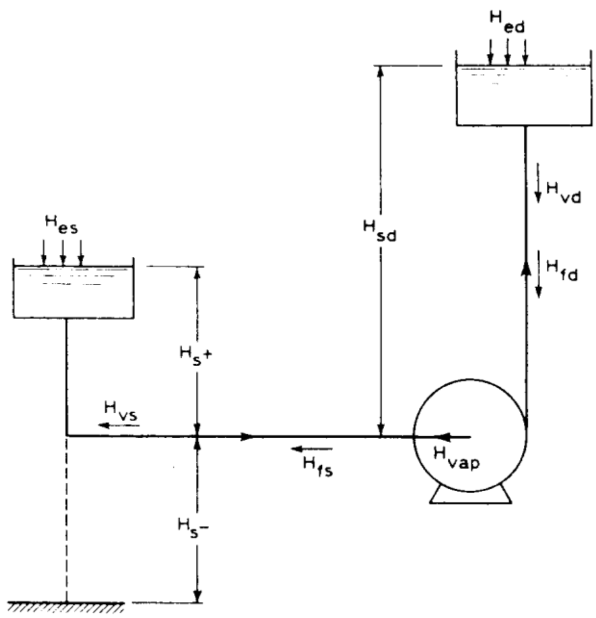
Pumps and pumping

A pump is a device which adds to the energy of a liquid or gas causing an increase in its pressure and perhaps a movement of the fluid. A simple pumping system is shown schematically in Figure3.1.
The basic system consists of a suction branch, a pump and a discharge branch.

PUMP CHARACTERISTICS



Suction conditions

The pump only adds to the energy of the system. The energy required to bring the fluid to the pump is an external one and in most practical conditions is provided by atmospheric pressure. In discussing Figure 3.1 it is assumed that the fluid being pumped is a liquid and that it is thus incompressible. The case of pumping gases is slightly more complicated and is only partially relevant to this chapter.

The diagram shows pressure head H_{es} acting on the liquid surface at the suction inlet. The vertical distance of the pump centre H_s from the surface of the liquid will affect the head available at the pump and must be added algebraically to H_{es} . If the pump is below the liquid level then H_s will be positive; if it is above the liquid level H_s will be negative. The pipe will have some frictional resistance resulting in a loss of pressure head H_{fs} . A further head loss H_v due to the velocity of the liquid will also occur but, except for very high velocities, is negligible.

Providing that the sum of these head losses－$H_v + H_{fs} \pm H_s$－ is less than H_{es}, the suction condition at the pump might be thought to be adequate . There are two further factors to take into consideration, however. There are the vapour pressure of the liquid being pumped and the amount of remaining positive suction head required at the pump suction to affect the designed delivery rate. This factor is known as the required NPSH(net positive suction head)

Every liquid has a pressure at which it will vaporise and this pressure varies with temperature. If the combination of pressure and temperature within the suction pipe is such that vaporisation occurs, the efficiency of the pump deteriorates and a condition can be reached where the pump will cease to function. The vapour pressure is thus usually shown as a suction head loss.

The summation $H_{es} \pm H_s - H_{fs} - H_{vs} - H_{vap}$ is know as the available NPSH(net positive suction head). In application to systems and neglecting the velocity head the expression becomes:

$$\text{Available NPSH} = \frac{10.2}{\rho}\left[P_{bar} + P_{es} - P_{vap}\right] - H_{fs} \pm H_s$$

Where:

$\rho =$ Density of liquid at max operating temp, Kg/litre.

$P_{bar} =$ Barometric pressure at the pump, bar.

$P_{es} =$ Minimum pressure on the free liquid level at the suction inlet (negative when under a vacuum), bar gauge

$P_{vap} =$ vapour pressure of the liquid at the maximum operating temperature, bar abs.

$H_s =$ Height of liquid free surface above centre line of pump (negative when level is below pump), m.

$H_{fs} =$ Friction head losses in suction piping system

PUMPS AND PUMPING

In application, the available NPSH must always be greater than the required NPSH. The former may be calculated knowing the details of the suction piping while the latter may be obtained from the pump manufacturer.

The significance of vapour pressure is most easily seen when considering a pump drawing from a negative suction head (usually referred to as a suction lift).

The theoretical suction lift of a pump at sea level with water at 15℃ is 1.013× 10.2 = 10.3 m, where the barometric pressure is 1.013 bar (1 atm) and 10.2 m is the head of water equivalent to 1 bar (1 bar =10^5 N/m^2 = 14.51 lb/in^2). In practice the suction lift will exceed 7 m only under very favourable conditions. This is because of friction losses in the suction pipe and because of the limitations of the pump design. Any increase in water temperature above 15℃ will have a detrimental effect on the vapour pressure; e.g. at 50℃ water will boil at an absolute pressure of 0.14 bar, so that the lift reduces to 10.2(1.013- 0.14) = 9 m, drastically reducing the available NPSH. It follows that suction lift should be as small as conditions allow and that for water temperatures above about;75℃ the suction head must be positive or if this is impossible the suction pipe must be short, straight, free from interference and the speed of flow must be low, say less than 1 m/sec.

Discharge conditions

Some of the energy fed into the pump will be dissipated as heat due to mechanical inefficiencies, the remainder will be converted into pressure rise and fluid velocity. Some of the pressure head generated will be lost in overcoming the friction of the discharge pipe H_{fd}， some in the static head of the pipe system H_{sd}, and some pressure head acting on the free surface at the terminal point H_{ed}. There will also be a velocity head loss but as in the case of the suction line, for most practical purposes this can be neglected.

Pump power

The total work done by the pump, neglecting losses within the pump itself will be proportional to the equivalent head difference between the points of suction and discharge. This is known as total head H_{tot}：

$$H_{tot} = H_{fs} + H_{fd} + H_{vap} + H_{sd} \pm H_s$$

The power absorbed by the pump, P_a，then becomes：

$$P_a = \frac{Q \times H_{tot} \times \varpi}{K}$$

where：

P_a = Power absorbed (KW)

Q = Quantity delivered in litres/s.

H_{tot}= Total head in metres.

ω = Density of liquid in gm/ml(1 for fresh water)

K = 101.9368(102)

The input power P_i to the pump required from the prime mover is

$$p_a \times \frac{1}{pumpe \quad fficiency}$$

For an electrically driven pump, the power consumed is

$$p_a \times \frac{1}{pumpe \quad fficiency} \times \frac{1}{motor \quad efficiency}(KW)$$

Where the head available is small, the suction line, passages and valves are specially designed and of large area to reduce the suction losses to a minimum. This increases the cost of the pump and installation and reduces efficiency, but is unavoidable for duties such as the extraction of condensate from a condenser where the head available
is frequently a matter of millimetres.

Generally speaking, suction heads require to be greater for high speed or large capacities than for low speed or small capacities. Condensate pumps, heater-drain pumps and feed pumps operating with direct-contact feed heaters, must be arranged below the water level as the static head of water is the only force available to cause the water to flow into the pump, because the water and the steam on the surface are at the same temperature.

Before liquid can flow into a pump, the air or vapour in the suction line must be evacuated sufficiently to cause the liquid to flow into the suction chamber.

Some pumps (known as self-priming pumps) do this automatically when they are started. In others special priming devices must be used to withdraw the air and lower the pressure in. the pump sufficiently to cause flow.

Friction losses

The sum of these losses depends upon the sectional area and the internal condition of the pipes and fittings, the velocity and viscosity of the liquid being pumped and the friction caused by bends, valves and other fittings. Frictional resistance to the flow of water varies approximately as the square of the velocity. Thus, if the frictional resistance of a condenser and system of piping is equivalent to a head of 5 m when 800 litres/s are passing, the frictional resistance would rise to 11.25 m with 1200 litres/s and to 20 m with 1600 litres/s. Table 3.1 gives the head in metres required to overcome the friction of flow in every 30 m of new straight cast-iron pipe.

The general law of frictional resistance due to the flow of water in a straight circular pipe running full of water may be expressed accurately enough for practical purposes as

$$H_m = \frac{KLV^2}{2GR} \quad \text{if} \quad R = \frac{area \quad of \quad pipe \quad bpre}{wetted \quad perimeter} = \frac{D}{4}$$

or $H_m = \dfrac{KLV^2}{2GR}$

where：

H_m=head loss(m)

L=length of pipe(m)

V=speed of flow(m/s)

D=bore of pipes(m)

G=Gravitational constant=9.81 m/s^2=9.81N/kg

To this must be added the loss due to bends each equivalent to from 3 to 6 m of straight pipe, depending upon the radius and due to fittings (Table 3.2) from which it can be seen that suction pipes, if not bell-mouthed, T-pieces and elbows give rise to the greater losses.

Example; Water flow 26.25 litres/s, static lift 20 m. The suction is through a strainer with bell-mouthed entry, a foot valve, 2 m of straight pipe 125 mm bore and a similar bend.

Suction loss(equivalent length)(Table 3.2)

Strainer	0.58 m
Foot valve	1.43 m
Straight pipe	2 m
Bend	4.27 m
	8.28 m

Table 3.1 Head loss in metres for each 30 m of straight pipe

Flow Litre/sec	Bore of pipe, mm 25	38	50	65	75	100	125	150
0.75	4.05	0.517	0.121	–	–	–	–	–
1.50	15.5	1.99	0.487	0.151	–	–	–	–
2.25	–	4.50	1.07	0.350	0.143	–	–	–
3.00	–	7.92	1.83	0.610	0.246	–	–	–
3.75	–	12.10	2.83	0.915	0.35	–	–	–
4.50	–	17.36	4.1	1.310	0.548	0.121	–	–
5.25	–	23.80	5.49	1.80	0.75	0.167	–	–
6.00	–	–	7.3	2.28	0.94	0.216	–	–
6.75	–	–	9.1	2.83	1.185	0.241	0.0884	–
7.50	–	–	11.3	3.65	1.22	0.338	0.11	0.048
9.00	–	–	15.5	5.05	2.07	0.486	0.151	0.067
10.50	–	–	21.0	6.7	2.77	0.650	0.2	0.09
12.00	–	–	–	8.84	3.65	0.840	0.265	0.121
13.50	–	–	–	10.95	4.54	1.03	0.35	0.151
15.00	–	–	–	13.70	4.90	1.295	0.41	0.181
18.75	–	–	–	21.30	8.40	1.96	0.62	0.274
22.50	–	–	–	–	12.20	2.84	0.91	0.396
26.25	–	–	–	–	16.15	3.8	1.21	0.53
30.00	–	–	–	–	–	5.37	1.58	0.7
33.75	–	–	–	–	–	6.10	1.99	0.85
37.50	–	–	–	–	–	7.6	2.42	1.03
45.00	–	–	–	–	–	10.3	3.45	1.46
52.50	–	–	–	–	–	–	4.69	1.98
60.00	–	–	–	–	–	–	5.9	2.53

Table 3.2 Loss for fittings in equivalent lengths of straight pi,'e (m)

Bore of pipe mm	*Vel. head for ordinary pipe*	*Vel. head for bell-mouthed entry*	*Bend*	*Foot valve*	*Non-re. ırn valve*	*Delivery valve full open*	*Strainer*	*Tees and elbows*
25	1.37	0.82	0.76	0.24	0.305	0.24	0.091	0.83
38	2.2	1.31	1.13	0.36	0.49	0.36	0.152	1.31
50	3.0	1.8	1.52	0.52	0.7	0.52	0.214	1.8
65	3.8	2.31	1.95	0.64	0.85	0.64	0.275	2.31
75	4.75	2.86	2.44	0.79	1.06	0.79	0.305	2.87
100	6.4	3.96	3.3	1.10	1.43	1.10	0.427	3.96
125	8.5	5.2	4.27	1.43	1.86	1.43	0.58	5.2
150	10.7	6.4	5.27	1.76	2.31	1.76	0.70	6.4

From Table3.1, the equivalent head loss is

$$\frac{1.21\times 8.28}{30}=0.33$$

Delivery loss(equivalent length)(Table 3.2)

Bell-mouthed entry	5.2 m
Delivery valve	1.43 m
Non-return valve	1.86 m
Straight pipe	15.25 m
Bend	4.27 m
	28.01 m

From Table 3.1： $\frac{1.21\times 28.01}{30}=1.13m$

Total loss is 0.33 + 1.13 = 1.46 m. Add say 25% for future roughening of surfaces, 1.46 + 0.38 = 1.84, to which must be added the static lift of 20 m or 21.84 m in all.

The figures in Tables 3.1 and 3.2 show the resulting power losses if a pipe system is complicated, tortuous and not generously dimensioned.

The pressure corresponding to 1 m of water is 0.098 bar or 98 mbar: conversely, the head corresponding to 1 bar is 10.17 m. It will be apparent that for practical purposes, these figures can be rounded to 0.1 or 100 mbar and 10 m respectively.

Drawings or prints are supplied with pumps by the manufacturers, giving sizes and particulars of flanges, positions of foundation bolts and other information necessary for the arrangements of pipe connections. These must be exactly adhered to; it is little use installing a highly efficient pump if the power is dissipated and increased by the use of unsuitable pipes and fittings, or by poor layout.