GENERAL ENGINEERING
FORMULAE

PUMPS & MOTORS

Flow rate (L/min)	$Q = \frac{Dn}{1000}$
Shaft torque (Nm)	$T = \frac{Dp}{20\pi}$
Shaft power (kW)	$P_{SH} = \frac{Tn}{9549.3}$
Hydraulic power (kW)	$P_H = \frac{Qp}{600}$

CYLINDERS

Pressure (N/m^2)	$\frac{F}{A}$
Flow rate (L/min)	$Q = 60 \times 10^3 \times Av$
Quick calculation	Power (kW) $P = \frac{\text{tonnes} \times \text{mm/sec}}{100}$

ABBREVIATIONS

F	Force (N)
A	Area (m^2)
V	Velocity (m/s)
P	Pressure (bar)
D	Displacement (cm^3/rev)
n	Shaft Speed (rev/min)
Øp	Pressure drop (bar)
Q	Flow Rate (L/min)
T	Shaft Torque (Nm)
P_{SH}	Shaft Power (kW)
P_H	Hydraulic Power (kW)

PRESSURE LOSS IN PIPES

Flow (L/min)	Tube bore size (mm)								
	5	7	10	13	16	21	25	30	36
1	0.69	0.22							
2	1.38	0.44							
3	2.07	0.66	0.17						
5	4.14	1.24	0.24						
7.5	6.55	1.72	0.31						
10		3.10	0.38	0.14					
15		5.38	0.69	0.21	0.08				
20			1.10	0.30	0.14				
30			2.21	0.69	0.25	0.04			
40				1.17	0.45	0.08	0.04		
50					0.59	0.12	0.07	0.03	
75					1.13	0.23	0.14	0.06	0.02
100						0.41	0.22	0.13	0.03
150							0.45	0.23	0.06
200								0.41	0.10
250									0.16

This chart gives the approximate pressure drop in smooth bore straight pipes, in bar per 3 m length. Bends and fittings will increase the above pressure losses and manufacturers should be consulted for more accurate figures.

PRESSURE DROP THROUGH PIPES

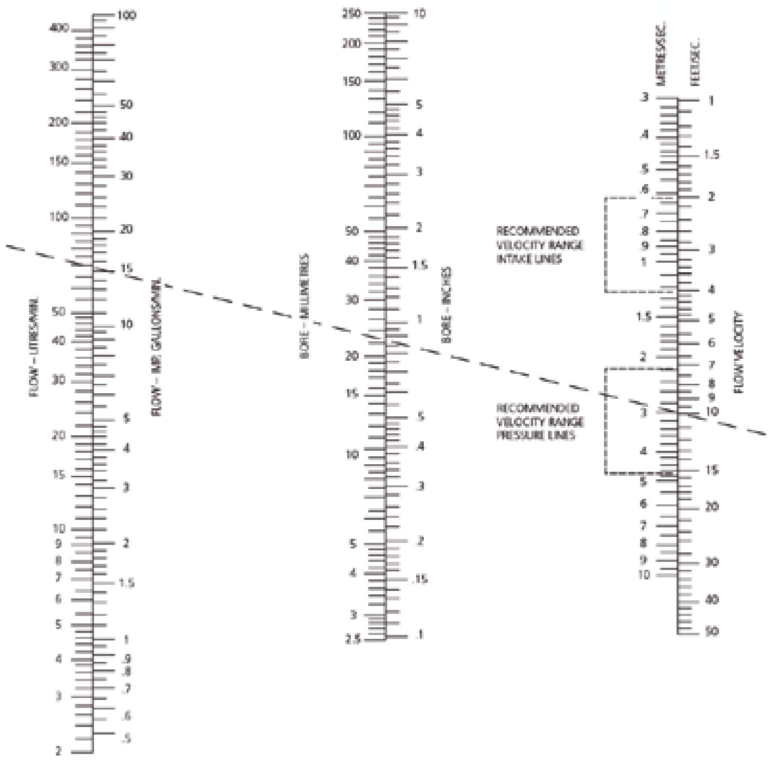
Øp	Pressure drop (bar)
Q	Free air flow (m^3/s) = l/s x 10^{-3}
L	Pipe length (m)
d	Internal pipe diameter (m)
p	Pressure (bar)

VELOCITY THROUGH PIPES

v	Flow velocity (m/s)
p	Initial pressure (bar)
d	Internal pipe diameter (mm)

If the free air flow is known, the minimum inside diameter to keep velocity below 6 m/s, can be found from:
For normal installations, where the pressure is about 7 bar gauge, this can be simplified to:
d (mm) should be greater than 5 × Q

PRESSURE DROP IN PIPES & HOSES



Nomogram for determining pipe sizes in relation to flow rates and recommended velocity ranges.

Based on the formula:

$$\text{Velocity of fluid in pipe (m/s)} = \frac{\text{Flow rate (l/min)} \times 21.22}{d2}$$

d = Bore of pipe (mm)

Recommended velocity ranges based on oils having a maximum viscosity grade of 70 cSt at 38˚C and operating between 18˚C and 51˚C.

Note: For pipe runs greater than 10 m pipe size should be increased correspondingly. Intake line should never exceed 1m in length.

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HYDRAULIC FLUIDS, SEALS & CONTAMINATION CONTROL

ISO Classification of hydraulic fluids – BS ISO 6743-4

HH	Non-inhibited refined mineral oils
HL	Refined mineral oils with improved anti-rust and anti-oxidation properties
HM	Oils of HL type with improved anti-wear properties
HV	Oils of HM type with improved viscosity/temperature properties HFAE Oil-in-water emulsions
HFAS	Chemical solutions in water
HFB	Water-in-oil emulsions
HFC	Water polymer solutions
HFDR	Synthetic fluids containing no water and consisting of phosphate esters
HFDU	Synthetic fluids containing no water and of other composition

Environmentally acceptable hydraulic fluids

HETG	Tryglycerides
HEPG	Polyglycols
HEES	Synthetic esters
HEPR	Polyalphaolefins

Viscosity classification of hydraulic fluids – ISO 3448 (BS 4231)
Each viscosity grade is designated by the nearest whole number to its mid-point kinematic viscosity in centistokes at 40 °C. It is abbreviated ISO VG. Common viscosity grades of hydraulic fluids are VG 22, 32, 46 and 68.

Thus HM32 is a mineral oil with improved anti-rust, anti- oxidation and anti-wear properties having a viscosity of approximately 32 centistokes at 40 °C.

SEALS

Seal Material	Recommended for:
Acrylonitrile butadiene (NBR)	Air, oil, water, water/glycol
Polyurethane (AU)	Oil
Polyurethane (EU)	Air, oil, water
Fluorocarbon rubber (FKM)	Air, oil, water, phosphate esters (except alkyl phosphates)
Ethylene propylene diene* (EPDM)	Air, water, water/glycol, phosphate esters
Polytetrafluoroethylene - virgin, bronze-filled, glass-filled, carbon-filled (PTFE)	Air, oil, water, water/glycol, phosphate esters
Thermoplastic polyester elastomer	Oil, water
Ultra high molecular weight polyethylene (UHMWPE)	Oil, water, water/glycol

*EPDM is not recommended for mineral oil as it will swell rapidly.

FLUID & HYDRAULIC CLEANLINESS

Cleanliness control

The presence of particulate contamination (dirt) is the single most important factor governing the life and reliability of fluid power systems. Operating with clean fluids is essential to achieve modern performance and reliability requirements.

Target cleanliness level (TCL) for a hydraulic system

The TCL is the operational cleanliness of the system and the level that should be achieved and maintained by the cleanliness control measures designed for that system.

The TCL should be selected at the design stage and used to define the cleanliness through the production and commissioning processes. The method for selecting the TCL described is based upon both the sensitivity of the system to particulate contamination and the life and reliability required by the user.

Design and cleanliness
Filtration Standards
A wide range of standards are available to test a filter's capability to perform under various system conditions, namely:-

Parameter	
Collapse/Burst Resistance	BS ISO 2941
Fabrication Integrity	BS ISO 2942
Fluid Compatibility	BS ISO 2943
End Load Strength	BS ISO 3723
Flow Fatigue Test	BS ISO 3724
Flow/Pressure Loss	BS ISO 3968
Pressure Fatigue (Housings)	BS ISO 10771-1
Filter Qualification Programme	BS ISO 10770
Testing differential pressure devices	BS ISO 16860
Filtration Performance	BS ISO 16889
Flow fatigue using high viscosity fluid	BS ISO 23181

Degree of filtration – BS ISO 16889
This ISO standard describes the "Multi-pass" method for evaluating the filtration performance of a hydraulic filter element. The element is subject to a constant circulation of oil during which fresh contaminant (ISO Medium Test Dust) is injected into the rig. The contaminant that is not removed by the element under test is re-circulated, thereby simulating service conditions. The test continues until the element is 'blocked'.

The measure of the filter's ability to remove contaminant is determined by the analysis of fluid samples extracted from upstream and downstream of the filter and expressed as the Filtration Ratio ßx(c), thus:- for the sizes measured.

BS ISO 16889 specifies a number of ratings to define the element's performance over a wide size range and gives the μm(c) rating at ß(c) values of 2, 10, 75, 100, 200 and 1000.

The test also gives a measure of the element's ability to retain quantities of ISO Medium Test Dust.

Cleanliness of components
Components should be cleaned to a level that is commensurate with the system TCL. Guidelines on how to achieve and measure component cleanliness are provided in BS ISO/TR 10949 and BS ISO 18413.

Flushing
Flushing is a process designed to remove dirt introduced into the system during manufacture, assembly and initial operation. It is also used when significant maintenance is undertaken. The requirements are summarised below:-

- A turbulent flow regime to pick up the particles from the walls of components and transport them to the flushing filter
- The Reynolds Number (Re) defines the flow condition and should be greater than 4,000 thus:-
  $Re = 21{,}200 \times Q/(v \times d)$
  or
  $Q > 0.189 \times v \times d$ (l/min) to achieve $Re \geq 4{,}000$

Q = Flow rate (L/min)
v = Viscosity (mm/s)
d = Pipe diameter (mm)

- A 'fine' filter to capture transported particles quickly and effectively

Taking fluid Samples
Fluid samples are extracted from the hydraulic system to determine the operating cleanliness level and whether the TCL is being achieved. To ensure that the data is representative, care must be taken with this process and pre-cleaned sample bottles are essential.

Measuring fluid cleanliness
The size range of interest in Fluid Power is generally from 2 to 100 µm. A range of instruments and techniques are available to measure the numbers or concentration of particles in either the hydraulic fluid or the component. These are:-

Measurement	
Gravimetric analysis (weight) (only suitable for ‘dirty’ systems or components)	ISO 4405
Optical Microscope and Image Analysis	BS ISO 4407
Automatic Particle Counting (APC)	BS ISO 11500
Filter/Mesh Blockage	BS ISO 21018 Part 3
Comparison Slide Method 05/44	BS 8465 and DEF STAN
Calibration of APCs (bottle analysis)	BS ISO 11171
Calibration of on-line APCs	BS ISO 11943

BS ISO 21018-1 gives guidance on both how to select the most suitable technique and monitor, and on the use of online instruments.

Reporting fluid cleanliness
A convenient and preferred method of reporting the data from the above techniques is to convert the particle numbers into broad codes, as described in BS ISO 4406. The interval between each code is effectively a doubling of contamination.

The code is constructed from the combination of three range numbers selected from the following table to describe the numbers of particles at that size.

Changes to certain ISO standards have resulted in differences in the labelling of sizes used in different techniques. These are described in BS ISO/TR 16386. For Automatic Particle Counters (APCs) the sizes are 4/6/14 µm(c), e.g. ISO 17/15/12 (note that ‘µm(c)’ refers to APCs calibrated to BS ISO 11171 or 11943). If the APC cannot count at the 4 µm(c) size, a hyphen (“-“) is used in place of the first code to signify this. Likewise, if the technique used does not include this size or it is not applicable, the other two sizes 6 and 14 µm (monitors) or 5 and 15 µm (microscopic techniques) are used. A typical code is ISO -/15/12. The last two sizes in both code formats are roughly comparable with each other.

Cleanliness management
Essential points:
• The system should be correctly designed to achieve and maintain the TCL.
• Inspect filters regularly for signs of blockage and replace when indicating blockage.
• Filter oil into the system.
• Monitor the fluid cleanliness on a regular basis.
• Promptly implement corrective actions if the TCL is exceeded to limit damage to components.
• Have specifications for both fluid cleanliness (TCL) and filters.
• Educate personnel involved with the process on the need and benefits of cleanliness.

Number of particles per millilitre		
More than	Up to and including	Scale number
40000	80000	23
20000	40000	22
10000	20000	21
5000	10000	20
2500	5000	19
1300	2500	18
640	1300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1