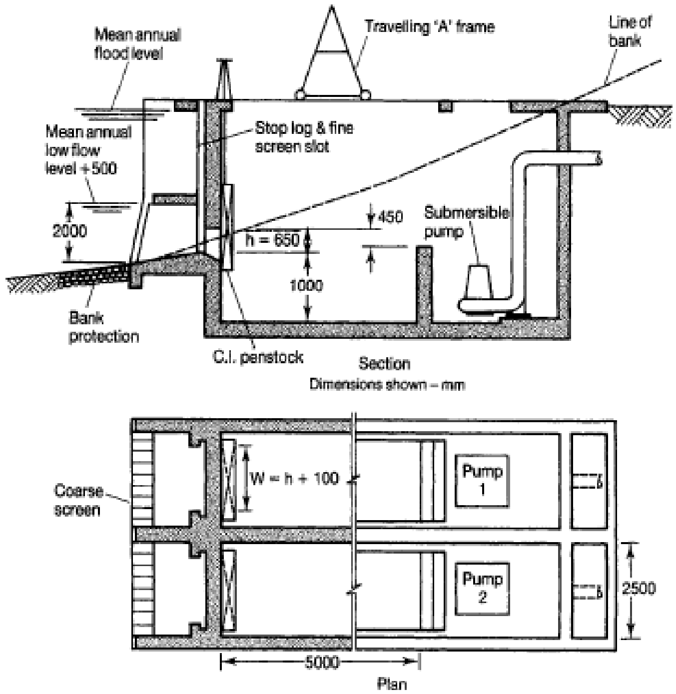


Fig.(31) River side intake

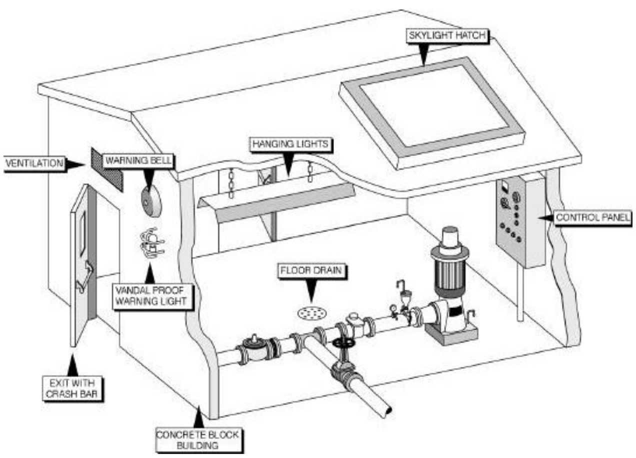


Fig.(32) Typical Pumping Station, US Army Corps of Engineers, [6]

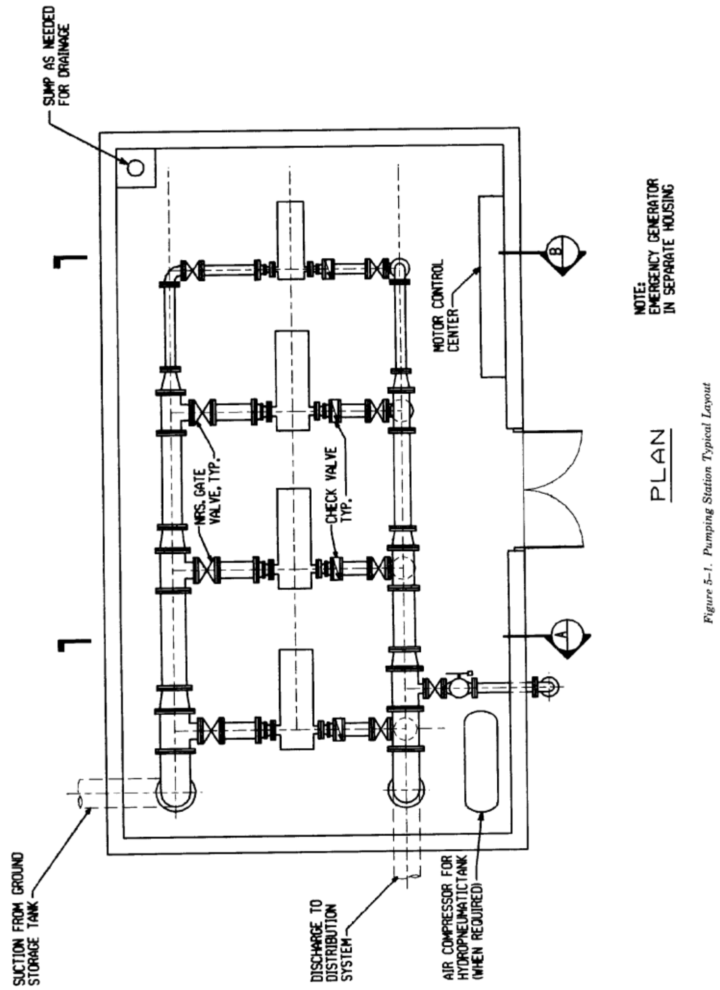


Fig.(33) Typical Pumping Station, plan, US DEP. OF THE ARMY [5]

Capacity & Operation

Operation methods:

a. Water pumped directly into the system.
   Characteristics:
   - Variation in use by turning on & turning off.
   - Interruption in service.
   - Pressure fluctuations.
   - Inefficiently & uneconomically.

b. Water pumped to a large elevated reservoir & discharged by gravity to the distributed system.
   Characteristics:
   - Uniform pumping rates.
   - Safety against interruption.
   - Little head change.

- Efficient use of pumps but cost of elevated storage.

c. Water is pumped into the system with excess into elevated tank.
   Characteristics:
   - Max. efficiency for pumps
   - Water for emergencies
   - Costly

There should be sufficient space in the station to allow repair work & space for installing additional pumps.
For proper O&M each unit should not be operated for more than 22 consecutive hours.
The station should be as close to the intake point as possible so that the length of suction pipe is short. The suction pipe should be air tight, but the water supply line has only to be water tight.

<u>Auxiliary Pumping Stations (Booster Pumps)(مضخات التقوية)</u>
Used for: 1. high ground elevation.
2. mains of inadequate size. The pump takes water from the largest main & discharges into a pipe of the problem, with excess into an elevated tank.
- This pump work automatically by;
a. A float rising & falling in the elevated tank.
b. A pressure pipe from the tank to the pump.
c. An altitude valve in discharge pipe from the tank closes when pressure reaches a certain height.
d. Electrode type of control.

Many water utilities refuse to accept in-line pumps as satisfactory for booster service & require construction of pressure equalizing storage reservoir. Horizontal & vertical booster pumps then take suction from the storage reservoir & return water at higher pressures to the mains.

<u>Valves & Piping Details</u>
- Foot valve: hold priming water in pump on suction side.
- Check valve: on discharge side; prevent backward surges.
- On outlet side of check valve a gate valve is required to permit repairs to the check valve & allow throttling centrifugal pump.
- Pressure-relief valve on discharge side of a reciprocating pump. So that stoppage will not cause damage to pump.
- Piping (suction & discharge)
  Free from bends & size with low friction head.

- Pressure gauge-gives pressure condition.
- A meter measuring output of each pump.

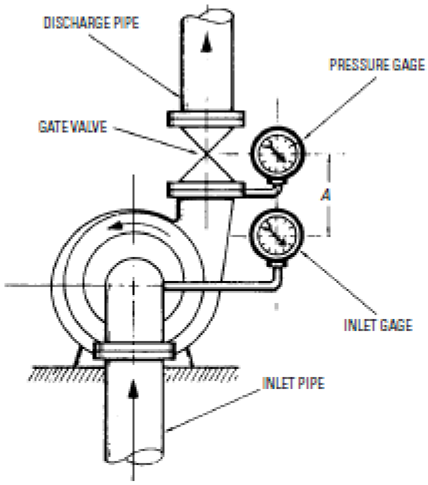


Fig.(34) Centrifugal pump, showing location of gages for taking readings to calculate total hydraulic load, R. Miller, et al. [4].

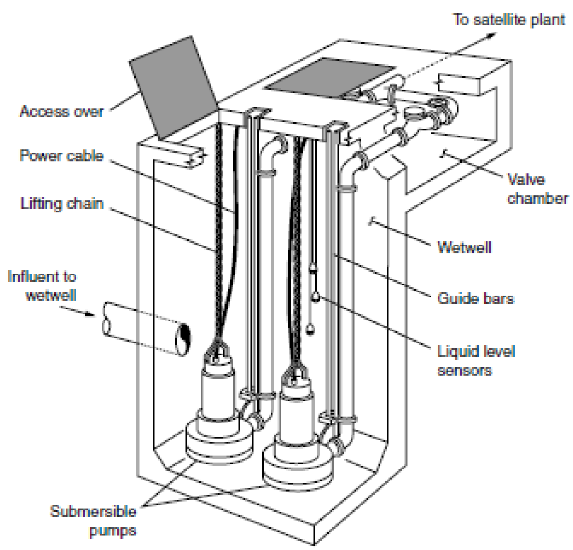


Fig.(35) Wet pit pump

Reference:

1. E.W. Steel, & T.J. McGhee, 1979,"Water Supply & Sewerage", 5th Ed., McGraw-HILL.
2. Hydraulic Institute , 1983, *"Hydraulic Institute Standards for Centrifugal, Rotary, & Reciprocating Pumps"*, 14th ed., 9 Sylvan Way, Parsippany, NJ 07054. www.pumps. Org
3. G.M. Jones (Editor-in-chief), 2006, "Pumping station design", 3rd Ed.
4. R. Miller, et al, 2004, "Pumps & Hydraulics", Wiley.
5. US DEPARTMENT OF THE ARMY, 1992, WATER SUPPLY: PUMPING STATIONS, TECHNICAL MANUAL.
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