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DEFINITIONS

1.1 UNITS

The units used throughout this book are those in common use in the pumping industry and defined in AS1686-Metric Units in Water Supply, Sewerage and Drainage (including pumping) and AS2417-Pumps, The International Acceptance Test Code. In addition, these standards should be read in conjunction with AS1000 - The International System of Units (SI) and its Application.

Although it is recommended to work in SI Pump Units, there may be occasions when it is necessary to convert Imperial or Metric Units to SI Units, and tables of conversion factors are given in Section 13.

1.2 NOTATION

The most commonly used pumping terms are:

Term	Notation	Unit customary in practice
Flowrate	Q	L/s
Head	H	m
Pressure	p	kPa
NPSH	NPSH	m
Velocity	v	m/s
Density	ϱ	kg/m^3
Gravitational acceleration	g	m/s^2
Efficiency	η	—
Rotational speed	N	r/min
Area	A	m^2
Absolute viscosity	μ	mPa.s
Kinematic viscosity	ν	mm^2/s
Specific weight	γ	$kg/m^2.s^2$
Specific volume	v	m^3/kg
Specific gravity	S.G.	—

1 .3 PUMPING TERMS

Pumping:

Pumping can be described as the addition of energy to a fluid to move it along a pipe, into a pressure vessel or to a higher level, i.e. a pump moves fluid from one point to another in a system.

Flowrate:

The flowrate (Q) is the flow (volume of liquid per unit of time) delivered by a pump through the outlet, normally expressed in litres per second (L/s).

Total Dynamic Head:

Total dynamic head (sometimes called differential or generated head) is a measure of the energy imparted to the liquid by the pump, and is equal to the algebraic difference between the total discharge head and the total suction head.

Total dynamic head, where suction lift exists, is the sum of the total discharge head and total suction lift. Where positive suction head exists, total dynamic head is the total discharge head minus the total suction head (Fig. 1 .3.1 and 1 .3.2).

The total dynamic head against which a pump operates comprises:

(a) Total static head.
(b) Friction losses.
(c) Velocity head.
(d) Entrance and exit losses.

where

(a) Total static head is the difference in elevation between the liquid levels of the suction and discharge. If the pump discharges into a pressure tank, then the total static head is the difference in elevation between liquid levels plus the pressure in the tank expressed in metres of liquid.

(b) Friction head is the equivalent head, expressed in metres of liquid, necessary to overcome friction on the interior surfaces of the pipework system including all valves, bends and fittings.

(c) Velocity head of a liquid moving with a certain velocity is the equivalent static head through which it would have to fall in order to attain that velocity. Velocity head is expressed by the formula:

$$H = \frac{v^2}{2g}$$

where
H is the velocity head, m.
v is the average velocity in the pipe, m/s.
g is the gravitational acceleration, m/s^2.

(d) Entrance and exit losses are usually comparatively small and can be neglected in the majority of industrial applications.

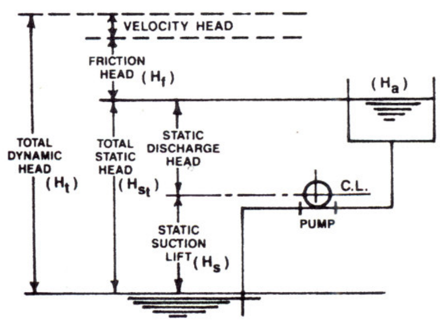


Fig. 1.3.1—Suction lift.

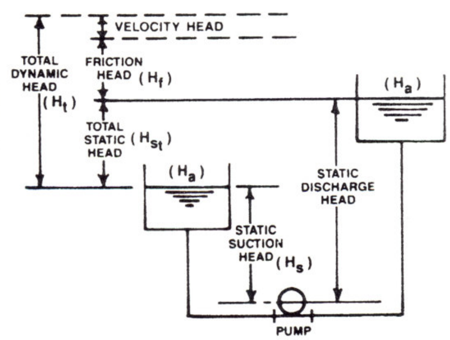


Fig. 1.3.2—Suction head.

Net Positive Suction Head (NPSH)

There are a number of factors which must be considered collectively in order to obtain a complete picture of conditions prevailing at the suction of a pump. The universally accepted practice is to express this calculation in the form of "Net Positive Suction Head" abbreviated as NPSH.

Calculation of NPSH involves consideration of fundamental fact that every liquid has a vapour pressure which is a function of the liquid and its temperature. Furthermore, if the pressure acting on a liquid is less than its vapour pressure the liquid will boil.

In any pumping system, there is always an absolute pressure available at the suction source. This pressure is reduced in the suction line due to such factors as static elevation, friction and turbulence losses, and energy expended in accelerating the liquid. Finally, there is a pressure drop within the pump itself caused by an increased velocity at the entrance to the impeller and shock losses in the impeller eye.

In order to prevent the liquid boiling, the suction pressure at the pump suction branch must be at least equal to the vapour pressure of the liquid at pumping temperature plus a margin to overcome losses in the pump. This margin of head available above the vapour pressure of the liquid is the nett positive suction head, defined as follows -

NPSH	Nett positive suction head - total head at the pump suction branch over and above the vapour pressure of the liquid being pumped.
NPSHR	NPSH required - is a function of the pump design and is the lowest value of NPSH at which the pump can be guaranteed to operate without significant cavitation. There is no absolute criterion for determining what this minimum allowable NPSH should be, but pump manufacturers normally select an arbitrary drop in total dynamic head (differential head) of 3% as the normal value for determining NPSHR.
NPSHA	NPSH available - is a function of the system in which the pump operates and is equal to the absolute pressure head on the liquid surface (H_a) plus the static liquid level above the pump centreline (negative for a suction lift) (H_s) minus the absolute liquid vapour pressure head at pumping temperature (H_{vap}) minus the suction friction head losses (H_f)

i.e. $NPSHA = H_a + H_s - H_{vap} - H_f$

Alternatively, where the suction pressure head (suction gauge reading) on site is known.

NPSHA	NPSH available at the pump inlet is equal to the absolute pressure head (H_a) plus the suction pressure head referred to pump centreline. (H_{sp}) minus the absolute liquid vapour pressure head at pumping temperature (H_{vap}) plus the suction velocity head ($v^2/2g$) i.e. $NPSHA = H_a + H_{sp} - H_{vap} + v^2/2g$

For successful operation NPSHA must be greater than NPSHR.
For sample calculations of NPSH refer Section 4.2.

Pump Suction Lift:

The concept of 'suction lift' is normally only applied to atmospheric suction systems, with an open tank or reservoir exposed to one atmosphere of pressure.

For a particular system —

Total Suction Lift (S_L) = Static difference in levels (H_a) + pipe friction loss between reservoir and pump including entry loss (H_f)
= Suction gauge reading corrected to pipe centre line (H_{SP}) and velocity head ($v^2/2g$)

Thus the maximum allowable suction lift is given by:

S_L (Max) = Atmospheric pressure - vapour pressure - NPSHR

Hence the maximum allowable suction lift depends on the local atmospheric pressure, the liquid vapour pressure and the NPSHR of the pump.
The theoretical maximum lift obtainable with an ideal pump with zero NPSHR is equal to atmospheric pressure minus vapour pressure.

Maximum Theoretical Suction Lift with Zero Pump NPSHR

(Basis: Water at 1 standard atmosphere of 1 01 .325 kPa.abs., g = 9.80 m/s)
Extracted from "APMA PIPE FRICTION HANDBOOK" 1982, APMA pp.112, 113.

Temperature	**Density**	**Vapour Pressure**	**Maximum Suction Lift**
°C	kg /m3	kPa	m
15	999.0	1.704	10.176
20	998.2	2.337	10.119
30	995.6	4.242	9.950
40	992.2	7.375	9.662
50	988.1	12.33	9.190
60	983.3	19.92	8.448
70	977.5	31.16	7.324

For systems with suction vessels at pressures other than atmospheric the NPSH should be calculated — Refer Section 4.2, Examples 5 and 6.

Density:

The density (ϱ) of a liquid is defined as the mass (kg) of that liquid per unit volume (m^3). Thus the units of density are kg/m^3.

For water at 20°C ϱ = 998.2 kg/m^3.

Specific Weight:

The specific weight (γ) is defined as the weight per unit volume and is expressed in $kg/m^2.s^2$.

Density and specific weight are related by $\gamma = \varrho.g$

For water at 20°C γ = 998.2 x 9.8

= 9782 $kg/m^2.s^2$

Specific Volume:

The specific volume $\bar{v}$ of a liquid is the reciprocal of density and is expressed in m^3/kg

$\bar{v} = 1/\varrho$

For water at 20°C $\bar{v} = \frac{1}{998.2} = 0.001\ m^3/kg$

Specific Gravity:

The specific gravity (or relative density) (S.G.) of a liquid is defined as the ratio of its density at a specified temperature to that of water at some standard temperature. Usually the temperatures are the same and 15.6°C/ 15.6°C (or rounded off to 15°C/15°C) is commonly used.

$$S.G. = \frac{\varrho \text{ (any liquid at specified temperature)}}{\varrho \text{ (water at 15.6°C)}}$$

e.g. for gasoline ϱ = 749.8 kg/m^3 @ 15.6°C

for water ϱ = 999.1 kg/m^3©15.6°C

therefore S.G. = 749.8/999.1 = 0.7505

Pressure:

Although it is preferable to express heads in metres of liquid (m) as this is independent of the temperature of the liquid being pumped, head can also be expressed as a pressure in kilopascals (kPa). However, these terms are mutually convertible one to the other as follows:

$$\frac{\text{Pressure in kPa x 1000}}{\text{Density in } kg/m^3 \text{ x g}} = \text{Head in metres}$$

E.g. 1 If the discharge gauge on a pump reads 20 kPa when pumping water at 15°C what is the discharge head in metres?

$$H = \frac{200 \times 1000}{999 \times 9.8} = 20.42 \text{ m}$$

Eg. 2 If in E.g. 1 the pumping temperature was 90°C, the density would be 965.2 kg/m^3 hence

$$H = \frac{200 \times 1000}{965.2 \times 9.8} = 21.1 \text{ m}$$

In addition for a given pump, the total dynamic head expressed in metres will remain constant at a given capacity for all fluids (except for viscous liquids). However, the pressure generated (kPa) at a given temperature will be affected by the specific gravity of the fluid pumped.

	SG	Head in m.	kPa
Water	1.0	20	195
Brine	1.2	20	235
Petrol	0.75	20	147

Pressure Terms:

The pressure terms used in discussing pumping applications may be defined as follows:

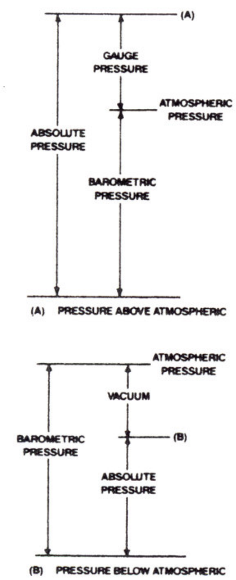
a) Absolute pressure:
Is the pressure above absolute zero, and is equal to the barometric pressure plus the gauge pressure.

b) Barometric pressure:
Is the atmospheric pressure at the altitude where it is measured.

c) Gauge pressure:
Is the pressure measured by a gauge and is the pressure above atmospheric pressure at the altitude being considered.

d) Vacuum:

Is any pressure below atmospheric, i.e. a negative gauge pressure.



Viscosity:

The viscosity of a fluid (liquid or gas) is that property which offers resistance to flow due to the existence of internal friction within the fluid. This resistance to flow, expressed as a co-efficient of dynamic (or absolute) viscosity is a measure of its tendency to resist internal deformation or shear. Molasses is a highly viscous fluid, water is comparatively much less viscous and the viscosity of gases is quite small compared to that of water.

Dynamic or absolute viscosity "μ" by definition is the ratio of shear stress to velocity gradient in the fluid. The unit of dynamic viscosity is N.s/m^2 which may be simplified to Pa.s. (Pascal-second). As this unit results in very small values of viscosity for common fluids, it is common practice to express dynamic viscosity in the unit of Centipoise (cP)

$$1 \text{ cP} = 10^{-3} \text{Pa.s} = 1 \text{ m Pa.s (millipascal-second)}$$

Kinematic viscosity "v" is defined by the ratio of dynamic viscosity to the fluid density

(i.e. $v = \mu/_{\varrho}$) and is commonly used in Reynolds number calculations.

The unit of kinematic viscosity is m^2/s which also results in very small values for common fluid. It is common practice to express kinematic viscosity in the units of Centistokes (cSt)

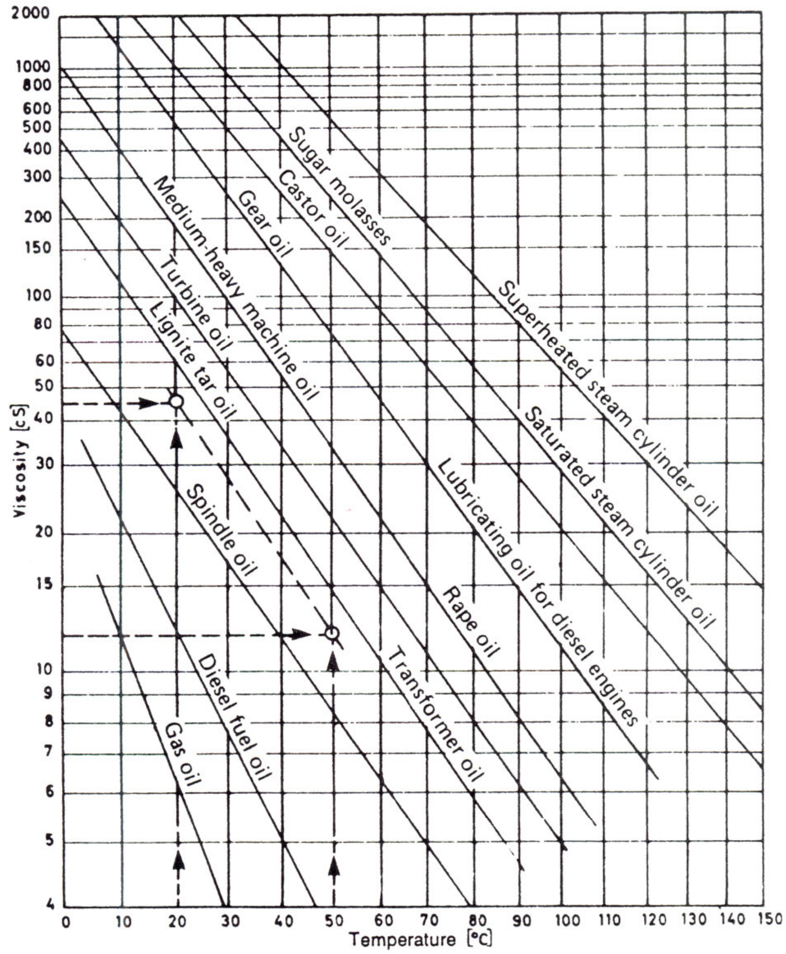
$$1cSt = 10^{-6}\ m^2/s = lmm^2/s$$

$$\text{Kinematic viscosity (cSt)} = \frac{\text{dynamic viscosity (cP)}}{\text{density (g/cm}^3\text{)}}$$

The viscosity of the fluid to be pumped should be determined for the range of operating conditions as the performance of a pump is affected by the viscosity which may change with temperature. A reduction in efficiency, increase in power, reduction in head and maximum allowable pump speed, and some reduction in capacity occurs with higher viscosities. Viscosity also affects pipe friction losses, i.e. an increase in pipe friction.

As pump performance curves are normally only available for clean cold water it is recommended that the pump manufacturer be consulted when considering viscous fluid applications.

Effects of Temperature on Viscosity:



The effects of temperature on viscosity. This chart can also be used to estimate the viscosity of other liquids when two sets of corresponding data only are known. These are plotted on the graph and joined by a straight line; the unknown value may then be simply read off. If the viscosity at only one temperature is known, this is plotted on the diagram and a straight line, usually parallel to the adjacent lines, is drawn through this point. All the viscosity-temperature relationships are approximate and do not give accurate values.

Example: Given: Oil having a viscosity of 11.8 cS at (50°C); to find: viscosity at (20°C).
Using the construction given above, the required value is found to be — 45 cS.

NOTE: Viscosity of water at 20°C = 1cS.

Fig. 1.3.4