Piped gas services

Natural gas

The piped gas provided for domestic purposes and for commercial and industrial utilization is currently supplied primarily from gas fields in the British sectors of the North Sea, with additional supplies from other fields, e.g.

Morecambe Bay.

Substitute natural gas (SNG) is manufactured as a direct substitute for natural gas and as a means of providing additional gas to meet peak loads. It can be made from a range of feed stocks in a number of different types of plant. Feed stocks commonly used are liquefied petroleum gas (LPG) and naphthas.

The properties of these gases compared with their methane content are given in Table 1.

The flow of gas In pipes

The Pole formula is used in the gas industry for determining the flow rate of gas in pipes. It is a simplification of the Darcy fluid flow formula.

The friction coefficient (f) applied in the Darcy formula is taken as a constant i.e.

f = 0.0065 for gas pipes of the diameter used for domestic supplies.

Pole Formula (SI units)

$$Q = 0.0071 \sqrt{\frac{d^5 \times h}{s \times l}}$$

where Q = flow (m^3/hr)

d = diameter of pipe (mm)

h = pressure drop (millibar)

l = length of pipe (m)

s = specific gravity of gas

Factors affecting pressure loss

By re-arranging the metric version of the Pole formula:

$$H = \frac{Q^2 \times s \times l}{D^5 (0.0071)^2}$$

It can be seen that a pressure drop of h;

varies with length $= \frac{1}{l}$

varies with quantity = Q

varies with specific gravity = s

varies with $\frac{1}{d}$ (ie. inversely as diameter)

The pipe friction is assumed to be constant and the specific gravity can also be assumed constant.

The following example is based on using 15mm copper tube to Manufacturers Reference (EN 1057-250 - 15 x 0.7mm) with an internal diameter of 13.567mm.

Example

Find Q (m^3/h) when d = 13.56mm, h = 1 mb, l = 9 m, s = 0.58

$$Q = 0.0071 \frac{\sqrt{d^5 \times h}}{s \times l}$$

$$= 0.0071 \frac{\sqrt{13.56^5 \times 1}}{0.58 \times 9}$$

$$= 0.0071 \times 296.356$$

$$= 2.104/m^3/h$$

Gas flow tables

When using Tables 2, 3, 4, 15a, 15b and 15c to solve practical problems, the pressure drop allowed for must include the losses of the measured pipe run plus an addition for fittings in the line from Table 5.

Table 1 Efficiency rating figures

Miscellaneous data	Natural gas	SNG	Methane
CV BTU/ft^3	1065.64	1000.00	995.00
CV mJ /m^3	39.70	38.00	37.00
Specific gravity	0.58	0.555	0.56
Wobbe No mJ/m^3	52.12	51.00	49.44
Air/Gas volume/volume	10.00	10.00	9.60
Flame speed	36cm/sec	36cm/sec	36cm/sec
Temp. for ignition	704°C	704°C	704°C

Table 2 Pipe sizing table *Natural gas*

Size of tube in mm			Length of tube in metres Discharge rate in m^3/h									
Wall thickness (mm)	Nominal size (mm)	I/D (mm)	3	6	9	12	15	20	25	30	40	50
0.6	6	4.76	0.266	0.188	0.154	0.133	0.119					
0.6	8	6.76	0.639	0.452	0.369	0.320	0.298	0.248	0.221	0.202	0.175	0.156
0.6	10	8.76	1.222	0.844	0.705	0.611	0.547	0.473	0.423	0.387	0.354	0.299
0.6	12	10.76	2.044	1.445	1.180	1.022	0.914	0.791	0.708	0.646	0.559	0.500
0.7	15	13.56	3.644	2.577	2.104	1.822	1.630	1.411	1.262	1.152	0.998	0.893
0.9	22	20.15	9.810	6.937	5.664	4.905	4.387	3.799	3.393	3.102	2.686	2.403
0.9	28	26.15	18.822	13.309	10.867	9.411	8.417	7.290	6.250	5.952	5.154	4.610
1.2	35	32.54	32.511	22.791	18.756	16.243	14.528	12.581	11.253	10.273	8.896	7.957
1.2	42	39.54	52.914	37.416	30.550	26.457	23.664	20.494	18.332	16.733	14.491	12.961
1.2	54	51.54	102.647	72.582	59.263	51.323	45.905	39.755	35.558	32.460	28.111	25.143
1.2	66.70	64.23	177.692	125.838	102.747	88.981	79.587	68.924	61.648	56.277	48.737	43.592
1.5	76.10	73.03	245.522	173.469	141.637	122.661	109.711	95.013	84.982	77.578	67.184	60.091
1.5	108.00	104.93	607.061	429.257	350.487	303.530	271.486	235.114	210.292	191.969	166.250	148.699
1.5	133.00	129.80	1033.166	730.559	596.499	516.583	462.046	400.143	357.899	326.716	282.944	253.073
2.0	159.00	154.80	1604.763	1134.739	926.510	802.381	717.672	621.522	555.906	507.470	439.482	393.085

(Discharge in a straight horizontal copper tube with 1.0mbar differential pressure between the ends, for gas of relative density 0.6 (air = 1) Natural gas copper tube to EN1057 - R250 Previous designation BS2871 Part 1 Table X 1971

Table 3 Pipe sizing table *Natural gas*

Size of tube in mm			Length of tube in metres Discharge rate in m³/h									
Wall thickness (mm)	N.S (mm)	I/D (mm)	3	6	9	12	15	20	25	30	40	50
2.3	8	8.70	1.201	0.849	0.693	0.600	0.537	0.465	0.416	0.379	0.329	0.294
2.3	10	12.20	2.798	1.978	1.615	1.399	1.251	1.083	0.969	0.884	0.766	0.685
2.6	15	15.90	5.425	3.836	3.132	2.712	2.426	2.101	1.879	1.715	1.485	1.329
2.6	20	21.40	11.402	8.063	6.583	5.701	5.099	4.416	3.950	3.605	3.122	2.793
3.2	25	27.00	20.388	14.417	11.771	10.194	9.118	7.896	7.062	6.447	5.583	4.994
3.2	32	35.70	40.987	28.982	26.664	20.493	18.330	15.874	14.198	12.961	11.224	10.039
3.2	40	41.60	60.078	42.481	34.686	30.039	26.867	23.268	20.811	18.998	16.453	14.716
3.6	50	52.60	108.006	76.371	62.357	54.003	48.301	41.830	37.414	34.154	29.578	26.455
3.6	65	68.20	206.749	146.194	119.366	103.374	92.461	80.073	71.620	65.379	56.620	50.643
4.0	80	80.10	309.075	218.549	178.445	154.537	138.222	119.704	107.067	97.738	84.281	75.707
4.5	100	104.30	597.990	422.843	343.250	298.995	267.429	231.600	207.150	189.101	163.766	146.477
5.0	125	128.70	1011.966	715.179	583.941	505.708	452.319	391.719	350.364	319.838	276.987	247.745
5.0	150	154.10	1586.683	1121.954	916.072	793.341	709.586	614.519	549.643	501.753	434.531	388.656

(Discharge in a straight horizontal steel pipe (to Table 2, medium, of BS 1387: 1967) with 1 .0mbar differential pressure between the ends, for gas of relative density 0.6 (air = 1))
Steel tube medium grade - BS 1387 General purpose tube to the quality Assurance requirement of (ISO 9002/BS 5750 Part 2)

Table 4 Pipe sizing table *Natural gas*

Size of tube in mm			Length of tube in metres Discharge rate in m³/h									
Wall thickness (mm)	N.S. (mm)	I/D (mm)	3	6	9	12	15	20	25	30	40	50
0.8	6	4.36	0.213	0.151	0.123	0.106	0.095	0.082	0.074	0.067	0.058	0.052
0.8	8	6.36	0.549	0.388	0.317	0.274	0.245	0.212	0.190	0.173	0.150	0.130
0.8	10	8.36	1.087	0.769	0.627	0.543	0.486	0.421	0.376	0.343	0.297	0.266
0.8	12	10.36	1.859	1.314	1.073	0.929	0.831	0.720	0.644	0.588	0.509	0.455
1.0	15	12.96	3.244	2.301	1.879	1.627	1.455	1.260	1.127	1.029	0.891	0.797
1.2	22	19.55	9.096	6.431	5.251	4.548	4.067	3.520	3.150	2.876	2.491	2.228
1.2	28	25.55	17.760	12.558	10.254	8.880	7.942	6.878	6.152	5.616	4.863	4.350
1.5	35	31.94	31.032	21.943	17.916	15.516	13.878	12.018	10.750	9.813	8.498	7.601
1.5	42	38.94	50.929	36.012	29.404	25.464	22.776	19.725	17.642	16.105	13.947	12.475
2.0	54	49.94	94.864	67.079	54.770	47.432	42.424	36.740	32.862	29.998	25.979	23.237
2.0	66.7	62.63	167.085	118.147	96.467	83.542	74.723	64.712	57.880	52.837	45.758	40.927
2.0	76.1	72.03	237.010	167.591	136.837	118.505	105.994	91.793	82.102	74.949	64.907	58.055
2.5	108.0	102.93	578.547	409.094	334.024	289.273	258.734	224.070	200.414	182.952	158.441	141.714

Copper Tube to EN 1057-R250 half hard straight lengths and EN 1057-R220 Soft Coils.
Previous designation BS 2871 Part 1 Table (Y) 1971

Table 5 Pipe sizing table

Nominal size				Approximate additional lengths to be allowed					
Cast iron or mild steel		Stainless steel or copper		Elbows		Tees		90° bends	
(mm)	(in)	(mm)	(in)	(m)	(ft)	(m)	(ft)	(m)	(ft)
Up to 25	1	Up to 28	1	0.5	2	0.5	2	0.3	1
32 to 40	$1^1/_4$ t0 $1^1/_2$	35 to 42	$1^1/_4$ to $1^1/_2$	1.0	3	1.0	3	0.3	1
50	2	54	2	1.5	5	1.5	5	0.5	2
80	3	76.1	3	2.5	8	2.5	8	1.0	3

(The effects of elbows, tees or bends inserted in a run of pipe [expressed as the approximate additional lengths to be allowed])

In the example given, h = 1 mb and l = 9m, from which pressure loss

$$\text{mb/m} = \frac{1}{9}\ 0.1111 \text{ mb/m.}$$

Referring to Table 2, it will be seen that the flow rate at this pressure loss and at the internal pipe diameter given, (d = 13.6mm) is 2.10 m^3/h agrees with the calculated result to 2dp.

Table 6 Pipe supports

Nominal size			Interval for vertical runs		Interval for horizontal runs	
Cast iron, mild steel	Stainless steel					
(mm)	(mm)	(in)	(m)	(ft)	(m)	(ft)
15	15	$^{1}/_{2}$	2.5	8	2.0	6
20	22	$^{3}/_{4}$	3.0	10	2.5	8
25	28	1	3.0	10	2.5	8
32	35	$1^{1}/_{4}$	3.0	10	2.7	9
40	42	$1^{1}/_{2}$	3.5	12	3.0	10
50	54	2	3.5	12	3.0	10
80	76.1	2	3.5	12	3.0	10
100	108	4	3.5	12	3.0	10

Maximum interval for cast iron, mild steel and stainless steel pipes

Table 7 Pipe supports

Nominal size		Interval for vertical runs		Interval for horizontal runs	
(mm)	(in)	(m)	(ft)	(m)	(ft)
Up to 15	Up to $^{1}/_{2}$	2.0	6	1.2	4
22	$^{3}/_{4}$	2.5	8	1.8	6
28	1	2.5	8	1.8	6
35	$1^{1}/_{4}$	3.0	10	2.5	8
42	$1^{1}/_{2}$	3.0	10	2.5	8
54	2	3.0	10	2.7	9
66.70	$2^{1}/_{2}$	3.5	12	3.0	10
76.1	3	3.5	12	3.0	10
108	4	3.5	12	3.0	10

Maximum interval for light gauge copper pipes

Domestic properties

Normal gas usage would be satisfied by the following meter size:

Table 8a Meter characteristics

Model type	Capacity per hour		Standard working pressure		Pressure loss at capacity		Capacity per revolution		Proving dial/circle		Meter connections
	(ft^3>	(m^3)	(psi)	(mbar)	('wg)	(mbar)	(ft^3)	(dm^3)	(ft^3)	(dm^3)	
U4/G2.5	141	4	0.7	50	<0.5	<1.22	.043	1.25	1	10	1" screwed to BS 746
U6/G4	212	6	0.7	50	<0.5	<1.22	.071	2.0	1	10	

Commercial properties

Usage will vary but the following Table would generally give a meter size to suit requirements:

Table 8b Meter characteristics

	U16		U25		U40		U65		U100		U160	
Capacity per hour	16m^3	565ft^3	25m^3	833ft^3	40m^3	1412ft^3	65m^3	2296ft^3	100m^3	353ft^3	160m^3	5650ft^3
Std. working Pressure	75mbar	1.0psi	75mbar	1.0psi	75mbar	1.0psi	75mbar	1.0psi	75mbar	1 .0psi	75mbar	1 .0psi
Mean pressure loss	1.22mbar	0.5"wg	1.62mbar	0.65'wg	1.22mbar	0.5"wg	2.36mbar	0.95"wg	1.32mbar	0.53"wg	2.91 mbar	1.17"wg
Capacity per revolution	4dm^3	0.142ft^3	10dm^3	0.353ft^3	20dm^3	0.714ft^3	25dm^3	1 .0ft^3	50dm^3	2.0ft^3	71.4dm^3	2.5ft^3
Proving circle (1 pulse =)	100dm^3	1ft^3	100dm^3	10ft^3	100dm^3	10ft^3	100dm^3	10ft^3	100dm^3	10ft^3	100dm^3	10ft^3
Standard connections	$1^{1}/_{4}$" screwed to BS746		2" screwed to BS746		2" screwed to BS746		65mm flanged BS4505.1 16/1		80mm flanged BS4505.1 16/1		100mm flanged BS4505.1 16/1	
Shipping weight	9.43kg	20.75lb	16.40kg	36lb	28kg	61.5lb	41.8kg	92lb	70kg	154lb	75kg	165lb

Standard working pressure is shown at 75mbar (1.0 psi) - meters can be supplied for higher working pressures.

Heat energy rates

The rate at which gas is used and heat produced in gas appliances may be expressed in several ways. The heat input rate can be calculated by multiplying the gas rate in m3 or ft3 by the relevant calorific value (CV). The relevant cv may vary seasonally slightly from region to region.

The current CV's are generally expressed as follows:

a. cv Btu/ft^3 = 1065.64

b. cv MJ/m^3 = 39.70

The gas discharge rate tables expressed as m3/h, can be converted to energy input rates using one or more of the listed conversion calculations from 1-8 and 9 for thermal efficiency.

It is essential however, that the heat output of appliances are kept reasonably constant and the gas quality maintained within close limits. The Wobbe number will give an indication of the heat output from burners using any of the three family gases. The Wobbe number can be derived using the following formula: -

$$\text{Wobbe No} = \frac{(\text{cv})}{(\sqrt{\text{sg}})}$$

Therefore if using natural gas with a cv of 39.70 and a sg of 0.58

$$= \frac{(39.70)}{(\sqrt{0.58})} = 52.12$$

Wobbe No = 52.12

Table 9 *Typical equipment gas consumption figures* *Natural gas*

Appliance	Gas consumption (m^3/hr)	(ft^3/hr)	(litres/sec)
45 litre boiling pan	2.5	90	0.7
90 litre boiling pan	3.4	120	0.95
135 litre boiling pan	4.3	150	1.2
180 litre boiling pan	5.0	175	1.4
1200mm hot cupboard	2.7	95	0.75
1800mm hot cupboard	3.0	110	0.85
Steaming oven	2.1 to 2.9	80 to 100	0.6 to 0.8
Double steaming oven	5.75	200	1.6
2 tier roasting oven	2.9	100	0.8
Double oven range	10.0 to 12.0	350 to 400	2.75 to 3.2
Roasting oven	1.7	60	0.47
Gas cooker	4.30	150	1.2
Hot cupboard	1.0	35	0.275
Drying cupboard	0.3	10	0.08
Gas iron heater	0.3	10	0.08
Washing machine	1.1	40	0.31
Wash boiler	1.7 to 2.9	60 to 100	0.47 to 0.8
Bunsen burner	0.15	5	0.04
Bunsen burner, full on	0.6	20	0.16
Glue kettle	0.6	20	0.16
Forge	0.85	30	0.23
Brazing hearth	1.7	60	0.47
Incinerator	0.36 to 1.2	12 to 40	0.1 to 0.32

Conversion examples

1. Btu to ft^3 $= \frac{\text{Btu}}{\text{cv}} = ft^3$

2. ft^3 to Btu $= ft^3 \times cv = $ Btu

3. m^3 to ft^3 $= m^3 \times 35.31 = ft^3$

4. m^3 to Btu $= m^3 \times ft^3 \times cv$

   $= 1m^3 \times 35.31 \times 1065.64$

   $= 37628$ Btus

5. m^3 to kW $= \frac{m^3 \times cv}{MJ/kW}$

   $= \frac{1\,m^3 \times 39.70}{3.60}$

   $= 11{,}028$kW

6. kW to m^3 $= \frac{kW \times Btu/kW}{cv \times Btu/MJ}$

   $= \frac{11.028 \times 3412}{39.70 \times 947.80}$

   $= \frac{37628}{37628} = 1m^3$

7. kW to Btu $= kW \times Btu/kW$

   $= 1kW \times 3412$

   $= 3412$ Btu

8. kW to MJ $= \frac{MJ/m^3}{kW/m3} = $MJ

   $= \frac{39.70}{11.028}$

   $= 3.60$MJ

9. Heat input rate example:

Assuming an appliance has a heat input rate of 2.5m^3/h and a calorific value of 39.70mj/m^3

Then: $= \frac{m^3\ /h \times cv}{MJ/kW}$

$= \frac{2.5 \times 39.70}{3.60}$

$= 27.57$kW/h

Or $= 27.57kW \times 3412$

$= 94069$ Btu/h

10. Thermal efficiency example:

Thermal efficiency

$= \frac{\text{heat output} \times 100}{\text{heat input}}$

Therefore a gas water heater has a gas rate of 2.5m^3/h and delivers 8 litres of water per minute raised 43°C assuming a cv = 39.70 MJ/m^3.

Heat output = 8 litres = 8kg/minute

= 8 x 60 - 480kg/h

$= 480 \times 43 \times 4.186$kJ/kg/°C

$= 86399.04$ kJ/h

$= 86.399$ MJ/h

Heat input $= 2.5m^3/h \times 39.70MJ/m^3$

$= 99.25$MJ/h

% Efficiency $= \frac{86.399 \times 100}{99.25}$

$= 87\%$

Liquefied petroleum gas installations

Introduction

Liquefied petroleum gas (LPG) is a generic term used to describe gases (predominantly C_3 and C_4 hydrocarbons) which exist as vapour at normal atmospheric temperature and pressure but which can be liquefied at only moderate pressure. When the pressure is released, the gas returns to its vapour state.

The two main liquefied petroleum gases in general use are commercial butane and commercial propane, both conforming with BS 4250. All persons involved with LPG installations should be familiar with the properties of commercial butane and commercial propane and the potential hazards involved, both for their own safety and that of others in the vicinity, including those involved in firefighting and control.

Building control and planning permission

It is essential that the local Building Control and Planning Departments are consulted at an early stage in any proposal to site LPG storage vessels, either cylinders or tanks. Planning permission is required and the Planning Department will normally consult with the Environmental Health Department,

Health and Safety Executive and Fire Brigade. If in doubt, ask - a telephone call to the local Planning Department could save considerable expense if the installation has to be changed later in order to comply with the Regulations.

Typical properties of commercial butane and propane gases, based on Appendix 1 in LPGITA Code of Practice No 1 are as Table 10 above:

Table 10 Liquid and vapour phase comparisons

	Commercial butane		Commercial propane	
Liquid phase				
Relative density (to water) of liquid at 15.6°C	0.57		0.51	
Litres/tonne	1750		1960	
Kg/litre	0.57		0.51	
Imperial gallons/ton	390		440	
Ib/imperial gallon	5.7		5.1	
Vapour phase				
Relative density (to air) at 15.6°C and 1015.9mbar	2.0		1.5	
Ratio of gas to liquid volume at 15.6°C and 1015.9mbar	240		270	
Boiling point at atmospheric pressure	-2°C		-45°C	
Vapour pressure (abs) (max)	(bar)	(psig)	(bar)	(psig)
20°C	2.5	40	9.0	130
50°C	7.0	100	19.6	283
Limits of flammability at atmospheric pressure				
(% gas in air)	1.8 to 90		2.2 to 10	
Calorific values (gross)	121,8MJ/m^3		MJ/m^3	
(net)	112.9MJ/m^3		MJ/m^3	

General properties

All personnel working with LPG should receive adequate initial and refresher training as appropriate. The notes in this Guide are not intended to cover all aspects of LPG installations but are a guide to the extent of information personnel engaged in small industrial, commercial and domestic installations would be expected to fully understand.

For reference and further information, the Codes and Standards listed at the end of this Section should be consulted. The values of the physical characteristics of the product have been 'rounded' to facilitate remembering; for exact values, refer to British Standards, LPGITA or the suppliers of the gas.

LPG is normally stored at ambient temperature as a liquid in steel vessels (or special lightweight alloy cylinders for touring caravans) under pressure. There are special applications where the liquid is stored under refrigerated conditions at a lower pressure but these applications do not normally apply to the type of projects being considered here.

The liquid is colourless and is approximately half the weight of an equivalent volume of water. If LPG is spilled on water, it will float on the surface before vaporising. The liquid occupies about 1 /250th of the volume needed if the product was stored as a gas. It is more practical therefore, to store and transport the product as a liquid under pressure than as a gas. However, a leakage of a small quantity of the liquid product can lead to large volumes of vapour/air mixtures and possible hazard.

LPG vapour is denser than air, commercial butane being about twice as heavy as air and commercial propane about one and a half times as heavy as air. Leakage of LPG will therefore flow to low points, for example, along the ground to the lowest level of the surroundings, into basements or into drains without water seals. If the air is still, any LPG vapour will disperse slowly and could be ignited a considerable distance from the original leakage, the flame travelling back to the source of leakage.

When LPG vapour is mixed with air in certain proportion, a lower flammable mixture is formed. Within the range of 2% (lower limit) to 10% (upper limit) of the vapour in air at atmospheric pressure, there is a risk of explosion. Outside this range, any mixture is either too weak or too rich to propagate flame but it is important to understand that over-rich mixtures can become diluted with air and becomes hazardous. At pressures higher than atmospheric, the upper limit of flammability is increased but the increase with pressure is not linear, e.g., doubling the pressure does not double the upper limit of flammability.

ON NO ACCOUNT SHOULD A NAKED FLAME BE USED TO DETECT A LEAK

An explosimeter, properly calibrated for LPG, must be used for testing the concentration of LPG vapour in the air. LPG vapour is slightly anaesthetic and may cause suffocation if present in sufficiently high concentrations. Extreme caution must be taken when testing for leaks and there should always be a second person stationed outside the area to supervise.

The LPG supplier should be consulted if a leak is suspected, particularly a leakage of liquid product. There is no acceptable percentage or degree of leakage with LPG.

LPG is normally odorised by the manufacture by the addition of an odorant such as ethyl mercaptan or dimethyl sulphide which give LPG its characteristic odour and enable leaks to be detected by smell at concentrations down to 0.4% of the gas in air (i.e., one- fifth of the lower limit of flammability). There are special applications where the LPG is not odorised, e.g., where the odorising material is harmful to a process or does not serve any useful purpose as a warning agent. In such applications, extra precautions and safety procedures must be taken in respect of marking storage vessels, installing pipelines externally, inspections daily, provision of automatic flammable gas detectors etc.

Vessels are never completely filled with liquid, the maximum percentage fill varying between 80-87% depending on the vessel size. The space above the liquid level allows for liquid expansion (due to temperature changes) and for a supply of compressed vapour for drawing-off by the consumer. When the pressure of the vapour in the space above the liquid falls, the liquid boils to produce more vapour and restore the pressure. The boiling point of propane is around -45°C at atmospheric pressure. The liquid takes heat (latent heat of vaporisation) from the liquid itself, the metal of the vessel in contact with the liquid and from the surrounding air. This cooling effect may cause condensation and even freezing of the water vapour in the air local to a leakage. This effect may show as a 'white frost' at the point of escape and make it easier to detect leakage. Leaks can sometimes be seen as a 'shimmering' due to the refractive index of LPG.

LPG, particularly liquid product, can cause severe frost burns (for reasons similar to those outlined in the previous paragraph) if brought into contact with the skin. Goggles, gloves and protective clothing should be worn if exposure to this hazard is likely to occur.

A vessel which has contained LPG and is 'empty' may still contain LPG in vapour form. In this state, the pressure in the vessel is approximately atmospheric and if the outlet valve is left open or is leaking, air can diffuse into the vessel forming a flammable mixture and creating a risk of explosion. Alternatively, LPG may diffuse from the vessel to the atmosphere.

LPG bulk tank location and safety distances

This section covers LPG bulk storage installations at industrial, commercial and domestic consumers' premises where the LPG is stored in a tank or tanks larger than 150 litres water capacity. For installations in refineries, bulk plants and large industrial plants, reference should be made to the publications issued by the Health and Safety Executive and the LPGITA.

Storage tanks should normally be installed above ground in the open air in a well ventilated position and should NOT be installed in basements or open pits. Tanks should not be installed one above the other. Vertical cylindrical storage tanks are commercially available and although used extensively abroad, vertical tank installations in the UK are not commonplace and are generally more expensive. However, a vertical tank may solve a problem on a restricted site but the LPG supplier should be consulted at an early stage.

Tanks may be installed underground but most LPG suppliers would prefer not to put tanks underground mainly because such installations have to be accessed for full internal visual examination and ultrasonic or hydrostatic testing every 5 years instead of every 10 years for an above ground tank. The cost of the associated attendances may make underground tank installations prohibitive.

Storage tanks should be sited and located in accordance with Table 11.Note that details for underground tanks have been omitted for clarity but details for these can be obtained from the LGPITA.

*A fire wall may be used under certain circumstances to reduce (to approximately half) the minimum separation distances shown above. For details see LPGITA publications.

The number of tanks in one group should not exceed six, subject to the maximum total capacity of a group given in Table 11. If more than one group is required, then any tank in one group should be at least 7.5 metres from any tank in another group unless a radiation wall is erected between the groups or adequate fixed water spray systems are provided.

Separation distances are intended to protect the LPG facilities from the radiation effects of fires involving other facilities as well as to minimise the risk of escaping LPG being ignited before being dispersed or diluted. The distances given are minimum recommendations and refer to the horizontal distance in plan between the nearest point on the storage tank and the nearest point of a specified feature (e.g., an adjacent storage tank, building, property line etc).

Radiation walls or adequate fixed water drenching systems may be provided to enable separation distances for above ground tanks to be reduced, but specialist advice should be obtained. If separation distances are reduced. It may be necessary to provide diversion walls or kerbs (maximum height 500 mm) to ensure that the path of leaking gas from a storage site to a specified feature is not less than that shown in Table 11.

Conventional bunds (an enclosure capable of retaining the total capacity, plus 10% margin, of all the vessels within the enclosure) around LPG storage tanks should NOT be used.

No LPG storage tank should be installed nearer than:

a. 6 metres to the bund wall of any tank containing a flammable liquid with a flash point below 32°C

b. 6 metres from any tank containing a flammable liquid with a flash point between 32°C and 65°C

c. 3 metres from the top of the bund wall of any tank containing a flammable liquid.

Table 11 Minimum recommended safety distances for LPG storage vessels Maximum water capacity

Maximum water capacity of any single tank in a group (litres)	Nominal LPG capacity (tonnes)	Maximum total water capacity of all tanks in a group (litres)	Minimum separation distance	
			From building boundary, property line (whether built or not) or fixed source of ignition* (metres)	Between tanks (metres)
150 to 500	0.05 to 0.25	1,500	2.5	1.0
>500 to 2,500	0.25 to 1.10	7,500	3.0	1.0
>2,500 to 9,000	1.10 to 4.00	27,000	7.5	1.0
>9,000 to 135,000	4.00 to 60.00	450,000	15.0	1.5

LPG storage tanks should be installed well away from tanks containing liquid oxygen or other toxic or hazardous substances (e.g., chlorine) - distances between 6 and 45 metres are not uncommon depending on the relative sizes of the vessels - but specialist advice should always be obtained.

No LPG storage tank should be installed within the bunded enclosure of a tank containing a flammable liquid, liquid oxygen or any other hazardous or cryogenic (producing low temperatures) substances. No LPG storage tank should be located in any bund where there is a permanent source of heat (e.g., steam mains) or within the bunded enclosure of a heated storage tank (e.g., fuel oil tank).

The vicinity of LPG storage tanks should be free of pits and depressions which might form gas pockets and affect the safety of the tanks. The ground beneath storage tanks should be either compacted or concreted and should be sloped to;

a. Prevent the accumulation of any liquid, including rainwater and cooling water applied under fire-fighting conditions, beneath the tanks

b. Ensure a flow of any liquid away from tanks so that other vessels or important areas are not affected.

LPG storage vessels should not be sited in locations known to be susceptible to flooding e.g., near rivers and streams which could overflow their banks during abnormal weather conditions.

To prevent tampering and possible vandalism, storage tanks should be enclosed by an industrial type fence which is at least 1.8 metres high and at a distance of not less than 1.5 metres from the LPG tanks, unless it is a boundary fence when the distances given in Table 12 will apply.

Around the immediate vessel area, fences should have at least two non-self-locking gates, not adjacent to each other and preferably at diagonally opposite corners of the fenced enclosure, opening outwards to provide easy means of exit in an emergency situation. It is preferable that the padlocks fitted to these gates should suit the master key system operated by most LPG suppliers as this can prevent problems and delays during deliveries. The gates must be unlocked when the compound is occupied.

The provision of a fence need not apply to tanks of 9,000 litres water capacity or less which are provided with a hinged, lockable cover to deny access to valves and fittings.

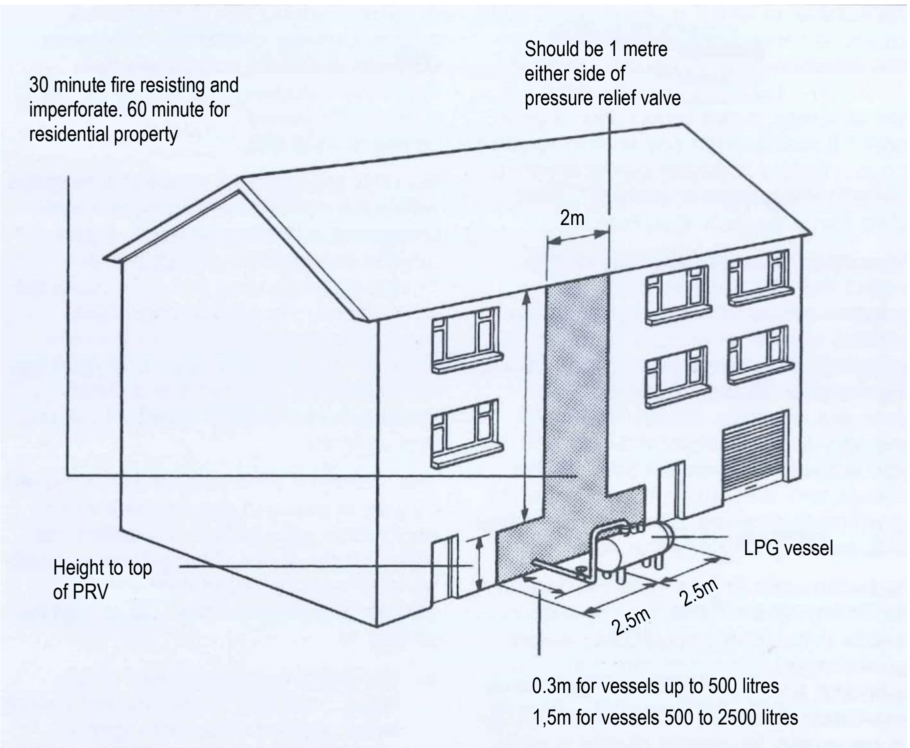


Figure 1 Small bulk vessel adjacent to building

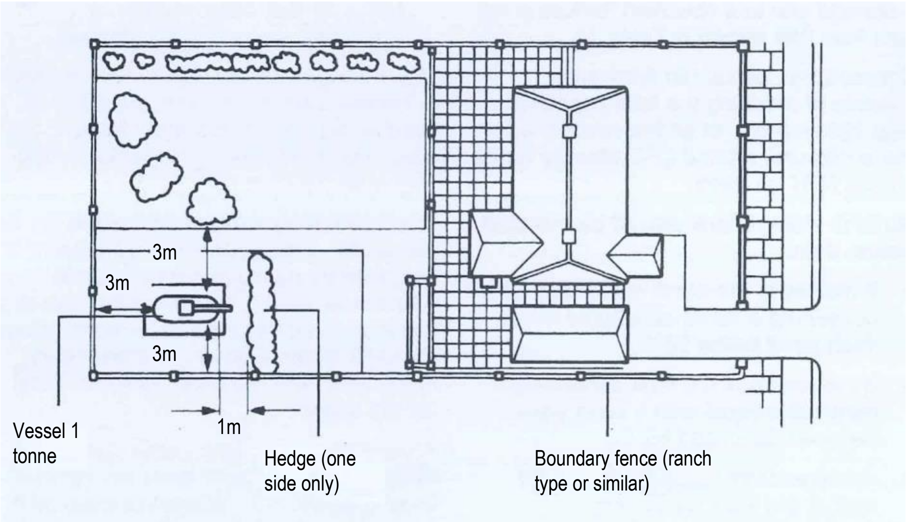


Figure 2 Small bulk vessel at domestic premises

However, should it be elected to erect a fence to prevent unauthorised interference, then the full provisions of the previous paragraph must be applied including the provision of two means of exit. Where there is surveillance at industrial premises, the site perimeter fence may suffice for security.

Where there is a possibility of mechanical damage to LPG storage and associated equipment from vehicles (e.g., in goods delivery yards, near site roads etc.), suitable protection must be provided by the use of crash barriers, vehicle impact bollards or a non- continuous wall not more than 500mm in height.

At least two NON SMOKING OR NAKED LIGHTS notices in red on white background shall be fixed to the outside of the compound surrounding wall or fence or, if these have not been provided, the notices shall be attached to the tank.

The size of the lettering shall be such that notices can be clearly read at the safety distances applicable to the installation and from points of access to the storage site.

Each storage tank shall be clearly and boldly marked:

HIGHLY FLAMMABLE - BUTANE (or PROPANE as appropriate)

Long grass, weeds and combustible material should be kept clear from an area within 3 metres of any storage tank of up to 2,250 litres of water capacity and within 6 metres of larger vessels.

Certain weed killers are a potential source of fire hazard and should not be used.

An effective earthing point and/or bonding connection should be provided at the consumer's storage site for discharging static electricity from bulk tanker vehicles prior to commencing the delivery operation. Consumer vessels greater than 2,250 litres water capacity should be electrically earthed as a protection against the accumulation of static electricity. The earthing point for the bulk tanker vehicle and the earth for the storage vessel should have electrical continuity and should be a common earth. The resistance to earth should not exceed 1 x 10^6 ohms.

Access is required for delivering and positioning the tanks. The smaller domestic tanks may be off-loaded from the delivery vehicle using the onboard vehicle crane and then man-handled into position using a tank trolley. A separate crane may be required to off-load and position larger tanks. Bulk LPG delivery tankers normally carry a 30 metre long hose which means that the tank has to be within approximately 25 metres from the road or hard standing for the tanker. Extended fill pipes are practicable but are normally used as a last resort in difficult commercial and industrial sites.

The tanker driver must be able to stand at the storage tank or filling point and be able to observe the vehicle whilst he is filling the tank. Access to the premises for a bulk tanker vehicle may be required under some site conditions. If the bulk tanker vehicle has to negotiate difficult bends or steep gradients, it is usually advisable to arrange for the LPG supplier to make a 'dummy delivery' before any work commences. Suppliers may charge more for the LPG if it is necessary to send a helper with the driver for deliveries to awkward sites.

Figure 1 shows the layout of a typical small bulk vessel adjacent to a building and Figure 2, a 1 tonne bulk vessel at domestic premises.

Storage tanks and fittings

Storage tanks are designed, fabricated and tested in accordance with British Standards, AOTC Rules and other recognised pressure vessel codes. Storage tanks are normally purchased or hired from the LPG supplier, who should assume responsibility for ensuring that the tanks, tank supports, protection against corrosion, testing and provision of tank fittings all comply with the rules and regulations.

The pressure of the vapour within a bulk storage vessel, under normal UK weather conditions, can vary between 2 and 9bar depending on the liquid product temperature. On average, the vapour pressure is about 7bar when liquid product temperature is 15°C. Safety pressure relief valves protect the vessel against excessive pressure due to exposure to heat in adjacent facilities.

A first stage regulator, mounted on the tank at the vapour off-take, reduces the varying high pressure to 0.75bar. A second stage regulator reduces the intermediate pressure of 0.75bar down to 37mbar which is the industry standard propane operating pressure for domestic appliances.

The second stage regulator incorporates safety features to protect the appliances against excessive pressure.

Tanks are sized in accordance with three main criteria:

Vapour offtake capacity

The tank must be able to boil-off liquid product faster than the vapour product is being drawn-off when all the gas appliances are operating at maximum capacity. This rate of gas production is known as the vapour offtake capacity of the tank and is a function, amongst other things, of the surface area of the tank; the larger the tank the larger the offtake capacity. It is normally quoted in cubic metres per hour (m^3/hr) or in kilograms per hour (kg/hr). Sometimes two figures are quoted; a figure for intermittent offtakes and a lower figure for continuous offtakes.

Storage capacity required

To ensure continuity and security of gas supplies under adverse weather conditions, storage should be sufficient for a minimum of six weeks gas supply at maximum use. (This allows for the tank being partially full, some of the gas being used and for three weeks adverse weather conditions in the UK when it may not be possible for delivery vehicles to get to the site). The consequences of the gas supply failing during adverse weather conditions, industrial action, etc should be considered (e.g., hospitals, old persons homes, etc) and additional storage provided if necessary.

Location for tank

Tanks must be located in accordance with the Codes of Practice and Regulations.

Each tank should be provided with at least one each of the following fittings suitable for LPG service over the range of pressures and temperatures appropriate to the operating conditions in service:

Table 12 Storage tank dimensions

Nominal LPG capacity (kg)	Water capacity (litres)	Diameter (mm)	Overall length (mm)	Approx. overall height (mm)	Continuous off-take (m^3/hr)
200	450	610	1675	900	2.26
600	1400	1000	1985	1310	5.66
1000	2250	1000	3042	1460	7.08
2000	4500	1220	4100	1685	10.19
7000	16000	1700	6782	3580*	28.30
1200	28000	2172	8600	3910*	39.62

**including platform and guard rails*

i. Pressure relief valve connected directly to the vapour space
ii. Drain or other means of removing the liquid contents
iii. A fixed maximum level device and preferably also an independent contents gauge
iv. A pressure gauge connected to the vapour space if the vessel is over 5,000 litres water capacity
v. A suitable earthing connection if the vessel is over 2,500 litres
vi. A filling connection.

It should be noted that some LPG suppliers provide a combination valve for certain sizes of tanks which includes:

i. A threaded filling connection incorporating a manual shut-off valve, a spring loaded back check valve, a relief valve to prevent pressure build up between the back check valve and the manual shut-off valve and a protective cap to prevent thread damage and ingress of foreign matter.
ii. A vapour off-take connection controlled by a diaphragm valve which can be fitted with a first stage regulator and pressure gauge.
iii. A fixed liquid level gauge incorporating a replaceable control valve.

For a detailed specification of tank fittings and piping, consult the references at the end of this section.

Figure 3 and Table 12 show typical LPG storage tank dimensions. For exact dimensions and a copy of a certified drawing, consult the LPG supplier of the tanks.

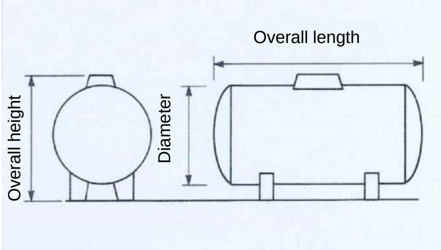


Figure 3 Storage tank dimensions

LPG storage in cylinders

The basic principles detailed in previous sections in respect of safety when handling and storing propane in tanks also apply to installations where the propane is stored in cylinders.

For permanently piped domestic installations with a low offtake rating, e.g., single cooker, two 19kg propane cylinders with a change-over regulator should be sufficient. Larger domestic and small commercial and industrial installations, with a higher offtake rating, e.g., central heating boilers and fires, Bunsen burners in laboratories etc, may require four 47kg propane cylinders. Each cylinder is fitted with a valve; the handwheel is turned anti-clockwise to open and clockwise to close. An excess pressure relief valve is also provided. The four cylinders, at the container pressure of up to 9 bar, are connected to a change-over valve by means of pigtails (see Figure 4). The change-over valve incorporates a regulator to reduce the pressure to 37 mbar for the supply to the appliances. The change-over valve connects two cylinders to the pipework system and, when these two cylinders are empty, the valve automatically changes over to the two reserve cylinders and indicates that these have been brought into use.

For indoor applications, e.g., portable domestic cabinet heaters where the cylinder is contained in or close to the unit, butane must be used.

Manufacturers of LPG may have different sizes and ranges of sizes of cylinders. Table 13 gives details of the popular sizes for a range of four propane cylinders and three butane cylinders.

Table 13 Cylinder sizes

Cylinder capacity (kg)		Overall height (mm)	Maximum diameter (mm)	Cylinder offtakes	
				Intermittent (m^3/h)	Continuous (m^3/h)
Propane	3.9	337	28	0.28	0.17
	13.0	584	318	0.57	0.28
	19.0	800	318	0.85	0.42
	47.0	1289	375	1.69	0.85
Butane	4.5	337	248	0.17	0.08
	7.0	495	256	0.21	0.10
	15.0	584	318	0.28	0.14

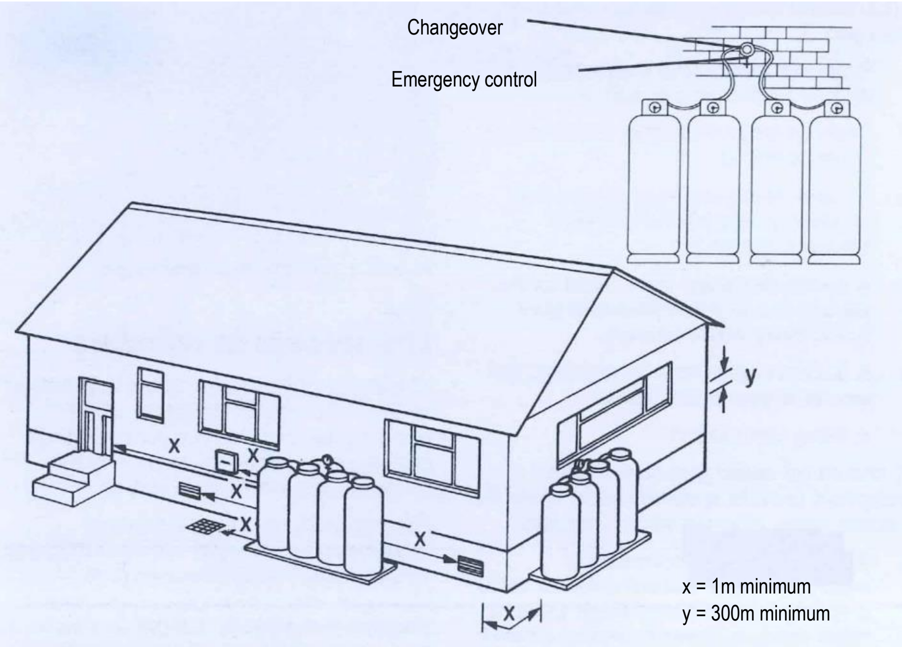


Figure 4 Cylinder storage

Pipe sizing

The industry standard operating pressure for propane is 37mbar and in order to obtain this pressure at the appliance, pipework must be of adequate diameter to pass the required rate of gas flow when all the appliances are operating at maximum output, without significant pressure drop due to friction losses.

Table 14 Guide to pipe sizes for appliances

Appliance	Metric (mm)	Imperial (in)
Central heating boilers	22	$^{3}/_{4}$
Cookers, domestic	15	$^{1}/_{2}$
Lights	6	$^{1}/_{4}$
Portable fires	10	$^{1}/_{4}$
Fixed fires	10	$^{3}/_{8}$
Water heaters		
Single-point instantaneous	10	$^{3}/_{8}$
Multi-point instantaneous	15	$^{1}/_{2}$
Bath heaters	15	$^{1}/_{2}$
Optional single or multi-point	10	$^{3}/_{8}$
Sink storage	6	$^{1}/_{4}$
Circulators	6	$^{1}/_{4}$

A pressure drop of not more than 2.5mbar between the second stage regulator and the appliance at maximum gas flow rates has been proven to give satisfactory results.

Consideration should be given when sizing main runs of pipework to future extensions and/or appliances being added to the installation.

Table 14 gives recommended sizes for short final connections to individual domestic appliances.

Tables 15a, 15b and 15c give pipe sizes and flow rates in longer runs and higher rates of flow, with a 2.5 mbar pressure drop. These tables should be used to determine the diameter of the main run.

Copper pipe to EN 1057 R250 with capillary and compression fittings to EN 1254 Parts 1-5 are suitable for LPG.

Galvanised screwed steel pipe, medium weight, to BS 1387: 1987 with screwed fittings to BS 143:1968 are also suitable for LPG installations. PTFE tape or a jointing compound specifically made for LPG must only be used. General purpose jointing materials with hemp are not suitable for LPG. Existing joints on pipework being converted to LPG must be examined and if made with general purpose jointing materials and hemp, must be dismantled and remade or the pipework scrapped.

Polyethylene may be used for underground pipework but the manufacturer’s instructions for jointing must be followed. Polyethylene must not be exposed to strong sunlight during transit and pending installation.

Underground pipework must be a minimum of 500mm below finished ground level. Trenches should be dug deeper than 500mm and all stones should be removed from the bottom of the excavation before backfilling and compacting the bottom 75mm of the trench with sifted material. The pipework should be supported with sifted material and a warning tape should be laid 150mm above the pipework to prevent possible damage during future excavations. All backfill should be carefully selected to remove all stones which could cause damage to the pipework due to settlement and compaction. Pipework should be protected if installed in corrosive soil conditions.

Pipework installations must be pressure tested and proved to be leak-free before connecting to the tank(s) or cylinder(s).

When installing Polythene pipework to convey gas it is recommended that advice from the pipe manufacturer is sought because there could be a variance between the internal dimensions (ID) and various manufacturers.

Table 15a *Steel tube medium grade - BS1387* *LP gas*

Size of tube in mm			Length of tube in metres Discharge rate in m^3/h									
Wall thickness	**NS (mm)**	**ID (mm)**	**3**	**6**	**9**	**12**	**15**	**20**	**25**	**30**	**40**	**50**
2.3	8	8.70	1.181	0.835	0.682	0.590	0.528	0.457	0.409	0.373	0.323	0.289
2.3	10	12.20	2.751	1.945	1.588	1.375	1.230	1.065	0.953	0.870	0.753	0.673
2.6	15	15.90	5.334	3.772	3.080	2.667	2.385	2.066	1.848	1.686	1.460	1.306
2.6	20	21.40	11.211	7.927	6.472	5.605	5.013	4.342	3.883	3.545	3.070	2.746
3.2	25	27.00	20.046	14.174	11.573	10.023	8.964	7.763	6.944	6.339	5.489	4.910
3.2	32	35.70	40.298	28.495	23.266	20.149	18.022	15.607	13.959	12.743	11.036	9.871

General purpose tube to the Quality Assurance requirements of ISQ9002/BS5750 Part 2

Table 15b *Copper tube to EN1057-R250* *LP gas*

Size of tube in mm			Length of tube in metres Discharge rate in m^3/h									
Wall thickness	**NS (mm)**	**ID (mm)**	**3**	**6**	**9**	**12**	**15**	**20**	**25**	**30**	**40**	**50**
0.60	6	4.76	0.261	0.184	0.151	0.130	0.116	0.101	0.090	0.082	0.071	0.064
0.60	8	6.76	0.628	0.444	0.363	0.314	0.281	0.243	0.217	0.198	0.172	0.154
0.60	10	8.76	1.201	0.849	0.693	0.600	0.537	0.465	0.416	0.380	0.329	0.294
0.60	12	10.76	2.009	1.421	1.160	1.00	0.898	0.778	0.696	0.635	0.550	0.492
0.70	15	13.56	3.583	2.533	2.068	1.791	1.602	1.387	1.241	1.133	0.981	0.877
0.90	22	20.15	9.645	6.820	5.568	4.822	4.313	3.735	3.341	3.050	2.641	2.362
0.90	28	26.15	18.505	13.085	10.684	9.252	8.275	7.167	6.410	5.851	5.067	4.532

Previous designation BS2871 Part 1 Table X 1971

Table 15c *Copper tube to EN1057-R250 half hard straights* *LP gas*

Size of tube in mm			Length of tube in metres Discharge rate in m^3/h									
Wall thickness	**NS (mm)**	**ID (mm)**	**3**	**6**	**9**	**12**	**15**	**20**	**25**	**30**	**40**	**50**
0.8	6	4.36	0.210	0.148	0.121	0.105	0.093	0.081	0.072	0.066	0.057	0.051
0.8	8	6.36	0.539	0.381	0.311	0.269	0.241	0.209	0.187	0.170	0.147	0.132
0.8	10	8.36	1.069	0.756	0.617	0.534	0.478	0.414	0.370	0.338	0.292	0.261
0.8	12	10.36	1.828	1.292	1.055	0.914	0.817	0.708	0.633	0.578	0.500	0.447
1.0	15	12.96	3.199	2.262	1.847	1.599	1.431	1.239	1.108	1.011	0.876	0.783
1.2	22	19.55	8.943	6.232	5.163	4.471	3.999	3.465	3.097	2.828	2.449	2.190
1.2	28	25.55	17.462	12.347	10.081	8.731	7.809	6.763	6.049	5.522	4.782	4.277

Copper tube to EN1057-R220 soft coils. Previous designation BS2871 Part 1 Table Y 1971

The discharge rate for any manufacturers pipe can be ascertained when applying the specific internal diameter using poles formula as shown earlier at the front of this section.

Compressed air

Compressing the air

There are many different types of machines for compressing air- reciprocating, rotary-vane, screw and turbine compressors. This section will cover reciprocating and rotary vane compressors only; turbine types are normally used only where extremely large quantities of compressed air are needed, often at relatively low pressures, and are outside the scope of the normal industrial installation.

The reciprocating compressor may have one or several stages. The rotary-vane compressor consists of a rotor, having blades free to slide in radial slots, rotating off centre in a cylindrical chamber.

Rotation causes the blades to be thrown out by centrifugal force and to sweep the compression chamber. A small amount of oil is admitted to the chamber to seal and lubricate the blades and to act as an internal coolant. Again, there may be one or more stages.

The screw compressor is a rotary positive displacement machine in which two intermeshing rotors each in helical configuration, displace and compress the air. Available in lubricated and non-lubricated (oil-free) construction, the discharge air is normally free from pulsation. The machine has a high rotation speed, and is available in single or twin stages.

There is no hard and fast rule about the choice of single or multi-stage compressors.

Table 16 Final temperature (°C) of adiabatic compression from free air at 1.013 bar at 20°C (SI metric units)

Gauge pressure (bar)	Single stage (°C)	Two stage (°C)
3	164	85
4	192	97
5	218	106
6	240	116
8	278	129
10	310	141
14	365	160

Table 17 Effect of altitude on compressor volumetric efficiency (SI metric units)

Altitude	Barometer pressure	Percentage relative volumetric efficiency compared with sea level	
(m)	(mbar)	(4 bar)	(7 bar)
Sea level	1013	100.0	100.0
500	945	98.7	97.7
1000	894	97.0	95.2
1500	840	95.5	92.7
2000	780	93.9	88.0
2500	737	92.1	87.0

Table 18 Cooling tank capacities

Compressor capacity (dm^3/h free air)	Tank capacity (litres)	Compressor capacity (cfm free air)	Tank capacity (gallons)
10	170	25	40
25	370	50	80
50	700	100	150
70	1020	150	225
100	1600	200	360
140	2200	300	480
200	3000	450	700
280	3800	600	850
350	4500	800	1000

A multi-stage machine will use less power to compress a given quantity of air, the power required being appreciably less as the pressure rises. But a multi-stage compressor can be more costly to purchase and so there must be an economic balance between the initial cost and the running cost.

It is therefore usual to find that for simplicity and low initial cost, single stage compressors are used for small duties and pressures up to about 7bar (1 00psi), whereas for pressures above this and for higher duties, compressors having two or more stages are used.

There is also considerable difference in the air temperature leaving a single or two stage compressor as Table 16 will show. The sizing of compressors is outside the scope of this Guide, but there are a number of points which should not be forgotten when sizing and choosing a compressor. One of these points covers the effect of altitude on the volumetric efficiency of the compressor, as shown in Table 17. Other aspects which should be considered include the following:

a. Future expansion requirements
b. Maximum and minimum pressures required in the system
c. Type of cooling required
d. Type of compressor
e. Running cost
f. Initial cost
g. Space
h. Type of control to meet anticipated plant requirement
i. Protection devices.

Compressor cooling

Because of the temperature rise which takes place when air is compressed, some form of cooling is required so that the temperature is not too high for satisfactory lubrication and to avoid excessively high thermal stresses in the machine structure. Cooling may be either by air or water.

Nowadays, air cooled compressors may have capacities up to 350dm3/s (750cfm), or be rated on continuous duty up to 14 bar (200psi). Air cooled cylinders are finned and additional cooling is provided by arranging for the flywheel or a fan to direct a stream of air onto the cylinder. Such compressors should not be run in a confined space, otherwise the high ambient temperature will prevent adequate air cooling.

A common method of compressor cooling is of course, to provide a water jacket. There are a number of ways in which such a jacket could be supplied with cooling water. It should however be remembered that, although the colder the water the more effective the inter or after cooler, cold water fed to the compressor jackets can be harmful. This is because it can cause water vapour in the compressed air to condense to the detriment of cylinder lubrication and also lead to possible corrosion.

Thermo-syphon circulation

Thermo-syphon circulation is satisfactory for small single-stage compressors and relies on convection to circulate the water which is heated by the compressor. The water circulates from the compressor jacket to a holding tank where the heat is lost. It is essential that the flow and return pipes have a fall from the tank to the compressor to ensure good circulation. Even a horizontal pipe will reduce the flow rate and may induce air locks. Preferably, the tank should be placed in the open-air and the top should be open to provide maximum cooling effect; however, adequate protection of the tank from birds etc must be ensured.

A tank having a large water surface area loses heat more quickly than a tall narrow tank. The drawback of such a tank is that it is liable to freeze if the compressor is shut down in cold weather. A stop valve should therefore be fitted in the cold water make-up line and on the tank outlet so that the compressor cooling jacket can be drained. To avoid draining an overnight shutdown, it is a good idea to fit a small electric immersion heater in the tank.

Pump assisted circulation

For larger single stage compressors, thermo-syphon circulation is too slow to dissipate the heat and a circulating pump must be installed to increase water velocity. The required water tank capacity should be discussed with the compressor manufacturer, but where information is not available, Table 18 can be used as a rough guide for compressors running at up to 7 bar (1 00psi).

Closed cycle cooling

It is usually better, particularly with larger compressors, to operate them on a closed circuit, the heat being dissipated either through a cooling tower or through a mechanical cooler.

A further advantage is that a closed circuit can eliminate jacket scaling, particularly if the water is treated. The use of the closed circuit does not mean that temperature control is unimportant. With the closed circuit, it is usually preferable to use a ‘three-way temperature control’. It is also important to remember that in severe winter conditions, it is not uncommon for cooling towers to freeze solid. Should this be the case, the compressor must be shut down.

Freezing of the sump in the cooling tower may be prevented by fitting a heating coil. To prevent the tower becoming a solid mass of ice, the line from the diversion control valve should be so valued that it can return the water from the compressor direct to the sump instead of to the top of the tower in such low temperature conditions. Under these circumstances, sufficient cooling can usually be maintained due to heat losses from the sump itself.

A mechanical cooler, where the cascade of water is cooled by forced or induced air draught, is much smaller than the cooling tower and the elements are almost totally enclosed offering less risk of freezing when shut down. However, any ice which does form will usually melt within seconds of the compressor starting up.

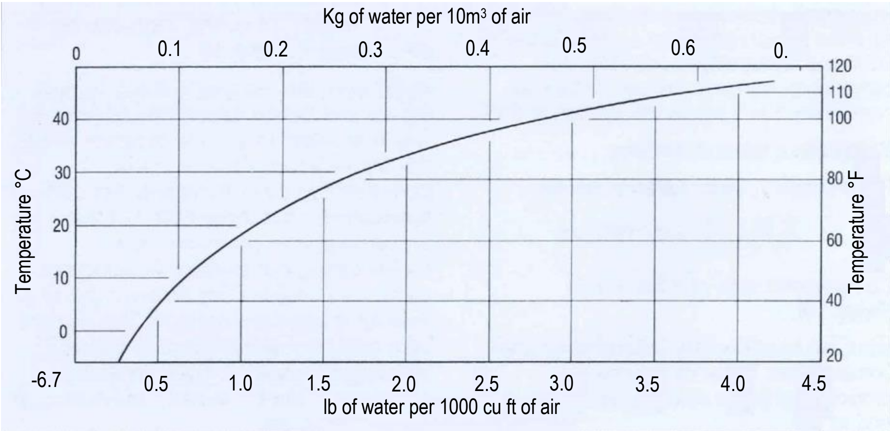
Rotary compressors

Where the compressor is of the rotary- vane or oil lubricated screw type it should be noted that oil is usually injected into the compression chamber to form a seal between the blades and the casing and to act as an internal coolant. The oil is removed from the air by a separator at the discharge and is then passed back to the sump by way of a water cooled heat exchanger.

Cooling the air

The whole purpose of the compressed air installation is to deliver air to the point of use in the best possible condition - clean, dry and with the minimum loss of pressure. If it fails on any one of these counts, then there is likely to be increased wear on tools, poor performance particularly of items such as paint spray equipment, and the operating costs will inevitably be higher than they ought to be.

***Graph 1** Moisture content of air (100% RH)*



Removing moisture

Atmospheric air always contains a proportion of water vapour, the amount depending on the relative humidity. In Britain, this may be between 50 and 70% (RH), this being highest in foggy or rainy weather or if the inlet of the compressor is adjacent or over a pond, stream or other damp area. It is important to note this latter point when installing compressors.

The amount of water which can be held by a given volume of air will depend on its temperature. The moisture carrying capacity of air increases with a rise in temperature, and at this stage, possibly of greater importance, it decreases with a fall in temperature (see Graph 1). Its moisture carrying capacity also falls as the pressure is increased. So, when ‘free air’ containing water vapour under average conditions enters the compressor, two things will happen. Its ability to hold the water will decrease as the air is compressed to a smaller volume but will increase because of the higher temperature resulting from the compression. Under average conditions, the air will leave the compressor, just able to carry its initial water content.

It will follow that any cooling which then takes place must cause the air to shed its excess water vapour by condensing and this can be accelerated by introducing artificial cooling devices such as intercoolers and aftercoolers.

Although it is customary to lag steam mains to retain heat, it is a potentially bad practice to lag the compressed air main between the compressor and the first major cooling plant (i.e., aftercooler or receiver). If the pipework is lagged, the nigh discharge temperature of the Compressed air may be sufficient to spontaneously ignite the deposits of oil, dirt, scale etc. commonly found in this first section of pipe. Once the air has cooled to near ambient temperature, this danger will not arise.

An intercooler is fitted between the stages of a multi-stage compressor; its purpose is to cool the air between the stages and in cooling the air, it also serves the very useful purpose of condensing out the surplus water vapour which, if allowed to pass to the next compression stage, could condense on the cylinder wall with resultant damage to the compressor.

It is essential that the water is drained away from the intercooler and this can best be done automatically using one of the range of compressed air traps. An aftercooler should be fitted immediately following the compressor so as to remove as much water as possible before the air reaches the receiver.

The water must be drained from the bottom of the aftercooler, and this is best done automatically. Manual drains will work only if they are attended to regularly. Rarely, if ever, is this possible, and an automatic drain trap is the best way of ensuring that the system operates properly.

The most efficient aftercoolers are usually water cooled and the lower the air temperature they can produce, the better. However, there is a point of maximum efficiency so, for reasons of economy, where mains water is used, it is well worth fitting a temperature control to the water outlet to keep consumption within reasonable bounds.

For those areas where cooling water is either not available or is too expensive, the air blast aftercooler becomes the first choice. Ambient air is blown by an electric motor fan over a bank of finned tubes, through which the compressed air flows. Although the compressed air discharge temperature is likely to be on average, approximately 6°C (10°F) higher than for a water cooled aftercooler, the unit will still require automatic drainage by a trap.

Example (SI metric units)

How much moisture will separate out from air if the compressor inlet conditions are 20°C and 70% relative humidity; the compressor delivers $1m^3$/sec of free air compressed to 7 bar to the system at 25°C.

Compressor takes in $1m^3$/sec

From Graph 1, water taken in will be:

$$\frac{0.18x70}{10x100} = 0.0126\text{kg/s}$$

Compression ratio at 7 bar = 7.91 (Table 19).

Next, we must find the volume of air after compression. Since its volume is proportional to the absolute temperature and to

$$\frac{1}{\text{compression ratio x } 1\text{m}^3}$$

will occupy:

$$\frac{1}{7.91} \text{ x } \frac{(273+25)}{(273+20)} = 0.128\text{m}^3$$

From the graph, $10m^3$ of air at 250°C can carry 0.24 kg of water

Therefore, 0.128 m^3 can carry:

$$0.128 \text{ x } \frac{0.24}{10} = 0.00307 \text{ kg}$$

Therefore, the amount of water which will separate out is:

0.0126 - 0.00307 = 0.00953kg/s

Receivers

Important as aftercoolers are, it would be very unusual for all the water vapour in the air to condense at this point. Further cooling almost always takes place in the receiver as well as from the distribution system. The water vapour, (and oil mist, if the compressor is of the lubricated type) condenses in the receiver and collects at the bottom. On those installations where the compression plant is small, an aftercooler may not be fitted, thus making the receiver the point at which most condensed liquid will be found. If these liquids are allowed to build up, carry-over into the mains system is likely. There is also the possibility of corrosion of the receiver itself.

It is therefore, important to ensure that these collected liquids and solids (atmospheric dust, pipe scale, carbon, rust etc.) are automatically removed as they collect. As the trap and its protective strainer will have to handle varying proportions of water, oil, emulsion, dirt, etc., regular cleaning is essential.

If excessive amounts of oil are being carried over from the compressor, it generally indicates that maintenance of the compressor is required.

If a manual drain cock is fitted to the receiver a short distance above the drain trap outlet, oil and scum floating on the water surface (which might foul up the trap) can be periodically drained off.

Apart from the receiver's ability to cool the air and hence deposit liquid (that is why it is better to site the receiver where the ambient temperature is low), it performs two other functions. For some applications, it is important that the pressure pulses produced by a reciprocating compressor be eliminated as far as possible. The receiver therefore acts as a pulsation damper. The receiver also acts as a power storage vessel, allowing intermittent high demands for compressed air to be met from a smaller compression set.

Being a pressure vessel and thus subject to regular inspection, a receiver is fitted with inspection covers and manholes. These also allow any solid contaminant build-up to be removed. To comply with Factory and Safety Acts, a receiver must be fitted with an adequately sized safety valve and generally a pressure gauge is also fitted.

On small horizontal receivers generally supplied with the smaller industrial or garage type compressor, automatic drainage may be more difficult. The drain point is often in the centre of the dished end of the receiver or on the top. In each case, an internal dip pipe is fitted to allow the air pressure to displace the collected liquid when the manual drain is opened. An automatic trap can be used.

It is also worthwhile considering the capacity of the receiver. This is usually sized on the actual output in 1 minute from the compressor, but where consumption is high and fairly constant, the air is in the receiver for too short a time to cool down very much. Where this is so, the storage capacity is obviously low and it is better to size the receiver on plant consumption rather than on compression output.

One compressor manufacturer recommends the following as a guide to receiver size:

Receiver capacity (m^3)

$$= \frac{\text{m}^3 \text{ of free air required}}{\text{Allowable pressure drop (bar)}}$$

and also;

Receiver capacity (cu ft)

$$= \frac{\text{cu ft of free air required x 14.7psi}}{\text{Allowable pressure drop (psi)}}$$

Example 1

A machine requires $3m^3$; available pressure is 7 bar and the minimum suitable pressure is 5.5 bar.

By using the formula to determine the receiver capacity;

$$\frac{3}{1.5} = 2\text{m}^3$$

Example 2

A machine requires 100 cu ft; available pressure is 10Opsi and the minimum suitable pressure is 80psi.

By using the formula to determine the receiver capacity;

$$\frac{100x14.7}{20} = 73.5 \text{ cu ft}$$

Layout

Although in an ideal system, all cooling and condensing should be carried out before the air leaves the receiver, this is not very often achieved in practice. It is in fact impossible where aftercoolers are not fitted. The whole of the compressed air mains therefore become additional cooling surfaces, the amount of condensing which takes place depending on the efficiency of moisture extraction before the air leaves the receiver and the temperature in the mains system itself.

It is useless to provide a compressed air gun to blow out particles of swarf after a machining operation if, every time the operator used the gun, he squirts water all over the finished job. Equally, it can be very expensive to pass this water through compressed air operated tools.

Care must therefore be taken in the layout of the mains so that adequate fall is given to proper drainage points.

The general layout of the building will dictate the best positions for drain points but in general, the main should be given a fall of not less than 1 m in 100m in the direction of air flow and the distance between draining points should not exceed 30m (100ft).

It is a good idea to form a distribution system as a ring main to help reduce pressure losses. It also makes the alteration of extension of the existing system easier. Drainage points should be provided by using equal tees and it assists in the separation of the water if these are arranged to change the direction of the flow as shown in Figure 5. Whenever a branch line is taken off the main, it should leave the top of it, so that any water in the main doesn't fall straight into the plant and the bottom of the falling pipe should be drained as in Figure 5.

Separators

Whilst automatic drain traps will effectively deal with any water which has collected at the bottom of the main or in a receiver of some kind, they can do nothing for the mist of water droplets which may be suspended in the air. For most everyday applications, much of this water can be removed by fitting a separator in the distribution mains as Figure 5.

When a separator is fitted in a ring main system, install it to allow for the normal direction of flow.

Dryers

There are applications where the air must not only be clean, but have a reduced dew point. This may call for more sophisticated and expensive methods to lower the dew point of the compressed air. There are three common systems used for this purpose.

Adsorption dryers

These consist of two pressure vessels filled with water adsorbing chemical. Wet compressed air is passed through one chamber until the chemical is saturated. Whilst this first chamber is being regenerated by heat and/or a purge of the ultra-dry air, the second chamber is adsorbing moisture. An automatic control system alternates the chambers, one operation, one regeneration.

Absorption dryers

These consist of a container of chemical through which compressed air passes. The chemical absorbs the water vapour, forming a solution which drains to the bottom of the container. This solution has to be discharged periodically by a drain trap, and the level of the desiccant then requires topping up. A domestic salt cellar is typical of this type.

Refrigerant or chiller dryers

These units are heat exchangers which will cool the air down to a theoretical dew point of 1 to 3°C (34 to 37°F) and thus precipitate out the moisture. The system is a straight mechanical refrigeration unit with one extra facility included. This is a second heat exchanger whereby the outgoing cold, dry air is used to pre-cool the incoming compressed air supply. In doing so, the outgoing cold air is warmed up to around ambient temperature.

All these units incur running costs of a kind, whether it be compressed air for purging, steam or electrical power to reactivate chemicals, or the replacement of desiccant.

Main pressure reduction

It is often necessary to reduce the mains pressure when supplying groups of plant or complete workshops. This requires a pressure reducing valve having quite a large capacity and very good flow characteristics. This unit is somewhat different from the small regulators used for individual items of plant.

Sizing compressed air mains

The compressed air mains are the all-important link between the compressor and the point of usage. It is thoroughly bad to install mains which are too small and cause high pressure drop. If for example, a compressor has to work at 8bar (120 psi) to cater for pressure drop conditions whereas 7bar (100 psi) would normally meet the case, it calls for an additional power input of as much as 10%.

Mains which are too small also cause high velocity, making it difficult to separate the water from the air because much of the condensed vapour running as a stream of water along the bottom of the pipe, will be whipped up by and carried along with the fast moving air stream. Whilst a watchful eye must be kept on the pressure drop, it is common practice to size compressed air mains on velocity and a reasonable figure for all practical problems is 6-9m/s (20-30ft/sec) which is sufficiently low to prevent excessive pressure drop on most systems and will allow moisture to precipitate out without re-entrainment.

Many compressed air systems are working inefficiently because the demand has outgrown the supply - new pneumatic plant has been added from time to time without addition to the compressor plant or mains.

In designing a new plant, some thought might be given to possible future demands and allowances made in the mains sizes. Sizing by velocity presents an easy form of determining pipe size for a given duty, but it must be remembered that the duty of a compressor and the demand of the equipment is usually expressed in dm3/s of free air and that when compressed, the volume will be less.

Table 19 shows that the ratio of compression and the actual volume occupied at any given pressure can be found by dividing the volume of free air by the ration of compression.

Example 1 (SI metric units)

At a gauge pressure of 8bar, Table 16 shows the ratio of compression as 8.9 so if we have 190dm3 of free air compressed to 8bar it will occupy a space of:

$$\frac{190}{8.9} = 21.35 \text{ dm}^3$$

By adding the equivalent lengths to the actual length of pipe, the loss in each section of a system can be easily found by reference to the Table 20.

***Graph 2** Compressed air sizing nomogram*

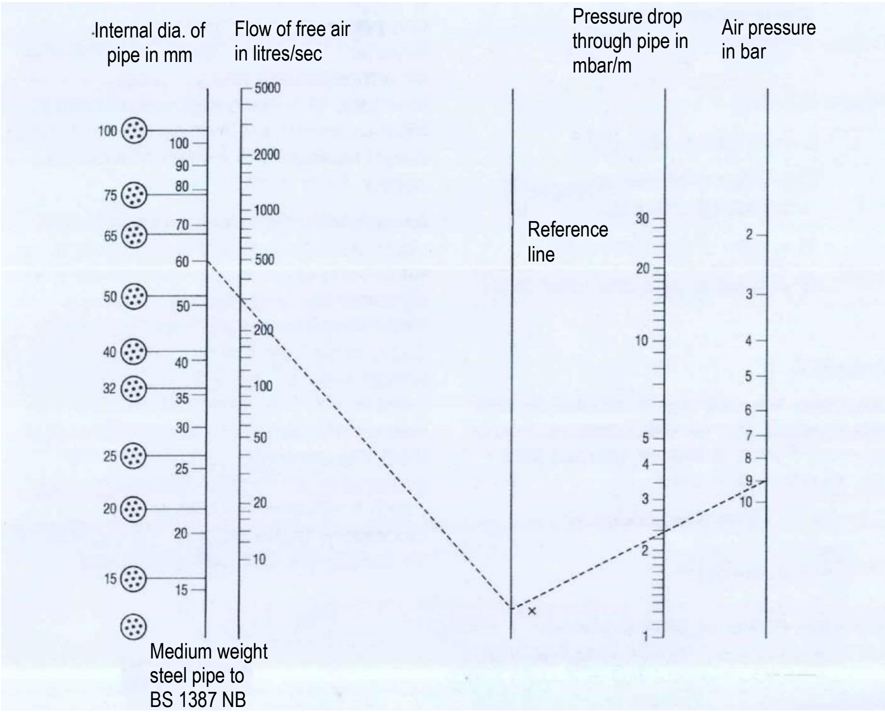


Table 19 Ratio of compression (metric units)

Gauge pressure (bar)	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**12**	**14**	**18**
Ratio of compression	1.5	1.99	2.97	3.96	4.95	5.94	6.92	7.91	8.9	10.87	12.85	14.82	18.77

Table 20 Resistance of pipe fittings (equivalent length in m)

Type of fitting	**Nominal size (mm)**									
	15	**20**	**25**	**32**	**40**	**50**	**65**	**75**	**100**	**125**
Elbow	0.26	0.37	0.49	0.67	0.76	1.07	1.37	1.83	2.44	3.2
90° bend (long)	0.15	0.18	0.24	0.38	0.46	0.61	0.76	0.91	1.2	1.52
Return bend	0.46	0.61	0.76	1.07	1.2	1.68	1.98	2.6	3.66	4.88
Globe valve	0.76	1.07	1.37	1.98	2.44	3.36	3.96	5.18	7.32	9.45
Gate valve	0.107	0.14	0.18	0.27	0.32	0.40	0.49	0.64	0.91	1.20
Run of standard tee	0.12	0.18	0.24	0.38	0.40	0.52	0.67	0.85	1.2	1.52
Through side outlet of tee	0.52	0.70	0.91	1.37	1.58	2.14	2.74	3.66	4.88	6.4

Table 21 Formula for converting volume of compressed air to volume of free air

Air tools are usually rated in cfm of free air. Where ratings of other air equipment are not given in terms of free air consumption, the following formulae may be used to convert.

$q=q_1\frac{P+1.033}{1.033}$	$Q=Q_1\frac{Q1+(P+101325}{101325}$	$Q=Q_1\frac{Q1+(P+14.7}{14.7}$
q = Litres free air	Q = Cubic metres free air	Q = Cubic ft of free air
q_1 = Litres compressed air	Q_1 = Cubic metres compressed air	Q_1 = Cubic ft of compressed air
p_1 = Compressed air pressure in kg/cm^2	P_1 = Compressed air pressure in Newtons/metre^2	P_1 = Compressed air pressure psig

Weight and volume of pure air. Pure air at 32°F (0°C) and 14.7psi (101,325Kn/m^2 absolute (atmospheric pressure). Weight 0.08073 lb/ft^2 (1.29g/litre). Volume 12.381ft^2/lb (772 litres/kg).

The nomogram shown in Graph 2 gives a ready means for determining pressure drops through pipes often found in industry. It is based on the following formula which can also be used for pipe sizes outside those shown in the table.

Pressure drop (bar) = $\frac{KL\,Q^2}{R \times d^{5.3}}$

Where K = 800

L = length of pipe (m)

Q = volume of free air passing through the pipe (l/sec)

R = ratio of compression

d = internal pipe diameter (mm)

Example 2

Determine the size of pipe needed to pass 300 litres /sec free air with pressure drop of not more than 300mbar in 125m of pipe run, air pressure is 9bar.

300mbar in 125m is equivalent to

$\frac{300}{125}$ = 2.4mbar/m

Join 9 bar on the air pressure line to 2.4mbar/m on the pressure drop line and produce to cut reference line at X. Join X to 300 litres/sec and produce to cut pipe size line at approximately 61mm.

Select pipe having a minimum bore of at least 61mm (a 65mm nominal bore pipe to BS 1387 has a bore of 69mm and would therefore be suitable with some margin).

Table 25 shows the amount of water which will accumulate every 8 hours in a compressed air system using 47 litres/sec of compressed air at different air temperatures and air pressure. For example, at 5.4bar, with a temperature of 32.2°C (90°F), a compressed air system would contain 7.419 litres of water in vapour form every 8 hours.

Ascertainment of peak capacities for compressed air systems is largely a matter of judgement. It is necessary to consider the probable use factors, determined by the devices requiring compressed air, the estimated number of people who will be drawing air from the system and the pattern of air use, with special attention paid to periods of high load. For example, compressed air demand in a two-man laboratory may reach 9 litres/sec of free air per laboratory, depending on the number of air outlets ($^1/_8$ inch orifices) in use.

Graph 3 Compressed air - laboratories

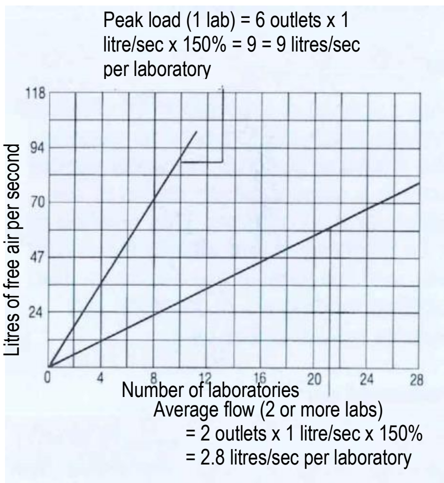


Table 22 *Relative discharging capabilities of steel tubes to BS 1387*

Nominal dia. of larger pipe		Nominal diameter of smaller pipe in in. and mm														
		1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	5	6	(in)
		3	8	10	15	20	25	32	40	50	65	75	100	125	150	(mm)
(in)	(mm)	Approximate number of small pipe flows served by larger pipe														
1/8	6	1	-	-	-	-	-	-	-	-	-	-	-	-	-	
1/4	8	2.1	1	-	-	-	-	-	-	-	-	-	-	-	-	
3/8	10	4.5	2.1	1	-	-	-	-	-	-	-	-	-	-	-	
1/2	15	8	3.8	1.8	1	-	-	-	-	-	-	-	-	-	-	
3/4	20	15	8	3.6	2	1	-	-	-	-	-	-	-	-	-	
1	25	30	15	6.6	3.7	1.8	1	-	-	-	-	-	-	-	-	
1 1/4	32	60	25	13	7	3.6	2	1	-	-	-	-	-	-	-	
1 1/2	40	90	40	20	10	5.5	2.9	1.5	1	-	-	-	-	-	-	
2	50	165	75	35	20	10	5.5	2.7	1.9	1	-	-	-	-	-	
2 1/2	65	255	120	55	30	16	8	4.3	2.9	1.6	1	-	-	-	-	
3	75	440	210	100	55	27	15	7	5	2.7	1.7	1	-	-	-	
4	100	870	400	190	100	55	30	15	10	5.3	3.4	2	1	-	-	
5	125	1500	720	330	180	90	50	25	17	9	6	3.5	1.8	1	-	
6	150	2400	1130	530	300	150	80	40	28	15	9	5.5	2.8	1.6	1	

Table 23 *Discharge of air through orifices*

Gauge pressure	Discharge of free air in litres/sec for various orifice diameters in m						
(bar)	0.5	1	2	3	4	10	12.5
0.5	0.06	0.22	0.92	2.1	5.7	22.8	35.5
1.0	0.08	0.33	1.33	3.0	8.4	33.6	52.6
2.5	0.14	0.58	2.33	5.5	14.6	58.6	91.4
5.0	0.25	0.97	3.92	8.8	24.4	97.5	152.0
7.0	0.33	1.31	5.19	11.6	32.5	129.0	202.0

Table 24 *Receivers for compressed air systems*

Compressor capacity		Receiver dimensions					
		Diameter		Length		Volume	
ft³/min	m³/min	(in)	(m)	(ft)	(m)	(ft³m)	(m³)
45	1.27	14	0.355	4	1.22	4.5	0.127
110	3.12	13	0.33	6	1.83	11	0.312
190	5.38	24	0.61	6	1.83	19	0.538
340	9.63	30	0.76	7	2.13	34	0.963
570	16.14	36	0.91	8	2.44	57	1.614
960	27.19	42	1.07	10	3.05	96	2.719
2115	59.90	48	1.22	12	3.66	151	4.276
3120	88.36	54	1.37	14	4.27	223	6.315
4400	124.61	60	1.52	16	4.88	314	8.892
6000	169.92	66	1.68	18	5.48	428	12.121

Table 25 *Vapour chart*

Temperature of air		Compressed air pressure in bars (litres of water)											
°C	°F												
		2	2.7	3.4	4	4.8	5.4	6	6.8	7.5	8.2	8.8	10
0	32	2.176	1.635	1.362	1.060	0.946	0.871	0.795	0.681	0.643	0.530	0.492	0.454
4.4	40	2.839	2.271	1.892	1.628	1.438	1.249	1.136	1.098	0.984	0.908	0.871	0.795
10	50	4.353	3.369	2.877	2.460	2.082	1/817	1.628	1.514	1.400	1.287	1.211	1.098
15.6	60	5.980	4.883	4.050	3.520	3.104	2.687	2.385	2.082	1.779	1.703	1.628	1.514
21.1	70	8.213	6.548	5.678	4.921	4.353	3.899	3.558	3.255	2.914	2.725	2.612	2.157
26.7	80	10.977	9.046	7.570	6.737	5.980	5.413	4.807	4.353	3.899	3.709	3.482	3.066
32.2	90	15.524	12.415	10.447	9.160	8.176	7.419	6.548	5.980	5.450	5.110	4.769	4.164
38.2	100	20.174	16.768	14.156	12.188	10.901	9.765	8. 706	8.176	7.570	6.964	6.548	5.905
43.3	110	26.495	21.764	18.547	16.086	14.194	12.642	11.431	10.447	9.841	8.993	8.251	7.381
48.2	120	35.958	28.198	24.792	20.893	18.433	15.540	15.216	13.929	12.642	11.961	11.128	9.803

Table 26 Volume of compressed air carried by medium grade steel pipes, of minimum bore, to BS 1387 at given velocities

Velocity	Flow of air (litres/sec) through medium grade steel pipe to BS 1387, minimum bore											
M/s	15mm	20mm	25mm	32mm	40mm	50mm	65mm	75mm	100mm	125mm	150mm	200mm
3.0	0.6	1.1	1.7	3.0	4.1	6.5	10.9	15.1	25.7	39.2	56.2	98.5
3.5	0.7	1.3	2.0	3.5	4.7	7.6	12.7	17.6	30.0	45.7	65.5	115.0
4.0	0.8	1.4	2.3	4.0	5.4	8.7	14.6	20.1	34.2	52,3	74.9	131.0
4.5	0.9	1.6	2.6	4.5	6.1	9.8	16.4	22.6	38.5	58.8	84.2	147.0
5.0	1.0	1.8	2.8	5.0	6.8	10.8	18.2	25.1	42.8	65.4	93.6	164.0
5.5	1.1	2.0	3.1	5.5	7.4	11.9	20.0	27.6	47.1	71.9	103.0	181.0
6.0	1.2	2.1	3.4	6.0	8.1	13.0	21.8	30.1	51.3	78.5	112.0	197.0
6.5	1.3	2.3	3.7	6.5	8.8	14.1	23.7	32.6	55.6	85.0	122.0	213.0
7.0	1.4	2.5	4.0	7.0	9.5	15.1	25.5	35.1	59.9	91.5	131.0	230.0
7.5	1.5	2.7	4.3	7.5	10.1	16.2	27.3	37.6	64.2	98.0	140.0	246.0
8.0	1.6	2.8	4.5	8.0	10.8	17.3	29.1	40.1	68.5	105.0	150.0	263.0
8.5	1.7	3.0	4.8	8.5	11.5	18.4	31.0	42.6	72.8	111.0	159.0	278.0
9.0	1.8	3.2	5.1	9.0	12.2	19.5	32.8	45.1	77.1	118.0	169.0	296.0

Table 27 Equivalent volume of compressed air at common pressure

Volume free	Equivalent volume (litres) when compared to gauge pressures of		
(litres)	4 bar	5 bar	7 bar
5	1.01	0.84	0.63
10	2.02	1.68	1.26
15	3.03	2.52	1.90
20	4.04	3.37	2.53
25	5.05	4.21	3.16
30	6.06	5.05	3.79
35	7.07	5.89	4.42
40	8.08	6.73	5.06
50	10.1	8.42	6.32
60	12.1	10.1	7.58
70	14.1	11.8	8.85
80	16.2	13.5	10.1
90	18.2	15.1	11.4
100	20.2	16.8	15.8
125	25.2	21.0	15.8
150	30.3	25.2	19.0
175	35.3	29.5	22.1
200	40.4	33.7	25.2
225	45.4	37.9	28.4
250	50.5	42.1	31.6
275	55.5	46.3	34.8
300	60.6	50.5	37.9
350	70.7	58.9	44.2
400	80.8	67.3	50.6
500	101.0	84.2	63.2
750	151.0	126.0	95.0
1000	202.0	168.0	126.0
1250	252.0	210.0	158.0

Table 28 Typical equipment consumption of compressed air

Appliance	Consumption free air (litres/sec)	Gauge pressure (bar)
Air motors per kW	16-22	-
Contractors' tools, breakers, diggers, etc.	2-35	5.5
Controls, typical	0.005-0.01	1.0
Laboratories, bench outlets	5-15	1.5-5.5
Workshop tools, blast clearers, small	10-13	6.5
Workshop tools, blast clearers, large	100-110	6.5
Percussive, light	2-8	5.5
Percussive, heavy	10-15	5.5
Rotary (e.g., drills, etc.)	2-15	3.5-5.0
Spray guns	0.5-10	2-5

Vacuum

There are three elementary questions that are always asked in connection with this subject; what is it, what is it used for and by whom?

In layman's terms, it can be described as a piped distribution system from a prime mover (this generally takes the form of an electrically operated vacuum pump), terminating in a number of outlet points which give facilities for obtaining a vacuum or negative pressure service. Hospital personnel also refer to this type of service as the medical suction system.

The uses for such a service are vast and varied. There is the simple school laboratory system where students carry out elementary filtrations under reduced pressure to speed up the filtration time cycle. On the other hand, we have the complex research and industrial systems whereby a vacuum of better than 10 torr is required. In between these two extremes, there is the complete medical field for ward suction, operating theatre, dentistry and x-ray bolus. Most hospitals also have a separate laboratory system for pathology and pharmacy work.

This section does not cover in detail, the rather specialized high vacuum systems (below 1 torr) which for reasons such as outgassing of line material and vapour pressure problems, form the subject of more specialized publications. It is written with the object of familiarising the plumbing engineer with the basic facts relating to the design and installation of a piped vacuum system. It is also important that the consultant who is asked to plan initially what is loosely termed a vacuum system, should know exactly what the client is going to use the system for, and it must firstly be determined what degree of vacuum is expected at the outlet points. This in itself is sometimes difficult to establish (very often because the user himself does not know), and is complicated further because vacuum can be identified in inches of mercury, millimetres of mercury or water gauge, and we also have the international term, torr (which for the purposes of this Guide, is equivalent to the millimetre of mercury).

Vacuum specialist firms always measure the degree of vacuum with atmosphere at 30in or 760 torr, and ultimate vacuum as 0, whereas the engineer thinks of vacuum in reverse, whereby atmospheric pressure is 0 and the ultimate is 760 torr or 30 inches of mercury.

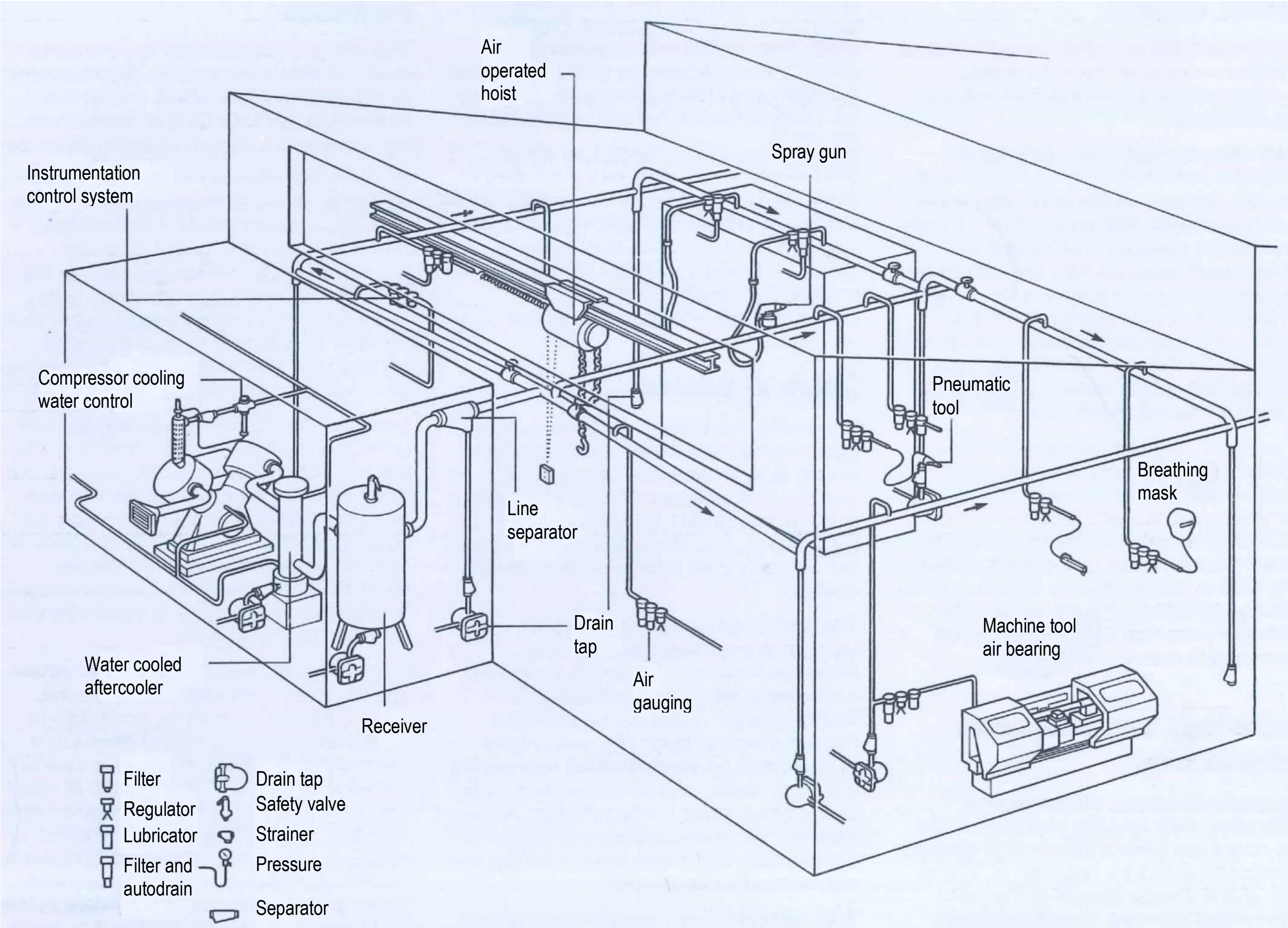


***Figure 5** Typical layout of a compressed air plant*

Also, manufacturers of vacuum gauges produce scales calibrated in both ways.

This guide therefore uses 0 as ultimate and 30in or 760 torr as atmosphere for the remainder of this summary.

The hospital system

Apart from the scientific and industrial fields, the main usage of vacuum is in the medical and medical research field which covers five main areas:

a. Ward suction

b. Theatre suction

c. X-ray bolus

d. Dental suction

e. Pathology and pharmacy laboratories.

As any hospital engineer will confirm, the provision of an efficient central vacuum system will cut his maintenance work considerably.

Ward suction

The free air displacement required at the bedside outlet varies of course, depending on the type of ward being served. For instance, in the respiratory ward, suction is required for quick removal of sputum etc, from the throat, and is not generally in use for long periods, whereas in the post-thoracotomy wards, the suction may be required for long periods of continuous duty. Therefore the outlet displacements can be anything from 1 litre per minute to an estimated maximum of 40 litres per minute (free air) at approximately 250 torr.

Theatre suction

The free air displaced in the theatre is naturally much higher than for general ward usage, and it is quite possible for the surgeon and anaesthetist to require suction to be available at up to 80 litres per minute in the theatre at any one time, and also at a pressure of 250 torr.

X-ray bolus

This is a technique using the suction system to evacuate bags filled with granules that are placed in position around the limb to be X-rayed, and on applying the suction, it is found that the limb will be held firmly in the pre-set position. The free air displaced here is quite small once the initial evacuation has taken place, and the degree of vacuum need not exceed 150 torr.

Dental suction

The usage here is mainly one of removal of saliva and water, the latter being sprayed on to the dentist's drill and the site of drilling.

There are at present two techniques used, the first involves a high degree of vacuum (30 torr) at low flows and known as the aspiration technique. This has one main disadvantage which is that the suction tube must be held very close to the tissues of the mouth in order to 'pick up' the fluid accumulating within the mouth, and sometimes these tissues can block the suction orifice and can both damage the mouth tissues and stop the water from being drawn away.

The second method, known as the high flow technique, employs suction at a great velocity, of the order of 50m/s, but the degree of vacuum required is only about 700 torr maximum. The 'pick up' bridge between fluid and sucker orifice in this case is approximately 12mm, and no damage to mouth tissues occurs. It is therefore essential to establish which technique is being employed.

Pathology and pharmacy laboratories

Generally speaking, the pathology laboratory user and the pharmacist are the only case where a fairly high degree of vacuum would be required i.e., 10-15 torr, and it should always be borne in mind when planning hospital systems, that the medical suction system should never be interconnected to the laboratory system.

The former requires a fairly high flow at relatively moderate suction pressure, i.e., rarely better than 125 torr, whereas the latter requires a low flow rate at a relatively high degree of vacuum (10-15 torr). There is also the fear that bacteria from laboratory experiments could find their way to patients if the systems were linked.

When considering a pipeline installation to serve these types of area, especially ward and theatre suction and X-ray bolus, it must be borne in mind as a rough guide that to remove 1 litre of liquid rapidly will require a free air displacement at atmosphere of approximately 4 litres per minute.

The modern trend of providing an efficient suction system for ward and theatre usage is to have what is known as a twin standby pumping set. This generally consists of two prime movers interconnected to a common reservoir with all necessary cycling and safety gear, which enables the second pump to operate if either the first pump fails or cannot maintain the pipeline system within the predetermined pressure, in which case, both pumps will operate until the vacuum in the system builds-up, and the two pumps will cut out in sequence.

Facilities are also provided by most manufacturers for alternating the duty pump. There is no reason why a series of pumps cannot be interconnected in this way and linked in pairs to pressure switches to enable further capacity to be provided as and when the new extensions are added to the system.

Siting of pumps

Preferably, the central vacuum pipeline pumping equipment should be grouped in one area to save the hospital engineer and his staff precious time in maintaining hospital equipment at various points in the building, and the actual positioning of the vacuum units is important on three counts.

The first is the noise factor. Not all vacuum pumps are silent, so it is imperative that any noise or vibration is not transferred to areas where such inconvenience could not be tolerated. Noise carried through the walls of the pipeline can be eliminated by interposing a simple rubber sleeve connection close to the prime mover. Alternatively, vacuum bellows with demountable vacuum union connections are sometimes used but are naturally more expensive.

The second is the case of maintenance. The pumps will need to be positioned for accessibility of servicing and running of water cooling lines if necessary.

Thirdly, the exhaust of gasses and perhaps equally important, the pump exhaust system. This should be run conveniently direct to atmosphere but away from windows, fresh air intake or any area where ignition would be possible should flammable vapours be discharged. It must be remembered that any rising exhaust line must be trapped to avoid condensates from running down into the pumping gear and more important, to prevent a back pressure.

The length of the exhaust line must be related to the bore of the exhaust pipe; for example, it may be quite permissible to run a 15mm bore exhaust line direct to atmosphere at low level through an exterior wall, but if the exhaust could only be piped to atmosphere via the roof at say 13m high, then the bore of pipe could easily be increased to 42mm bore or greater. One answer to this problem is to site the problem gear on the top floor, but this is only possible if weight of pumps and availability of running services permit.

Pipelines

The actual pipelines that are provided must be designed to allow displacement of the required flow of air, and at the same time, be leak-tight at better than the ultimate vacuum required by the user.

For very low pressure or rough suction systems, i.e., in the order of 450 torr, it is quite possible to obtain a satisfactory result by using gas-barrel tube with threaded fittings suitably sealed on the threads, but this material will be quite unsuitable for systems where better than 200 torr is required. One of the most reliable and well-tried materials is copper tube with capillary fittings.

Some of the modern materials such as uPVC pipe and stainless steel tube are also quite suitable for most systems, but one has to be careful that the vapours and condensates pumped over are not solvents of the line material, and they will only be accepted where the risk of destruction by fire or heat does not apply. In general, copper tube is used by most vacuum specialist firms.

If the client is likely to pump over actual liquids, it is necessary to incorporate traps that would preclude such liquids from entering the pumping gear. On a multi-storey building, such traps can be conveniently placed at the base of each riser; also they should preferably be of a design whereby they can be emptied without interference of the main vacuum line. If the building is so designed that there are no main risers, i.e., single storey buildings, then it is preferable that each branch should be individually trapped.

Laboratory systems

The design of vacuum installations to serve university and college laboratory systems is far more critical; the demand of the user calls for a much more accurate control of the line pressure, because the student often has to carry out long term experiments at a controlled pressure and therefore cannot tolerate the wide pressure differentials that can be allowed with absolute safety on the medical suction system.

There exists a resistance by some heads of departments in some of our premier academic establishments, to the central vacuum system. They are suspicious of replacing the well-tried water jet pump with which they could control their vacuum by adjustment to the water tap pressure. (This pressure should ideally be constant at between 2 and 2.8bar).

The fact is that even the latest water jet pumps will consume between 0.15 and 0.19 litres of water per second and the very suggestion of running a new university chemistry block with up to 400 laboratory places fitted with water jet pumps is not permissible by with the Water Companies in most areas.

Even if the case is put that only a quarter of these outlets would be in use for say four hours per day, the possible water consumption is going to be about 270m3 per day. Due to this, the central vacuum pipeline system is here to stay for some time.

To overcome the water shortage, the obvious solution is to first look at a water recirculation system, but this has two main disadvantages. The ultimate vacuum obtainable is dependent upon the vapour pressure of water, and provided the water is maintained at an ambient temperature of 15°C, then a vacuum of 15 torr can be expected.

However, the distribution pipes and tanks need to be internally treated and unless the recirculating water is filtered and cooled, the temperature will rise, thus affecting the ultimate vacuum obtained, i.e., if the water temperature rose to 50°C, then the ultimate vacuum would be in the order of 100 torr as against the 15 torr at 15°C.

It may be permissible to allow a minimum number of water jet pump positions which could be reserved for pumping really corrosive vapours that would otherwise be detrimental to the working mechanism of the central vacuum pump, and this compromise may be accepted if it can be demonstrated that adequate protection is provided to prevent backflow in the water system. Most laboratories will require a pressure at the bench outlets at least as good as a water jet pump, namely between 12 and 15 torr absolute, and the speed of evacuation found to be most suitable is about 6 litres per minute, which is a little faster than most water jet pumps.

The consultant or planning authority can generally base laboratory requirements on these figures, but a close check should be made during discussion with the client and establish quite clearly what pressure is to be provided, and if a pressure of better than 12 torr is wanted, say for instance 1 torr, then the problems increase considerably, and these cases will be discussed later.

We are now at the stage where the pipelines and accessories should be discussed, having established that a standard system is wanted for normal filtration through buncher flasks and possibly, some distillations etc, are to be carried out. If the system is to maintain a vacuum of 12-15 torr, then the lines, joints, isolation valves, traps and most important, the bench valves, must be proved free from vacuum leakage at better than 10 torr.

Nowadays, many contracts are split into mains services and then bench furniture and services separately. This is not a convenient arrangement for most services, but in case of vacuum, it is not at all satisfactory.

If, upon completion of the laboratory, only 50 torr vacuum can be created at the bench outlet, where is the fault? The vacuum pump, the main distribution system, the bench pipe run or the bench outlet? Such a situation could involve up to four different contractors, and to find a small leak in an already completed vacuum system can be a very tedious and expensive business.

One should check that the specification states quite clearly, the degree of vacuum at which the whole installation is to undergo a pressure rise test, and also the operating pressure at which the line will be maintained.

Bench outlets

There are several good vacuum bench valves on the market in this country and the types that give a good flow control and easy replacement of working parts are preferred. For instance, never install metal-to-metal cone-type vacuum cocks with a grease seal where hydrocarbon vapours are present, because the vapours will quickly dissolve the grease and a pressure rise will take place, causing the pumping unit to cycle at frequent intervals.

Valves having a stuffing-box shaft seal are not considered suitable.

The push-in or bayonet type of outlet is very practical provided that flow control is not essential and is favoured on industrial projects. Its use in the teaching or research field is limited and its leak tightness in some cases is suspect.

The sizing of the bench runs is not difficult in this pressure range, and as a guide, a 15mm copper line could serve up to four outlets on a 4 metre bench, a 22mm line would serve up to eight outlets and a 28mm line up to 16 outlets. A 15mm line to each bench valve is preferred, and if elementary work is being carried out or the laboratory is to be used for a high density of students, then under-bench traps should be incorporated at a convenient position in each bench run. These traps should be designed to incorporate an isolation valve and an air admittance facility to enable the trap to be emptied without interference to the vacuum system. The laboratory steward would no doubt be responsible for emptying these traps, and it is most important that they are not installed in inaccessible positions where major work has to be carried out before the trap is exposed.

In senior and research laboratories, traps are not considered necessary because this calibre of student using the vacuum system would interpose his own trap on the bench top between the process being carried out and the bench valve, and this trap would be charged with a suitable desiccant to neutralize the particular vapour being pumped.

The sizes of the main runs do, of course, depend upon the total number of outlets to be served, and on the general layout of the building. If, for example, there is a tower block of laboratories four storeys high, having 50 outlets on the first two floors, 10 on the third and 40 on the top floor, a suitable arrangement would be a 54mm diameter riser to the second floor and 42mm extending to the top floor. This riser must be suitably trapped at the base.

The first two floors would have 42mm subsidiary mains reducing at the bench runs, the third floor would only require a 28mm diameter floor run but the top floor would probably be best served by a 42mm main floor run.

As with the hospital system, copper tube with capillary fittings has been found trouble-free in this pressure range, but again, a rigid PVC line can be maintained at better than 10 torr, but it is essential to study the vapour content likely to be pumped to make sure that the material chosen for the line will not be adversely affected by vapours pumped over.

Pumping units

Vacuum pump manufacturers in this country whose pumps can achieve the desired pressures are limited, and all have merits of their own. The three most essential points to look for in a vacuum pump to serve laboratories are:

a. That it will achieve and maintain the pressure required
b. That it is designed to discharge, or has facilities for dealing with corrosive vapours pumped over
c. That its noise will not give cause for complaint.

It is not essential that a twin standby unit is provided, although many modern colleges are favouring this arrangement. However, it must be decided whether the prime mover is to be automatically controlled or manually operated.

The automatic unit is designed to provide a 'vacuum on tap' service at all times of the night and day, and is generally controlled by switches which operate from a vacuum bellows.

Thus, the pump only runs when a pressure rise takes place in the line. The differential between the cutting-in and cutting-out pressure can be limited to about 5 torr if necessary. This type of controlled system is ideal for laboratories or research areas that have intermittent use.

The manually operated plant has to be turned on when vacuum is required, and this does mean that there is a time delay (which varies depending on pump speed and line capacity) in pumping out the system. It also means that a lower pressure can eventually be achieved provided that the line is leak tight. The main advantage with this type of system, as opposed to the automatic one is cost; also the manually operated unit is most suitable for large teaching laboratories where the vacuum service is only required for a short period each day but because of the high percentage of bench valves in use simultaneously, there is no real point in providing an automatic pumping unit. In fact, if automatic gear is provided in such areas, there is sometimes a risk that because of frequent cycling of the pumps, the starters and switch gear could become overloaded..

High vacuum systems

In certain laboratories, there may be a call for vacuum to be provided at better than 1 torr. An example would be for a rotary evaporator in pharmaceutical research work. This is a special requirement and to obtain such conditions, it will be necessary to take great care in the planning and installation of the system.

Although this pressure is still within the viscous flow range, it will be necessary to install the vacuum pump as close to the outlets as possible and keeping the bore of the pipelines as wide as possible. It is not practicable to try and obtain a 1 torr working system from a central pumping set as previously described, and each bench run would therefore have to be provided with its own pump and pipeline system. This presents two problems, the first is to make suitable arrangements to house the pump within the bench area without the noise level interfering with the user, and secondly, to run the pump exhaust to atmosphere at a convenient place.

As this type of system would generally consist of a small rotary oil-sealed high vacuum pump and motor and would be manually controlled, i.e., no safety or cycling switches, it must be firmly established that the personnel using the system will interpose a desiccant flask between their process and the bench outlet which will preclude any liquids being accidentally pumped over and also that the vapours being pumped will be partially dried by the desiccant.

If this simple precaution is taken, it will ensure that the small pump will not become contaminated by carelessness; this will add considerable life to the rotary pump.

When providing these small systems with individual pumps, the biggest hazard is to the working parts of the pump; for example, if soluble organic acids are to be pumped, the oil film in the pump gives no protection at all to the working parts and formic and acetic acids will cause quite severe corrosion depending on the number of outlets in use. The only way to prevent such acids from entering the pump is by the use of conical flasks on the bench tops, these containing sodium hydroxide pellets mixed with indicating soda lime.

The question of explosion risk in small rotary pumps is sometimes raised, especially when ether-air mixture is present, but the risk is very small because the temperature at which automatic ignition takes place would be about 180°C which is at least twice the maximum running temperature of most conventional vacuum pumps.

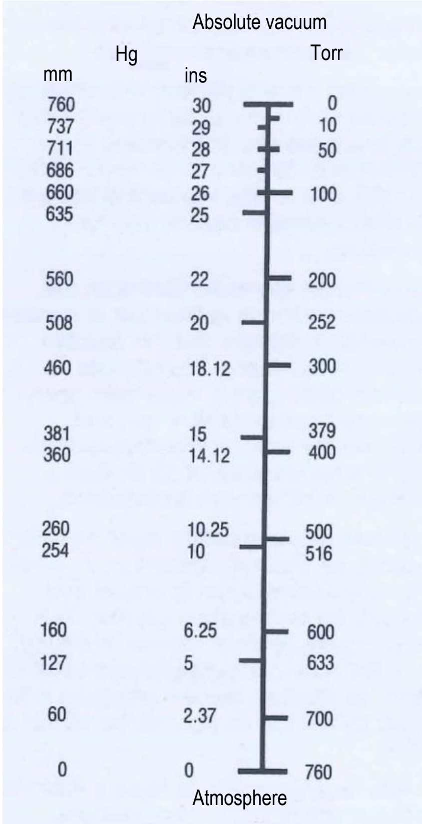
If requests are made for a central vacuum system calling for bench outlet pressures of better than 0.5 torr, then the problems are increased even further because at these pressures, we are moving from the viscous flow to molecular flow and such conditions are not generally accepted as economically practical on a pipeline system.

Certainly, the use of 90° elbows and sharp tees would not be permissible, and the lines would possibly have to be in some other material such as glass, and these problems would cover outgassing of the line material, vapour content to be pumped, and speed of displacement required at any specific pressure.

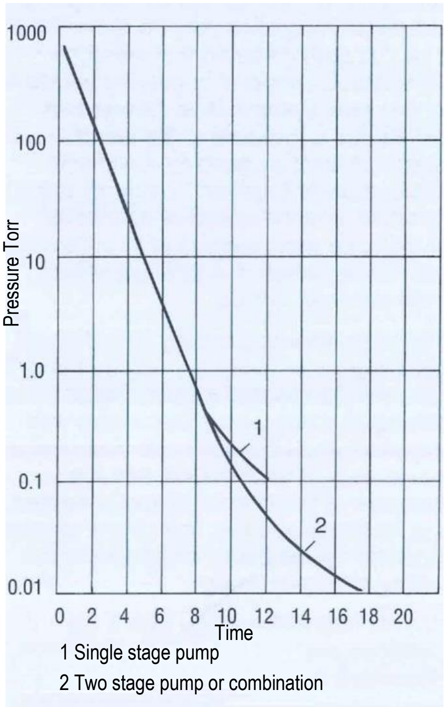
Pipe sizing

The difficulty experienced in trying to calculate pipeline sizes is bound up with the fact that is very rarely that the designer really knows what materials are going to be pumped in a particular pipeline system. It may be that the system will be required to deal with high vapour pressure materials which even at the pipeline pressure, produces very large quantities of vapour which obviously have to be handled by the mechanical pump and pipeline systems, and this makes the whole question of accurately sizing pipelines a very difficult one to resolve.

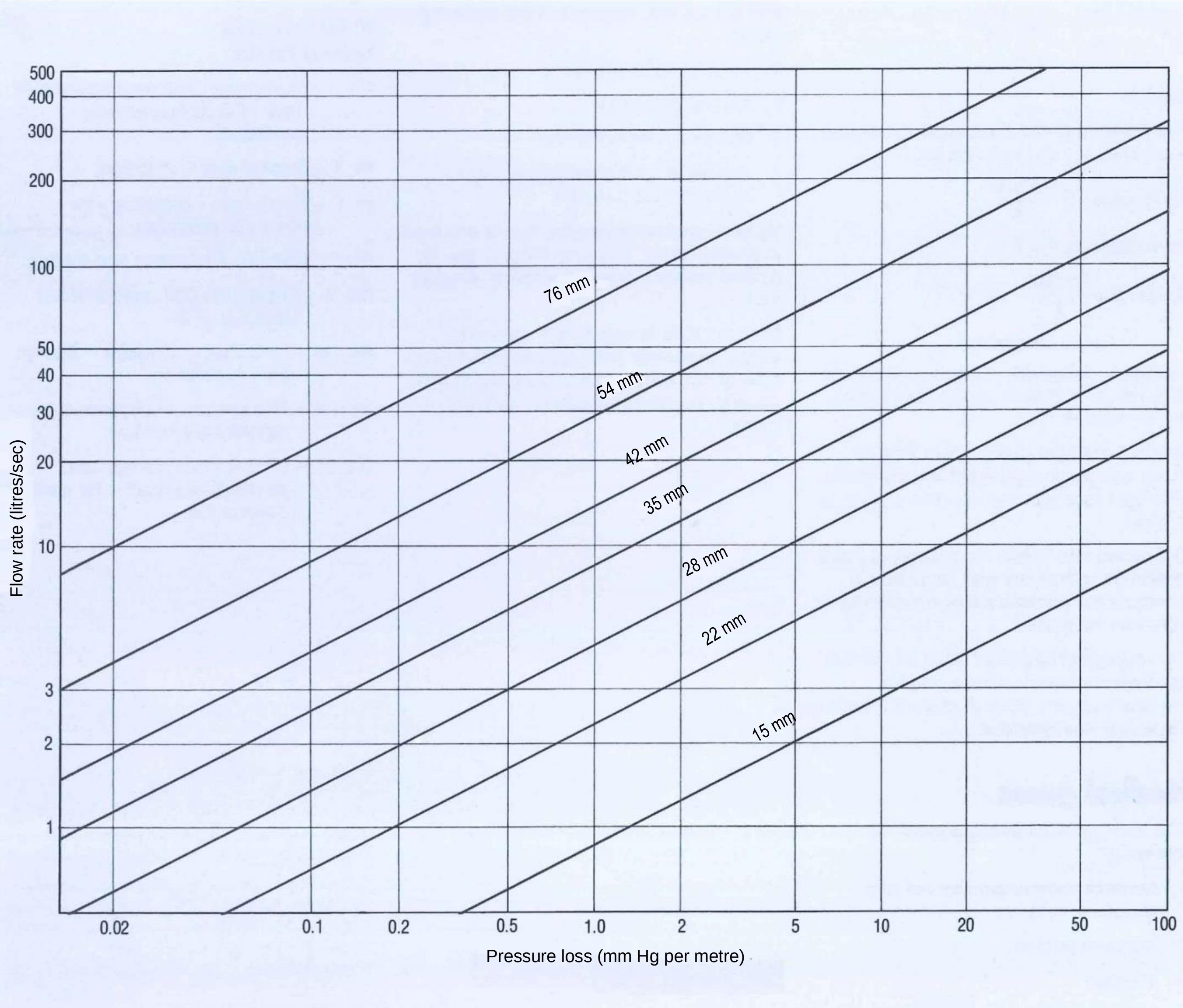
Graph 4 Comparative vacuum scale



Graph 5 Pump sizing



Graph 6 Vacuum pipe sizing, copper tube to EN 1057-250



As a crude example, a gramme of water at, say 10 torr, will evolve about 100 litres of water vapour in the system, and other vapours will have a similar or even greater volumetric effect on the system. It has been found that the best approach is one based on discussion with the user, in order that the possible vapour content can be considered, and this, coupled with previous experience gained, should enable a sensible sizing of the lines to be possible.

The suggestions already given for pipe sizing may form a useful guide for those persons who have to design or install a piped vacuum system. It must be remembered however that there is no straightforward scale on pipe sizing for vacuum systems unless of course, the system is only going to handle clean, dry air, which for 99% of the time, will not be the case.

Summary

Figure 5 is indicative of air which is fairly dry, and consideration must be taken of excess moisture that may be generated. First establish usage and determine what pressures and displacements are required.

Clarify these usages, i.e., medical or laboratory.

Discuss the various types of outlets, the siting of the pumps, the provision of an efficient exhaust system, and choose a line material which is both leak-tight at the desired pressure and one that is functional in use.

Pump sizing for individual chamber work

T = pump-down time (excavation time)

F = pump-down factor from Graph 5 for given pressure

S = pump speed (free air displacement)

V = system volume

NOTE
V and S must be consistent units (i.e., litres and litres/min).

To calculate the time taken to reach certain pressure in a given system with a given pump:

$$T = \frac{F \times V}{S}$$

To calculate pump speed required to reach a given pressure in a given time:

$$S = \frac{F \times V}{T}$$

Example

Pump size required to excavate a chamber of 60 litres to 1 torr in 3 minutes.

Pump speed $S = \frac{F \times V}{T}$

From Graph 5, F = 7

Hence, $S = \frac{7 \times 60}{3}$

=140 litres/min

Therefore, pump with displacement of 140 litres/min and ultimate vacuum better than 1 torr is required.

Graph 5 enables pump-down time or pump size to be evaluated for any clean, leak-tight rotary pumped system down to 01.torr.

Due allowance made for change of pump volumetric efficiency with reduction in pressure but impedance of connecting pipelines neglected.

For recommended plant layouts, consult specialized manufacturers and for medical vacuum, consult current Health Technical Memorandum.

Medical gases

The term medical gases covers the following:

1. Medical compressed air (oil and moisture free)
2. Vacuum suction
3. Oxygen
4. Nitrous oxide
5. Nitrous oxide/oxygen mixture N_2O/O_2.

Oxygen and vacuum are used extensively throughout most hospitals and are usually required in the following areas:

1. In-patient departments
2. Operating suites
3. Maternity departments
4. Accidents and emergency areas including out-patients.

Vacuum and compressed air are required in dental suites, and operating suites for patient ventilators and operating surgical tools.

Nitrous oxide is required in operating suites, maternity units and accidents and emergency areas. In addition, N20/02 is usually required in maternity delivery rooms.

References

LP Gas Association Codes of Practice

No. 1 - Installation and maintenance of bulk LPG at consumer's premises.

Pt. 1 - Design and installation.

Pt. 2 - Small bulk installations for domestic premises.

Pt. 3 - Periodic inspection and testing.

No. 3 - Prevention and control of fire involving LPG.

No. 22 - LPG Piping systems - Design and installation.

No. 24 - The use of LPG cylinders at residential premises.

No. 25 - LPG Central storage and distribution systems for multiple consumers.