Fluid Power

DATA BOOK

A collection of useful fluid power data, published in this condensed form for convenient reference. For expanded educational material on fluid power, see textbook listings on the back cover.

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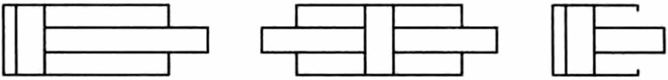
Graphic Symbols

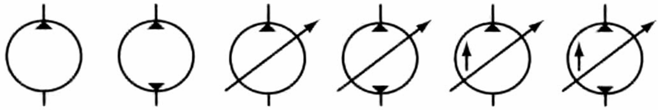
For Use on Fluid Power Drawings

These are the more common ANSI graphic symbols from the American National Standards Institute for use on fluid power circuit drawings. A more complete list can be obtained from the National Fluid Power Association, 3333 N. Mayfair Rd., Milwaukee, WI 53222. Write for listing and prices.



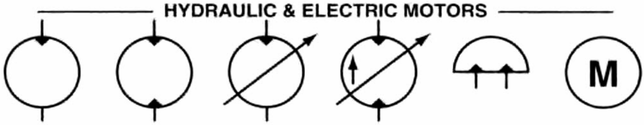
Double-Acting Cylinder — Double-Acting Cylinder with Double End Rod — Single-Acting Cylinder

HYDRAULIC PUMPS



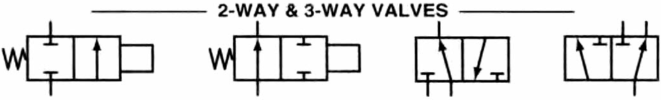
Fixed Displ. Unidirect. — Fixed Displ. Bidirect. — Variable Displ. Unidirect. — Variable Displ. Over Cntr. — Variable Displ., Pres. Compensator — Over Center w/Comp.

HYDRAULIC & ELECTRIC MOTORS



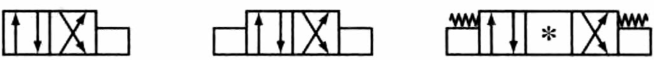
Fixed Displ. Unidirect. — Fixed Displ. Bidirect. — Variable Displ. Unidirect. — Bidirect. w/Press. — Partial Revolution Oscillator — Electric Motor

2-WAY & 3-WAY VALVES



2-Way, N.C. 2-Position — 2-Way, N.O. 2-Position — 3-Way, Directional Control — 3-Way Selector

4-WAY VALVES



2-Position Single Actuator — 2-Position Double Actuator — 3-Position Spring Centered

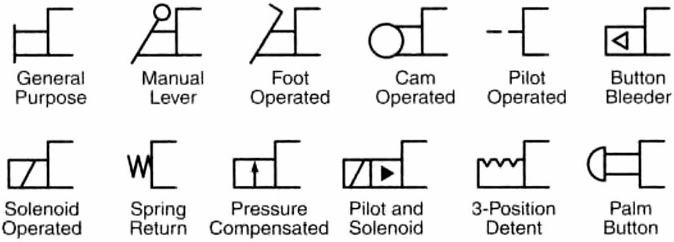
*SPOOL CENTERS FOR 3-POSITION VALVES

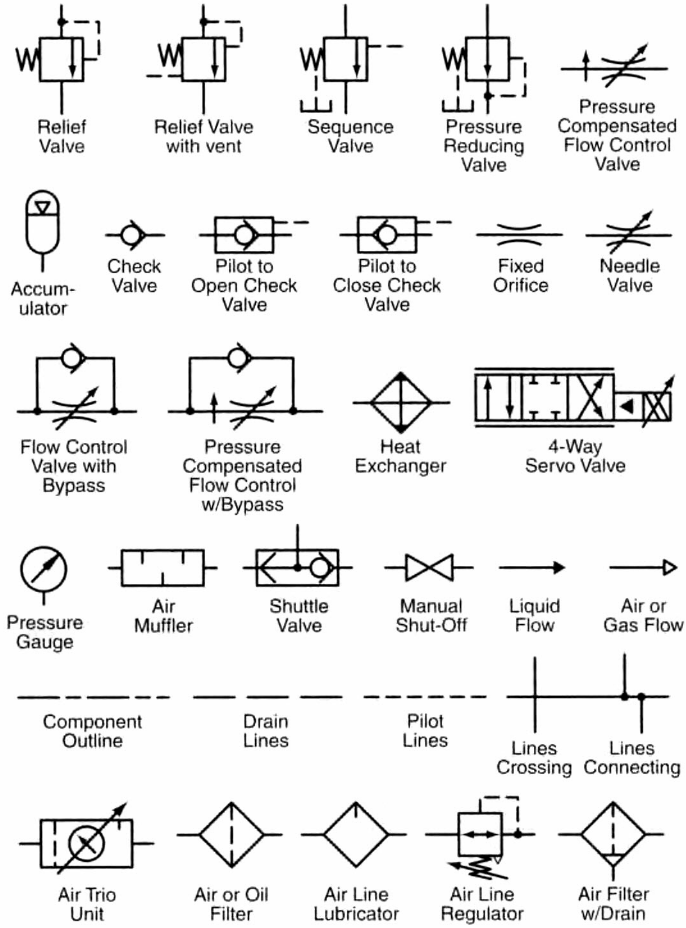
Closed Center — Tandem Center — Float Center — Open Center

Proportional Solenoid Valve

Graphic Symbols (continued)

ACTUATORS FOR VALVES



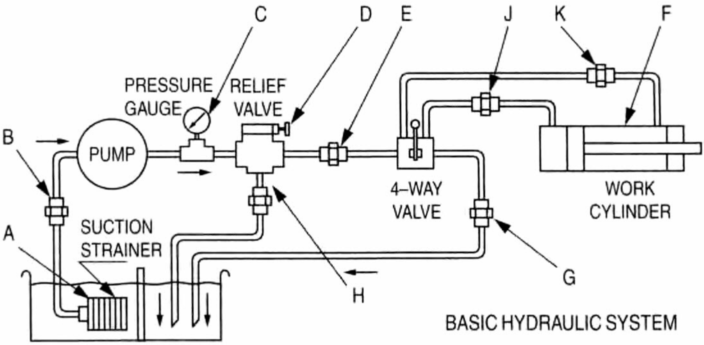


Hydraulic Troubleshooting

Many of the failures in a hydraulic system show similar symptoms: a gradual or sudden loss of high pressure, resulting in loss of power or speed in the cylinders. In fact, the cylinders may stall under light loads or may not move at all. Often the loss of power is accompanied by an increase in pump noise, especially as the pump tries to build up pressure.

Any major component (pump, relief valve, directional valve, or cylinder) could be at fault. In a sophisticated system other components could also be at fault, but this would require the services of an experienced technician.

By following an organized step-by-step testing procedure in the order given here, the problem can be traced to a general area, then if necessary, each component in that area can be tested or replaced.



BASIC HYDRAULIC SYSTEM

STEP 1 – Pump Suction Strainer ...

Probably the trouble encountered most often is cavitation of the hydraulic pump inlet caused by restriction due to a dirt build-up on the suction strainer. This can happen on a new as well as an older system. It produces the symptoms described above: increased pump noise, loss of high pressure and/or speed.

If the strainer is not located in the pump suction line it will be found immersed below the oil level in the reservoir (point **A**). Some operators of hydraulic equipment never give the equipment any attention or maintenance until it fails. Under these conditions, sooner or later, the suction strainer will probably become sufficiently restricted to cause a breakdown of the whole system and damage to the pump.

The suction strainer should be removed for inspection and should be cleaned before re-installation. Wire mesh strainers can best be cleaned with an air hose, blowing from inside out. They can also be washed in a solvent which is compatible with the reservoir fluid. Kerosene may be used for strainers operating in petroleum base hydraulic oil. Do not use gasoline or other explosive or flammable solvents. The strainer should be cleaned even though it may not appear to be dirty. Some clogging materials cannot be seen except by close inspection. If there are holes in the mesh or if there is mechanical damage, the strainer should be replaced. When reinstalling the strainer, inspect all joints for possible air leaks, particularly at union joints (points **B**, **E**, **G**, **H**, **J**, and **K**). There must be no air leaks in the suction line. Check the reservoir oil level to be sure it covers the top of the strainer by at least 3″ at minimum oil level, with all cylinders extended. If it does not cover to this depth there is danger of a vortex forming which may allow air to enter the system when the pump is running.

STEP 2 – Pump and Relief Valve ...

If cleaning the pump suction strainer does not correct the trouble, isolate the pump and relief valve from the rest of the circuit by disconnecting at point **E** so that only the pump, relief valve, and pressure gauge remain in the pump circuit. Cap or plug both ends of the plumbing which was disconnected. The pump is now deadheaded into the relief valve. Start the pump and watch for pressure build-up on the gauge while tightening the adjustment on the relief valve. If full pressure can be developed, obviously the pump and relief valve are operating correctly, and the trouble is to be found further down the line. If full pressure cannot be developed in this test, continue with **STEP 3**.

STEP 3 – Pump or Relief Valve ...

If high pressure cannot be obtained in **STEP 2** by running the pump against the relief valve, further testing must be conducted to see whether the fault lies in the pump or in the relief valve. Proceed as follows:

If possible, disconnect the reservoir return line from the relief valve at point **H**. Attach a short length of hose to the relief valve outlet. Hold the open end of this hose over the reservoir filler opening so the rate of oil flow can be observed. Start the pump and run the relief valve adjustment up and down while observing the flow through the hose. If the pump is bad, there will probably be a full stream of oil when the relief adjustment is backed off, but this flow will diminish or stop as the adjustment is increased.

If a flowmeter is available, the flow can be measured and compared with the pump catalog rating. If a flowmeter is not available, the rate of flow on small pumps can be measured by discharging the hose into a bucket while timing with a watch. For example, if a volume of 10 gallons is collected in 15 seconds, the pumping rate is 40 GPM, etc.

If the gauge pressure does not rise above a low value, say 100 PSI, and if the volume of flow does not substantially decrease as the relief valve adjustment is tightened, the relief valve is probably at fault and should be cleaned or replaced as instructed in **STEP 5**. If the oil substantially decreases as the relief valve adjustment is tightened, and if only a low or moderate pressure can be developed, this indicates trouble in the pump. Proceed to **STEP 4**.

STEP 4 – Pump ...

If a full stream of oil is not obtained in **STEP 3**, or if the stream diminishes as the relief valve adjustment is tightened, the pump is probably at fault. Assuming that the suction strainer has already been cleaned and the inlet plumbing has been examined for air leaks, as in **STEP 1**, the oil is slipping across the pumping elements inside the pump. This can mean a worn-out pump, or too high an oil temperature. High slippage in the pump will cause the pump to run considerably hotter than the oil reservoir temperature. In normal operation, with a good pump, the pump case will probably run about 20°F above the reservoir temperature. If greater than this, excess slippage, caused by wear, may be the cause.

Check also for slipping belts, sheared shaft pin or key, broken shaft, broken coupling, or loosened set screw.

STEP 5 – Relief Valve ...

If the test in **STEP 3** has indicated the trouble to be in the relief valve, point **D**, the quickest remedy is to replace the valve with one known to be good. The faulty valve may later be disassembled for inspection and cleaning. Pilot-operated relief valves have small orifices which may be blocked with accumulations of dirt. Blow out all passages with an air hose and run a small wire through orifices. Check also for free movement of the spool. In a relief valve with pipe thread connections in the body, the spool may bind if pipe fittings are over-tightened. If possible, test the spool for bind before unscrewing threaded connections from the body, or screw in fittings tightly during inspection of the valve.

STEP 6 – Cylinder ...

If the pump will deliver full pressure when operating across the relief valve in **STEP 2**, both pump and relief valve can be considered good, and the trouble is further downstream. The cylinder should be tested first for worn-out or defective packings by the method described on page 7.

STEP 7 – Directional Control Valve ...

If the cylinder has been tested (**STEP 6**) and found to have reasonably tight piston seals, the 4-way valve should be checked next. Although it does not often happen, an excessively worn valve spool can slip enough oil to prevent build-up of maximum pressure. Symptoms of this condition are a loss of cylinder speed together with difficulty in building up to full pressure even with the relief valve adjusted to a high setting. This condition would be more likely to occur with high pressure pumps of low volume output, and would develop gradually over a long period of time. Four-way valves may be tested by the method described on page 7.

Other Components ...

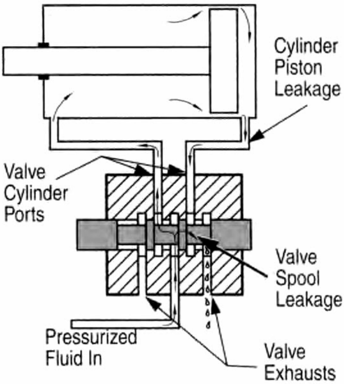
Check other components such as bypass flow controls, hydraulic motors, etc. Solenoid 4-way valves of the pilot-operated type with tandem or open center spools may not have sufficient pilot pressure to shift the spool.

Cylinder and Valve Testing

On an air system, if air is detected escaping from a 4-way valve exhaust while the cylinder is stopped, this air is either blowing by worn-out piston seals, or is leaking across the spool in the 4-way valve. These two leakage paths are shown in the figure to the right.

Most air cylinders and valves have soft seals and should be leak-tight. However, those air valves having a metal-to-metal seal between spool and body may be expected to have a small amount of leakage.

If leakage is noted, it is more likely to be coming through the cylinder than across the valve spool, and the cylinder should be tested first.



Two Leak Paths

Cylinder Testing ...

Run the piston to one end of its stroke and leave it stalled in this position under pressure. Crack the fitting on the same end of the cylinder to check for fluid leakage.

After checking, tighten the fitting and run the piston to the opposite end of the barrel and repeat the test. Occasionally a cylinder will leak at one point in its stroke due to a scratch or dent in the barrel. Check suspected positions in mid stroke by installing a positive stop at the suspected position and run the piston rod against it for testing. Once in a great while a piston seal may leak intermittently. This is usually caused by a soft packing or O-ring moving slightly or rolling into different positions on the piston, and is more likely to happen on cylinders of large bore.

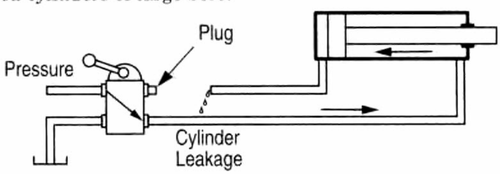


Diagram for Cylinder Testing

When making this test on hydraulic cylinders, the line should be completely removed from a cylinder port during the test. The open line from the valve should be plugged or capped since a slight back pressure in the tank return line would spill oil from the line if not plugged. Pistons with metal ring seals can be expected to have a small amount of leakage across the rings, and even "leak-tight" soft seals may have a small bypass during new seal break-in or after the seals are well worn.

4-Way Valve Testing ...

For testing 4-way valves, either air or hydraulic, it is necessary to obtain access to the exhaust or tank return ports so that the amount of leakage can be observed. To make the test, disconnect both cylinder lines and plug these ports on the valve. Start up the system and shift the valve to one working position. Any flow out the exhausts or tank return line while the valve is under pressure is the amount of leakage. Repeat the test in all other working positions of the valve.

Safe Pump Inlet Vacuum

	Gear Pumps	Vane Pumps	Piston Pumps
Max. Safe Inlet Vacuum, PSI	3 to 5	2 to 3	2
Max. Safe Inlet Vacuum, In. Hg	6 to 10	4 to 6	4

The suction strainer should be cleaned or replaced when inlet vacuum on a hydraulic pump reaches these values. Sustained operation at these vacuums may damage the pump. When the suction strainer is clean, the inlet vacuum should not be more than 1/3 of these values.

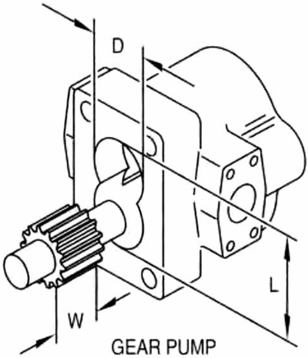
Replacement of Pump or Motor

Calculating the Theoretical GPM of a Pump by Measuring Its Internal Parts.

To select a replacement for a broken or worn out hydraulic pump or motor which has no nameplate or has no rating marked on its case, use the formulas below after making internal physical measurements.

When replacing a pump, catalog ratings will usually be shown in GPM at a specified shaft speed. On a motor, catalog ratings will usually be in C.I.R. (cubic inches displacement per shaft revolution). Formulas are given for calculating either GPM at 1800 RPM or calculating C.I.R. Use the formula which is appropriate. Make all measurements in inches, as accurately as possible. Convert fractional dimensions into decimal equivalents for use in the formulas.

Make sure the catalog pressure rating is adequate for your application, and in the case of a pump, be sure direction of shaft rotation is correct.



GEAR PUMP

Gear Pumps and Motors

1. Measure gear width, **W**.
2. Measure bore diameter of one of the gear chambers: this is **D**.
3. Measure distance across both gear chambers; this is **L**.

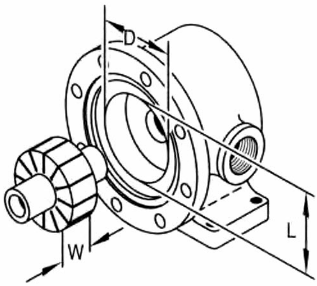
GPM @ 1800 RPM =

$$47 \times W \times (2D - L) \times \frac{(L - D)}{2}$$

A speed of 1800 RPM is used in the formula. At other speeds, GPM is proportional to RPM.

C.I.R. Displacement =

$$6 \times W \times (2D - L) \times \frac{(L - D)}{2}$$



VANE PUMP (Balanced Type Only)

Vane Pumps and Motors

(Balanced type, not variable displ.)

1. Measure width of rotor. This is **W**.
2. Measure shortest distance across bore; this is **D**.
3. Measure longest distance across bore: this is **L**.

GPM @ 1800 RPM =

$$94 \times W \times \frac{(L + D)}{4} \times \frac{(L - D)}{2}$$

A speed of 1800 RPM is used in the formula. At other speeds, GPM is proportional to RPM.

C.I.R. Displacement =

$$12 \times W \times \frac{(L + D)}{4} \times \frac{(L - D)}{2}$$

Piston Pumps and Motors

1. Find piston area from piston diameter; this is **A** in formula.
2. Measure length of stroke; this is **L** in formula.
3. Count number of pistons; this is **N** in formula.

$$\text{GPM @ 1800 RPM} = A \times L \times N \times 1800 \div 231$$

A speed of 1800 RPM is used in formula. At other speeds, GPM is proportional to RPM.

$$\text{C.I.R. Displacement} = A \times L \times N$$

If a pump of higher GPM has to be used, it will require more HP at the same pressure and cylinders in the system will move faster. If one with lower GPM is used, the system will have plenty of power but cylinders will move more slowly than originally.

If a motor with greater displacement is used, it will deliver more torque at a reduced RPM, but will require no more fluid HP from the pump. If it has less displacement it will rotate faster with less torque.

Fluid Power Formulas

Torque and horsepower Relations:
$T = HP \times 5252 \div RPM$
$HP = T \times RPM \div 5252$
$RPM = HP \times 5252 \div T$
Torque values are in foot pounds.

Hydraulic (fluid power) horsepower:
$HP = PSI \times GPM \div 1714$
PSI is gauge pressure in pounds per square inch; **GPM** is oil flow in gallons per minute.

Velocity of oil flow in pipe:
$V = GPM \times 0.3208 \div A$
V is oil velocity in feet per second; **GPM** is flow in gallons per minute; **A** is inside area of pipe in square inches.

Charles' Law for behavior of gases:
$T_1V_2 = T_2V_1$, or $T_1P_2 = T_2P_1$
T_1, P_1, and V_1 are initial temperature, pressure, and volume, and T_2, P_2, and V_2 are final conditions.

Boyle's Law for behavior of gases:
$P_1V_1 = P_2V_2$
P_1 and V_1 are initial pressure and volume; P_2 and V_2 are final conditions.

Circle formulas:
Area = πr^2, or $\pi D^2 \div 4$
Circumference = $2\pi r$, or πD
r is radius; **D** is diameter, inches.

Heat equivalent of fluid power:
BTU per hour = PSI × GPM × 1½

Hydraulic cyl. piston travel speed:
$S = CIM \div A$
S is piston travel speed, inches per minute; **CIM** is oil flow into cylinder, cubic inches per minute; **A** is piston area in square inches.

Force or thrust of any cylinder:
$F = A \times PSI$
F is force or thrust, in pounds; **A** is piston net area in square inches; **PSI** is gauge pressure.

Force for piercing or shearing sheet metal:
$F = P \times T \times PSI$
F is force required, in pounds; **P** is perimeter around area to be sheared, in inches; **T** is sheet thickness in inches; **PSI** is the shear strength rating of the material in pounds per square inch.

Side load on pump or motor shaft:
$F = (HP \times 63024) \div (RPM \times R)$
F is the side load, in pounds, against shaft; **R** is the pitch radius, in inches, of sheave on pump shaft; **HP** is driving power applied to shaft.

Effective force of a cylinder working at an angle to direction of the load travel:
$F = T \times \sin A$
T is the total cylinder force, in pounds; **F** is the part of the force which is effective, in pounds; **A** is the least angle, in degrees, between cylinder axis and load direction.

Heat radiating capacity of a steel reservoir:
$HP = 0.001 \times A \times TD$
HP is the power radiating capacity expressed in horsepower; **A** is surface area, in square feet; **TD** is temperature difference in degrees F between oil and surrounding air.

Burst pressure of pipe or tubing:
$P = 2t \times S \div O$
P is burst pressure in PSI; **t** is wall thickness, in inches; **S** is tensile strength of material in PSI; **O** is outside diameter, in inches.

Relationship between displacement and torque of a hydraulic motor:
$T = D \times PSI \div 24\pi$
T is torque in foot-lbs.; **D** is displacement in cubic inches per revolution; **PSI** is pressure difference across motor; $\pi = 3.14$.

Rules-of-Thumb

Horsepower for driving a pump:
For every 1 HP of drive, the equivalent of 1 GPM @ 1500 PSI can be produced.

Horsepower for idling a pump:
To idle a pump when it is unloaded will require about 5% of its full rated horsepower.

Compressibility of hydraulic oil:
Volume reduction is approximately 1/2% for every 1000 PSI of fluid pressure.

Compressibility of water:
Volume reduction is about 1/3% for every 1000 PSI pressure.

Wattage for heating hydraulic oil:
Each watt will raise the temperature of 1 gallon of oil by 1°F per hour.

Flow velocity in hydraulic lines:
Pump suction lines 2 to 4 feet per second; pressure lines up to 500 PSI, 10 to 15 feet per sec; pressure lines 500 to 3000 PSI, 15 to 20 feet per sec.; pressure lines over 3000 PSI, 25 feet per sec.; all oil lines in air-over-oil system, 4 feet per sec.

Fluid Power Formulas

in SI Metric Units

Fluid power formulas in English units are shown in the left column. SI (International) unit equivalents of these formulas are shown in the right column.

English Units	***Metric (SI) Units***

Torque, HP, Speed Relations in Hydraulic Pumps & Motors

English Units	Metric (SI) Units
T = HP × 5252 ÷ RPM **HP = T × RPM ÷ 5252** **RPM = HP × 5252 ÷ T**	**T = Kw × 9543 ÷ RPM** **Kw = T × RPM ÷ 9543** **RPM = Kw × 9543 ÷ T**
T = Torque, foot-lbs. **RPM** = Speed, revs/minute **HP** = Horsepower	**T** = Torque, Nm (Newton-meters) **RPM** = Speed, revs/minute **Kw** = Power in kilowatts

Hydraulic Power Flowing through the Pipes

English Units	Metric (SI) Units
HP = PSI × GPM ÷ 1714	**Kw = Bar × dm^3/min ÷ 600**
HP = Horsepower **PSI** = Gauge pressure, lbs/sq. inch **GPM** = Flow, gallons per minute	**Kw** = Power in kilowatts **Bar** = System pressure **dm^3/min** = Flow, cu. dm/minute

Force Developed by an Air or Hydraulic Cylinder

English Units	Metric (SI) Units
F = A × PSI	**N = A × Bar × 10**
F = Force or thrust, lbs. **A** = Piston area, square inches **PSI** = Gauge pressure, lbs/sq. inch	**N** = Cylinder force in Newtons **A** = Piston area, sq. centimeters **Bar** = Gauge pressure

Travel Speed of a Hydraulic Cylinder Piston

English Units	Metric (SI) Units
S = V ÷ A	**S = V ÷ A**
S = Travel Speed, inches/minute **V** = Volume of oil to cyl., cu. in/min. **A** = Piston area, square inches	**S** = Travel Speed, meters/sec. **V** = Oil flow, dm^3/minute **A** = Piston area, square centimeters

Barlow's Formula — Burst Pressure of Pipe & Tubing

English Units	Metric (SI) Units
P = 2t × S ÷ O	**P = 2t × S ÷ O**
P = Burst pressure, PSI **t** = Pipe wall thickness, inches **S** = Tensile strength, pipe mat'l, PSI **O** = Outside diameter of pipe, inches	**P** = Burst pressure, Bar **t** = Pipe wall thickness, mm **S** = Tensile strength, pipe mat'l, Bar **O** = Outside diameter of pipe, mm

Velocity of Oil Flow in Hydraulic Lines

English Units	Metric (SI) Units
V = GPM × 0.3208 ÷ A	**V = dm^3/min ÷ 6A**
V = Velocity, feet per second **GPM** = Oil flow, gallons/minute **A** = Inside area of pipe, sq. inches	**V** = Oil velocity, meters/second **dm^3/min** = Oil flow, cu. dm/minute **A** = Inside area of pipe, sq. cm

Recommended Maximum Oil Velocity in Hydraulic Lines

English Units	Metric (SI) Units
fps = feet per second	**mps** = Meters per second
Pump suction lines – **2 to 4 fps** Pres. lines to 500 PSI – **10 to 15 fps** Pres. lines to 3000 PSI – **15 to 20 fps** Pres. lines over 3000 PSI – **25 fps** Oil lines in air/oil system – **4 fps**	Pump suction lines – **0.6 to 1.2 mps** Pres. lines to 35 bar– **3 to 4½ mps** Pres. lines to 200 bar– **4½ to 6 mps** Pres. lines over 200 bar– **7½ mps** Oil lines in air/oil system – **1¼ mps**

English/Metric Conversions

Pressure – PSI and Bar

1 PSI = 0.0689655 bar			
PSI	Bar	PSI	Bar
20	1.379	1100	75.86
30	2.069	1200	82.76
40	2.759	1300	89.66
50	3.448	1400	96.55
60	4.138	1500	103.5
70	4.828	1600	110.3
80	5.517	1700	117.2
90	6.207	1800	124.1
100	6.897	1900	131.0
200	13.79	2000	137.9
300	20.69	2250	155.2
400	27.59	2500	172.4
500	34.48	2750	189.7
600	41.38	3000	206.9
700	48.28	3500	241.4
800	55.17	4000	275.9
900	62.07	4500	310.3
1000	68.97	5000	344.8

1 bar = 14.5 PSI			
Bar	PSI	Bar	PSI
1	14.50	55	797.5
2	29.00	60	870.0
3	43.50	65	942.5
4	58.00	70	1015
5	72.50	75	1088
6	87.00	80	1160
7	101.5	85	1233
8	116.0	90	1305
9	130.5	95	1378
10	145.0	100	1450
15	217.5	150	2175
20	290.0	200	2900
25	362.5	250	3625
30	435.0	300	4350
35	507.5	350	5075
40	580.0	400	5800
45	652.5	450	6585
50	725.0	500	7250

Hydraulic Flow – GPM and Liters per Minute

GPM = 3.785 liters/min			
GPM	l/min	GPM	l/min
1	3.785	75	283.9
2	7.570	80	302.8
3	11.36	85	321.7
4	15.14	90	340.7
5	18.93	85	359.6
10	37.85	100	378.5
15	56.78	125	473.1
20	75.70	150	567.8
25	94.63	175	662.4
30	113.6	200	757.0
35	132.5	225	851.6
40	151.4	250	946.3
45	170.3	275	1041
50	189.3	300	1136
55	208.2	325	1230
60	227.1	350	1325
65	246.0	375	1420
70	265.0	400	1514

1 liter/min = 0.2642 GPM			
l/min	GPM	l/min	GPM
5	1.32	300	79.3
10	2.64	350	92.5
20	5.28	400	106
30	7.93	450	119
40	10.6	500	132
50	13.2	550	145
60	15.9	600	159
70	18.5	650	172
80	21.1	700	185
90	23.8	750	198
100	26.4	800	211
125	33.0	900	238
150	39.6	1000	264
175	46.2	1100	291
200	52.8	1200	317
225	59.4	1300	343
250	66.1	1400	370
275	72.7	1500	396

Air Flow – CFM and Cubic Decimeters per Second

1 CFM = 0.47195 cu. dm/sec (dm^3/s)			
CFM	dm^3/s	CFM	dm^3/s
1	0.472	75	35.40
2	0.944	80	37.76
3	1.416	85	40.12
4	1.888	90	42.48
5	2.360	95	44.84
10	4.720	100	47.20
15	7.079	125	58.99
20	9.439	150	70.79
25	11.80	175	82.59
30	14.16	200	94.39
35	16.52	225	106.2
40	18.88	250	118.0
45	21.24	275	129.8
50	23.60	300	141.6
55	25.96	325	153.4
60	28.32	350	165.2
65	30.68	375	177.0
70	33.04	400	188.8

1 cu. dm/sec = 2.1187 CFM (dm^3/s)			
dm^3/s	CFM	dm^3/s	CFM
5	10.59	225	476.7
10	21.19	250	529.7
15	31.78	300	635.6
20	42.37	350	741.5
25	52.97	400	847.5
30	63.56	450	953.4
35	74.15	500	1059
40	84.75	550	1165
45	95.34	600	1271
50	105.9	700	1483
60	127.1	800	1695
70	148.3	900	1907
80	169.5	1000	2119
100	211.9	1100	2331
125	264.8	1200	2542
150	317.8	1300	2754
175	370.7	1400	2966
200	423.7	1500	3178

Fluid Power Equivalents

Exact Equivalents

1 U.S. gallon:
= 231 cubic inches
= 4 quarts or 8 pints
= 128 ounces (Liquid)
= 133.37 ounces (weight)
= 8.3356 pounds
= 3.785 liters

1 Imperial gallon = 1.2 U.S. gal.

1 Liter = 0.2642 U.S. gallons

1 Cubic foot:
= 7.48 gallons
= 1728 cubic inches
= 62.4 pounds (water)

1 Cu. ft. water weighs 62.4 lbs.

1 Bar at sea level:
= 14.504 PSI
= 0.98692 atmosphere
= 33.6 foot water column
= 41 foot oil column

Approx. 1/2 PSI decrease each 1000 feet of elevation.

1″ Hg = 0.490 PSI
= 1.131 ft. water

1 Horsepower:
= 33,000 ft. lbs. per minute
= 550 ft. lbs. per second
= 42.4 BTU per minute
= 2545 BTU per hour
= 746 watts or 0.746 kw

1 PSI = 2.0416″ Hg
= 27.71″ water
= 0.0689 bar

1 Atmosphere:
= 1.013 bar
= 29.921″ Hg
= 14.696 PSI
= 760 mm Hg

1 Foot water column = 0.432.PSI

1 Foot oil column = 0.354 PSI

1 Barrel oil = 42 gallons

1 Micro-meter (μm):
= 0.000001 meter (micron)
= 0.001 centimeter
= 0.00004 inch

25 Micro-meters = 0.001 inch

Approximate Equivalents

1 Pint = 2 cups = 32 tablespoons = 96 teaspoons = 16 fl. oz. = 1 lb.

1 Quart = 4 cups = 2 pints = 32 fluid ounces = 2 pounds.

1 Gallon = 16 cups = 4 quarts = 8 pints = 128 fl. oz. = 231 cu. ins.

1 Cup = 16 tablespoons = 48 tsp.

1 Tablespoon = 3 tsp. = 1/2 fluid oz.

1 Fluid oz. (volume) = 600 drops hydraulic oil.

1 Cubic inch = 330 drops (oil).

Fluid Power Abbreviations

abs	absolute (as in psia)
AC	alternating current
Bhn	Brinell hardness number
Btu	British thermal unit
C	degrees Centigrade (Celsius)
cc	closed center
ccw	counter clockwise
cfm	cubic feet per minute
cfs	cubic feet per second
cir	cubic inches per revolution
cim	cubic inches per minute
com	Common
cpm	cycles per minute
cps	cycles per second
cu. in/rev	cubic inches per revolution
cw	clockwise
cyl	cylinder
DC	direct current
dia	diameter
ext	external
F	degrees Fahrenheit
fl	fluid
fpm	feet per minute
ft	foot
ft-lb	foot pound
gal	gallon
gpm	gallons per minute
Hg	Mercury
HP	horsepower
Hz	Hertz
ID	inside diameter
in	inch
in-lb	inch pound
int	internal
ipm	inches per minute
ips	inches per second
lb	pound
max	maximum
min	minimum
mtd	mounted
NC	normally closed
NO	normally open
NPT	national pipe thread
NPTF	dryseal pipe threads
oc	open center
oz.	ounce
P.O.	pilot operated
pres	pressure
PSI	pounds/square inch
psia	psi absolute
psig	psi gauge
pt	pint
qt	quart
r	radius
rms	root mean square
rpm	revolutions per minute
rps	revolutions per second
scfm	standard cu. ft. per minute
Smls	seamless
sol	solenoid
SSU	Saybolt seconds universal
SUS	Saybolt universal seconds
μ	micro-meters or microns
T	torque
vac	vacuum
VI	viscosity index
visc	viscosity

Vehicle Drive Calculations

The force to drive a vehicle is composed of the sum of (1) road resistance, (2) force necessary to climb a grade, (3) force needed to accelerate to final velocity in the allowable time, (4) force to overcome air resistance, on fast moving vehicles. Each of these forces can be calculated or estimated from the formulas on this page, then added together. In selecting an engine, allow enough extra power to make up for losses in the mechanical transmission system including gear boxes, clutches, differentials, chain or belt drives.

Travel Speed in M.P.H. (miles per hour) is found by multiplying wheel RPM × wheel circumference.

M.P.H. = RPM × d ÷ 336, or

RPM = 336 × M.P.H. ÷ d

d is wheel diameter in inches.

Axle Torque for driving the vehicle is found by multiplying drawbar pull (or push) times wheel radius.

T = F × r or, F = T ÷ r

T is axle torque in inch pounds.
F is drawbar pull in pounds.
r is wheel radius in inches.

Drawbar Pull to keep the vehicle in steady motion on level ground depends on the road surface. The following figures are pounds of drawbar pull per 1000 lbs. of vehicle weight.

Concrete	10 to 20 lbs.
Asphalt	12 to 22 lbs.
Macadam	15 to 37 lbs.
Cobbles	55 to 85 lbs.
Snow	25 to 37 lbs.
Dirt	25 to 37 lbs.
Mud	37 to 150 lbs.
Sand	60 to 300 lbs.

Horsepower required on vehicle wheels is torque times RPM:

HP = T × RPM ÷ 63024

T is wheel torque in inch pounds.

NOTE: Additional HP is required at the engine to overcome transmission system losses.

Conversion Formula between torque, HP, and speed.

T = HP × 63024 ÷ RPM

Torque values are in inch pounds.

Momentum of a vehicle is equivalent to that constant force which would bring it to rest in one second by resisting its movement.

Momentum = Weight × V ÷ g

Weight is in pounds.
V is velocity in feet per second.
g is gravity acceleration = 32.16

Acceleration of a vehicle is expressed in this formula involving weight, accelerating force, and time.

F = (V × W) ÷ (g × T)

F is accelerating force in pounds.
V is final velocity in feet per second.
W is vehicle weight in pounds.
g is gravity acceleration = 32.16
T is time in seconds that force acts.

Note: The gravity acceleration symbol, g, converts weight into mass.

Grade, in mobile work, is usually expressed in percentage rather than in degrees. For example, a 10% grade has a rise of 10 feet in a distance of 100 feet, etc.

Grade Resistance is the drawbar pull needed to keep the vehicle in constant motion up a grade. This is in addition to the drawbar pull to overcome road resistance as expressed by another formula.

F = GR × W

F is drawbar pull in pounds.
GR is grade resistance in percent (20% is written as 0.20, etc.)
W is gross vehicle weight in pounds.

Air Resistance will be important only on fast moving vehicles (over 20 to 30 M.P.H.).

F = FA × 0.0025 × M.P.H.^{2}

F is additional drawbar pull needed to overcome air resistance.
FA is frontal area of vehicle in square feet.
M.P.H. is vehicle speed, miles per hour.

Axles and drive shafts must have a diameter large enough to transmit the torque without excessive deflection. The angle of deflection for a solid round axle may be calculated from this formula:

A = 583.6 × T × L ÷ (D^4 × E)

A is angle of deflection in degrees.
T is applied torque in inch pounds.
L is shaft length in inches.
E is modulus of elasticity of material. (12,000,000 for steel)
D is shaft diameter in inches.

Some authorities say that a steel shaft should be limited to an angular deflection of 0.08 degrees per foot of length to avoid failure.

Hydraulic Cylinder Force & Speed Calculations

Calculation of Hydraulic Cylinder Force...

EXAMPLE: A certain application requires a cylinder force of 25 tons. What should be the cylinder bore diameter used and at what gauge pressure?

SOLUTION: The required force is 25 tons × 2000 = 50,000 pounds. Refer to the "Hydraulic Cylinder Force" table on pages 15 and 16 which shows several combinations of piston diameter and PSI pressure which will produce 50,000 pounds of force or more. For example, a 6 inch piston will produce 56,550 pounds at 2000 PSI; a 7 inch piston will produce 57,725 lbs at 1500 PSI; an 8 inch piston will produce 50,265 lbs at 1000 PSI, a 10 inch piston will produce 58,900 lbs. at 750 PSI, etc. So there are many combinations which could be used, and the final choice is a matter of preference or of matching the pressure and flow capability of other components, particularly the pump.

In practice, choose a combination which will produce from 10% to 25% more than actually required by the load alone. This will provide a safety allowance which will take care of pressure losses in valves and piping, and mechanical losses in the cylinder.

EXAMPLE: How many pounds of force will be developed on the extension stroke of a 3¼″ bore cylinder operating at 1500 PSI? If this cylinder has a 1¾″ diameter piston rod, how much force will be developed on the retraction stroke?

SOLUTION: Refer to the "Hydraulic Cylinder Force" table on pages 15 and 16. The chart shows 12,444 lbs. A solution can also be obtained by using the piston area (8.296 square inches) and multiplying by the pressure (1500 PSI); 8.296 square inches × 1500 PSI = 12,444 lbs.

On the retraction stroke the amount of force developed on the 2.41 square inch rod area must be subtracted: 12,444 – 3608 = 8836 lbs.

EXAMPLE: What PSI gauge pressure is required for retraction of a 50,000 lb. load with an 8 inch bore cylinder having a 4 inch diameter rod?

SOLUTION: The net piston area must be found which is the full piston area minus the rod area. 50.27 (piston area) – 12.57 (rod area) = 37.7 square inches. PSI = 50,000 ÷ 37.7 = 1326 PSI. The actual pressure will be slightly greater due to friction of the piston in the barrel.

Calculation of Hydraulic Cylinder Speed...

EXAMPLE: At what speed would the piston of a 4 inch bore cylinder extend on an oil flow of 12 GPM?

SOLUTION: The table of "Hydraulic Cylinder Speeds" on pages 17 and 18 may be used or the speed figured with the formula which says that "speed is equal to the incoming flow of oil in cubic inches per minute, divided by the square inch area of the piston". The speed will be in inches per minute.

A flow of 12 GPM is 231 × 12 = 2772 cubic inches per minute. The speed is 2772 (flow rate) ÷ 12.57 (piston area) = 220.5 inches per minute. This checks very closely with the value shown in the table on page 17.

EXAMPLE: Find the GPM flow necessary to cause a 5 inch bore cylinder to travel at a rate of 175 inches per minute while extending.

How fast would this cylinder retract on the same oil flow if it had a 2 inch diameter piston rod?

SOLUTION: Flow is determined by multiplying the piston area in square inches times the travel rate in inches per minute. This gives flow in cubic inches per minute. Divide by 231 to convert to GPM: 19.64 (piston area) × 175 = 3437 cubic inches per minute. 3437 ÷ 231 = 14.88 GPM. This checks very closely with 15 GPM at 174 inches per minute shown on the chart on page 17.

To find the retraction speed on 14.88 GPM, the net piston area must be found. This is the full piston area minus the rod area: 19.64 (piston area) – 6.5 (rod area) = 16.5 square inches. The flow rate is 3437 cubic inches per minute (equivalent to 14.88 GPM) ÷ 16.5 (net area) = 208 inches per minute. Note that this is faster than the extension speed on the same oil flow.

Hydraulic Cylinder Force

Low Pressure Range – 500 to 1500 PSI – 1½″ to 14″ Bores

Cylinder forces, both extension and retraction, are shown in pounds. The chart on this page covers cylinder operation in the pressure range of 500 to 1500 PSI, and the chart on the next page covers the 2000 to 5000 PSI range. Lines in **bold type** show extension force, using the full piston area. Lines in ***italic type*** show retraction force with various size piston rods.

Remember that force values are theoretical, derived by calculation. Experience has shown that probably 5%, but certainly no more than 10% additional pressure will be required to make up cylinder losses.

For pressures not shown, the effective piston areas in the third column can be used as power factors. Multiply effective area times (continued on page 16)

Bore Dia., In.	Rod Dia., In.	Effec. Area, Sq. In.	Pressure Differential Across Cylinder Ports				
			500 PSI	750 PSI	1000 PSI	1250 PSI	1500 PSI
1½	**None***	**1.7672**	**884**	**1325**	**1767**	**2209**	**2651**
	5/8	*1.4604*	*730*	*1095*	*1460*	*1826*	*2191*
	1	*0.9818*	*491*	*736*	*982*	*1227*	*1473*
2	**None***	**3.1416**	**1571**	**2356**	**3142**	**3927**	**4712**
	1	*2.3562*	*1178*	*1767*	*2356*	*2945*	*3534*
	1⅜	*1.6567*	*828*	*1243*	*1657*	*2071*	*2485*
2½	**None***	**4.9087**	**2454**	**3682**	**4909**	**6136**	**7363**
	1	*4.1233*	*2062*	*3092*	*4123*	*5154*	*6185*
	1⅜	*3.4238*	*1712*	*2568*	*3424*	*4280*	*5136*
	1¾	*2.5034*	*1252*	*1878*	*2503*	*3129*	*3755*
3	**None***	**7.0686**	**3534**	**5301**	**7069**	**8836**	**10,603**
	1	*6.2832*	*3142*	*4712*	*6283*	*7854*	*9425*
	1⅜	*5.5837*	*2792*	*4188*	*5584*	*6980*	*8376*
	1¾	*4.6633*	*2332*	*3498*	*4664*	*5830*	*6996*
3¼	**None***	**8.2958**	**4148**	**6222**	**8296**	**10,370**	**12,444**
	1⅜	*6.8109*	*3405*	*5108*	*6811*	*8514*	*10,216*
	1¾	*5.8905*	*2945*	*4418*	*5891*	*7363*	*8836*
	2	*5.1542*	*2577*	*3866*	*5154*	*6443*	*7731*
4	**None***	**12.567**	**6284**	**9425**	**12,567**	**15,709**	**18,851**
	1¾	*10.162*	*5081*	*7622*	*10,162*	*12,703*	*15,243*
	2	*9.4254*	*4713*	*7069*	*9425*	*11,782*	*14,138*
	2½	*7.6583*	*3829*	*5744*	*7658*	*9573*	*11,487*
5	**None***	**19.635**	**9818**	**14,726**	**19,635**	**24,544**	**29,453**
	2	*16.493*	*8247*	*12,370*	*16,493*	*20,616*	*24,740*
	2½	*14.726*	*7363*	*11,045*	*14,726*	*18,408*	*22,089*
	3	*12.566*	*6283*	*9425*	*12,566*	*15,708*	*18,849*
	3½	*10.014*	*5007*	*7511*	*10,014*	*12,518*	*15,021*
6	**None***	**28.274**	**14,137**	**21,206**	**28,274**	**35,343**	**42,411**
	2½	*23.365*	*11,683*	*17,524*	*23,365*	*29,206*	*35,048*
	3	*21.205*	*10,603*	*15,904*	*21,205*	*26,506*	*31,808*
	3½	*18.653*	*9327*	*13,990*	*18,653*	*23,316*	*27,980*
	4	*15.707*	*7854*	*11,780*	*15,707*	*19,634*	*23,561*
7	**None***	**38.485**	**19,243**	**28,864**	**38,485**	**48,106**	**57,728**
	3	*31.416*	*15,708*	*23,562*	*31,416*	*39,270*	*47,124*
	3½	*28.864*	*14,432*	*21,648*	*28,864*	*36,080*	*43,296*
	4	*25.918*	*12,959*	*19,439*	*25,918*	*32,398*	*38,877*
	4½	*22.581*	*11,291*	*16,936*	*22,581*	*28,226*	*33,872*
	5	*18.850*	*9425*	*14,138*	*18,850*	*23,563*	*28,275*
8	**None***	**50.266**	**25,133**	**37,700**	**50,266**	**62,833**	**75,399**
	3½	*40.645*	*20,323*	*30,484*	*40,645*	*50,806*	*60,968*
	4	*37.699*	*18,850*	*28,274*	*37,699*	*47,124*	*56,549*
	4½	*34.362*	*17,181*	*25,772*	*34,362*	*42,953*	*51,543*
	5	*30.631*	*15,316*	*22,973*	*30,631*	*38,289*	*45,947*
	5½	*26.508*	*13,254*	*19,881*	*26,508*	*33,135*	*39,762*
10	**None***	**78.540**	**39,270**	**58,905**	**78,540**	**98,175**	**117,810**
	4½	*62.636*	*31,318*	*46,977*	*62,636*	*78,295*	*93,954*
	5	*58.905*	*29,453*	*44,179*	*58,905*	*73,631*	*88,358*
	5½	*54.782*	*27,391*	*41,087*	*54,782*	*68,478*	*82,173*
	7	*40.055*	*20,028*	*30,041*	*40,055*	*50,069*	*60,082*
12	**None***	**113.10**	**56,550**	**84,825**	**113,100**	**141,375**	**169,650**
	5½	*89.339*	*44,670*	*67,004*	*89,339*	*111,673*	*134,009*
14	**None***	**153.94**	**76,970**	**115,455**	**153,940**	**192,425**	**230,910**
	7	*115.46*	*57,730*	*86,595*	*115,460*	*144,325*	*173,190*

*These figures are for extension force. No piston rod diameter is involved.

Hydraulic Cylinder Force

High Pressure Range – 2000 to 5000 PSI – 1½″ to 14″ Bores

(continued from page 15) pressure to obtain cylinder force produced. Values in two or more columns can be added for a pressure not listed, or, force values can be obtained by interpolating between the next higher and the next lower pressure columns.

Pressure values along the top, of each chart are differential pressures across the two cylinder ports. This is the pressure to just balance the load, and not the pressure which must be produced by the system pump. There will be circuit flow losses in pressure and return lines due to oil flow, and these will require extra pressure. When designing a system, be sure to allow sufficient pump pressure, probably an extra 25% to 30% on the average, to supply both the cylinder and to satisfy system flow losses.

Bore Dia., In.	Rod Dia., In.	Effec. Area, Sq. In.	Pressure Differential Across Cylinder Ports				
			2000 PSI	2500 PSI	3000 PSI	4000 PSI	5000 PSI
1½	None*	1.7672	3534	4418	5302	7069	8836
	5/8	1.4604	2921	3651	4381	5842	7302
	1	0.9818	1964	2455	2945	3927	4909
2	None*	3.1416	6283	7854	9425	12,566	15,708
	1	2.366	4712	5891	7069	9425	11,781
	1⅜	1.6567	3313	4142	4970	6627	8284
2½	None*	4.9087	9817	12,272	14,726	19,635	24,544
	1	4.1233	8247	10,308	12,370	16,493	20,617
	1⅜	3.4238	6848	8560	10,271	13,695	17,119
	1¾	2.5034	5007	6259	7510	10,014	12,517
3	None*	7.0686	14,137	17,672	21,206	28,274	35,343
	1	6.2832	12,566	15,708	18,850	25,133	31,416
	1⅜	5.5837	11,167	13,959	16,751	22,335	27,919
	1¾	4.6643	9329	11,661	13,992	18,657	23,322
3¼	None	8.2958	16,592	20,740	24,887	33,183	41,479
	1⅜	6.8109	13,622	17,027	20,433	27,244	34,055
	1¾	5.8905	11,781	14,726	17,672	23,562	29,453
	2	5.1542	10,308	12,886	15,463	20,617	25,771
4	None*	12.567	25,134	31,418	37,701	50,268	62,835
	1¾	10.162	20,324	25,405	30,486	40,648	50,810
	2	9.4254	18,851	23,564	28,266	37,702	47,127
	2½	7.6583	15,317	19,146	22,975	30,633	38,292
5	None*	19.635	39,270	49,088	58,905	78,540	98,175
	2	16.493	32,986	41,233	49,479	65,972	82,465
	2½	14.726	29,450	36,815	44,178	58,904	73,630
	3	12.566	25,132	31,415	37,698	50,264	62,830
	3½	10.014	20,028	25,035	30,042	40,056	50,070
6	None*	28.274	56,548	70,685	84,822	113,096	141,370
	2½	23.365	46,730	58,413	70,095	93,460	116,825
	3	21.205	42,410	53,013	63,615	84,820	106,025
	3½	18.653	37,306	46,633	55,959	74,612	93,265
	4	15.707	31,414	39,268	47,121	62,828	78,535
7	None*	38.485	76,970	96,213	115,455	153,940	192,425
	3	31.416	62,832	78,540	94,248	125,664	157,080
	3½	28.864	57,728	72,160	86,592	115,456	144,320
	4	25.918	51,836	64,795	77,754	103,672	129,590
	4½	22.581	45,162	56,453	67,743	90,324	112,905
	5	18.850	37,700	47,125	56,550	75,400	94,260
8	None*	50.266	100,532	125,665	150,798	201,064	251,330
	3½	40.645	81,290	101,613	121,935	162,580	203,225
	4	37.699	75,398	94,248	113,097	150,796	188,495
	4½	34.362	68,724	85,905	103,086	137,448	171,810
	5	30.631	61,262	76,578	91,893	122,524	153,155
	5½	26.508	53,016	66,270	79,524	106,032	132,540
10	None*	78.540	157,080	196,350	235,620	314,160	392,700
	4½	62.636	125,272	156,590	187,908	250,544	313,180
	5	58.905	117,810	147,263	176,715	235,620	294,525
	5½	54.782	109,564	136,955	164,346	219,128	273,910
	7	40.055	80,110	100,138	120,165	160,220	200,275
12	None*	113.10	226,200	282,750	339,300	452,400	565,500
	5½	89.339	178,678	223,348	268,017	357,356	446,695
14	None*	153.94	307,880	384,850	461,820	615,760	769,700
	7	115.46	230,920	288,650	346,380	461,840	577,300

*These figures are for extension force. No piston rod diameter is involved.

Hydraulic Cylinder Speeds

Figures in body of chart are cylinder piston speeds in inches per minute. Piston and rod diameters are in inches. Horizontal lines in **bold type** are extension speeds. Lines in ***italic type*** are retraction speeds for the bore and rod diameters shown in the first two columns, using "net" piston area.

For Fluid Flows from 1 to 20 GPM

Piston Diam.	Rod Diam.	1 GPM	3 GPM	5 GPM	8 GPM	12 GPM	15 GPM	20 GPM
1½	None*	**131**	**392**	**654**	----	----	----	----
	5/8	*158*	*475*	*791*	----	----	----	----
	1	*236*	*706*	----	----	----	----	----
2	None*	**74**	**221**	**368**	**588**	**882**	----	----
	3/4	*86*	*257*	*428*	*684*	----	----	----
	1	*98*	*294*	*490*	*784*	----	----	----
	1⅜	*139*	*418*	*697*	----	----	----	----
2½	None*	**47**	**141**	**235**	**376**	**565**	**706**	**941**
	1	*56*	*168*	*280*	*448*	*672*	*840*	----
	1⅜	*67*	*202*	*337*	*540*	*810*	----	----
	1¾	*92*	*277*	*461*	*738*	----	----	----
3	None*	**33**	**98**	**163**	**261**	**392**	**490**	**654**
	1	*37*	*110*	*184*	*294*	*441*	*551*	*735*
	1½	*44*	*131*	*218*	*349*	*523*	*654*	*871*
	2	*59*	*176*	*294*	*471*	*706*	*882*	----
3¼	None*	**28**	**84**	**139**	**223**	**334**	**418**	**557**
	1⅜	*34*	*102*	*170*	*271*	*407*	*509*	*678*
	1¾	*39*	*118*	*196*	*314*	*471*	*588*	*784*
	2	*45*	*134*	*224*	*359*	*538*	*672*	*896*
3½	None*	**24**	**72**	**120**	**192**	**288**	**360**	**480**
	1¼	*28*	*83*	*138*	*220*	*330*	*413*	*550*
	1¾	*32*	*96*	*160*	*256*	*384*	*480*	*640*
	2	*36*	*107*	*178*	*285*	*428*	*535*	*713*
	2⅜	*44*	*133*	*222*	*356*	*534*	*667*	*890*
4	None*	**18**	**55**	**92**	**147**	**221**	**276**	**368**
	1¼	*20*	*61*	*102*	*163*	*244*	*306*	*407*
	1¾	*23*	*68*	*114*	*182*	*273*	*341*	*455*
	2	*25*	*74*	*123*	*196*	*294*	*368*	*490*
	2½	*30*	*90*	*151*	*241*	*362*	*452*	*603*
	2¾	*35*	*105*	*174*	*279*	*418*	*523*	*697*
5	None*	**12**	**35**	**59**	**94**	**141**	**176**	**235**
	1½	*13*	*39*	*65*	*103*	*155*	*194*	*259*
	2	*14*	*42*	*70*	*112*	*168*	*210*	*280*
	2½	*16*	*47*	*78*	*125*	*188*	*235*	*314*
	3	*18*	*55*	*92*	*147*	*221*	*276*	*368*
	3½	*23*	*69*	*115*	*186*	*277*	*346*	*461*
6	None*	**8.2**	**25**	**41**	**65**	**98**	**123**	**163**
	1¾	*8.9*	*27*	*45*	*71*	*107*	*134*	*179*
	2½	*10*	*30*	*49*	*79*	*119*	*148*	*198*
	3	*11*	*33*	*54*	*87*	*131*	*163*	*218*
	3½	*12*	*37*	*62*	*99*	*149*	*186*	*248*
	4	*15*	*44*	*74*	*118*	*176*	*221*	*294*
7	None*	**6.0**	**18**	**30**	**48**	**72**	**90**	**120**
	3	*7.4*	*22*	*37*	*59*	*88*	*110*	*147*
	3½	*8.0*	*24*	*40*	*64*	*96*	*120*	*160*
	4	*8.9*	*27*	*45*	*71*	*107*	*134*	*178*
	4½	*10*	*31*	*51*	*82*	*123*	*153*	*205*
	5	*12*	*37*	*61*	*98*	*147*	*184*	*245*
8	None*	**4.6**	**14**	**23**	**37**	**55**	**69**	**92**
	3½	*5.7*	*17*	*28*	*45*	*68*	*85*	*114*
	4	*6.1*	*18*	*31*	*49*	*74*	*92*	*123*
	4½	*6.7*	*20*	*34*	*54*	*81*	*101*	*134*
	5	*7.5*	*23*	*38*	*60*	*90*	*113*	*151*
	5½	*8.7*	*26*	*44*	*70*	*105*	*131*	*174*
10	None*	**2.9**	**8.8**	**15**	**24**	**35**	**44**	**59**
	4½	*3.7*	*11*	*18*	*30*	*44*	*55*	*74*
	5	*3.9*	*12*	*20*	*31*	*47*	*59*	*78*
	5½	*4.2*	*13*	*21*	*34*	*51*	*63*	*84*
	7	*5.8*	*17*	*29*	*46*	*69*	*87*	*115*

*These figures are for extension speed. No piston rod diameter is involved.

Cylinder Speeds for Fluid Flows From 25 to 100 GPM

Piston Diam.	Rod Diam.	25 GPM	30 GPM	40 GPM	50 GPM	60 GPM	75 GPM	100 GPM
3	None*	817	980	----	----	----	----	----
	1	919	----	----	----	----	----	----
3¼	None*	696	835	----	----	----	----	----
	1⅜	848	----	----	----	----	----	----
	1¾	980	----	----	----	----	----	----
3½	None*	600	720	960	----	----	----	----
	1¼	688	825	----	----	----	----	----
	1¾	800	----	----	----	----	----	----
	2	891	----	----	----	----	----	----
4	None*	460	551	735	919	----	----	----
	1¼	509	611	815	----	----	----	----
	1¾	568	682	909	----	----	----	----
	2	613	735	980	----	----	----	----
	2½	754	905	----	----	----	----	----
	2¾	871	----	----	----	----	----	----
5	None*	294	353	471	588	706	882	----
	1½	323	388	517	646	776	970	----
	2	350	420	560	700	840	----	----
	2½	392	471	627	784	941	----	----
	3	460	551	735	919	----	----	----
	3½	577	692	923	----	----	----	----
6	None*	204	245	327	409	490	613	817
	1¾	223	268	357	446	536	670	893
	2½	247	297	395	494	593	741	989
	3	272	327	436	545	654	817	----
	3½	310	372	495	619	743	929	----
	4	368	441	588	735	882	----	----
7	None*	150	180	240	300	360	450	600
	3	184	221	294	368	441	551	735
	3½	200	240	320	400	480	600	800
	4	223	267	357	446	535	668	891
	4½	256	307	409	511	614	767	----
	5	306	368	490	613	735	919	----
8	None*	115	138	184	230	270	345	460
	3½	142	170	227	284	341	420	568
	4	153	184	245	306	368	460	613
	4½	168	202	269	336	403	504	672
	5	189	226	302	377	452	566	754
	5½	218	261	349	436	523	654	871
10	None*	74	88	118	147	176	221	294
	4½	92	111	148	184	221	277	369
	5	98	118	157	196	235	294	392
	5½	105	127	169	211	253	316	422
	7	144	173	231	288	346	433	577
12	None*	51	61	82	102	123	153	204
	5½	65	78	103	129	155	194	259
	7	77	93	124	155	186	232	310
	8½	102	123	164	205	246	307	410
14	None*	38	45	60	75	90	113	150
	7	50	60	80	100	120	150	200
	8½	59	71	95	119	143	178	238
	10	77	92	123	153	184	230	306

*These figures are for extension speed. No piston rod diameter is involved.

Interpolation of Cylinder Speed Charts

Cylinder speed is directly proportional to **GPM**. To find speed at a flow not shown in charts, add speeds in two columns. **Example:** Speed with 35 **GPM** is the sum of speeds in the 5 **GPM** and 30 **GPM** columns.

Calculation of Cylinder Speed

These charts were calculated from the formula: $S = CIM \div A$, in which **S** is piston speed in inches per minute; **CIM** is flow in cubic inches per minute; and **A** is cross sectional area of cavity being filled, in square inches. **GPM** flows must be converted to cubic inches per minute. Multiply **GPM** times 231.

Extension speeds are calculated with full piston area, retraction speeds with "net area" which is piston area minus rod area. **(See Hydraulic Cylinder Force)** .

Pneumatic Cylinder Air Consumption

The purpose of estimating air consumption of a cylinder is usually to find the HP capacity which must be available from the air compressor to operate the cylinder on a continuous cycling application.

Air consumption can be estimated from the table below. The consumption can then be converted into compressor HP.

Using the Table to Calculate Air Consumption

Figures in the body of the table are air consumptions for cylinders with standard diameter piston rods. The saving of air for cylinders with larger diameter rods is negligible for most calculations.

Air consumption was calculated assuming the cylinder piston will be allowed to stall, at least momentarily, at each end of its stroke, giving it time to fill up with air to the pressure regulator setting. If reversed at either end of its stroke before full stall occurs, air consumption will be less than shown in the table.

The first step in the calculation is to be sure that the bore size of the selected cylinder will just balance the load at a pressure of 75% or less of the maximum pressure available to the system. This leaves about 25% of available pressure which can be used to overcome flow losses through piping and valving. This surplus pressure must be available or the cylinder cannot travel at normal speed.

Determine the exact air pressure needed to just balance the load resistance. Add about 25% for flow losses and set the system regulator to this pressure. This is also the pressure figure which should be used when going into the table.

After determining the regulator pressure, go into the proper column of the table. The figure shown in the table is the air consumption for a 1-inch stroke, forward and return. Take this figure and multiply times the number of inches of stroke and by the number of complete cycles, forward and back which the cylinder is expected to make in one minute. This gives the SCFM for the application.

Cylinder Air Consumption per 1-inch Stroke, Forward and Return

Regulator Outlet PSI (At Least 25% Above Load Balance PSI)

Cyl. Bore	60 PSI	70 PSI	80 PSI	90 PSI	100 PSI	110 PSI	120 PSI	130 PSI	140 PSI	150 PSI
1.50	.009	.010	.012	.013	.015	.016	.017	.018	.020	.021
2.00	.018	.020	.022	.025	.027	.029	.032	.034	.036	.039
2.50	.028	.032	.035	.039	.043	.047	.050	.054	.058	.062
3.00	.039	.044	.050	.055	.060	.066	.070	.076	.081	.087
3.25	.046	.053	.059	.065	.071	.078	.084	.090	.096	.102
4.00	.072	.081	.091	.100	.110	.119	.129	.139	.148	.158
5.00	.113	.128	.143	.159	.174	.189	.204	.219	.234	.249
6.00	.162	.184	.205	.227	.249	.270	.292	.314	.335	.357
8.00	.291	.330	.369	.408	.447	.486	.525	.564	.602	.642
10.0	.455	.516	.576	.637	.698	.759	.820	.881	.940	1.00
12.0	.656	.744	.831	.919	1.01	1.09	1.18	1.27	1.36	1.45
14.0	.890	1.01	1.13	1.25	1.37	1.49	1.61	1.72	1.84	1.96

Converting SCFM Into Compressor HP

Compression of air is an inefficient process because part of the energy is lost as heat of compression and can never be recovered. By over-compressing the air and then reducing it to a lower pressure through a regulator, the system losses are increased. The amount of this loss is nearly impossible to calculate, but on the average system may amount to 5 or 10%. Also, there is a small loss due to flow resistance through the regulator.

After finding the SCFM to operate the cylinder, refer to the tables on page 30. Convert into HP according to the kind of compressor used. Add 5 to 10% for the miscellaneous losses described above. This should be very close to the actual HP capacity needed.

EXAMPLE: Find compressor HP needed to cycle an air cylinder through a 28-inch stroke, 11 times a minute, against a load resistance of 1000 lbs.

SOLUTION: A 4″ bore cylinder working at 80 PSI would balance the 1000 lb. load. Add 25% more pressure (20 PSI) and set the pressure regulator at 100 PSI. From the above table, air consumption would be:

0.110 × 28 (stroke) × 11 (times a minute) = 33.88 SCFM

Refer to page 30. Assume a 2-stage compressor. At 100 PSI, 0.164 HP is required for each 1 SCFM. Total HP = 0.164 × 33.88 = 5.57 HP. Add 5% (or 0.278 HP) for miscellaneous losses. Total compressor HP = 5.57 + 0.278 = 5.848 HP.

Pneumatic Cylinder Force

Extension and Retraction – 60 to 130 PSI Pressure Range

Cylinder forces are shown in pounds for both extension and retraction. Lines in **bold type** show extension forces, using the full piston area. Lines in ***italic type*** show retraction forces with various size piston rods. Remember that force values are *theoretical*, derived by calculation.

Pressures along the top of the chart do not represent air supply pressure; they are differential pressures across the two cylinder ports. In practice, the air supply line must supply another 5% of pressure to make up for cylinder loss, and must supply an estimated 25 to 50% additional pressure to make up for flow losses in lines and valving so the cylinder will have sufficient travel speed.

For good design and highest circuit efficiency, open the cylinder speed control valves as wide as practical and reduce the pressure regulator setting to as low a pressure as will give satisfactory cylinder force and speed.

For pressures not shown, use the effective areas in the third column as power factors, Multiply effective area times differential pressure to obtain theoretical cylinder force.

Piston Dia., In.	Rod Dia., In.	Effec. Area, Sq. In.	60 PSI	70 PSI	80 PSI	90 PSI	100 PSI	110 PSI	120 PSI	130 PSI
1½	**None**	**1.77**	**106**	**124**	**142**	**159**	**177**	**195**	**212**	**230**
	5/8	*1.46*	*88*	*102*	*117*	*132*	*146*	*161*	*176*	*190*
	1	*.985*	*59*	*69*	*79*	*89*	*98*	*108*	*118*	*128*
1¾	**None**	**2.41**	**144**	**168**	**192**	**216**	**241**	**265**	**289**	**313**
	5/8	*2.10*	*126*	*147*	*168*	*189*	*210*	*231*	*252*	*273*
	1¼	*1.18*	*71*	*83*	*95*	*106*	*118*	*130*	*142*	*154*
2	**None**	**3.14**	**188**	**220**	**251**	**283**	**314**	**345**	**377**	**408**
	5/8	*2.83*	*170*	*198*	*227*	*255*	*283*	*312*	*340*	*368*
	1	*2.35*	*141*	*165*	*188*	*212*	*235*	*259*	*283*	*306*
2½	**None**	**4.91**	**295**	**344**	**393**	**442**	**491**	**540**	**589**	**638**
	5/8	*4.60*	*276*	*322*	*368*	*414*	*460*	*506*	*552*	*598*
	1	*4.12*	*247*	*289*	*330*	*371*	*412*	*454*	*495*	*536*
	1⅜	*3.43*	*206*	*240*	*274*	*308*	*343*	*377*	*411*	*445*
3	**None**	**7.07**	**424**	**495**	**565**	**636**	**707**	**778**	**848**	**919**
	1	*6.28*	*377*	*440*	*503*	*565*	*628*	*691*	*754*	*817*
	1¾	*4.66*	*280*	*326*	*373*	*420*	*466*	*513*	*560*	*606*
3¼	**None**	**8.30**	**498**	**581**	**664**	**747**	**830**	**913**	**996**	**1079**
	1	*7.51*	*451*	*526*	*601*	*676*	*751*	*827*	*902*	*977*
	1⅜	*6.82*	*409*	*477*	*545*	*613*	*681*	*750*	*818*	*886*
	1¾	*5.89*	*354*	*413*	*472*	*531*	*589*	*648*	*707*	*766*
3½	**None**	**9.62**	**577**	**674**	**770**	**866**	**962**	**1058**	**1155**	**1251**
	1	*8.84*	*530*	*618*	*707*	*795*	*884*	*972*	*1060*	*1149*
4	**None**	**12.57**	**754**	**880**	**1006**	**1131**	**1257**	**1382**	**1508**	**1634**
	1	*11.78*	*707*	*825*	*943*	*1061*	*1178*	*1296*	*1415*	*1532*
	1⅜	*11.09*	*665*	*776*	*887*	*998*	*1109*	*1219*	*1330*	*1441*
	1¾	*10.16*	*610*	*712*	*813*	*915*	*1016*	*1118*	*1220*	*1321*
5	**None**	**19.64**	**1178**	**1375**	**1571**	**1768**	**1964**	**2160**	**2357**	**2553**
	1	*18.85*	*1131*	*1320*	*1508*	*1697*	*1885*	*2074*	*2263*	*2451*
	1⅜	*18.16*	*1089*	*1271*	*1452*	*1634*	*1816*	*1997*	*2179*	*2360*
6	**None**	**28.27**	**1696**	**1979**	**2262**	**2544**	**2827**	**3110**	**3392**	**3675**
	1⅜	*26.79*	*1607*	*1875*	*2143*	*2411*	*2679*	*2946*	*3214*	*3482*
	1¾	*25.90*	*1552*	*1811*	*2069*	*2328*	*2586*	*2845*	*3104*	*3362*
7	**None**	**38.49**	**2309**	**2694**	**3079**	**3464**	**3849**	**4234**	**4619**	**5004**
	1⅜	*37.01*	*2220*	*2590*	*2960*	*3331*	*3701*	*4071*	*4441*	*4811*
8	**None**	**50.27**	**3016**	**3519**	**4022**	**4524**	**5027**	**5530**	**6032**	**6535**
	1⅜	*48.79*	*2927*	*3415*	*3903*	*4391*	*4879*	*5366*	*5854*	*6342*
	1¾	*47.90*	*2872*	*3351*	*3829*	*4308*	*4786*	*5265*	*5744*	*6222*
10	**None**	**78.54**	**4712**	**5498**	**6283**	**7069**	**7854**	**8639**	**9425**	**10210**
	1¾	*76.14*	*4568*	*5329*	*6091*	*6852*	*7614*	*8375*	*9136*	*9898*
	2	*75.40*	*4524*	*5278*	*6032*	*6786*	*7540*	*8294*	*9048*	*9802*
12	**None**	**113.1**	**6786**	**7917**	**9048**	**10179**	**11310**	**12441**	**13572**	**14703**
	2	*110.0*	*6598*	*7697*	*8797*	*9896*	*10996*	*12095*	*13195*	*14295*
	2½	*108.2*	*6491*	*7573*	*8655*	*9737*	*10819*	*11901*	*12983*	*14075*
14	**None**	**153.9**	**9234**	**10773**	**12312**	**13851**	**15390**	**16929**	**18468**	**20007**
	2½	*149.0*	*8939*	*10429*	*11919*	*13409*	*14899*	*16389*	*17879*	*19369*
	3	*146.8*	*8810*	*10278*	*11747*	*13215*	*14683*	*16151*	*17620*	*19088*

Internal Fluid PSI on Tubing

This table is for use in selecting wall thickness of tubing. Figures in the body of the table are internal fluid pressures in PSI that will produce a fiber stress of 10,000 PSI along the circumference, tending to rupture the tubing. If a tube is made of steel with an ultimate strength of 40,000 PSI, the safety factor would be 4.

Tube	Thickness of Tubing Wall, Inches											
O.D.	**.120**	**.156**	**.187**	**.219**	**.250**	**.313**	**.375**	**.500**	**.625**	**.750**	**.875**	**1.000**
1½	1600	2080	2493	2920	3333	4173	5000	6667	8333	---	---	---
1¾	1371	1783	2137	2503	2857	3577	4286	5714	7143	---	---	---
2	1200	1560	1870	2190	2500	3130	3750	5000	6250	7500	---	---
2¼	1067	1387	1662	1947	2222	2782	3333	4444	5556	6667	---	---
2½	960	1248	1496	1752	2000	2504	3000	4000	5000	6000	7000	---
2¾	873	1135	1360	1593	1818	2276	2727	3636	4545	5455	6364	7273
3	800	1040	1247	1460	1667	2087	2500	3333	4167	5000	5833	6667
3¼	738	960	1151	1348	1538	1926	2308	3077	3846	4615	5385	6154
3½	686	891	1069	1251	1429	1789	2143	2857	3571	4286	5000	5714
3¾	640	832	997	1168	1333	1669	2000	2667	3333	4000	4667	5333
4	600	780	935	1095	1250	1565	1875	2500	3125	3750	4375	5000
4¼	565	734	880	1031	1176	1473	1765	2353	2941	3529	4118	4706
4½	533	693	831	973	1111	1391	1667	2222	2778	3333	3889	4444
4¾	505	657	787	922	1053	1318	1579	2105	2632	3158	3684	4211
5	480	624	748	876	1000	1252	1500	2000	2500	3000	3500	4000
5½	436	567	680	796	909	1138	1364	1818	2273	2727	3182	3636
6	400	520	623	730	833	1043	1250	1667	2083	2500	2917	3333
6½	369	480	575	674	769	963	1154	1538	1923	2308	2692	3077
7	---	446	534	626	714	894	1071	1429	1786	2143	2500	2857
7½	---	416	499	584	667	835	1000	1333	1667	2000	2333	2667
8	---	---	468	548	625	783	938	1250	1563	1875	2188	2500
8½	---	---	---	515	588	736	882	1176	1471	1765	2059	2353
9	---	---	---	---	556	696	833	1111	1389	1667	1944	2222
9½	---	---	---	---	526	659	789	1053	1316	1579	1842	2105
10	---	---	---	---	500	626	750	1000	1250	1500	1750	2000
10½	---	---	---	---	476	596	714	952	1190	1429	1667	1905

The above table is calculated by Barlow's formula: $\mathbf{P} = \mathbf{2t} \times \mathbf{S} \div \mathbf{O}$ in which **P** is the internal pressure in PSI, **t** is wall thickness of tubing in inches, **S** is the fiber stress allowable in the tubing in PSI (a value of 10,000 PSI is used in the table), **O** is the outside diameter of the tubing in inches.

Piston Rod Column Strength

Long, slim piston rods may buckle if subjected to too heavy a push load. The table below suggests the minimum diameter piston rod to use under various conditions of load and unsupported rod length, and is to be used in accordance with the instructions in the next paragraph. There must be no side load or bending stress at any point along the rod.

How to Use the Table. Exposed rod length is shown along the top of the table. This is usually somewhat longer than the actual stroke of the cylinder. The vertical scale, column 1, shows the load on the cylinder, and is expressed in English tons (1 ton = 2000 lbs.). If both the end of the rod and the FRONT end of the cylinder barrel are rigidly supported, a smaller rod will have sufficient column strength, and you may use, as **Exposed Length of Piston Rod**, one-half of the actual rod length.

For example, if the actual length is 80", and if the cylinder barrel and rod end are supported as described, you could enter the table in the column marked 40. On the other hand if hinge mounting is used on both cylinder and rod (pin-to-pin), you may not be safe in using actual exposed rod length, and should use about twice the actual length. For example, if the actual length is 20", you should enter the table in the 40" column.

Minimum Piston Rod Diameter

Figures in body of chart are suggested minimum rod diameters, in inches.

	Exposed Length of Piston Rod, Inches							
Tons	**10**	**20**	**40**	**60**	**70**	**80**	**100**	**120**
1/2			3/4	1				
3/4			13/16	1 1/16				
1		5/8	7/8	1 1/8	1 1/4	1 3/8		
1 1/2		11/16	15/16	1 3/16	1 3/8	1 1/2		
2		3/4	1	1 1/4	1 7/16	1 9/16	1 3/16	
3	13/16	7/8	1 1/8	1 3/8	1 9/16	1 5/8	1 7/8	
4	15/16	1	1 3/16	1 1/2	1 5/8	1 3/4	2	2 1/4
5	1	1 1/8	1 5/16	1 9/16	1 3/4	1 7/8	2 1/8	2 3/8
7 1/2	1 3/16	1 1/4	1 7/16	1 3/4	1 7/8	2	2 1/4	2 1/2
10	1 3/8	1 7/16	1 5/8	1 7/8	2	2 1/8	2 7/16	2 3/4
15	1 1/16	1 3/4	1 7/8	2 1/8	2 1/4	2 3/8	2 1/16	3
20	2	2	2 1/8	2 3/8	2 1/2	2 5/8	2 7/8	3 1/4
30	2 3/8	2 7/16	2 1/2	2 3/4	2 3/4	2 7/8	3 1/4	3 1/2
40	2 3/4	2 3/4	2 7/8	3	3	3 1/4	3 1/2	3 3/4
50	3 1/8	3 1/8	3 1/4	3 3/8	3 1/2	3 1/2	3 3/4	4
75	3 3/4	3 3/4	3 7/8	4	4	4 1/8	4 3/8	4 1/2
100	4 3/8	4 3/8	4 3/8	4 1/2	4 3/4	4 3/4	4 7/8	5
150	5 3/8	5 3/8	5 3/8	5 1/2	5 1/2	5 1/2	5 3/4	6

CAUTION: Hinge mounted cylinders, when mounted horizontally or at any angle other than vertical, create a bending stress on the rod when extended, due to cylinder weight. On large bore and/or long stroke hinge mounted cylinders, the trunnion mounting rather than tang or clevis mounting should be used, and the trunnion should be located in a position which will balance the cylinder weight when extended.

Horsepower to Drive a Pump

Figures in the body of this table show the horsepower needed to drive a hydraulic pump having an efficiency of 85%. Most positive displacement pumps fall in the range of 80% to 90% efficiency, so this chart should be accurate to within 5% for nearly any pump. The table was calculated from the formula: **HP = PSI × GPM ÷ (1714 × 0.85)**. For pumps with other than 85% efficiency, this formula can be used, substituting actual efficiency in place of 0.85.

Using the Table ...

The range of 500 to 5000 PSI covers most hydraulic systems, but power requirements can be determined for conditions outside the table, or for intermediate values, by combining values in the table; For example, power at 4000 PSI will be exactly twice the figures shown for 2000 PSI. At 77 GPM, power will be the sum of the figures shown in the 75 and 2 GPM lines, etc.

For systems of less than 500 PSI, horsepower calculations tend to become inaccurate because mechanical friction losses reduce pump efficiency.

Rule – Of – Thumb ...

Approximate power requirements can be figured with simple mental arithmetic with this rule-of-thumb:

1 HP is required for each 1 GPM @ 1500 PSI

For example, a 5 GPM pump operating at 1500 PSI would need 5 HP, or at 3000 would need 10 HP. A 10 GPM pump at 1000 PSI would need 6⅔ HP, or the same pump operating at 1500 PSI would need 10 HP, etc.

Another rule-of-thumb states that about 5% of the pump maximum rated horsepower is required to idle that pump when it is "unloaded" and the oil is circulating at zero PSI. This amount of power is consumed in flow losses plus mechanical friction losses in bearings and pumping elements.

Figures in table are HP's required to drive a hydraulic pump.

GPM	500 PSI	750 PSI	1000 PSI	1250 PSI	1500 PSI	1750 PSI	2000 PSI	2500 PSI	3000 PSI	5000 PSI
1/2	.172	.257	.343	.429	.515	.600	.686	.858	1.03	1.72
1	.343	.515	.686	.858	1.03	1.20	1.37	1.72	2.06	3.43
1½	.515	.772	1.03	1.29	1.54	1.80	2.06	2.57	3.09	5.15
2	.686	1.03	1.37	1.72	2.06	2.40	2.75	3.43	4.12	6.86
2½	.858	1.29	1.72	2.14	2.57	3.00	3.43	4.29	5.15	8.58
3	1.03	1.54	2.06	2.57	3.09	3.60	4.12	5.15	6.18	10.3
3½	1.20	1.80	2.40	3.00	3.60	4.20	4.80	6.00	7.21	12.0
4	1.37	2.06	2.75	3.43	4.12	4.80	5.49	6.86	8.24	13.7
5	1.72	2.57	3.43	4.29	5.15	6.00	6.86	8.58	10.3	17.2
6	2.06	3.09	4.12	5.15	6.18	7.21	8.24	10.3	12.4	20.6
7	2.40	3.60	4.80	6.00	7.21	8.41	9.61	12.0	14.4	24.0
8	2.75	4.12	5.49	6.86	8.24	9.61	11.0	13.7	16.5	27.5
9	3.09	4.63	6.18	7.72	9.27	10.8	12.4	15.4	18.5	30.9
10	3.43	5.15	6.86	8.58	10.3	12.0	13.7	17.2	20.6	34.3
12	4.12	6.18	8.24	10.3	12.4	14.4	16.5	20.6	24.7	41.2
15	5.15	7.72	10.3	12.9	15.4	18.0	20.6	25.7	30.9	51.5
20	6.86	10.3	13.7	17.2	20.6	24.0	27.5	34.3	41.2	68.6
25	8.58	12.9	17.2	21.4	25.7	30.0	34.3	42.9	51.5	85.8
30	10.3	15.4	20.6	25.7	30.9	36.0	41.2	51.5	61.8	103
35	12.0	18.0	24.0	30.0	36.0	42.0	48.0	60.0	72.1	120
40	13.7	20.6	27.5	34.3	41.2	48.0	54.9	68.6	82.4	137
45	15.4	23.2	30.9	38.6	46.3	54.1	61.8	77.2	92.7	154
50	17.2	25.7	34.3	42.9	51.5	60.0	68.6	85.8	103	172
55	18.9	28.3	37.8	47.2	56.6	66.1	75.5	94.4	113	189
60	20.6	30.9	41.2	51.5	61.8	72.1	82.4	103	124	206
65	22.3	33.5	44.6	55.8	66.9	78.1	89.2	112	134	223
70	24.0	36.0	48.0	60.0	72.1	84.1	96.1	120	144	240
75	25.7	38.6	51.5	64.3	77.2	90.1	103	129	154	257
80	27.5	41.2	54.9	68.6	82.4	96.1	110	137	165	275
85	29.2	43.8	58.3	72.9	87.5	102	117	146	175	292
90	30.9	46.3	61.8	77.2	92.7	108	124	154	185	309
95	32.6	48.9	65.2	81.5	97.8	114	130	163	196	326
100	34.3	51.5	68.6	85.8	103	120	137	172	206	343

Torque/HP/Speed Relations

This chart can be used to find the torque, horsepower or speed of any kind of drive (electric motor, hydraulic or pneumatic motor, engine, rotary actuator, etc.) if two of those three values are known. The chart is a tabular solution to the following basic formulas:

To find Horsepower (**HP**), use the formula: **HP = (T × RPM) ÷ 5252**
To find Torque in ft. lbs. (**T**), use the formula: **T = (HP × 5252) ÷ RPM**
To find Speed (**RPM**), use the formula: **RPM = (HP × 5252) ÷ T**

The figures in the body of the chart are torque values in foot/pounds

	RPM (Revolutions Per Minute)									
HP	**100**	**500**	**750**	**1000**	**1200**	**1500**	**1800**	**2400**	**3000**	**3600**
1/4	13.1	2.63	1.76	1.31	1.10	.876	.730	.548	.438	.365
1/3	17.5	3.50	2.34	1.75	1.46	1.17	.972	.730	.584	.486
1/2	26.3	5.25	3.50	2.63	2.20	1.75	1.46	1.10	.875	.730
3/4	39.4	7.87	5.24	3.94	3.28	2.62	2.18	1.64	1.31	1.09
1	52.5	10.5	7.00	5.25	4.38	3.50	2.92	2.19	1.75	1.47
1½	78.8	15.7	10.5	7.88	6.56	5.26	4.38	3.28	2.63	2.19
2	105	21.0	14.0	10.5	8.76	7.00	5.84	4.38	3.50	2.92
3	158	31.5	21.0	15.8	13.1	10.5	8.76	6.57	5.25	4.38
5	263	52.5	35.0	26.3	22.0	17.5	14.6	11.0	8.75	7.30
7½	394	78.8	53.2	39.4	32.8	26.3	21.8	16.4	13.1	10.9
10	525	105	70.0	52.5	43.8	35.0	29.2	21.9	17.5	14.6
15	788	158	105	78.8	65.6	52.6	43.8	32.8	26.5	21.9
20	1050	210	140	105	87.6	70.0	58.4	43.8	35.0	29.2
25	1313	263	175	131	110	87.7	73.0	54.8	43.8	36.5
30	1576	315	210	158	131	105	87.4	65.7	52.6	43.7
40	2100	420	280	210	175	140	116	87.5	70.0	58.2
50	2626	523	350	263	220	175	146	110	87.5	72.8
60	3131	630	420	315	262	210	175	131	105	87.4
75	3940	788	525	394	328	262	218	164	131	109
100	5250	1050	700	525	438	350	292	219	175	146
125	6565	1313	875	657	548	437	364	274	218	182
150	7878	1580	1050	788	656	526	438	328	265	219
200	10,500	2100	1400	1050	876	700	584	438	350	292
250	13,130	2630	1750	1310	1100	877	730	548	438	365

Pump and Motor Torque

This chart can be applied either to a hydraulic motor or pump. Figures in the chart are theoretical torque values, in foot pounds, required to turn the shaft of a hydraulic pump or that will be placed on the shaft of a hydraulic motor. Chart values were calculated from the formula:

$$T = D \times PSI \div 24\pi$$

Where: **T** is torque in foot pounds, **D** is displacement in cubic inches per revolution (**C. I. R.**), **PSI** is pressure across pump or motor, and $\pi = 3.14$

The figures in the body of the chart are torque values in foot pounds

GPM @ 1200 RPM	**DISPL. C. I. R.**	PSI (Pounds Per Square Inch)								
		250	**500**	**750**	**1000**	**1250**	**1500**	**2000**	**2500**	**3000**
3	0.577	1.91	3.82	5.74	7.65	9.57	11.5	15.3	19.1	23.0
5	0.962	3.19	6.38	9.56	12.7	15.9	19.1	25.5	31.9	38.2
8	1.54	5.22	10.4	15.7	20.9	26.1	31.3	41.8	52.2	62.7
10	1.92	6.37	12.7	19.1	25.5	31.9	38.2	51.0	63.7	76.5
12	2.31	7.64	15.3	22.9	30.6	38.2	45.8	61.1	76.4	91.6
18	3.46	11.4	22.9	34.4	45.9	57.4	68.8	91.7	115	138
25	4.81	15.9	31.9	47.9	63.9	79.7	95.7	127	159	191
40	7.70	25.5	51.1	76.5	102	127	153	204	255	306
50	9.62	31.9	63.8	95.6	127	159	191	255	319	382
75	14.43	47.8	95.6	144	191	239	287	383	478	574
85	16.43	54.2	108	163	217	271	325	434	542	651
100	19.2	63.7	127	191	255	319	382	510	637	765

Mechanical Transmission Efficiency

A hydraulic motor coupled to a load through mechanical transmission items must have additional power to supply transmission losses. Values given below are average, and where calculations must be precise, efficiency ratings should be requested from the transmission item manufacturer. Losses must be figured progressively through each stage of mechanical transmission. For example: start with the final stage. Figure loss through this stage. Add the extra power required. Then proceed to the next stage upstream on the power flow. Figure extra power for this stage, add it to the total, then proceed to the next stage, etc., up to the driving motor or engine.

The following chart shows typical efficiencies for various mechanical transmission items.

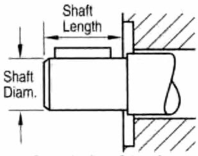
Typical Power Transmission Efficiencies

Machine	Typical Efficiency
V-belt drives	95%
Timing belt drives	98%
Poly-V or ribbed belt drives	97%
Flat belt drives, leather or rubber	98%
Nylon core	98% to 99%
Variable speed, spring loaded, wide range	
V-belt drives	80% to 90%
Compound drive	75% to 90%
Cam-reaction drive	95%
Helical gear reducer	
Single-stage	98%
Two-stage	96%
Worm gear reducer	
10:1 ratio	86%
25:1 ratio	82%
60:1 ratio	66%
Roller chain	98%
Leadscrew, 60 deg. helix angle	65% to 85%
Flexible coupling, shear-type	99%+

Pump/Motor Shafts & Flanges

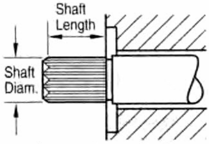
ANSI Shaft and flange code assignments for fluid power pumps and motors. Complete dimensions may be obtained from ANSI B93.6-1972.

ANSI Shaft Code	Shaft Diam.	Short Shaft Lgth.	Long Shaft Lgth.	Key Width	SAE Shaft Code
13-1	.500	0.750	---	0.125	A-A
16-1	.625	0.938	2.000	0.156	A
22-1	.875	1.312	2.500	0.250	B
25-1	1.000	1.500	2.750	0.250	B-B
32-1	1.250	1.875	3.00	0.312	C
38-1	1.500	2.125	3.250	0.375	C-C
44-1	1.750	2.625	3.625	0.437	D, E



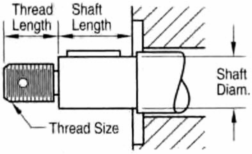
Straight Shaft (Without Threads)

ANSI Shaft Code	Shaft Diam.	Shaft Lgth.	Spline Specifications	SAE Shaft Code
13-4	.500	0.750	9T, 20/40 DP	A-A
16-4	.625	0.938	9T, 16/32 DP	A
22-4	.875	1.312	13T, 16/32 DP	B
25-4	1.000	1.500	15T, 16/32 DP	B-B
32-4	1.250	1.875	14T, 12/24 DP	C
38-4	1.500	2.125	17T, 12/24 DP	C-C
44-4	1.750	2.625	13T, 8/16 DP	D, E
50-4	2.000	3.125	15T, 8/16 DP	F



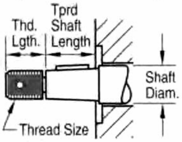
30° Involute Spline

ANSI Shaft Code	Shaft Diam.	Str. Shaft Lgth.	Thd. Size	Thd. Lgth.	Key Width
13-2	0.500	0.750	3/8-24	0.532	.125
16-2	0.625	0.938	1/2-20	0.719	.156
22-2	0.875	1.312	5/8-18	0.906	.250
25-2	1.000	1.500	3/4-16	1.062	.250
32-2	1.250	1.875	1-12	1.219	.312
38-2	1.500	2.125	1-1/8-12	1.375	.375
44-2	1.750	2.625	1-1/4-12	1.562	.437



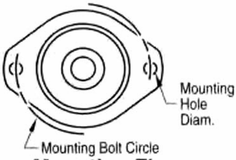
Straight Shaft (With Threads)

ANSI Shaft Code	Shaft Diam.	Tprd. Shaft Lgth.	Thd. Shaft Lgth.	Thread Size	Key Width
13-3	0.500	0.688	0.500	5/16-32	.125
16-3	0.625	0.688	0.719	1/2-20	.156
22-3	0.875	1.125	0.906	5/8-18	.250
25-3	1.000	1.375	1.062	3/4-16	.250
32.3	1.250	1.375	1.219	1½	.312
38-3	1.500	1.875	1.375	1⅛-12	.375
44-3	1.750	2.125	1.562	1¼-12	.437
50-3	2.000	2.875	1.562	1¼-12	.500



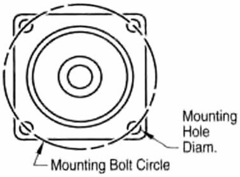
Tapered Shaft (With Threads)

ANSI Flange Code	SAE Flange Code	SAE HP Rating	Mount Bolt Circle	Mount Hole Diam.	Pilot Diam., In.
50-2	A-A	5	3.250	.406	2.00
82-2	A	10	4.188	.438	3.25
101-2	B	25	5.750	.562	4.00
127-2	C	50	7.125	.688	5.00
152-2	D	100	9.000	.812	6.00
165-2	E	200	12.500	1.062	6.50
177-2	F	300	13.781	1.062	7.00



Mounting Flange (Two Bolt)

ANSI Flange Code	SAE Flange Code	SAE HP Rating	Mount Bolt Circle	Mount Hole Diam.	Pilot Diam., In.
101-4	B	25	5.000	.5625	4.00
127-4	C	50	6.375	.5625	5.00
152-4	D	100	9.000	.8125	6.00
165-4	E	200	12.500	.8125	6.50
177-4	F	300	13.78	1.063	7.00



Mounting Flange (Four Bolt)

Required Flow for Operating an Air Cylinder

$$C_v = \frac{Area \times Stroke \times A \times Cf}{Time \times 29}$$

Area = $\pi \times$ dia^2/4 or see Table 2 (sq. in.)

Stroke = Travel (in.)

A = pressure drop constant see Table 1

Cf = Compression Factor see Table 1

Time = seconds

Table 1 – Compression Factors and "A" Constants

Inlet Pressure (PSIG)	*Cf* Compression Factor	"A" Constants for Various Pressure Drops		
		2 PSI ΔP	5 PSI ΔP	10 PSI ΔP
10	1.6	0.155	0.102	
20	2.3	0.129	0.083	0.066
30	3.0	0.113	0.072	0.055
40	3.7	0.097	0.064	0.048
50	4.4	0.091	0.059	0.043
60	5.1	0.084	0.054	0.040
70	5.7	0.079	0.050	0.037
80	6.4	0.075	0.048	0.035
90	7.1	0.071	0.045	0.033
100	7.8	0.068	0.043	0.031
110	8.5	0.065	0.041	0.030
120	9.2	0.062	0.039	0.029

Table 2 – Cylinder Area

Bore Size	Cylinder Area (sq. in.)	Bore Size	Cylinder Area (sq. in.)
3/4"	0.44	4"	12.57
1"	0.79	4½"	15.90
1⅛"	0.99	5"	19.64
1¼"	1.23	6"	28.27
1½"	1.77	7"	38.48
1¾"	2.41	8"	50.27
2"	3.14	10"	78.54
2½"	4.91	12"	113.10
3¼"	8.30	14"	153.94
3⅝"	10.32		

Note: Use "A" constant at 5 PSI ΔP for most applications. On very critical applications, use "A" at 2 PSI ΔP. You will find in many cases, a 10 PSI ΔP is not detrimental, and can save money and mounting space.

Required Flow for Operating a Hydraulic Cylinder

$$GPM = \frac{Area \times Stroke \times 60}{Time \times 231}$$

Area = $\pi \times$ dia^2/4 or see Table 2 (sq. in.)

Stroke = Travel (in.)

Time = seconds

HP to Compress Air

These tables show the approximate HP required to compress 1 SCFM (standard cubic foot per minute) of air from atmospheric pressure of 0 PSI to the pressures shown in the tables. Since isothermal and adiabatic compression are both theoretical conditions, these tables were calculated for compression conditions about halfway between these two theoretical extremes. Inlet air is assumed to be about room temperature.

Tables are shown for single-stage, two-stage, and three-stage piston-type compressors, assuming their efficiency to be about 85%. The effect of jacket cooling water was not considered.

The tables were prepared from information published in *Machinery's Handbook*. Please refer to your copy of the handbook for additional information on the compression of air.

HP to Operate Air Cylinders

One important use for these tables is to estimate the compressor HP capacity needed to operate an air cylinder. The SCFM required by the cylinder under stated operating conditions must first be calculated by the method on page 19. Then the appropriate column in the table below can be used to convert SCFM into HP. For example, if cylinder consumption has been calculated to be 24 SCFM and if the compressor is a 2-stage model, the HP needed at 90 PSI will be: HP = 24 × 0.156 = 3.74.

Power Loss Through a Pressure Regulator

Air compressor power is wasted by compressing air to a pressure higher than necessary then reducing it through a regulator. The power wasted cannot be easily calculated because accurate data cannot be obtained. But it can be estimated with sufficient accuracy with this method.

Use the chart below for your kind of compressor. Calculate the HP to compress 1 SCFM of air to the regulator inlet pressure. Then calculate the HP to compress 1 SCFM to the regulator outlet or reduced pressure. Subtract the two. This will show the HP wasted for every 1 SCFM passing through the regulator. Multiply times the SCFM air flow through the circuit.

Horsepower for Compressing Air

Efficiency of All Compressors is Assumed to Be 85%

1-Stage Compressor PSI	HP*	2-Stage Compressor PSI	HP*	3-Stage Compressor PSI	HP*
5	.021	50	.116	100	.159
10	.040	60	.128	150	.190
15	.056	70	.138	200	.212
20	.067	80	.148	250	.230
25	.079	90	.156	300	.245
30	.095	100	.164	350	.258
35	.099	110	.171	400	.269
40	.107	120	.178	450	.279
45	.116	130	.185	500	.289
50	.123	140	.190	550	.297
55	.130	150	.196	600	.305
60	.136	160	.201	650	.311
65	.143	170	.206	700	.317
70	.148	180	.211	750	.323
75	.155	190	.216	800	.329
80	.160	200	.220	850	.335
85	.166	210	.224	900	.340
90	.170	220	.228	950	.345
95	.175	230	.232	1000	.350
100	.179	240	.236	1050	.354
110	.188	250	.239	1100	.358
120	.196	260	.243	1150	.362
130	.204	270	.246	1200	.366
140	.211	280	.250	1250	.370
150	.218	290	.253	1300	.374
160	.225	300	.255	1350	.378
170	.232	350	.269	1400	.380
180	.239	400	.282	1450	.383
190	.244	450	.293	1500	.386
200	.250	500	.303	1550	.390

*HP to compress 1 SCFM from 0 PSI to the values shown.

NOTE: The power required from other types of compressors of the same number of stages will be related to these values as the efficiency of the other compressor is to the assumed 85% efficiency used for these tables.

Tank Pump-Down Time

For Large Vacuum Tanks

Use this chart or the formula at the foot of this page to estimate the time to evacuate a tank to a desired degree of vacuum starting either from atmosphere or from a partial vacuum.

The chart is for a small vane or piston type vacuum pump which will deadhead (with inlet blocked) at a vacuum of 27 or 28″ Hg (when the barometer is at 30″ Hg). If using a vacuum pump much different from this, calculate running time from the formula.

The chart shows running time, in minutes, for a vacuum pump with a free running displacement (both ports open to atmosphere) of 1 SCFM. For pumps with a different displacement the running time must be adjusted by dividing chart values by the actual pump displacement.

Running time values are approximate because the efficiency will vary between pumps of different manufacture.

Running Time on a 1 SCFM Vacuum Pump

Cu. Ft.	3½	5	7½	10	17½	25	40	55	85	130
Gallons	26.2	37.4	56.1	74.8	131	187	300	411	636	972
Vac ″Hg	Time, in Minutes, to Evacuate Tank									
9	1.4	1.9	2.9	3.9	6.8	9.7	15.5	21.3	33.0	50.4
10	1.5	2.2	3.3	4.4	7.7	11.1	17.7	24.3	37.6	57.5
11	1.7	2.5	3.7	4.9	8.6	12.3	19.7	27.1	41.9	64.1
12	2.0	2.8	4.2	5.6	9.8	14.0	22.4	30.8	47.6	72.7
13	2.2	3.1	4.7	6.2	10.9	15.6	25.0	34.3	53.1	81.2
14	2.4	3.5	5.2	6.9	12.1	17.3	27.7	38.1	58.9	90.1
15	2.7	3.8	5.8	7.7	13.4	19.2	30.7	42.2	65.2	100
16	3.0	4.2	6.4	8.5	14.8	21.2	33.9	46.6	72.0	110
17	3.3	4.7	7.0	9.3	16.3	23.4	37.4	51.4	79.4	121
18	3.6	5.1	7.1	10.3	18.0	25.7	41.2	56.6	87.5	134
19	4.0	5.7	8.5	11.3	19.9	28.4	45.4	62.4	96.5	148
20	4.4	6.3	9.4	12.5	21.9	31.3	50.1	68.9	106	163
21	4.9	6.9	10.4	13.9	24.3	34.7	55.5	76.2	118	180
22	5.4	7.7	11.6	15.4	27.0	38.5	61.6	84.7	131	200
23	6.0	8.6	12.9	17.2	30.1	43.1	68.9	94.8	146	224
24	6.8	9.7	14.6	19.4	34.1	48.6	77.8	107	165	253
25	8.2	11.7	17.5	23.3	40.8	58.4	93.4	128	198	303
26	9.2	13.3	19.8	26.4	46.2	66.0	106	145	224	343
27	11.7	16.7	25.0	33.3	58.3	83.3	133	183	283	433

How to Use the Chart

Tank volumes, both in cubic feet and gallons, are shown along the top of the chart. Degree of vacuum is shown in the left column.

EXAMPLE of running time starting with atmospheric pressure: Estimate pumping time on a 300 gallon tank to a vacuum level of 20″ Hg using a vacuum pump having a free running displacement of 9 SCFM.

SOLUTION: From the chart find the running time of 50.1 minutes for a pump having a free running displacement of 1 SCFM.

Time = 50.1 ÷ 9 = 5.67 minutes

EXAMPLE of running time starting with a partial vacuum: Estimate pumping time to develop a 24″ Hg vacuum in a 25-cubic foot tank, starting with 12″ Hg vacuum and using a 6 SCFM vacuum pump:

SOLUTION: First estimate time from atmosphere up to the present 12″ Hg vacuum, then estimate time from atmosphere to the new vacuum of 24″ Hg. Then subtract these times to find the running time between 12″ Hg and 24″ Hg vacuum:

Atmosphere to 12″ Hg = 14.0 minutes per 1 SCFM capacity
Atmosphere to 24″ Hg = 48.6 minutes per 1 SCFM capacity
48.6 – 14.0 = 34.6 minutes per 1 SCFM capacity
Adjust for 6 SCFM pump: Time = 48.6 ÷ 6 = 5.77 minutes

Formula for Any Vacuum Pump

This formula, published by Gast, should give a close estimate for any vacuum pump, used on any tank, and to any degree of vacuum up to 27" Hg.

$$T = [V \div D] \times \text{Log}_e [A \div (A - B)]$$

T is pumping time, in minutes; **V** is tank volume, in cubic feet; **D** is free running displacement, in SCFM; **A** is deadhead rating of pump in ″Hg (with inlet blocked; **B** is the desired level of vacuum in tank, in ″Hg.

Cooling in Hydraulic Systems

Heat Generation

Heat is generated in a hydraulic system whenever oil dumps from a higher to a lower pressure without producing a mechanical work output. Examples are: oil flowing to tank through a relief valve, flowing through a flow control or pressure reducing valve, or simply flowing through small piping. Pressure drops noted from one cylinder port to another do not produce heat because the energy is being converted to work output.

In lower power hydraulic systems this waste heat is radiated by the walls of the reservoir. In larger systems a heat exchanger must be added. Oil temperature should be held to 130° to 140°F in an industrial system, but on moving equipment where heat removal is difficult, the temperature is sometimes allowed to reach 200°F although this is not desirable as it is destructive to the oil and to components. At high temperatures various chemical reactions produce sludges which interfere with system operation by clogging orifices and producing excessive wear in moving parts.

Heat Generation Formulas

Heat generated by oil flow through a valve, piping, or through a relief valve can be calculated with the formula below if the PSI pressure difference across the device is known or can be measured, and if the GPM flow through it is known. Formulas are given for converting heat into other units.

1 HP = 2545 BTU/hr = 42.4 BTU/min = 33,000 ft. lbs/min = 746 watts

HP = PSI × GPM ÷ 1714 or, BTU/hr = 1½ × PSI × GPM

1 BTU/hr = .0167 BTU/min = .00039 HP

EXAMPLE: 12 GPM bypassing a relief valve at a pressure drop of 500 PSI generates 3½ HP of heat, most of which is carried back to the tank.

NOTE: Heat is generated only when no mechanical work is produced.

Estimating Heat Build-Up

In most systems the main source of heat may be from the relief valve. If this valve is in action for only a part of every cycle, find the heat generated while it is passing oil, by the formula above. Then average this for the entire cycle. For example, if oil is passing the relief for about 1/3 of the time in each cycle and generating 3 HP heat while flowing, then the average rate of heat generation is 1 HP.

Another source of heat is flow control valves used to regulate speed of hydraulic cylinders or motors. The metered oil generates heat when the cylinder or motor is running unloaded or lightly loaded. In addition, any oil forced across the system relief valve because of metering to the cylinder or motor also generates heat. Flow control valves connected in a by-pass arrangement tend to generate less heat than series connected flow controls.

Pressure reducing valves generate heat during the time oil is flowing through them and during the time when pressure difference is greatest between their inlet and outlet ports.

If the hydraulic system is plumbed with pipe sizes adequate to carry the flow at recommended velocity, heat generated by oil flow through the lines will usually be small compared with other sources of heat in the system.

In addition to these major causes for overheating there will be heat generated from mechanical losses, mainly in the pump, or in a hydraulic motor. About 15% of the input power will go into heat for each pump or motor. As a rule-of-thumb, an allowance of 25% of the input power will usually be adequate to take care of all miscellaneous losses (and heat) including flow loss through 4-way valves, piping, and mechanical loss in one pump. If there is a hydraulic motor, or more than one pump in the system, the losses will be somewhat higher. Then, to this 25%, add the losses through relief, reducing, and flow control valves, if any, and this will be a good approximation of the heat generated in the system.

Cooling Capacity of Steel Reservoirs

After estimating the HP or BTU heat generation in your hydraulic system, the next step is to decide whether this heat can be radiated entirely from the walls of the oil tank or whether a heat exchanger is needed.

In many systems about 1/3 the heat is radiated from walls of cylinders, pumps, fluid motors, valves, and plumbing. The remainder is radiated from the side walls and top of the reservoir. Radiation from the bottom of the reservoir can be counted if the reservoir is elevated at least 6 inches from the floor. The amount of heat which can be radiated from the surface of steel tanks can be calculated from this formula:

$$HP\ (heat) = 0.001 \times TD \times A$$

A is the surface area in square feet; **TD** is the temperature difference in degrees fahrenheit between surrounding air and oil temperature inside the tank.

Oil tanks should be installed where there is free air circulation around all sides and under the tank. A forced blast of air directed on the side of the tank can increase the radiation capacity as much as 50%.

Cooling Capacity of Standard Oil Tanks

This table shows heat radiating capacity of commercially available steel hydraulic oil reservoirs having a 6-inch space underneath and free air circulation on all sides. Figures in the body of table show HP radiating ability of tanks from 10 to 200 gallon capacity at various temperature differences between oil temperature and surrounding air temperature.

EXAMPLE: If a 100-gallon reservoir is installed in a room with 70°F ambient temperature and the desired maximum oil temperature is 150°F, the temperature difference is 80°F and the heat radiating ability is 3.6 HP according to the table.

Figures in body of chart are heat radiation capacities in HP

Nominal Gallon Capacity	Sq. Ft. Surface Area	Temperature Difference – Oil to Air °F							
		30	40	50	60	70	80	90	100
10	10.8	.32	.43	.54	.65	.76	.86	.97	1.1
15	12.8	.38	.51	.64	.77	.90	1.0	1.2	1.3
20	14.0	.42	.56	.70	.84	.98	1.1	1.3	1.4
30	16.1	.48	.64	.81	.97	1.1	1.3	1.5	1.6
40	24.3	.73	.97	1.2	1.5	1.7	1.9	2.2	2.4
50	29.2	.88	1.2	1.5	1.8	2.0	2.3	2.6	2.9
60	31.6	.95	1.3	1.6	1.9	2.2	2.5	2.9	3.2
80	40.2	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
100	47.4	1.4	1.8	2.2	2.7	3.1	3.6	4.0	4.4
120	52.9	1.6	2.1	2.6	3.2	3.7	4.2	4.8	5.3
150	55.4	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.5
200	69.8	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0

To Reduce Heat Build-Up

1. Unload the pump during intervals when pressure is not required.

2. On presses where a high active pressure must be held for a long time, an air operated pressure intensifier or an accumulator may be used.

3. Use as large a reservoir as practical, with a large surface area to dissipate heat.

4. Pressure compensated flow control valves, if used, should be connected as "bypass" instead of "series" control if possible.

5. Set the main pump relief valve to the lowest pressure that will do the work.

6. Locate oil reservoirs in the open where they will have free air circulation. Enclosing the reservoir in a closed compartment will cause the system to operate at a higher oil temperature. Shading the oil reservoir from direct sunlight will also reduce the oil temperature.

Sizing Shell and Tube Heat Exchangers

Surface Area Required. On shell and tube heat exchangers there must be at least 0.46 square feet of heat transfer surface for each 1 HP heat load. 2.16 HP heat load can be removed for every square foot of heat transfer surface under the following conditions of usage:

1. Hydraulic oil in the shell side at entering temperature of 160°F, leaving temperature of 140°F.

2. Water in the tube side with a flow equal to 1/2 the oil flow, and at a temperature not over 90°F.

3. Correct flow velocity in oil and water to obtain optimum heat transfer.

Baffles. Baffle spacing should be arranged to give a velocity of 3 ft. per sec. in the oil but not outside the range of 2 to 6 feet per second.

Passes. End bonnets should have the correct number of passes on the water side to give 3 feet per second velocity, but not outside the range of 2 to 5 feet per second.

Accumulator Sizing

Accumulator Ratings ...

Accumulators are catalog-rated by the gas volume when all fluid has been discharged, and are usually rated in English measure, as pints, quarts, and gallons, (1 U.S. gallon = 231 cubic inches). The amount of fluid which can be stored in an accumulator is always less than its total gas volume. Only part of the stored fluid can be used each cycle because the fluid pressure decreases as fluid is discharged, and when the fluid pressure decreases to the minimum usable value which will perform the work in the hydraulic circuit, no more fluid can be displaced from the accumulator. The actual amount is determined by the ratio of maximum system pressure divided by precharge pressure (example: 3000/750 = 4:1, maximum fluid volume in this example is 75% of accumulator volume). In summary, the change in pressure controls the change in volume.

The problem in selecting an accumulator is to select a size which will deliver a sufficient amount of fluid each cycle without the system pressure dropping too low. Selection is described in detail later on this page. Required information for selection; system minimum pressure, system maximum pressure, fluid volume to be discharged, and fluid volume discharge time.

Precharge Pressure ...

Gas Charging

⚠ CAUTION **PRESSURIZED VESSEL – USE DRY NITROGEN GAS ONLY!**

Precharge new or repaired accumulators with dry nitrogen gas to the recommended gas precharge pressure (P0) listed below, prior to applying hydraulic system pressure.

For Energy Storage	$P_0 = 0.9 \times P_1$
For Shock Absorption	$P_0 = (0.6 \text{ to } 0.9) \times P_m$
For Pulsation Dampening	$P_0 = (0.6 \text{ to } 0.8) \times P_m$
P_1 **= minimum working pressure**	P_m **= median working pressure**

Having the precharge pressure set below the minimum system pressure allows a small amount of fluid to remain in the accumulator, thus preventing the elastomer from chafing against the valve on each cycle.

Estimating Fluid Requirements ...

1. Leakage Make-Up on bonding, curing, or laminating operation. If the cylinder has leak-tight piston seals, most of the fluid will be lost through the spool of the 4-way directional valve. The valve manufacturer's specifications for maximum spool leakage can be used, with an additional allowance for increased leakage as the valve wears. The spool leakage in cubic inches per minute multiplied by the minutes of holding time will give the amount of discharge fluid required from the accumulator.

2. Rapid Cylinder Travel. When an accumulator is used to supplement the flow from a pump for rapid travel of a cylinder, the accumulator discharges while the cylinder is in motion, and recharges each time the cylinder is at rest (between cycles).

3. Pulsation/Shock Absorption. Accumulators are beneficial in reducing the intensity of pulsations from pumps and shock from valve shifts or pump start-up or shutdown.

There is no easy way of calculating the required capacity of the accumulator for absorption applications. Gas precharge for an absorption application should be set at 60 to 90% of the system minimum pressure (start at 90% if the response is too "rigid" reduce the precharge pressure until the desired affect is achieved).

Caution must be used in adding an accumulator to an existing hydraulic system because an accumulator will reduce the "rigidity" of the system, and this may be unacceptable in some applications.

Discharge Flow Rate ...

A discharge flow rate of 2 gpm or less is considered slow, the precharge gas does not loose significant heat, meaning that the gas precharge pressure remains constant, and so does the fluid discharge volume (ideal condition, but not always real world). This is considered an isothermal exchange.

A discharge flow rate of 2 gpm or more is considered rapid, the precharge gas does loose significant heat, meaning that the gas precharge pressure changes as the precharge gas temperature changes and so does the fluid discharge volume due to rapid compression and expansion of the gas (most like real world). This is considered an adiabatic exchange. The volume of usable fluid is less with a rapid (adiabatic) exchange.

The selection chart below has been calculated based on the rapid (adiabatic) design principle.

Summary...

The sizing information is intended to allow the hydraulic system designer the ability to estimate the approximate accumulator size for a given application. There are many factors that go into the final selection of an accumulator, for that reason it is suggested that you consult Womack. Always design cylinders or hydraulic motors of sufficient size to do satisfactory job at this decreased pressure.

Using the Selection Chart...

STEP 1. Calculate or estimate the fluid volume, in cubic inches, which will be required on every discharge of the accumulator. Consider the design parameters as previously described.

STEP 2. Decide on an acceptable decrease in system pressure when the accumulator has discharged the volume of fluid estimated in Step 1. System pressure always decreases when a charged accumulator delivers a flow of fluid. When using the chart, the minimum acceptable system pressure is listed in the first column while the fully charged accumulator (and system) pressure is shown along the top.

STEP 3. With the data from Steps 1 and 2 enter the chart in the column headed by Maximum System Pressure. Go down this column to the line showing the minimum acceptable system pressure. The figure shown is the number of cubic inches of oil delivered from a "1-gallon" accumulator during its discharge from fully charged to minimum acceptable system pressure. A 5-gallon accumulator will deliver approximately five times (within 90%) this amount and a 10-gallon accumulator will deliver approximately ten times (within 90%) this amount, etc. From this information an accumulator of sufficient gallonage can be selected which will do the job.

Minimum Acceptable System Pressure (PSI)	Maximum System Pressure (PSI)									
	3000	2750	2500	2250	2000	1750	1500	1250	1000	750
2700	9	---	---	---	---	---	---	---	---	---
2600	14	5	---	---	---	---	---	---	---	---
2500	18	9	Cubic inches of oil delivered by a "1-gallon" accumulator							
2400	23	14	5	---	---	---	---	---	---	---
2300	25	18	9	---	---	---	---	---	---	---
2200	30	23	14	---	---	---	---	---	---	---
2100	35	28	18	7	---	---	---	---	---	---
2000	39	32	23	12	---	---	---	---	---	---
1900	44	37	28	18	5	---	---	---	---	---
1800	49	42	32	23	12	---	---	---	---	---
1700	53	46	39	28	18	---	---	---	---	---
1600	60	51	44	35	23	9	---	---	---	---
1500	65	58	51	42	30	16	---	---	---	---
1400	---	62	58	49	37	25	7	---	---	---
1300	---	---	62	55	44	32	16	---	---	---
1200	---	---	---	62	51	39	25	---	---	---
1100	---	---	---	---	60	49	35	14	---	---
1000	---	---	---	---	---	58	44	25	---	---
900	---	---	---	---	---	67	53	37	12	---
800	---	---	---	---	---	---	62	49	25	---
700	---	---	---	---	---	---	---	60	39	9
600	---	---	---	---	---	---	---	---	53	25
500	---	---	---	---	---	---	---	---	69	44

NOTE 1: 231 cubic inches = 1 U.S. gallon.

NOTE 2: This chart is calculated using a precharge pressure equal to 90% of the minimum acceptable system pressure with an ambient temperature range between 50°F and 120°F.

Viscosity Rating Systems

Kinematic Viscosity expresses total resistance to fluid flow including internal fluid friction plus effect of mass or weight of the fluid. It is measured in several systems, with equivalent values shown in the chart compared to SUS ratings in the first column. All these systems are based on the time for a quantity of fluid to flow through a standard orifice under specified conditions. In the U.S. the Saybolt Universal Second (SUS) rating is most often used. It is derived from English units. The Centistoke is the standard for international fluid power. It is derived from metric units. **(1 Stoke = 100 Centistokes)**.

Absolute Viscosity is an expression only of the internal fluid friction without taking into account the effect of the mass or weight of the fluid. A statement of absolute viscosity must also include a statement of the specific gravity of the fluid. The international standard unit for absolute viscosity is the Poise or Centipoise **(1 Poise = 100 Centipoise)**. It is derived from metric units. In the English system the unit is the Reyn. Centipoise viscosities in the last column of the chart are for any fluid, including standard hydraulic oil, which has a specific gravity of 0.9. The Centipoise is related to the Centistoke. Any value of kinematic viscosity in Centistokes can be converted to absolute viscosity in Centipoise by multiplying Centistokes times the specific gravity. Thus water, with specific gravity of 1.0, has the same kinematic and absolute viscosity ratings.

While absolute viscosity is important in scientific processes, it is of little value in fluid power because viscosity effects such as pump cavitation, pressure losses in valving and piping are produced not only by internal fluid friction but by the weight (specific gravity) of the fluid as well. Thus, we express viscosity in kinematic SUS values almost entirely, in the U.S.A.

Kinematic Viscosities						Absolute Viscosity
SUS Saybolt Universal Seconds	SSF Saybolt Seconds Furol	Centistokes	Redwood No. 1 Standard Seconds*	Ford No. 3 Seconds	Engler Specific Degrees**	Centipoises at 0.9 Specific Gravity†
10,000	1000	2200	9000	875	290	1980
9,000	900	1950	8100	788	266	1755
8,000	800	1700	7200	700	236	1530
7,000	700	1500	6300	613	207	1350
6,000	600	1300	5400	525	177	1170
5,000	500	1050	4500	438	148	945
4,000	400	850	3600	350	118	765
3,000	300	630	2700	263	89	567
2000	200	420	1800	175	59	378
1500	150	315	1350	131	44	284
1000	100	220	900	87.5	30	198
900	90	195	810	78.5	27	175
800	80	170	720	70.0	24	153
700	70	150	630	61.3	21	135
600	60	130	540	52.5	18	117
500	50	110	450	43.8	15	99
400	40	87	360	35.0	12	78.3
300	33	65	270	26.3	8.9	58.5
200	24	43	180	17.5	5.9	38.7
100	15	20.8	90	8.8	3.0	18.7
90	——	18.3	81	7.9	——	16.5
80	——	15.8	72	7.0	——	14.2
70	——	13.3	63	6.1	——	12.0
60	——	10.5	54	5.3	——	9.5
55	——	8.9	50	4.8	——	8.0
50	——	7.5	45	4.4	——	6.8
45	——	5.9	41	3.9	——	5.3
40	——	4.3	36	3.5	——	3.9
35	——	2.7	32	3.1	——	2.4

*For Redwood No. 2 Admiralty Seconds viscosity, divide values in this column by 10.
**For Engler viscosity values in seconds, multiply values in this column by 50.
†Absolute viscosity in Centipoises is related to the specific gravity of the fluid. Values in this column are for hydraulic oil of 0.9 specific gravity. For fluids with other values of specific gravity, Centipoise viscosity is found by multiplying values in **Centistokes** column by specific gravity of fluid.

SUS Viscosity Variation with Temperature

Oil Type	Oil Temperature 0°F	20°F	40°F	60°F	80°F	90°F	100°F	110°F	120°F	130°F	140°F	150°F	160°F	180°F	200°F
750 SUS Hvd.Oil	— — —	35,000	10,000	3500	1500	1050	750	550	400	310	240	195	155	110	82
500 SUS Hyd.Oil	55,000	15,000	5000	2000	925	650	500	360	280	220	175	140	115	86	68
300 SUS Hyd.Oil	22,000	6500	2500	1100	550	400	300	230	185	150	122	110	89	69	58
225 SUS Hyd.Oil	12,000	3800	1500	720	380	285	225	165	140	115	100	85	75	61	52
150 SUS Hyd.Oil	5000	1900	850	430	240	190	150	140	100	87	76	68	62	53	47
100 SUS Hyd.Oil	2200	900	440	240	150	120	100	85	74	66	60	55	51	46	43
90 SUS Hyd.Oil	1700	700	360	200	130	105	90	77	68	61	56	52	49	44	42
SAE 10	10,000	3200	1250	600	310	240	180	145	140	100	84	74	66	55	48
SAE 20	27,000	7500	2800	1150	550	400	300	230	180	145	115	99	84	66	55
SAE30	90,000	20,000	6200	2300	1000	680	500	360	280	215	170	135	110	80	64
SAE 40	— — —	45,000	12,000	4000	1600	1200	750	550	400	300	240	185	150	105	77
SAE 50	— — —	— — —	30,000	9000	3200	2000	1400	950	680	500	370	280	210	140	99
Pydraul F9	— — —	19,000	4300	1250	500	325	230	157	125	100	81	70	62	51	45
Pydraul 312	55,000	12,000	3600	1300	600	420	310	230	175	140	110	93	80	63	54
Pydraul 625			60,000	9000	2000	1200	630	400	260	175	125	98	79	58	49
Skydrol 500A	420	240	150	100	75	67	61	56	52	49	47	45	43	41	— — —
Skydrol 7000	1900	650	300	165	105	88	77	68	61	56	52	49	46	42	40
MIL-H-5606A	650	360	220	142	100	88	78	70	64	59	55	52	49	45	42
MIL-L-7808	625	310	175	110	78	69	62	56	52	48	46	43	42	39	
Houghto-Safe 620	4800	2000	980	500	300	240	190	155	130	110	95	83	75	62	54
Kerosene	160	110	80	65	55	52	49	47	45	43	41	40	39		
Diesel Fuel	75	54	45	39	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —
JP4 Fuel	47	43	40	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —
SAE 140 Gear Oil	— — —	— — —	55,000	18,000	6500	4000	2700	1900	1350	1000	750	550	420	260	175

Identification of the petroleum base hydraulic oils in the first 7 lines of this chart is by their SUS viscosity ratings at 100°F. This data should be approximately correct for any brand of petroleum oil. The values in the chart were taken from the standard SAE viscosity chart.

SAE ratings usually cover a range of viscosities, and the approximate SUS range covered by each SAE number is shown to the right.

SUS Range Covered By SAE Oil Ratings

SAE No.	SUS Range @ 100°F	SAE No.	SUS Range @ 100°F	SAE No.	SUS Range @ 100°F
5W	30-140	20	170-370	50	810-1300
10W	140-210	30	370-560	60	1300-1600
20W	210-500	40	560-810	70	1600-2100

Seal Compatibility with Common Fluids

Material	Brass	Buna-N	EPR, EPDM (Nitrile Rubber)	Leather (Thiokol Impregnated)	Neoprene	Nylon	Polyethylene Low Density	Polyethylene High Density	Polypropylene 120° (Noryl)	Polyurethane, Urethane	PVC Polyvinyl Chloride	Teflon 120o	Viton
Air	▼	☆	☆	▼	☆	▼	▼	▼	▼	☆	▼	☆	☆
Alkaline Solutions	▼	☆	☆	▼	☆	▼	(☆)	(☆)	▼	☆	▼	☆	☆
Anti-Freeze (Alcohol Base)	▼	☆	☆	▼	☆	▼	▼	▼	▼	▼	▼	☆	☆
Anti-Freeze (Glycol Base)	▼	☆	☆	▼	★	▼	▼	▼	▼	▼	▼	☆	☆
ASTM Reference Fuel A	▼	☆	■	▼	★	▼	▼	▼	▼	☆	▼	▼	☆
ASTM Reference Fuel B	▼	☆	■	▼	■	▼	▼	▼	▼	★	▼	▼	☆
ASTM Reference Fuel C	▼	☆	■	▼	■	▼	▼	▼	▼	■	▼	▼	☆
Automatic Transmission Fluid	▼	☆	■	▼	★	▼	☆	☆	▼	★	▼	☆	☆
Automotive Gasoline (Standard)	▼	☆	■	▼	■	▼	☆	☆	▼	★	▼	☆	☆
Aviation Gasoline, Mil.	▼	★	■	▼	▼	▼	▼	▼	▼	▼	▼	☆	☆
Chlorinated Water – Saturated	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	☆	▼
De-Ionized Water	▼	☆	☆	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
Diesel Oil (Fuel ASTM #2)	▼	☆	■	☆	■	☆	☆	☆	▼	■	★	☆	☆
Drinking Water	▼	☆	☆	▼	★	▼	☆	☆	▼	■	▼	☆	☆
Gasoline (Sour)	▼	■	▼	☆	■	▼	☆	☆	★	▼	★	☆	▼
Gasoline (Meter)	■	☆	■	☆	■	■	☆	☆	★	☆	★	☆	☆
Gasoline (Aviation)	☆	★	▼	☆	■	▼	▼	▼	▼	▼	▼	☆	▼
Houghto-Safe 271 (Water/Glycol)	▼	☆	☆	▼	★	▼	▼	▼	▼	■	▼	▼	★
Houghto-Safe 620 (Water/Glycol)	▼	☆	☆	▼	★	▼	▼	▼	▼	■	▼	▼	★
Houghto-Safe 1010 (Phosphate Ester)	▼	■	☆	▼	■	▼	▼	▼	▼	▼	▼	▼	☆
Houghto-Safe 1055 (Phosphate Ester)	▼	■	☆	▼	■	▼	▼	▼	▼	▼	▼	▼	☆
Houghto-Safe 1120 (Phosphate Ester)	▼	■	☆	▼	■	▼	▼	▼	▼	■	▼	▼	☆
Houghto-Safe 5040 (Water/Oil Emulsion)	▼	☆	■	▼	★	▼	▼	▼	▼	■	▼	▼	☆
Hydraulic Oils (Petroleum)	☆	☆	■	☆	★	☆	▼	▼	▼	▼	☆	☆	☆
Hydraulic Oils (Synthetic)	☆	■	☆	★	▼	▼	▼	▼	▼	▼	☆	☆	☆
JP-4 (Mil-J-5624)	▼	☆	■	▼	■	▼	☆	☆	▼	☆	▼	☆	☆
JP-5 (Mil-J-5624)	▼	☆	■	▼	■	▼	☆	☆	▼	☆	▼	☆	☆
Kerosene	☆	☆	■	☆	■	☆	■	▼	★	☆	■	☆	☆
Mineral Oil	☆	☆	■	☆	★	☆	▼	☆	☆	☆	★	☆	☆
Petroleum Ether	▼	☆	☆	▼	▼	▼	■	■	▼	☆	▼	☆	☆
Petroleum Oils (Refined)	☆	☆	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
Petroleum Oils (Sour)	■	■	▼	▼	★	▼	▼	▼	▼	▼	▼	▼	▼
Petroleum Oils (Crude)	▼	☆	■	▼	★	▼	▼	▼	▼	☆	▼	▼	☆
Petroleum Oils (Crude, Below 250° F)	▼	☆	■	▼	★	▼	▼	▼	▼	★	▼	▼	☆
Petroleum Oils (Crude, Above 250° F)	▼	■	■	▼	■	▼	▼	▼	▼	■	▼	▼	★
Phosphate Esters	▼	▼	☆	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
Skydrol 500	▼	■	☆	▼	■	▼	▼	▼	▼	■	▼	✦	■
Skydrol 7000	▼	■	☆	▼	■	▼	▼	▼	▼	■	▼	✦	★
Transmission Fluid, Type A	▼	☆	■	▼	☆	▼	▼	▼	▼	▼	▼	☆	☆
Water, Fresh	■	☆	☆	☆	☆	☆	☆	☆	▼	☆	★	☆	☆
Water, Distilled	☆	☆	☆	☆	☆	☆	☆	☆	▼	☆	★	☆	☆

Legend: ☆ = Recommended; Performance is not affected. ★ = Fair; Some loss of properties may occur. ■ = Not recommended; Material is unsuitable for service. ▼ = No data available at this time. ( ) = Brackets around a rating letter. No data is available, but the rating is made on the basis of exposure tests in similar chemical groups

Hydraulic Pipe Table

Physical Dimensions and Pressure Ratings

Schedule 40 (Standard Weight) Pipe

Pipe Size	O.D.	I.D.	Wall Thickness	Inside Area	Working PSI*	Burst PSI
1/8	.405	.269	.068	.0568	2238	13,432
1/4	.540	.364	.088	.1040	2173	13,037
3/8	.675	.493	.091	.1908	1797	10,785
1/2	.840	.622	.109	.3037	1730	10,380
3/4	1.050	.824	.113	.5330	1435	8609
1	1.315	1.049	.133	.8649	1348	8091
1¼	1.660	1.380	.140	1.495	1124	6747
1½	1.900	1.610	.145	2.035	1017	6105
2	2.375	2.067	.154	3.354	864	5187
2½	2.875	2.469	.203	4.785	941	5648
3	3.500	3.068	.216	7.390	823	4937

Schedule 80 (Extra Strong Weight) Pipe

Pipe Size	O.D.	I.D.	Wall Thickness	Inside Area	Working PSI*	Burst PSI
1/8	.405	.215	.095	.0363	3128	18,765
1/4	.540	.302	.119	.0716	2938	17,630
3/8	.675	.423	.126	.1405	2489	14,933
1/2	.840	.546	.147	.2340	2333	14,000
3/4	1.050	.742	.154	.4320	1955	11,733
1	1.315	.957	.179	.7190	1815	10,890
1¼	1.660	1.278	.191	1.282	1534	9205
1½	1.900	1.500	.200	1.766	1403	8421
2	2.375	1.939	.218	2.951	1224	7343
2½	2.875	2.323	.276	4.236	1280	7680
3	3.500	2.900	.300	6.600	1143	6857

Schedule 160 Pipe

Pipe Size	O.D.	I.D.	Wall Thickness	Inside Area	Working PSI*	Burst PSI
1/2	.840	.464	.188	.1690	2984	17,904
3/4	1.050	.612	.219	.2940	2781	16,686
1	1.315	.815	.250	.5214	2535	15,200
1¼	1.660	1.160	.250	1.056	2008	12,048
1½	1.900	1.338	.281	1.405	1972	11,831
2	2.375	1.687	.344	2.234	1931	11,587
2½	2.875	2.125	.375	3.545	1739	10,435
3	3.500	2.624	.438	5.405	1668	10,011

*Working PSI at a safety factor of 6:1.

The above charts are for welded and seamless wrought steel pipe. Wall thickness on wrought iron pipe is slightly greater than for steel pipe, and the inside area is, therefore, slightly smaller. Burst strength is about the same.

Schedule 40 is the same as "standard wall" up to 10 inch size. Schedule 80 is the same as "extra strong" up to 8 inch size. There is no schedule number for "double extra strong". Schedule 160 is lighter than "double extra strong" and heavier than "extra strong".

Pressure Ratings ...

Burst strength has been figured on a tensile strength of 40,000 PSI for butt welded steel pipe. Lap welded steel pipe has a strength of 50,000 PSI, and will stand 20% more pressure than shown in the tables. Burst strength is by Barlow's Formula: **P** = **2t** × **S** ÷ **O** in which **P** is bursting pressure in PSI, **t** is wall thickness in inches, **S** is tensile strength of material in PSI, and **O** is outside diameter of pipe in inches.

Safety Factor ...

The working pressure ratings in the next to last column are figured with a safety factor of 6. In the usual hydraulic system a factor of at least 6 should be used. However, to find working pressure at another safety factor, take the burst pressure rating and divide by the desired safety factor.

Oil Flow Capacity of Pipes

Schedule 40 (Standard Weight) Pipe

Pipe NPT	2 Ft/Sec. GPM	4 Ft/Sec. GPM	10 Ft/Sec. GPM	15 Ft/Sec. GPM	20 Ft/Sec. GPM	30 Ft/Sec. GPM
1/8	0.35	0.71	1.77	2.66	3.54	5.31
1/4	0.65	1.30	3.24	4.87	6.49	9.73
3/8	1.19	2.38	5.95	8.93	11.9	17.85
1/2	1.89	3.79	9.47	14.21	18.94	28.41
3/4	3.32	6.65	16.62	24.93	33.25	49.87
1	5.39	10.78	26.94	40.41	53.88	80.82
1¼	9.32	18.65	46.62	69.93	93.25	139.87
1½	12.69	25.38	63.46	95.19	126.92	190.38
2	20.92	41.84	104.60	156.90	209.20	313.79
2½	29.85	59.70	149.24	223.86	298.48	447.72
3	46.09	92.18	230.44	345.66	460.88	691.31

Schedule 80 (Extra Strong Weight) Pipe

Pipe NPT	2 Ft/Sec. GPM	4 Ft/Sec. GPM	10 Ft/Sec. GPM	15 Ft/Sec. GPM	20 Ft/Sec. GPM	30 Ft/Sec. GPM
1/8	0.23	0.45	1.13	1.70	2.26	3.40
1/4	0.45	0.89	2.23	3.35	4.47	6.70
3/8	0.88	1.75	4.38	6.57	8.76	13.14
1/2	1.46	2.92	7.30	10.95	14.60	21.90
3/4	2.70	5.39	13.48	20.22	26.96	40.44
1	4.48	8.97	22.42	33.63	44.84	67.26
1¼	8.00	15.99	39.99	59.98	79.97	119.96
1½	11.02	22.03	55.08	82.63	110.17	165.25
2	18.41	36.82	92.04	138.07	184.09	276.13
2½	26.42	52.84	132.11	198.17	264.22	396.33
3	41.18	82.36	205.89	308.84	411.78	617.67

Schedule 160 Pipe

Pipe NPT	2 Ft/Sec. GPM	4 Ft/Sec. GPM	10 Ft/Sec. GPM	15 Ft/Sec. GPM	20 Ft/Sec. GPM	30 Ft/Sec. GPM
1/2	1.05	2.11	5.27	7.91	10.54	15.81
3/4	1.83	3.67	9.17	13.75	18.34	27.51
1	3.25	6.50	16.26	24.39	32.52	48.78
1¼	6.59	13.18	32.94	49.41	65.89	98.83
1½	8.76	17.52	43.80	65.70	87.59	131.39
2	13.93	27.87	69.67	104.51	139.35	209.02
2½	22.11	44.22	110.55	165.83	221.10	331.65
3	33.71	67.43	168.57	252.85	337.13	505.70

Pipe size should be selected on the basis of oil flow velocity. Undersizing results in a high pressure and power loss and system overheating. Oversizing reduces pressure and power losses but may be unnecessarily expensive to plumb.

Pump Suction Lines ...

Schedule 40 pipe should be used and a size chosen which will keep oil velocity within the range of 2 to 4 feet per second.

Oil Return Lines ...

Schedule 40 pipe should be used and a size chosen which will keep oil velocity within the range of 10 to 15 feet per second.

Medium Pressure Lines ...

In those lines carrying 500 to 2000 PSI, flow velocity should be kept at 15 to 20 feet per second. Use Schedule 80 or 160 pipe, or use steel tubing as listed on the next page.

High Pressure Lines ...

Flow velocity may be allowed up to 30 feet per second in lines carrying 3000 to 5000 PSI. Normally, steel tubing is used, but the tables may be used for finding pipe size, then tubing should be selected with the same inside area.

Oil Pressure Loss Through Pipes

Table 1 shows the pressure loss per 100 feet of Schedule 40 pipe. It is for standard hydraulic oil of 0.9 specific gravity and 220 SUS viscosity. For other specific gravities and viscosities, see information at the bottom of this page.

Table 1. Pressure Loss Per 100 Feet of Schedule 40 Pipe

GPM	Pipe Size*	Pres** Drop	Flow Vel.†	GPM	Pipe Size*	Pres** Drop	Flow Vel.†	GPM	Pipe Size*	Pres** Drop	Flow Vel.†
10	3/8	185	17	35	1/2	249	36	70	3/4	205	42
	1/2	73	11		3/4	83	21		1	63	26
	3/4	24	6.0		1	32	13		1¼	21	15
	1	9.0	3.7		1¼	11	7.5		1½	11	11
	1¼	3.0	2.2		1½	5.7	5.5		2	4.2	6.7
15	1/2	109	16	40	3/4	95	24	80	1	75	31
	3/4	36	9.0		1	36	15		1¼	24	17
	1	14	5.6		1¼	12	8.6		1½	13	13
	1¼	4.5	3.2		1½	6.5	6.3		2	4.8	7.7
	1½	2.4	2.4		2	2.4	3.8		2½	2.3	5.4
20	1/2	146	21	45	3/4	106	27	90	1	80	33
	3/4	47	12		1	41	17		1¼	27	19
	1	18	7.4		1¼	14	9.7		1½	15	14
	1¼	6.0	4.3		1½	4.4	7.1		2	5.4	8.6
	1½	3.2	3.2		2	2.7	4.3		2½	2.6	6.0
25	1/2	180	26	50	3/4	122	31	100	1	92	38
	3/4	59	15		1	46	19		1¼	30	22
	1	23	9.3		1¼	15	11		1½	16	16
	1¼	7.6	5.4		1½	8.1	7.9		2	6.0	9.6
	1½	4.0	3.9		2	3.0	4.8		2½	2.9	6.7
30	1/2	214	31	60	3/4	142	36	125	1	114	47
	3/4	71	18		1	53	22		1¼	38	27
	1	27	11		1¼	18	13		1½	20	20
	1¼	9.0	6.4		1½	9.8	9.5		2	7.5	12
	1½	4.8	4.7		2	3.6	5.7		2½	9.8	8.4

Table 2. Conversion Factors for Tubing

For pressure loss per 100 feet of tubing, find tubing I.D. in table below. The next larger NPT size is shown in Column 2. Refer back to Table 1 for pressure loss for this pipe size. Multiply times factor in Column 3 of **Table 2**;

EXAMPLE: For 50 GPM flow through a tube with 1.310 I.D., Column 2 shows 1¼″ NPT to be the next larger pipe size. From **Table 1**, pressure loss is 15 PSI for 1¼″ pipe. Multiply this times the factor from column 3 of **Table 2**: 15 PSI × 1.11 = 16.65 (or 17) PSI pressure loss per 100 feet.

For other schedules of pipe or for hose, flow loss will be in proportion to the inside area of pipe compared to one of the pipe sizes in **Table 1**.

Tube I. D.	Use NPT	Mult. by	Tube I. D.	Use NPT	Mult. by	Tube I. D.	Use NPT	Mult. by
0.334	3/8	2.18	.760	3/4	1.17	1.134	1¼	1.48
0.356	3/8	1.92	.782	3/4	1.11	1.152	1¼	1.43
0.370	3/8	1.77	.810	3/4	1.03	1.260	1¼	1.20
0.384	3/8	1.65	.834	1	1.58	1.282	1¼	1.16
0.402	3/8	1.50	.856	1	1.50	1.310	1¼	1.11
0.416	3/8	1.40	.870	1	1.45	1.334	1¼	1.07
0.430	3/8	1.31	.884	1	1.41	1.356	1¼	1.04
0.532	1/2	1.37	.902	1	1.35	1.370	1¼	1.01
0.560	1/2	1.23	1.010	1	1.08	1.732	2	1.42
0.584	1/2	1.13	1.032	1	1.03	1.760	2	1.38
0.606	1/2	1.08	1.060	1¼	1.69	1.782	2	1.34
0.620	1/2	1.01	1.084	1¼	1.62	1.810	2	1.30
0.634	3/4	1.69	1.106	1¼	1.56	1.834	2	1.27
0.652	3/4	1.60	1.120	1¼	1.52	1.856	2	1.24

For Flows Not Shown: Pressure loss increases approximately in proportion to the increase in flow or flow velocity.

Adjusting for Other Viscosities: Pressure loss through a pipe is directly proportional to fluid viscosity (on SUS of 100 and above). A 440 SUS fluid would have approximately twice the pressure loss shown in the tables.

Adjusting for Specific Gravity: Pressure loss is directly proportional to specific gravity. Water/oil emulsions will have 7% higher, water/glycol fluids will have 14%, and phosphate ester fluids will have 22% higher pressure loss than calculated from the tables.

*Schedule 40 pipe. **PSI loss per 100 feet. †Oil flow velocity, ft/second.

Carbon Steel Tubing Data

Steel tubing is called out by outside diameter and wall thickness. For hydraulic plumbing a low carbon seamless steel tubing should be used which can be bent and flared without cracking. Order "hydraulic grade" tubing.

Pressure ratings in this table are based on a tubing with tensile strength of 55,000 PSI, and were calculated by Barlow's formula: **P** = **2t** × **S** ÷ **O**, in which **P** = burst strength in PSI, **t** = wall thickness, **S** = tensile strength in PSI, and **O** = outside diameter. This formula may be used to calculate tubing sizes not listed. All dimensions in the table are in inches.

For hydraulic plumbing, a safety factor of at least six should be used and ratings for this factor are shown in the table. For pressure rating at other safety factors, take burst PSI and divide by desired safety factor.

Tube O.D.	Wall Thick	Tube I.D.	Inside Area	Burst PSI	Working PSI @ 6*	Working PSI @ 8**
1/8	.028	.069	.0037	24,640	4,107	3,080
	.032	.061	.0029	28,160	4,693	3,520
	.035	.055	.0024	30,800	5133	3,850
3/16	.032	.1235	.0120	18,773	3,130	2,347
	.035	.1175	.0108	20,533	3,422	2,567
1/4	.035	.180	.0254	15,400	2,567	1,925
	.042	.166	.0216	18,480	3,080	2,310
	.049	.152	.0181	21,560	3,593	2,695
	.058	.134	.0141	25,520	4,253	3,190
	.065	.120	.0113	28,600	4,767	3,575
5/16	.035	.2425	.0462	12,320	2,053	1,540
	.042	.2285	.0410	14,784	2,464	1,848
	.049	.2145	.0361	17,248	2,875	2,156
	.058	.1965	.0303	20,416	3,403	2,552
	.065	.1825	.0262	22,880	3,813	2,860
3/8	.035	.305	.0730	10,267	1,711	1,283
	.042	.291	.0665	12,320	2,053	1,540
	.049	.277	.0602	14,373	2,396	1,797
	.058	.259	.0527	17,013	2,835	2,127
	.065	.245	.0471	19,067	3,178	2,383
1/2	.035	.430	.1452	7,700	1,283	963
	.042	.416	.1359	9,240	1,540	1,155
	.049	.402	.1269	10,780	1,797	1,348
	.058	.384	.1158	12,760	2,127	1,595
	.065	.370	.1075	14,300	2,383	1,788
	.072	.356	.0995	15,840	2,640	1,980
	.083	.334	.0876	18,260	3,043	2,283
5/8	.035	.555	.2418	6,160	1,027	770
	.042	.541	.2298	7,392	1,232	924
	.049	.527	.2180	8,624	1,437	1,078
	.058	.509	.2034	10,208	1,701	1,276
	.065	.495	.1923	11,440	1,907	1,430
	.072	.481	.1816	12,672	2,112	1,584
	.083	.459	.1654	14,608	2,435	1,826
	.095	.435	.1485	16,720	2,787	2,090
3/4	.049	.652	.3337	7,187	1,198	898
	.058	.634	.3155	8,507	1,418	1,063
	.065	.620	.3018	9,533	1,589	1,192
	.072	.606	.2813	10,560	1,760	1,320
	.083	.584	.2677	12,173	2,029	1,522
	.095	.560	.2462	13,933	2,322	1,742
	.109	.532	.2222	15,987	2,664	1,998
7/8	.049	.777	.4739	6,160	1,027	770
	.058	.759	.4522	7,291	1,215	911
	.065	.745	.4357	8,171	1,362	1,021
	.072	.731	.4195	9,051	1,509	1,131
	.083	.709	.3946	10,434	1,739	1,304
	.095	.685	.3683	11,943	1,990	1,493
	.109	.657	.3388	13,703	2,284	1,713
1	.049	.902	.6387	5,390	898	674
	.058	.884	.6134	6,380	1,063	798
	.065	.870	.5942	7,150	1,192	894
	.072	.856	.5752	7,920	1,320	990
	.083	.834	.5460	9,130	1,522	1,141
	.095	.810	.5150	10,450	1,742	1,306
	.109	.782	.4801	11,990	1,998	1,500
	.120	.760	.4534	13,200	2,200	1,650

*Safety factor of 6 **Safety factor of 8. Table continued on next page.

Carbon Steel Tubing Data (cont.)

Tube O.D.	Wall Thick	Tube I.D.	Inside Area	Burst PSI	Working PSI @ 6*	Working PSI @ 8**
1¼	.490	1.152	1.0418	4,312	719	539
	.058	1.134	1.0095	5,104	851	638
	.065	1.120	.9847	5,720	953	715
	.072	1.106	.9602	6,336	1,056	792
	.083	1.084	.9224	7,304	1,217	913
	.095	1.060	.8820	8,360	1,393	1,045
	.109	1.032	.8360	9,592	1,600	1,200
	.120	1.010	.8008	10,560	1,760	1,320
1½	.065	1.370	1.4734	4,767	794	596
	.072	1.356	1.4434	5,280	880	660
	.083	1.334	1.3970	6,087	1,014	761
	.095	1.310	1.3471	6,967	1,161	871
	.109	1.282	1.2902	7,993	1,332	1,000
	.120	1.260	1.2463	8,800	1,467	1,100
1¾	.065	1.620	2.0602	4,086	681	511
	.072	1.606	2.0247	4,526	754	566
	.083	1.584	1.9696	5,217	870	652
	.095	1.560	1.9104	5,971	995	746
	.109	1.532	1.8424	6,851	1,142	856
	.120	1.510	1.7899	7,543	1,257	943
	.134	1.482	1.7241	8,423	1,404	1,053
2	.065	1.870	2.7451	3,575	596	447
	.072	1.856	2.7041	3,960	660	495
	.083	1.834	2.6404	4,565	761	571
	.095	1.810	2.5717	5,225	871	653
	.109	1.782	2.4928	5,995	1,000	749
	.120	1.760	2.4316	6,600	1,100	825
	.134	1.732	2.3549	7,370	1,228	921

Copper Tubing Data

Burst pressures are calculated by Barlow's formula: **P** = **2t** × **S** ÷ **O** in which **P** is burst pressure PSI; **t** is tubing wall thickness; **S** is ultimate strength of material (32,000 PSI for copper); and **O** is outside diameter of tubing.

Tube O.D.	Wall Thick	Tube I.D.	Inside Area	Burst PSI	Working PSI @ 6*	Working PSI @ 8**
1/4	†.030	.190	.0283	7,680	1,280	960
	.049	.152	.0181	12,544	2,090	1,568
5/16	†.032	.249	.0485	6,554	1,092	819
	.049	.215	.0361	10,035	1,673	1,254
3/8	†.032	.311	.0759	5,461	910	683
	.058	.259	.0527	9,899	1,650	1,237
	.072	.231	.0419	12,288	2,048	1,536
1/2	†.032	.436	.1492	4,096	683	512
	.049	.402	.1269	6,272	1,045	784
	.058	.384	.1158	7,424	1,237	928
	.072	.356	.0995	5,376	896	672
5/8	†.035	.555	.2418	3,584	597	448
	.049	.527	.2180	5,018	836	627
	.065	.495	.1923	6,656	1,109	832
3/4	†.035	.680	.3630	2,987	498	373
	.049	.652	.3371	4,181	697	523
	.065	.620	.3018	5,547	924	693
7/8	†.045	.785	.4837	3,291	549	411
	.065	.745	.4357	4,754	792	594
1	.065	.870	.5942	4,160	693	520
1⅛	†.050	1.025	.8247	2,844	474	356
1¼	.083	1.084	.9224	4,250	708	531
1⅜	†.055	1.265	1.2562	2,560	427	320

*Safety factor of 6:1 **Safety factor of 8:1

†These are standard refrigeration sizes available at all mill supply houses.

Stainless Steel Tubing Data

Stainless steel tubing is sometimes employed either to handle corrosive fluids or higher pressures. If assembled with flare-type fittings, great care must be used not to crack the tubing while flaring.

Pressure ratings are based on a maximum strength of 75,000 PSI, typical of Types 302, 303, 304, 309, 310, 316, 321, and 416. Types 202 and 440C have 100,000 PSI while Types 410 and 430 have only 60,000 PSI maximum.

In hydraulic systems, a safety factor of at least six (6) should be used if there is likely to be any shock in the system. To calculate working pressure at any safety factor, take burst strength and divide by desired safety factor.

Pressure ratings were calculated by Barlow's formula: **P** = **2t** × **S** ÷ **O**, in which **P** is burst pressure in PSI, **t** is tubing wall thickness, **S** is maximum strength of tube material in PSI, **O** is tube O.D. All dimensions are in inches.

Tube O.D.	Wall Thickness	Tube I.D.	Inside Area	Burst PSI	Working PSI @ 6*	Working PSI @ 8**
1/8	.032	.061	.0029	38,400	6,400	4,800
3/16	.032	.124	.0120	25,600	4,267	3,200
	.035	.118	.0108	28,000	4,667	3,500
1/4	.035	.180	.0254	21,000	3,500	2,625
	.049	.152	.0181	29,400	4,900	3,675
5/16	.035	.243	.0462	16,800	2,800	1,000
	.049	.215	.0361	23,520	3,920	2,940
	.058	.197	.0303	27,840	4,640	3,480
3/8	.035	.305	.0730	14,000	2,333	1,750
	.049	.277	.0602	19,600	3,267	2,456
	.058	.259	.0527	23,200	3,867	2,900
	.065	.245	.0471	26,000	4,333	3,250
1/2	.035	.430	.1452	10,500	1,750	1,313
	.049	.402	.1269	14,700	2,450	1,842
	.058	.384	.1158	17,400	2,900	2,175
	.065	.370	.1075	19,500	3,250	2,438
	.072	.356	.0995	21,600	3,600	2,700
	.083	.334	.0876	24,900	4,150	3,113
5/8	.049	.527	.2180	11,760	1,960	1,470
	.058	.509	.2034	13,920	2,320	1,740
	.065	.495	.1923	15,600	2,600	1,950
	.072	.481	.1816	17,280	2,880	2,160
	.083	.459	.1654	19,920	3,320	2,490
	.095	.435	.1485	22,800	3,800	2,850
3/4	.049	.652	.3337	9,800	1,633	1,225
	.058	.634	.3155	11,600	1,933	1,450
	.065	.620	.3018	13,000	2,167	1,625
	.072	.606	.2883	14,400	2,400	1,800
	.083	.584	.2677	16,600	2,767	2,075
	.095	.560	.2462	19,000	3,167	2,375
7/8	.049	.777	.4739	8,400	1,400	1,050
	.058	.759	.4522	9,943	1,657	1,243
	.065	.745	.4357	11,143	1,857	1,393
	.072	.731	.4195	12,343	2,057	1,543
	.083	.709	.3946	14,229	2,371	1,779
	.095	.685	.3683	18,153	3,025	2,269
	.109	.657	.3388	18,686	3,114	2,336
1	.049	.902	.6387	7,350	1,225	919
	.058	.884	.6134	8,700	1,450	1,088
	.065	.870	.5942	9,750	1,625	1,219
	.072	.856	.5752	10,800	1,800	1,350
	.083	.834	.5460	12,450	2,075	1,556
	.095	.810	.5150	14,250	2,375	1,781
	.109	.782	.4801	16,350	2,725	2,044
1¼	.083	1.084	.9224	9,960	1,660	1,245
	.095	1.060	.8820	11,400	1,900	1,425
	.109	1.032	.8360	13,080	2,180	1,635
	.120	1.010	.8008	14,400	2,400	1,800
1½	.095	1.310	1.3471	9,500	1,583	1,188
	.109	1.282	1.2902	10,900	1,817	1,363
	.120	1.260	1.2463	12,000	2,000	1,500
	.134	1.232	1.1915	13,400	2,233	1,675

*Safety factor of 6:1 **Safety factor of 8:1

Oil Flow Capacity of Tubing

Figures in the chart are GPM flow capacities of tubing, and were calculated from the formula: **GPM = V x A ÷ 0.3208**, in which **V** = velocity of flow in feet per second, and **A** is inside square inch area of tubing.

Figures in body of chart are GPM flows

Tube O.D.	Wall Thick	2 Ft/Sec GPM	4 Ft/Sec GPM	10 Ft/Sec GPM	15 Ft/Sec GPM	20 Ft/Sec GPM	30 Ft/Sec GPM
1/2	.035	.905	1.81	4.52	6.79	9.05	13.6
	.042	.847	1.63	4.23	6.35	8.47	12.7
	.049	.791	1.58	3.95	5.93	7.91	11.9
	.058	.722	1.44	3.61	5.41	7.22	10.8
	.065	.670	1.34	3.35	5.03	6.70	10.1
	.072	.620	1.24	3.10	4.65	6.20	9.30
	.083	.546	1.09	2.73	4.09	5.46	8.18
5/8	.035	1.510	3.01	7.54	11.3	15.1	22.6
	.042	1.430	2.85	7.16	10.7	14.3	21.4
	.049	1.360	2.72	6.80	10.2	13.6	20.4
	.058	1.270	2.54	6.34	9.51	12.7	19.0
	.065	1.200	2.40	6.00	9.00	12.0	18.0
	.072	1.130	2.26	5.66	8.49	11.3	17.0
	.083	1.030	2.06	5.16	7.73	10.3	15.5
	.095	.926	1.85	4.63	6.95	9.26	13.9
3/4	.049	2.08	4.17	10.4	15.6	20.8	31.2
	.058	1.97	3.93	9.84	14.8	19.7	29.6
	.065	1.88	3.76	9.41	14.1	18.8	28.2
	.072	1.75	3.51	8.77	13.2	17.5	26.4
	.083	1.67	3.34	8.35	12.5	16.7	25.0
	.095	1.53	3.07	7.67	11.5	15.3	23.0
	.109	1.39	2.77	6.93	10.4	13.9	20.8
7/8	.049	2.95	5.91	14.8	22.2	29.5	44.3
	.058	2.82	5.64	14.1	21.1	28.2	42.3
	.065	2.72	5.43	13.6	20.4	27.2	40.7
	.072	2.62	5.23	13.1	19.6	26.2	39.2
	.083	2.46	4.92	12.3	18.5	24.6	36.9
	.095	2.30	4.60	11.5	17.2	23.0	34.4
	.109	2.11	4.22	10.6	15.8	21.1	31.7
1	.049	3.98	7.96	19.9	29.9	39.8	59.7
	.058	3.82	7.65	19.1	28.7	38.2	57.4
	.065	3.70	7.41	18.5	27.8	37.0	55.6
	.072	3.59	7.17	17.9	26.9	35.9	53.8
	.083	3.40	6.81	17.0	25.5	34.0	51.1
	.095	3.21	6.42	16.1	24.1	32.1	48.2
	.109	3.00	6.00	15.0	22.4	29.9	44.9
	.120	2.83	5.65	14.1	21.2	28.3	42.4
1¼	.049	6.50	13.0	32.5	48.7	64.9	97.4
	.058	6.29	12.6	31.5	47.2	62.9	94.4
	.065	6.14	12.3	30.7	46.0	61.4	92.1
	.072	6.00	12.0	30.0	44.9	59.9	89.8
	.083	5.75	11.5	28.8	43.1	57.5	86.3
	.095	5.50	11.0	27.5	41.2	55.0	82.5
	.109	5.21	10.4	26.1	39.1	52.1	78.2
	.120	5.00	10.0	25.0	37.4	50.0	74.9
1½	.065	9.19	18.4	45.9	68.9	91.9	138
	.072	9.00	18.0	45.0	67.5	90.0	135
	.083	8.71	17.4	43.5	65.3	87.1	131
	.095	8.40	16.8	42.0	63.0	84.0	126
	.109	8.04	16.1	40.2	60.3	80.4	121
	.120	7.77	15.5	38.8	58.3	77.7	117
1¾	.065	12.8	25.7	64.2	96.3	128	193
	.072	12.6	25.2	63.1	94.7	126	189
	.083	12.3	24.6	61.4	92.1	123	184
	.095	11.9	23.8	59.6	89.3	119	179
	.109	11.5	23.0	57.4	86.1	115	172
	.120	11.2	22.3	55.8	83.7	112	167
	.134	10.7	21.5	53.7	80.6	107	161
2	.065	17.1	34.2	85.6	128	171	257
	.072	16.9	33.7	84.3	126	169	253
	.083	16.5	32.9	82.3	123	165	247
	.095	16.0	32.1	80.2	120	160	240
	.109	15.5	31.1	77.7	117	155	233
	.120	15.2	30.3	75.8	114	152	227
	.134	14.7	29.4	73.4	110	147	220

Air Line Pipe Size

Figures in body of chart are pipe sizes on a 100 PSI air system to carry air at about a 1 PSI per 100 feet pressure loss. When measuring piping distances, to be conservative, count each pipe fitting as equal to 5 feet of pipe. At other than 100 PSI, flow capacity will be in inverse proportion to pressure (as based on PSIA (absolute) pressure levels and calculated by Boyle's Law).

SCFM Flow	Length of Run – Feet 25	50	75	100	150	200	300	500	1000	Compr. HP
6	1/2	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4	1
18	1/2	1/2	1/2	3/4	3/4	3/4	3/4	1	1	3
30	3/4	3/4	3/4	3/4	1	1	1	1¼	1¼	5
45	3/4	3/4	1	1	1	1	1¼	1¼	1¼	7½
60	3/4	1	1	1	1¼	1¼	1¼	1½	1½	10
90	1	1	1¼	1¼	1¼	1¼	1½	1½	2	15
120	1	1¼	1¼	1¼	1½	1½	1½	2	2	20
150	1¼	1¼	1¼	1½	1½	2	2	2	2½	25
180	1¼	1½	1½	1½	2	2	2	2½	2½	30
240	1¼	1½	1½	2	2	2	2½	2½	3	40
300	1½	2	2	2	2	2½	2½	3	3	50
360	1½	2	2	2	2½	2½	2½	3	3	60
450	2	2	2	2½	2½	3	3	3	3½	75
600	2	2½	2½	2½	3	3	3	3½	4	100
750	2	2½	2½	3	3	3	3½	3½	4	125

Air Pressure Loss

Figures in this table are approximate PSI compressed air pressure losses for every 100 feet of clean commercial steel pipe, Schedule 40.

Nominal Pipe Diameter

CFM Free Air	1/2 INCH		3/4 INCH		1 INCH		1¼ INCH		1½ INCH	
	80 PSI	125 PSI	80 PSI	125 PSI	80 PSI	125 PSI	80 PSI	125 PSI	80 PSI	125 PSI
10	.45	.30	.11	.08	.04	.02	---	---	---	---
20	1.75	1.15	.40	.28	.15	.08	---	---	---	---
30	3.85	2.55	.90	.60	.30	.20	---	---	---	---
40	6.95	4.55	1.55	1.05	.45	.30	---	---	---	---
50	10.5	7.00	2.40	1.60	.75	.50	.18	.12	---	---
60	---	---	3.45	2.35	1.00	.70	.25	.17	---	---
70	---	---	4.75	3.15	1.35	.90	.35	.23	.16	.10
80	---	---	6.15	4.10	1.75	1.20	.45	.30	.20	.14
90	---	---	7.75	5.15	2.25	1.50	.55	.40	.25	.17
100	---	---	9.60	6.35	2.70	1.80	.65	.45	.30	.20
125	---	---	15.5	9.80	4.20	2.80	1.05	.70	.45	.32
150	---	---	23.0	14.5	5.75	4.00	1.45	1.00	.65	.45
175	---	---	---	---	8.10	5.45	2.00	1.30	.90	.60
200	---	---	---	---	10.9	7.10	2.60	1.75	1.15	.80
250	---	---	---	---	---	---	4.05	2.65	1.80	1.20
300	---	---	---	---	---	---	5.80	3.85	2.55	1.70
350	---	---	---	---	---	---	7.90	5.15	3.55	2.35
400	---	---	---	---	---	---	10.3	6.75	4.55	3.05
450	---	---	---	---	---	---	---	---	5.80	3.80
500	---	---	---	---	---	---	---	---	7.10	4.70

Air Flow Loss Through Pipes

Table of Factors – See Instructions for use on page 46.

SCFM	Pipe Size – NPT							
	1/2	3/4	1	1¼	1½	1¾	2	2½
5	12.7	1.2	0.5	---	---	---	---	---
10	50.7	7.8	2.2	0.5	---	---	---	---
15	114	17.6	4.9	1.1	---	---	---	---
20	202	30.4	8.7	2.0	---	---	---	---
25	316	50.0	13.6	3.2	1.4	0.7	---	---
30	456	70.4	19.6	4.5	2.0	1.1	---	---
35	621	95.9	26.6	6.2	2.7	1.4	---	---
40	811	125	34.8	8.1	3.6	1.9	---	---
45	---	159	44.0	10.2	4.5	2.4	1.2	---
50	---	196	54.4	12.6	5.6	2.9	1.5	---
60	---	282	78.3	18.2	8.0	4.2	2.2	---
70	---	385	106	24.7	10.9	5.7	2.9	1.1
80	---	503	139	32.3	14.3	7.5	3.8	1.5
90	---	646	176	40.9	18.1	9.5	4.8	1.9
100	---	785	217	50.5	22.3	11.7	6.0	2.3
110	---	950	263	61.1	27.0	14.1	7.2	2.8
120	---	---	318	72.7	32.2	16.8	8.6	3.3
130	---	---	369	85.3	37.8	19.7	10.1	3.9
140	---	---	426	98.9	43.8	22.9	11.7	1.4
150	---	---	490	113	50.3	26.3	13.4	5.2
160	---	---	570	129	57.2	29.9	15.3	5.9
170	---	---	628	146	64.6	33.7	17.6	6.7
180	---	---	705	163	72.6	37.9	19.4	7.5
190	---	---	785	177	80.7	42.2	21.5	8.4
200	---	---	870	202	89.4	46.7	23.9	9.3
220	---	---	---	244	108	56.5	28.9	11.3
240	---	---	---	291	128	67.3	34.4	13.4
260	---	---	---	341	151	79.0	40.3	15.7
280	---	---	---	395	175	91.6	46.8	18.2
300	---	---	---	454	201	105	53.7	20.9

SCFM	Larger Pipe Size – NPT							
	2	2½	3	3¼	3½	4	4½	5
320	61.1	23.8	7.5	3.5	---	---	---	---
340	69.0	26.8	8.4	3.9	2.0	---	---	---
360	77.3	30.1	9.5	4.4	2.2	---	---	---
380	86.1	33.5	10.5	4.9	2.5	---	---	---
400	94.7	37.1	11.7	5.4	2.7	---	---	---
420	105	40.9	12.9	6.0	3.1	---	---	---
440	116	44.9	14.1	6.6	3.4	---	---	---
460	126	48.8	15.4	7.1	3.7	2.0	---	---
480	138	53.4	16.8	7.8	4.0	2.2	---	---
500	150	58.0	18.3	8.5	4.3	2.4	---	---
525	165	64.2	20.2	9.4	4.8	2.6	---	---
550	182	70.2	22.1	10.2	5.2	2.9	---	---
575	197	76.7	24.2	11.2	5.7	3.1	---	---
600	215	83.5	26.3	12.2	6.2	3.4	---	---
625	233	92.7	28.5	13.2	6.8	3.7	---	---
650	253	98.0	30.9	14.3	7.3	4.0	2.2	---
675	272	106	33.3	15.4	7.9	4.3	2.4	---
700	294	114	35.8	16.6	8.5	4.6	2.6	---
750	337	131	41.1	19.0	9.7	5.3	2.9	---
800	382	148	46.7	21.7	11.1	6.1	3.3	---
850	433	168	52.8	24.4	12.5	6.8	3.8	---
900	486	188	59.1	27.4	14.0	7.7	4.2	---
950	541	209	65.9	30.5	15.7	8.6	4.7	---
1,000	600	232	73.0	33.8	17.3	9.5	5.2	1.9
1,050	658	256	80.5	37.3	19.1	10.4	5.8	2.1
1,100	723	281	88.6	40.9	21.0	11.5	6.3	2.4
1,150	790	307	96.6	44.7	22.9	12.5	6.9	2.6
1,200	850	344	105	48.8	25.0	13.7	7.5	2.8
1,300	---	392	123.4	57.2	29.3	16.0	8.8	3.3
1,400	---	---	---	66.3	33.9	18.6	10.2	3.8

Instructions

For Estimating Air Flow Loss Through Pipes

To estimate the air pressure loss through a pipe, find the factor from the chart on page 45 according to the pipe size and SCFM flow. Take the factor and divide it by the ratio of compression (calculated in absolute pressure values). Compression ratio will be **[gauge pressure + 14.5] ÷ 14.5 PSI**. Then multiply this number by actual length of pipe, in feet, then divide by 1000. This will give pressure loss in PSI.

Pressure Loss Through Fittings

Figures in the body of this chart are air pressure flow losses through screw fittings expressed in equivalent lengths of straight pipe of the same diameter. For example, on a 1″ gate valve the flow resistance would be the same as 0.57 foot of straight 1″ pipe.

Pipe Size NPT	Gate Valve	Long Radius Ell or *	Medium Radius Ell or **	Standard Ell or ***	Angle Valve	Close Return Bend	Tee Thru Side	Globe Valve
1/2	0.31	0.41	0.52	0.84	1.1	1.3	1.7	2.5
3/4	0.44	0.57	0.73	1.2	1.6	1.8	2.3	3.5
1	0.57	0.77	0.98	1.6	2.1	2.3	3.1	4.7
1¼	0.82	1.1	1.4	2.2	2.9	3.3	4.4	6.5
1½	0.98	1.3	1.6	2.6	3.5	3.9	5.2	7.8
2	1.3	1.7	2.2	3.6	4.8	5.3	7.1	10.6
2½	1.6	2.2	2.8	4.4	5.9	6.6	8.7	13.1
3	2.1	2.8	3.6	5.7	7.7	8.5	11.4	17.1
4	3.0	3.9	5.0	7.9	10.7	11.8	15.8	23.7
5	3.9	5.1	6.5	10.4	13.9	15.5	20.7	31

*Or on run of standard tee.
**Or on run of tee reduced in size 25%
***Or on run of standard tee reduced in size 50%

Friction of Air in Hose

Pressure drop per 25 feet. In proportion for longer or shorter lengths

Size	SCFM	50 PSI	60 PSI	70 PSI	80 PSI	90 PSI	100 PSI	110 PSI
1/2″ ID	20	1.8	1.3	1.0	0.9	0.8	0.7	0.6
	30	5.0	4.0	3.4	2.8	2.4	2.3	2.0
	40	10.1	8.4	7.0	6.0	5.4	4.8	4.3
	50	18.1	14.8	12.4	10.8	9.5	8.4	7.6
	60	---	23.4	20.0	17.4	14.8	13.3	12.0
	70	---	---	28.4	25.2	22.0	19.3	17.6
	80	---	---	---	34.6	30.5	27.2	24.6
3/4″ ID	20	0.4	0.3	0.2	0.2	0.2	0.2	0.1
	30	0.8	0.6	0.5	0.5	0.4	0.4	0.3
	40	1.5	1.2	0.9	0.8	0.7	0.6	0.5
	50	2.4	1.9	1.5	1.3	1.1	1.0	0.9
	60	3.5	2.8	2.3	1.9	1.6	1.4	1.3
	70	4.4	3.8	3.2	2.8	2.3	2.0	1.8
	80	6.5	5.2	4.2	3.6	3.1	2.7	2.4
	90	8.5	6.8	5.5	4.7	4.0	3.5	3.1
	100	11.4	8.6	7.0	5.8	5.0	4.4	3.9
	110	14.2	11.2	8.8	7.2	6.2	5.4	4.9
1″ ID	30	0.2	0.2	0.1	0.1	0.1	0.1	0.1
	40	0.3	0.3	0.2	0.2	0.2	0.2	0.2
	50	0.5	0.4	0.4	0.3	0.3	0.2	0.2
	60	0.8	0.6	0.5	0.5	0.4	0.4	0.3
	70	1.1	0.8	0.7	0.7	0.6	0.5	0.4
	80	1.5	1.2	1.0	0.8	0.7	0.6	0.5
	90	2.0	1.0	1.3	1.1	0.9	0.8	0.7
	100	2.6	2.0	1.6	1.4	1.2	1.0	0.9
	110	3.5	2.6	2.0	1.7	1.4	1.2	1.1

Data on pages 45 and 46 were adapted from the Trade Standards adopted by the ***Compressed Air and Gas Institute***.

Air Flow Through Orifices

Figures in this chart show theoretical SCFM air flow through sharp edged orifices. In practice, only about 2/3rds of this flow is obtained. The chart may be useful for roughly estimating travel speed of a loaded air cylinder. Assume about 75% of the line PSI is actually working on the load, with the remaining 25% consumed in flow losses in the 4–way valve and connecting lines. Calculate 75% of your incoming line PSI and use this figure to enter the first column in this chart. Move across the table to the column headed by the actual port size of the 4–way valve in the circuit. Use about half the flow shown, because a 4–way valve is not a sharp edged orifice, and will usually pass only about half as much air as a sharp edged orifice.

After finding the SCFM (free air) flow, convert this to CFM (compressed air flow) at the pressure required to move the load. From this the speed of travel of the air cylinder can be estimated.

Chart shows approximate SCFM (free air) flow through sharp edged orifices.

PSI Across Orifice	Orifice Diameter, in Inches										
	1/64	1/32	1/16	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1
5	.062	.249	.993	3.97	15.9	35.7	63.5	99.3	143	195	254
6	.068	.272	1.09	4.34	17.4	39.1	69.5	109	156	213	278
7	.073	.293	1.17	4.68	18.7	42.2	75.0	117	168	230	300
9	.083	.331	1.32	5.30	21.2	47.7	84.7	132	191	260	339
12	.095	.379	1.52	6.07	24.3	54.6	97.0	152	218	297	388
15	.105	.420	1.68	6.72	26.9	60.5	108	168	242	329	430
20	.123	.491	1.96	7.86	31.4	70.7	126	196	283	385	503
25	.140	.562	2.25	8.98	35.9	80.9	144	225	323	440	575
30	.158	.633	2.53	10.1	40.5	91.1	162	253	365	496	648
35	.176	.703	2.81	11.3	45.0	101	180	281	405	551	720
40	.194	.774	3.10	12.4	49.6	112	198	310	446	607	793
45	.211	.845	3.38	13.5	54.1	122	216	338	487	662	865
50	.229	.916	3.66	14.7	58.6	132	235	366	528	718	938
60	.264	1.06	4.23	16.9	67.6	152	271	423	609	828	1082
70	.300	1.20	4.79	19.2	76.7	173	307	479	690	939	1227
80	.335	1.34	5.36	21.4	85.7	193	343	536	771	1050	1371
90	.370	1.48	5.92	23.7	94.8	213	379	592	853	1161	1516
100	.406	1.62	6.49	26.0	104	234	415	649	934	1272	1661
110	.441	1.76	7.05	28.2	113	254	452	705	1016	1383	1806
120	.476	1.91	7.62	30.5	122	274	488	762	1097	1494	1951
130	.494	1.98	7.90	31.6	126	284	506	790	1138	1549	2023

Vacuum Flow Through Orifices

This chart approximates the flow that might be expected through a practical orifice. Flows are about 2/3rds the theoretical flow obtained through a sharp edged orifice. At best, these figures are only approximate because the flow characteristic of your orifice can only be determined by actual measurement under specified conditions.

DESIGN NOTE: This chart shows that multiple-hole grippers work more efficiently at reasonably high vacuums. For example, looking at the chart for a 1/4″ diameter hole, the first 6″ Hg of vacuum flows 8.25 SCFM, while the increase in flow over the last 6″, from 18″ to 24″, is only 2.2 SCFM. The more efficient design would be to use more smaller holes working at a higher vacuum.

Figures in body of chart are air flows in SCFM (standard cubic feet/minute)

Orifice Diam., Inches	Degree of Vacuum Across Orifice, Inches Mercury (″Hg)								
	2″	4″	6″	8″	10″	12″	14″	18″	24″
1/64	.018	.026	.032	.037	.041	.045	.048	.055	.063
1/32	.074	.100	.128	.148	.165	.180	.195	.220	.250
1/16	.300	.420	.517	.595	.660	.725	.780	.880	1.00
1/8	1.20	1.68	2.06	2.37	2.64	2.89	3.12	3.53	4.04
1/4	4.78	6.74	8.25	9.52	10.6	11.6	12.4	14.0	16.2
3/8	10.8	15.2	18.5	21.4	23.8	26.0	28.0	31.8	36.4
1/2	19.1	27.0	33.0	38.5	42.3	46.3	50.0	56.5	64.6
5/8	30.0	42.2	51.7	59.5	66.2	72.6	78.0	88.0	101
3/4	43.0	60.6	74.0	85.3	95.2	104	112	127	145
7/8	58.8	82.6	101	116	130	142	153	173	198
1	76.5	108	131	152	169	185	200	225	258

Oil Flow Through Orifices

These charts show PSI pressure drops to be expected in hydraulic oil when flowing through sharp edged orifices. **Caution!** Calculated pressure drops are only approximate because factors such as specific gravity, viscosity, shape of orifice, and plumbing ahead of and following the orifice may cause variations. It is best to make the orifice slightly undersize to start, then to gradually enlarge it while measuring actual pressure drop.

By making the orifice as sharp edged as possible, it becomes less sensitive to oil temperature changes (which affect oil viscosity).

Specific gravity of the fluid significantly influences the pressure drop, which increases approximately as the square of the increase of specific gravity. The charts were calculated for oil with a gravity of 0.9, a close approximation for hydraulic oil. Using other fluids, a multiplying factor must be applied to chart values. For example, to find the pressure drop of water, which has a gravity of 1.00, find the multiplier as follows:

$$(1.00)^2 \div (0.9)^2 = 1.00 \div 0.81 = 1.23 \text{ Multiplying Factor}$$

Therefore, multiply all chart values by 1.23 when calculating for water flow.

These charts were calculated from information supplied by Double A Products Co. The constant, 23.5, shown in the formula below was developed experimentally by measuring pressure drops across average orifices. Values not shown may be calculated from the same basic formula used in calculating the chart:

$$\text{Pressure Drop } (\Delta P) = [\text{GPM} \div (23.5 \times A)]^2$$

Pressure Drop Across Orifices from 3/64″ to 3/16″

Figures in the body of these charts are PSI pressure drops to be expected in a flow of hydraulic oil across sharp edged orifices of various diameters.

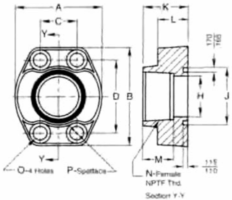
	Orifice Diameters in Inches									
GPM	**3/64**	**1/16**	**5/64**	**3/32**	**7/64**	**1/8**	**9/64**	**5/32**	**11/64**	**3/16**
3	5445	1730	710	340	185	110	68	44	30	21
4	----	3075	1260	608	328	192	120	79	54	38
5	----	4803	1970	950	513	300	188	123	84	59
7½	----	----	4430	2140	1155	677	422	277	189	134
10	----	----	----	3800	2050	1205	750	493	336	238
12½	----	----	----	----	3205	1880	1175	770	526	371
15	----	----	----	----	4615	2705	1690	1110	757	534
17½	----	----	----	----	----	3685	2300	1510	1030	727
20	----	----	----	----	----	4810	3005	1970	1345	950
22½	----	----	----	----	----	----	3800	2495	1705	1205
25	--- Chart Values are in PSI ---						4690	3080	2100	1485
27½	----	----	----	----	----	----	----	3725	2545	1795
30	----	----	----	----	----	----	----	4435	3025	2140
35	----	----	----	----	----	----	----	----	4120	2910
40	----	----	----	----	----	----	----	----	----	3800

Pressure Drop Across Orifices from 13/64″ to 1/2″

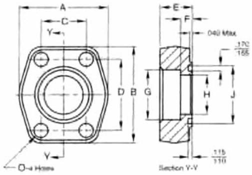
	Orifice Diameters in Inches									
GPM	**13/64**	**7/32**	**15/64**	**1/4**	**9/32**	**5/16**	**11/32**	**3/8**	**7/16**	**1/2**
3	16	12	----	----	----	----	----	----	----	----
4	28	21	16	12	--- Chart Values are in PSI ---					
5	43	32	25	19	12	----	----	----	----	----
7½	97	72	55	42	26	17	12	----	----	----
10	172	128	98	75	47	31	21	15	----	----
12½	270	200	153	117	73	48	33	23	13	----
15	388	288	220	169	106	69	47	33	18	11
17½	528	393	300	230	144	94	64	45	25	14
20	690	513	392	301	188	123	84	59	32	19
22½	873	649	496	380	237	156	106	75	41	24
25	1075	800	612	470	293	192	131	93	50	29
27½	1305	970	741	568	355	233	159	112	61	36
30	1550	1155	880	675	420	277	189	134	72	42
35	2115	1570	1200	920	575	377	258	182	98	58
40	2760	2050	1570	1200	751	492	336	237	128	75

Flange Dimensional Data

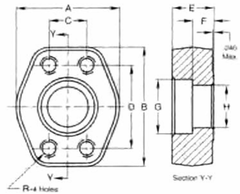
Pipe Threaded O-Ring Flange
3000 PSI Only



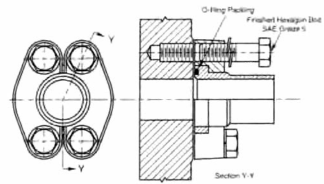
Socket Weld O-Ring Flange
500 PSI, 3000 PSI, 6000 PSI



Socket Weld Flange
500 PSI, 3000 PSI, 6000 PSI



Four Bolt Split Flange
500 PSI, 3000 PSI, 6000 PSI



Nom. Flng. Size	A	B	C +0.010	D +0.010	E	F	G DIA.	H DIA.	J DIA.	K	L	M	N NPTF Thrd.	O DIA.	P DIA.	R Thrd. UNC-3	SOC HD Cap Screw (Thrd. Flng.)	HEX or SOC HD Cap Screw (Socket Weld)	O-Ring ARP-568 Uniform Dash #
3000 PSI Recommended Working Pressure																			
1/2	1.87	2.12	0.688	1.500	0.75	0.19	0.855	0.50	1.005/1.000	1.25	0.91	0.87	1/2	0.344	0.469	5/16-18	5/16-18x1½" Lg.	5/16-18x1½" Lg.	-210
3/4	2.06	2.56	0.875	1.875	0.75	0.19	1.063	0.75	1.255/1.250	1.25	0.84	0.87	3/4	0.406	0.594	3/8-16	3/8-16x1½" Lg.	3/8-16x1½" Lg.	-214
1	2.31	2.75	1.031	2.062	0.87	0.25	1.328	1.00	1.565/1.560	1.37	0.97	1.12	1	0.406	0.594	3/8-16	3/8-16x1¾" Lg.	3/8-16x1¾" Lg.	-219
1¼	2.88	3.12	1.188	2.312	0.94	0.25	1.672	1.25	1.755/1.750	1.50	1.03	1.12	1¼	0.469	0.656	7/16-14	7/16-14x1¾" Lg.	7/16-14x1¾" Lg.	-222
1½	3.25	3.69	1.406	2.750	1.19	0.44	1.923	1.50	2.125/2.115	1.62	1.09	1.12	1½	0.531	0.781	1/2-13	1/2-13x2" Lg.	1/2-13x2¼" Lg.	-225
2	3.81	4.00	1.688	3.062	1.37	0.50	2.406	2.00	2.500/2.490	1.62	1.09	1.12	2	0.531	0.781	1/2-13	1/2-13x2" Lg.	1/2-13x2½" Lg.	-228
2½	4.28	4.50	2.000	3.500	1.75	0.75	2.906	2.50	3.005/2.995	2.00	1.47	1.56	2½	0.531	0.781	1/2-13	1/2-13x2½" Lg.	1/2-13x2¾" Lg.	-232
3	5.16	5.31	2.438	4.188	2.12	0.87	3.547	3.00	3.625/3.615	2.00	1.59	1.72	3	0.656	0.937	5/8-11	1/2-13x2¾" Lg.	5/8-11x3" Lg.	-237
500 PSI Recommended Working Pressure																			
3	5.12	5.31	2.438	4.188	1.37	0.25	3.547	3.00	3.625/3.615					0.656		5/8-11		5/8-11x2½" Lg.	-237
3½	5.50	6.00	2.750	4.750	1.44	0.25	4.047	3.50	4.115/4.095					0.656		5/8-11		5/8-11x2½" Lg.	-241
4	6.00	6.38	3.062	5.125	1.50	0.25	4.578	4.00	4.615/4.595					0.656		5/8-11		5/8-11x2½" Lg.	-245
5	7.12	7.25	3.625	6.000	1.75	0.37	5.797	5.00	5.615/5.595					0.656		5/8-11		5/8-11x2½" Lg.	-253
6000 PSI Recommended Working Pressure																			
1/2	1.88	2.22	0.718	1.594	0.87	0.25	0.855	0.50	1.005/1.000					0.344		5/16-18		5/16-18x1½" Lg.	-210
3/4	2.38	2.81	0.937	2.000	0.87	0.25	1.063	0.75	1.255/1.250					0.406		3/8-16		3/8-16x1½" Lg.	-214
1	2.75	3.19	1.093	2.250	1.00	0.37	1.328	1.00	1.565/1.560					0.469		7/16-14		7/16-14x1¾" Lg.	-219
1¼	3.06	3.75	1.250	2.625	1.25	0.56	1.672	1.25	1.755/1.750					0.531		1/2-13		1/2-13x2¼" Lg.	-222
1½	3.75	4.44	1.437	3.125	1.50	0.75	1.923	1.50	2.125/2.115					0.656		5/8-11		5/8-11x2½" Lg.	-225
2	4.50	5.25	1.750	3.812	1.75	0.87	2.406	2.00	2.500/2.490					0.781		3/4-10		3/4-10x3" Lg.	-228
2½	5.87	6.87	2.312	4.875	2.06	1.06	2.906	2.50	3.005/2.995					0.906		7/8-9		7/8-9x3½" Lg.	-232
3	7.00	8.50	2.812	6.000	2.62	1.37	3.547	3.00	3.625/3.615					1.156		1⅛-7		1⅛-7x4½" Lg.	-237

Straight Thread Fitting Sizes

This chart gives thread size and O-ring size as used on straight thread connectors, straight thread tube fittings, etc. These sizes are applicable for SAE, AN, and MS connections. O-rings used for straight connectors do not conform to so-called "standard size". They should be purchased specifically for this service and should conform to dimensions shown.

Fitting Dash No.	Tubing O.D.	Thread Size	ARP 568 Uniform Dash No.	O-Ring I.D.	O-Ring Thickness
–2	1/8″	5/16–24	–902	0.239	0.064
–3	3/16″	3/8–24	–903	0.301	0.064
–4	1/4″	7/16–20	–904	0.351	0.072
–5	5/16	1/2–20	–905	0.414	0.072
–6	3/8″	9/16–18	–906	0.468	0.078
–8	1/2″	3/4–16	–908	0.644	0.087
–10	5/8″	7/8–14	–910	0.755	0.097
–12	3/4″	1 1/16–12	–912	0.924	0.116
–14	7/8″	1 3/16–12	–914	1.048	0.116
–16	1″	1 5/16–12	–916	1.171	0.116
–20	1 1/4″	1 5/8–12	–920	1.475	0.118
–24	1 1/2″	1 7/8–12	–924	1.720	0.118
–32	2″	2 1/2–12	–932	2.337	0.118

Equivalent Pipe and Tubing Sizes

This table suggests a comparable size when going from pipe into tubing and vice versa. These sizes have approximately equal flow capacity. For sizes over one inch, use pipe and tubing of the same size rating.

Tubing O.D., Inches	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1
Pipe Size NPT	1/8	1/8	1/4	3/8	1/2	3/4	3/4	1

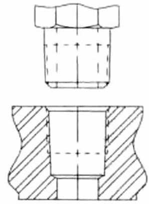
ISO Standardization Effort

The International Standards Organization (ISO) is attempting to establish a set of port and tube/hose connection standards for worldwide use. They intend to recognize 10 standards as outlined in the table below. They endorse strongly the ISO 6149 port standard for all "new" designs in hydraulic fluid power.

Application	Port	Tube/Hose Connection			
		24° Cone Bite Type	37° Flare	Metric ORFS	24° Cone Weld Nipple
For All Designs	Metric ISO 6149 (SAE J2244)	ISO 8434-1	ISO 8434-2	ISO 8434-3	ISO 8434-4
Not For New Designs In Hydraulic Fluid Power	BSPP ISO 1179 (DIN 3852-2)	ISO 8434-1	ISO 8434-2	– – –	ISO 8434-4
	Metric ISO 9974 (DIN 3852-1)	ISO 8434-1	– – –	– – –	ISO 8434-4
	UN/UNF ISO 11926 (SAE J1926)	– – –	ISO 8434-2	– – –	– – –

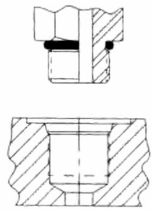
Thread Forms of Fluid Connectors

National Pipe Thread Fuel (NPTF)



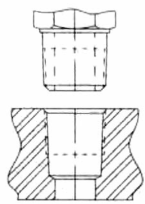
- Thread conforms to ANSI B1.20.3
- Physically interchangeable with NPT but has modified threads for better pressure tight sealing
- Tapered thread profile seals by metal to metal interference fit, usually requires sealing compound for pressure tight connections
- Pitch and diameter are measured in inches
- Taper angle is 0.75″ per foot or 1° 47′
- Thread angle is 60°

Straight Thread O-Ring (SAE)



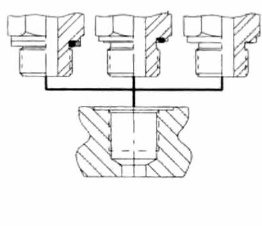
- Thread conforms to ISO 263 and ANSI B1.1 Unified
- Port conforms to ISO 11926 and SAE J1926
- Commonly called straight thread O-ring fittings
- Pitch and diameter are measured in inches, 1 1/16-12 UN-2B
- Threads are parallel and requires O-ring for pressure tight connection
- Thread angle is 60°

British Standard Pipe Tapered (BSPT)



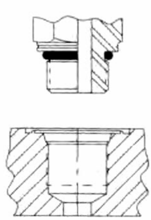
- Thread conforms to ISO 7
- Pitch and diameter are measured in inches, e.g. G3/8-19
- Tapered thread profile seals by metal to metal interference fit, usually requires sealing compound for pressure tight connection
- Taper angle is 1° 47′, the same as NPT(F)
- Thread angle is 55°
- Not interchangeable with NPT(F)

British Standard Pipe Parallel (BSPP)



- Thread conforms to ISO 228-1
- Port conforms to ISO 1179
- Pitch and diameter measured in inches, e.g. G1/4-19
- Parallel threads require O-ring, crush washer, gasket or metal to metal seal between connections for pressure tight connection
- Thread angle is 55°
- Not interchangeable with SAE or NPT(F)

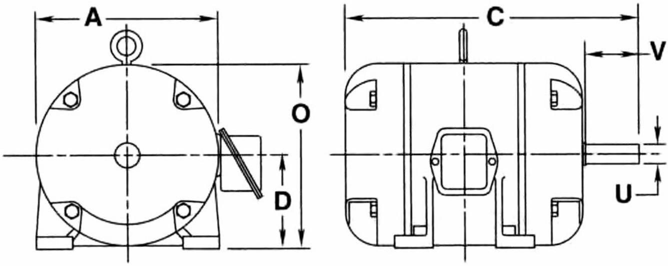
Metric Straight Thread O-Ring



- Thread conforms to ISO 261
- Port conforms to ISO 6149 and SAE J2244
- Pitch and diameter measured in millimeters, e.g. M22 × 1.5
- Parallel threads require O-ring for pressure tight connection
- Thread angle is 60°
- Easily identified by raised ridge on female port counterbore
- Not interchangeable with SAE or BSPP

Three–Phase Motor Data

Frame Assignments and Dimensions for Squirrel-Cage Induction Motors — 3-Phase, 60 Hz, Design B



Drip-proof (Open Type) Enclosures

HP	Speed RPM	NEMA Frame	U	C*	A	D	O	V	Shaft Key
1	1200	145T	7/8	12¾	6½	3½	6¾	2¼	3/16
1	1800	172T	7/8	12¾	6½	3½	6¾	2¼	3/16
1½	1200	145T	1⅛	12¾	9½	4½	9¼	2¾	1/4
1½	1800	145T	7/8	12¾	6½	3½	6¾	2¼	3/16
1½	3600	143T	7/8	12¾	6½	3½	6¾	2¼	3/16
2	1200	184T	1⅛	13¾	9½	4½	9¼	2¾	1/4
2	1800	145T	7/8	13¼	9½	3½	6¾	2¼	3/16
2	3600	145T	7/8	13¼	6½	3½	6¾	2¼	3/16
3	1200	213T	1⅜	15¾	11	5¼	10¾	3⅜	5/16
3	1800	182T	1⅛	12¾	9½	4½	9¼	2¾	1/4
3	3600	145T	7/8	13¼	6½	3½	6¾	2¼	3/16
5	1200	215T	1⅜	17¼	11	5¼	10¾	3⅜	5/16
5	1800	184T	1⅛	13¾	9½	4½	9¼	2¾	1/4
5	3600	182T	1⅛	12¾	9½	4½	9¼	2¾	1/4
7½	1200	254T	1⅝	20½	13⅛	6¼	12⅞	4	3/8
7½	1800	213T	1⅜	15¾	11	5¼	10¾	3⅜	5/16
7½	3600	184T	1⅛	13¾	9½	4½	9¼	2¾	1/4
10	1200	256T	1⅝	22¼	13⅛	6¼	12⅞	4	3/8
10	1800	215T	1⅜	17¼	11	5¼	10¾	3⅜	5/16
10	3600	213T	1⅜	15¾	11	5¼	10¾	3⅜	5/16
15	1200	284T	1⅞	23½	14⅝	7	14⅜	4⅝	1/2
15	1800	254T	1⅝	20½	13¼	6¼	12⅞	4	3/8
15	3600	215T	1⅜	17⅛	11	5¼	10¾	3⅜	5/16
20	1200	286T	1⅞	25	14⅝	7	14⅜	4⅝	1/2
20	1800	256T	1⅝	22¼	13¼	6¼	12⅞	4	3/8
20	3600	254T	1⅝	20½	13⅛	6¼	12⅞	4	3/8
25	1200	324T	2⅛	26	16¾	8	16⅜	5¼	1/2
25	1800	284T	1⅞	23½	14⅝	7	14⅜	4⅝	1/2
25	3600	256T	1⅝	22¼	13⅛	6¼	12⅞	4	3/8
30	1200	326T	2⅛	27½	16¾	8	16⅜	5¼	1/2
30	1800	286T	1⅞	24⅞	14⅝	7	14⅜	4⅝	1/2
30	3600	284TS	1⅝	22	14⅝	7	14⅜	3¼	3/8
40	1200	364T	2⅜	28¾	18⅝	9	18⅜	5⅞	5/8
40	1800	324T	2⅛	26	16¾	8	16½	5¼	1/2
40	3600	286TS	1⅝	23½	14⅝	7	14⅜	3¼	3/8
50	1200	365T	2⅜	29¾	18⅝	9	18⅜	5⅞	5/8
50	1800	326T	2⅛	27½	16¾	8	16½	5¼	1/2
50	3600	324TS	1⅞	24½	16⅞	8	16½	3¾	1/2
60	1200	404T	2⅞	32¾	21	10	20½	7¼	3/4
60	1800	364T	2⅜	28¾	18⅝	9	18⅜	5⅞	5/8
60	3600	326TS	1⅞	26	16⅞	8	16½	3¾	1/2
75	1200	405T	2⅞	34¼	21	10	20½	7¼	3/4
75	1800	365T	2⅜	29¾	18⅝	9	18⅜	5⅞	5/8
75	3600	364TS	1⅞	26½	18⅝	9	18⅜	3¾	1/2
100	1200	444T	3⅜	39⅝	22½	11	22³⁄₁₆	8½	7/8
100	1800	404T	2⅞	32¾	21	10	20½	7¼	3/4
100	3600	365TS	1⅞	27½	18⅝	9	18⅜	3¾	1/2

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HP	Speed RPM	NEMA Frame	U	C*	A	D	O	V	Shaft Key
125	1200	445T	3⅜	39¾	23½	11	22¾	8½	7/8
125	1800	405T	2⅞	34¼	21	10	20½	7¼	3/4
125	3600	404TS	2⅛	29¾	21	10	20½	4¼	1/2
150	1800	444TS	2⅜	34	23½	11	22¾	4¾	5/8
150	3600	405TS	2⅛	31¼	21	10	20½	4¼	1/2
200	1800	445TS	2⅜	36	23½	11	22¾	4¾	5/8
200	3600	444TS	2⅜	34	23½	11	22¾	4¾	5/8
250	1800	445T	3⅜	39⅝	22½	11	22 3/16	8½	7/8
250	3600	445TS	2⅜	36	23½	11	22¾	4¾	5/8

Totally Enclosed, Fan Cooled (TEFC)

HP	Speed RPM	NEMA Frame	U	C*	A	D	O	V	Shaft Key
1	1200	145T	7/8	13	7	3½	7	2¼	3/16
1	1800	143T	7/8	13	7	3½	7	2¼	3/16
1½	1200	182T	1⅛	14⅜	9½	4½	9½	2¾	1/4
1½	1800	145T	7/8	13	7	3½	7	2¼	3/16
1½	3600	143T	7/8	13	7	3½	7	2¼	3/16
2	1200	184T	1⅛	15⅜	9½	4½	9½	2¾	1/4
2	1800	145T	7/8	13½	7	3½	7	2¼	3/16
2	3600	145T	7/8	13½	7	3½	7	2¼	3/16
3	1200	213T	1⅜	17⅝	11⅛	5¼	10⅞	3⅜	5/16
3	1800	182T	1⅛	14⅜	9½	4½	9½	2¾	1/4
3	3600	182T	1⅛	14⅜	9½	4½	9½	2¾	1/4
5	1200	215T	1⅜	19⅛	11⅛	5¼	10⅞	3⅜	5/16
5	1800	184T	1⅛	15⅜	9½	4½	9½	2¾	1/4
5	3600	184T	1⅛	15⅜	9½	4½	9½	2¾	1/4
7½	1200	254T	1⅝	22⅞	13¼	6¼	12⅞	4	3/8
7½	1800	213T	1⅜	17⅝	11⅛	5¼	11	3⅜	5/16
7½	3600	213T	1⅜	17⅝	11⅛	5¼	11	3⅜	5/16
10	1200	256T	1⅝	24⅝	13¼	6¼	12⅞	4	3/8
10	1800	215T	1⅜	19⅛	11⅛	5¼	11	3⅜	5/16
10	3600	215T	1⅜	19⅛	11⅛	5¼	11	3⅜	5/16
15	1200	284T	1⅞	25⅞	14¾	7	14½	4⅝	1/2
15	1800	254T	1⅝	22⅞	13¼	6¼	13	4	3/8
15	3600	254T	1⅝	22⅞	13¼	6¼	13	4	3/8
20	1200	286T	1⅞	27⅜	14¾	7	14½	4⅝	1/2
20	1800	256T	1⅝	24½	13¼	6¼	13	4	3/8
20	3600	256T	1⅝	24½	13¼	6¼	13	4	3/8
25	1200	324T	2⅛	28¾	16½	8	16½	5¼	1/2
25	1800	284T	1⅞	25⅞	14¾	7	14½	4⅝	1/2
25	3600	284TS	1⅝	24½	14¾	7	14½	3¼	3/8
30	1200	326T	2⅛	30¼	16½	8	16½	5¼	1/2
30	1800	286T	1⅞	27⅜	14¾	7	14½	4⅝	1/2
30	3600	286TS	1⅝	26	14¾	7	14½	3¼	3/8
40	1200	364T	2⅜	32½	19⅛	9	18⅝	5⅞	5/8
40	1800	324T	2⅛	28¾	16⅞	8	16½	5¼	1/2
40	3600	324TS	1⅞	27¼	16⅞	8	16½	3¾	1/2
50	1200	365T	2⅜	33½	19⅛	9	18⅝	5⅞	5/8
50	1800	326T	2⅛	30¼	16⅞	8	16½	5¼	1/2
50	3600	326TS	1⅞	26	16⅞	8	16½	3¾	1/2
60	1200	404T	2⅞	36⅝	21½	10	20¾	7¼	3/4
60	1800	364T	2⅜	32½	19⅛	9	18⅝	5⅞	5/8
60	3600	364TS	1⅞	30⅜	19⅛	9	18½	3¾	1/2
75	1200	405T	2⅞	38⅛	21½	10	20¾	7¼	3/4
75	1800	365T	2⅜	32¼	18⅝	9	18⅜	5⅞	5/8
75	3600	365TS	1⅞	31⅜	19⅛	9	18½	3¾	1/2
100	1200	444T	3⅜	42⅛	24¼	11	23¼	8½	7/8
100	1800	405T	2⅞	38⅛	21½	10	20¾	7¼	3/4
100	3600	405TS	2⅛	35⅛	21½	10	20¾	4¼	1/2
125	1200	445T	3⅜	44⅛	24¼	11	23¼	8½	7/8
125	1800	444T	3⅜	42⅛	24¼	11	23¼	8½	7/8
125	3600	444TS	2⅜	38⅜	21½	11	23¼	4¾	5/8
150	1800	445T	3⅜	44⅛	24¼	11	23¼	8½	7/8
150	3600	445TS	2⅜	40⅜	24¼	11	23¼	4¾	5/8

NOTES: Dimensions are given to the nearest sixteenth of an inch to standard NEMA specification. ***Dim. C** will vary with motor brand as this is not specified by NEMA.

Motor Installation Data

3–Phase Motor Starters

1/2 To 20 H.P. Motor HP, 3Ø	1/2		3/4		1		1½		2		3		5		7½		10		15		20	
Voltage	230	460	230	460	230	460	230	460	230	460	230	460	230	460	230	460	230	460	230	460	230	460
Full Load Current (Average Values)	2.0	1.0	2.8	1.4	3.6	1.8	5.2	2.6	6.8	3.4	9.6	4.8	15.2	7.6	22	11	28	14	42	21	54	27
Max. Fuse Amps. — Standard N.E.C.†	6	3	10	3	10	6	15	10	20	10	25	15	45	20	60	30	80	40	125	60	150	80
Max. Fuse Amps. — Dual Element†	3	1	3	1	6	1	6	3	10	6	15	6	15	6	25	10	35	15	70	35	90	45
Circuit Breaker Max. Amps.†	15	15	15	15	15	15	15	15	20	15	25	15	25	15	40	20	60	30	110	60	150	70
Minimum Wire Size — T, TW	14	14	14	14	14	14	14	14	14	14	14	14	12	14	10	14	8	12	6	10	4	8
Min. Wire Size — RH, RHW, THW, THWN	14	14	14	14	14	14	14	14	14	14	14	14	12	14	10	14	8	12	6*	10	6	8
Min. Wire Size — RHH, THHN, XHHW	14	14	14	14	14	14	14	14	14	14	14	14	12	14	10	14	8	12	6*	10	6	8

3–Phase Motor Starters

25 To 200 H.P. Motor HP, 3Ø	25		30		40		50		60		75		100		125		150		200	
Voltage	230	460	230	460	230	460	230	460	230	460	230	460	230	460	230	460	230	460	230	460
Full Load Current (Average Values)	68	34	80	40	104	52	130	65	154	77	192	96	248	124	312	156	360	180	480	240
Max. Fuse Amps. — Standard N.E.C.†	200	100	200	100	300	150	350	75	450	225	500	250	700	350	800	450	1000	500	—	600
Max. Fuse Amps. — Dual Element†	100	50	125	70	175	90	200	100	250	125	300	150	400	200	500	250	600	300	700	400
Circuit Breaker Max. Amps.†	175	90	200	100	300	150	350	175	400	200	500	250	700	350	800	400	1000	450	1200	600
Minimum Wire Size — T, TW	3	6	1	6	00	4	000	3	0000	2	300	0	500	000	750	0000	1000	300	—	500
Min. Wire Size — RH, RHW, THW, THWN	4	8	3	6	1	6	00	4	000	3	250	1*	250	00	600*	000	750*	0000	1500*	350*
Min. Wire Size — RHH, THHN, XHHW	4	8	3	6	1	6	00	4	000	3										

Single Phase Motor Starters

1/6 To 5 H.P. Motor HP, 1Ø	1/6		1/4		1/3		1/2		3/4		1		1½		2		3		5	
Voltage	115	230	115	230	115	230	115	230	115	230	115	230	115	230	115	230	115	230	115	230
Full Load Current (Average Values)	4.4	2.2	5.8	2.9	7.2	3.6	9.8	4.9	13.8	6.9	16	8	20	10	24	12	34	17	56	28
Max. Fuse Amps. — Standard N.E.C.†	15	6	15	10	20	10	25	15	40	20	45	20	45	20	70	35	100	50	150	80
Max. Fuse Amps. — Dual Element†	7	3½	10	5	12	6¼	15	8	20	10	25	12	30	15	35	17½	50	25	90	45
Circuit Breaker Max. Amps.†	15	15	15	15	20	15	25	15	35	20	40	20	50	25	60	30	90	45	150	70
Minimum Wire Size — T, TW	14	14	14	14	14	14	14	14	12	14	12	4	10	14	10	14	6	10	4	8
Min. Wire Size — RH, RHW, THW, THWN	14	14	14	14	14	14	14	14	12	14	12	14	12	10	10	14	8	10	4	8
Min. Wire Size — RHH, THHN, XHHW	14	14	14	14	14	14	14	14	12	14	12	14	12	10	10	14	8	10	4	8

†Motor branch circuit protection. *Use one size smaller wire for RHH, THHN, XHHW
NOTE: All information based on 1971 N.E.C. and NEMA Standards.

Wire Selection Guide

Two important considerations in choosing the conductor size for electric wiring are: (1) the safe current carrying capacity, and (2) the voltage loss due to wire resistance. On short runs, up to 20 feet, voltage loss is very low and need not be considered. Wire size should be selected for its current capacity as shown in Chart 1.

On longer runs, several hundred feet or more, the voltage loss may be too high if wire size is selected solely on the basis of current capacity. A larger wire size should be used to keep voltage loss to a selected minimum. Chart 2 may be used for this.

Permissible Voltage Loss ...

There is always a voltage loss on any wiring run. The designer must decide on how much loss can be tolerated without seriously affecting performance, and must select a wire size in which this loss will not be exceeded. A rule-of-thumb suggests that electric motors should not be run on a voltage less than about 10% of their nameplate rating. In deciding on allowable voltage loss in the wiring a designer must consider the minimum available power line voltage which may occur at a certain time of the day. For example, a 230-volt rated motor should not be run on less than 208 volts (which is 10% less than nameplate voltage Rating). If the lowest power line voltage is 220 volts, then the wiring should not have more than 12 volts loss.

A rule that works in most cases is to choose a wire size which does not give more than a 5% loss of input voltage.

Chart 1 – Wire Ampacity For Short Wiring Runs

"Ampacity" is an abbreviation for ampere capacity. This chart is for short wiring runs of less than 20 feet. Ampere capacity is taken from the NEC (National Electrical Code) on wire sizes of No. 14 and larger. It is for insulated copper wire of the kind that is widely used for house and building wiring. A larger ampere capacity is allowed on wire with certain types of insulation when used under certain conditions, but the NEC handbook should be consulted.

Amperage Rating for Copper Wires

Wire size, AWG	18	16	14	12	10	8	6	4	3	2	1	0	00	000
In raceway or cable	6	9	15	20	30	40	55	70	80	95	110	125	145	165
In open air	8	12	20	25	40	55	80	105	120	140	165	195	225	260

Chart 2 – Voltage Loss on Long Wiring Runs

This chart is for long wiring runs of several hundred feet or more. To use the chart, several facts must be established: (1) the current draw of the device to be operated must be determined; (2) the amount of voltage loss that can be tolerated must be decided on; and (3) the length of wire must be estimated or measured, using the sum of outgoing and return wire lengths.

On 3-phase devices such as electric motors, each of the three wires must carry the current shown on the motor nameplate. Wire length is the sum of two (not all three) connecting wires.

Read across the top of the chart to find the column which matches the amperage rating of the device. Figures in this column show voltage losses for 1000 feet of wire, outgoing plus return. If for example, your total wire length was 250 feet, voltage losses would be 1/4th that shown in the chart.

Figures in Chart Show Voltage Loss Per 1000 Feet of Wire

Wire Size AWG	Current Flow, Amperes									
	5	10	15	20	25	30	40	50	75	100
18	32.55	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
16	20.47	40.94	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
14	12.8S	25.75	38.63	– – –	– – –	– – –	– – –	– – –	– – –	– – –
12	8.095	16.19	24.28	32.38	– – –	– – –	– – –	– – –	– – –	– – –
10	5.090	10.18	15.27	20.36	25.45	30.54	– – –	– – –	– – –	– – –
8	3.203	6.405	9.608	12.81	16.02	19.22	25.62	– – –	– – –	– – –
6	2.014	4.028	6.042	8.056	10.07	12.08	16.11	20.14	– – –	– – –
4	1.267	2.533	3.800	5.068	6.335	7.602	10.14	12.68	– – –	– – –
3	1.005	2.009	3.014	4.020	5.025	6.030	8.040	10.05	15.08	– – –
2	– – –	1.593	2.390	3.184	3.980	4.776	6.368	7.960	11.94	– – –
1	– – –	1.264	1.896	2.528	3.160	3.792	5.056	6.320	9.480	12.64
0	– – –	1.002	1.503	2.004	2.505	3.006	4.008	5.010	7.515	10.02
00	– – –	– – –	1.193	1.592	1.990	2.388	3.184	3.980	5.970	7.960
000	– – –	– – –	– – –	1.260	1.575	1.890	2.520	3.150	4.725	6.300
0000	– – –	– – –	– – –	1.000	1.250	1.500	2.000	2.500	3.750	5.000

Table of Equivalents

To convert units appearing in Column 1 (left column) into equivalent values in Column 2 (center column), multiply by factor in Column 3. **Example:** To convert 7 gallons into cubic inches multiply 7 × 231 = 1617.

To convert units appearing in Column 2 (center) into equivalent values of units in Column 1 (left), divide by factor in Column 3. **Example:** To convert 25 horsepower into BTU per minute, divide 25 by 0.02356 = 1061.

To Convert... →	Into... →	Multiply By...
Into... ←	**To Convert... ←**	**Divide By...**
Atmospheres	Feet of Water	33.9
Atmospheres	Inches of Mercury (Hg)	29.92
Atmospheres	PSI (Pounds per Sq. Inch)	14.7
BTU	Foot Pounds	778.3
BTU per Hour	Watts	0.2931
BTU per Minute	Horsepower	0.02356
Celsius (Centigrade)	Fahrenheit	°C × 1.8 + 32
Centimeters	Inches	0.3937
Cubic Centimeters	Gallons (U.S. Liquid)	0.0002642
Cubic Centimeters	Liters	0.001
Cubic Feet	Cubic Inches	1728
Cubic Feet	Gallons (U.S. Liquid)	7.48052
Cubic Inches	Cubic Feet	0.0005787
Cubic Inches	Gallons (U.S. Liquid)	0.004329
Days	Seconds	86,400
Degrees (Angle)	Radians	0.01745
Feet	Meters	0.3048
Feet	Miles	0.0001894
Feet of Water	Atmospheres	0.0295
Feet of Water	Inches of Mercury (Hg)	0.8826
Feet of Water	PSI (Pounds per Sq. Inch)	0.4335
Feet per Minute	Miles per Hour	0.01136
Feet per Second	Miles per Hour	0.6818
Foot-Pounds	BTU	0.001286
Foot-Pounds per Minute	Horsepower	0.0000303
Foot-Pounds per Second	Horsepower	0.001818
Gallons (U.S. Liquid)	Cubic Feet	0.1337
Gallons (U.S. Liquid)	Cubic Inches	231
Gallons of Water	Pounds of Water	8.3453
Horsepower	BTU per Minute	42.44
Horsepower	Foot-Pounds per Minute	33,000
Horsepower	Foot-Pounds per Second	550
Horsepower	Watts	745.7
Hours	Days	0.04167
Hours	Weeks	0.005952
Inches	Centimeters	2.54
Inches of Mercury (Hg)	Atmospheres	0.03342
Inches of Mercury (Hg)	Feet of Water	1.133
Inches of Mercury (Hg)	PSI (Pounds per Sq. Inch)	0.4912
Inches of Water	PSI (Pounds per Sq. Inch)	0.03613
Liters	Cubic Centimeters	1000
Liters	Gallons (U.S. Liquid)	0.2642
Micron	Inches	0.00004
Miles (Statute)	Feet	5280
Miles per Hour (M.P.H.)	Feet per Minute	88
Miles per Hour	Feet per Second	1.467
Ounces (Weight)	Pounds	0.0625
Ounces (Liquid)	Cubic Inches	1.805
Pints (Liquid)	Quarts (Liquid)	0.5
Pounds	Grains	7000
Pounds	Grams	453.59
Pounds	Ounces	16
PSI (Pounds per Sq. Inch)	Atmospheres	0.06804
PSI (Pounds per Sq. Inch)	Feet of Water	2.307
PSI (Lbs per Square Inch)	Inches of Mercury (Hg)	2.036
Quarts	Gallons	0.25
Square Feet	Square Inches	144
Temperature (°F - 32)	Temperature (°C)	0.5555
Tons (U.S.)	Pounds	2000
Watts	Horsepower	0.001341

Decimal and Metric

Equivalents of Common Fractions of an Inch

64ths	32nds	16ths	8ths	Decimal	mm
1/64				0.01562	0.397
	1/32			0.03125	0.794
3/64				0.04688	1.191
		1/16		0.06250	1.588
5/64				0.07812	1.984
	3/32			0.09375	2.381
7/64				0.10938	2.778
			1/8	0.12500	3.175
9/64				0.14062	3.572
	5/32			0.15625	3.969
11/64				0.17188	4.366
		3/16		0.18750	4.763
13/64				0.20312	5.159
	7/32			0.21875	5.556
15/64				0.23438	5.953
			1/4	0.25000	6.350
17/64				0.26562	6.747
	9/32			0.28125	7.144
19/64				0.29688	7.541
		5/16		0.31250	7.938
21/64				0.32812	8.334
	11/32			0.34375	8.731
23/64				0.35938	9.128
			3/8	0.37500	9.525
25/64				0.39062	9.922
	13/32			0.40625	10.319
27/64				0.42188	10.716
		7/16		0.43750	11.113
29/64				0.45312	11.509
	15/32			0.46875	11.906
31/64				0.48438	12.303
			1/2	0.50000	12.700
33/64				0.51562	13.097
	17/32			0.53125	13.494
35/64				0.54688	13.891
		9/16		0.56250	14.288
37/64				0.57812	14.684
	19/32			0.59375	15.081
39/64				0.60938	15.478
			5/8	0.62500	15.875
41/64				0.64062	16.272
	21/32			0.65625	16.669
43/64				0.67188	17.066
		11/16		0.68750	17.463
45/64				0.70312	17.859
	23/32			0.71875	18.256
47/64				0.73438	18.653
			3/4	0.75000	19.050
49/64				0.76562	19.447
	25/32			0.78125	19.844
51/64				0.79688	20.241
		13/16		0.81250	20.638
53/64				0.82812	21.034
	27/32			0.84375	21.431
55/64				0.85938	21.828
			7/8	0.87500	22.225
57/64				0.89062	22.622
	29/32			0.90625	23.019
59/64				0.92188	23.416
		15/16		0.93750	23.813
61/64				0.95312	24.209
	31/32			0.96875	24.606
63/64				0.98438	25.003
1	1	1	1	1.00000	25.400

Conversions

From English to Metric Units

Pressure:
1 PSI = 0.06897 bar
1 bar = 14.5 PSI

Measurements:
1 inch = 2.54 cm
1 cm = 0.3937 in

Volume:
1 CFM = 28.03 liters/min
1 liter/min = 0.0356 CFM

Conversions Between English and (SI) Standard Units

SI (International Standards) units should be used on documents prepared for international circulation.

Quantity	SI Unit for Fluid Power	Customary U.S.Unit	Conversion Factor
Length	millimeter (mm)	inch (in.)	1 inch = 25.4 mm
Pressure*	bar (bar g, or bar a)	pounds/sq. in (PSIG or PSIA)	1 bar = 14.5 PSI
Pressure**	mm of mercury (mm Hg)	inches of mercury (in. Hg.)	1″ Hg = 25.4 mm Hg.
Flow***	liters per minute (l/min)	U.S. gallons per minute (U.S. GPM)	1 U.S GPM = 3.79 l/min.
Flow†	cubic decimeters/sec (dm^3/sec)	cubic feet per minute (cfm)	1 dm^3/sec = 2.12 cfm
Force	Newton (N)	pound (f) or lb (f) (force)	1 lb (f) = 4.44 N
Mass	kilogram (Kg)	pound (m) or lb (m) (mass)	1 Kg = 2.2 lb (m)
Time	second (sec)	second (sec)	— — — — —
Volume***	liter (l)	gallon (U.S. gal)	1 U.S. gal. = 3.79 liters
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	°C = 5/9 (°F – 32)
Torque	Newton-meters (Nm)	pounds (f) – inches [lbs (f) – in.]	1 Nm = 8.88 lb (f) – in.
Power	kilowatt (kw)	horsepower (HP)	1 kw = 1.34 HP
Shaft speed	revolutions per minute (rpm)	revolutions per minute (rpm)	— — — — —
Frequency	Hertz (Hz)	cycles per second (cps)	1 Hz = 1 cps
Displacement	milliliters/revolution (ml/rev)	cu. inches per rev (cir)	1 ml/rev = 0.061 cir
Kinematic viscosity	centistokes (cSt)	Saybolt Universal Seconds (SUS or SSU)	cSt = SSU ÷ 4.635††
Velocity	meter per second (m/s)	feet per second (fps)	1 m/s = 3.28 fps

*Pressure above atmospheric, **Pressure below atmospheric, ***Liquid, †Gas, ††Approx. for SSU 225 and over

PSI Gauge Pressure Converted from English to Metric Units

This table is calculated on the basis of 1 PSI = 0.0689655 bar, or 1 bar = 14.5 PSI

PSI	10	50	100	250	500	750	1000	1500	2000	2500	3000	5000
Bar	0.69	3.49	6.90	17.2	34.5	51.7	69.0	103.4	138.0	172.4	206.0	344.8

GPM Oil Flow Converted from U.S.Gallons to Metric Units

This table is calculated on the basis of 1 U.S.GPM = 3.79 liters per minute (liquid) or 1 liter per minute = 0.2638 GPM

GPM	5	8	12	15	20	25	30	35	40	50	75	100
Liters/min	18.95	30.32	45.48	56.85	75.80	94.75	113.7	132.7	151.6	189.5	284.3	379.0

SCFM Air Flow Converted from English to Metric Units

This table is calculated on the basis of 1 SCFM = 0.4716 cubic decimeters per second, or 1 dm^3/sec = 2.12 SCFM

SCFM	5	10	15	25	50	75	100	150	200	250	300	350
Dm^3/sec	2.358	4.716	7.074	11.79	23.58	35.37	47.16	70.74	94.32	117.9	141.5	165.1

Interchange Between Units

International Metric – Old Metric – U.S. Customary Units

These charts will interchange values between the SI International Standard, the U.S. or English system, and the older metric systems. The left column of each chart shows the basic unit in the SI system.

Equivalent values of all units are shown on the same line. The easiest way to use the charts is to look down the column of the unit which is to be converted and find the one on which the figure "1" appears. Then move to the left or right on the same one to the column of the new unit. The value shown is a multiplier to convert to the new unit.

Conversions can be easily made with a pocket calculator which has an exponent key or can be made manually.

For manual calculations remember that the + or – sign in front of an exponent tells whether to move the decimal point to the right (for a + sign) or to the left (for a – sign) and how far to move it. **Examples:** 2.640 x 10-5 is 0.0000264, and 3.048 x 102 = 304.8, etc.). Conversion examples are:

Convert 627 inches into centimeters. In the LENGTH chart, look down the Inch column to the figure "1". Then move left on this line to the Centimeter column. Use the conversion multiplier 2.540: 627 × 2.540 = 1592.58 centimeters = 15.93 meters = 15,925.8 millimeters.

Convert 5000 PSI (pounds/sq. inch) into Bar. Use the UNIT PRESSURE chart on the next page. Look down the Pounds/inch^2 column to the figure "1". Then move left on the same line to the Bar column. The figure 0.06897 is a multiplier. Multiply 5000 × 0.06887 = 344.86 bar.

Most western countries have abandoned the older metric systems in favor of the new SI metric system. The USA is the only major country which has not officially adopted the SI system of units.

Torque

Newton-Meters	Kilopond-Meters	Foot-Lbs	Inch-Lbs
1	1.020×10^{-1}	7.376×10^{-1}	8.851
9.807	1	7.233	86.80
1.356	1.382×10^{-1}	1	12
1.130×10^{-1}	1.152×10^{-2}	8.333×10^{-2}	1

Gravity Acceleration

In the U.S. system, the acceleration due to gravity or "g" is 32.2 feet per second per second. In the metric system "g" is 9.81 meters per second per second.

Length (Linear Measurement)

Meter	Centimeter	Kilometer	Mile	Inch	Foot
1	100	1×10^{-3}	6.214×10^{-4}	39.370	3.281
0.01	1	1×10^{-5}	6.214×10^{-6}	3.937×10^{-1}	3.281×10^{-2}
1×10^{-3}	0.10	1×10^{-6}	6.214×10^{-7}	3.937×10^{-2}	3.281×10^{-3}
1×10^{3}	1×10^{5}	1	6.214×10^{-1}	3.937×10^{4}	3.281×10^{3}
1.609×10^{3}	1.609×10^{5}	1.609	1	6.336×10^{4}	5280
2.540×10^{-2}	2.540	2.540×10^{-5}	1.578×10^{-5}	1	8.333×10^{-2}
3.048×10^{-1}	30.479	3.048×10^{-4}	1.894×10^{-4}	12	1

1 millimeter = 0.001 meter = 0.10 centimeter = 0.000001 kilometer = 0.03937 inch = 0.003281 foot

Area (Square Measurement)

Square Meter	Sq Centimeter	Sq Kilometer	Square Inch	Square Foot	Square Mile
1	1×10^{4}	1×10^{6}	1.550×10^{3}	10.764	3.861×10^{-7}
1×10^{-4}	1	1×10^{-10}	1.550×10^{-1}	1.076×10^{-3}	3.861×10^{-11}
1×10^{-6}	1×10^{-2}	1×10^{-12}	1.550×10^{-3}	1.076×10^{-5}	3.861×10^{-13}
1×10^{6}	1×10^{-10}	1	1.550×10^{9}	1.076×10^{7}	3.861×10^{-1}
6.452×10^{-4}	6.452	6.452×10^{-10}	1	6.944×10^{-3}	2.491×10^{-10}
9.290×10^{-2}	9.290×10^{2}	9.290×10^{-8}	144	1	3.587×10^{-8}
2.590×10^{6}	2.590×10^{10}	2.590	4.014×10^{9}	2.788×10^{7}	1

1 square millimeter = 0.000001 square meter = 0.00155 square inch = 0.00001076 square foot

Volume (Cubic)

Cubic Meter	Cu Decimeter	Cu Centimeter	U.S. Gallon	Cubic Inch	Cubic Foot
1	1×10^{3}	1×10^{6}	2.642×10^{2}	6.102×10^{4}	35.314
1×10^{-3}	1	1×10^{3}	2.642×10^{-1}	61.024	3.531×10^{-2}
1×10^{-6}	1×10^{-3}	1	2.642×10^{-4}	6.102×10^{-2}	3.531×10^{-5}
4.546×10^{-3}	4.546	4.546×10^{3}	1.200	2.774×10^{2}	1.605×10^{-1}
3.785×10^{-3}	3.785	3.785×10^{3}	1	2.310×10^{2}	1.337×10^{-1}
1.639×10^{-5}	1.639×10^{-2}	16.387	4.329×10^{-3}	1	5.787×10^{-4}
2.832×10^{-2}	28.317	2.832×10^{4}	7.481	1.728×10^{3}	1

1 imperial gallon = 1.2 U.S. gallon = 0.004546 cubic meter = 4.546 liter = 4546 cubic centimeters

Force (Including Force Due to Weight)

Newton	Dyne	Kilopond	Metric Ton	U.S. Ton	Pound
1	1×10^{5}	1.020×10^{-1}	1.020×10^{-4}	1.124×10^{-4}	2.248×10^{-1}
1×10^{-5}	1	1.020×10^{-6}	1.020×10^{-9}	1.124×10^{-9}	2.248×10^{-6}
9.807	9.807×10^{5}	1	1×10^{-3}	1.102×10^{-3}	2.205
9.807×10^{3}	9.807×10^{8}	1000	1	1.102	2.205×10^{3}
9.964×10^{3}	9.964×10^{8}	1.016×10^{3}	1.016	1.120	2.240×10^{3}
8.896×10^{3}	8.896×10^{8}	9.072×10^{2}	9.072×10^{-1}	1	2000
4.448	4.448×10^{5}	4.536×10^{-1}	4.536×10^{-4}	5×10^{-4}	1

1-long ton = 9964 Newtons= 1016 kiloponds = 1.016 metric tons = 1.120 U.S. tons = 2240 pounds

Mass (Not Weight)

Kilogram	Gram	Metric Ton	Newton	Pound	U.S. Ton
1	1000	1×10^{-3}	9.807	2.205	1.102×10^{-3}
1×10^{-3}	1	1×10^{-6}	9.807×10^{-3}	2.205×10^{-3}	1.102×10^{-6}
1×10^{3}	1×10^{6}	1	9.807×10^{3}	2.205×10^{3}	1.10^{2}
1.020×10^{-1}	1.020×10^{2}	1.020×10^{-4}	1	2.248×10^{-1}	1.124×10^{-4}
4.536×10^{-1}	4.536×10^{2}	4.536×10^{-4}	4.448	1	5×10^{-4}
14.594	1.459×10^{4}	1.459×10^{-2}	1.431×10^{2}	32.170	1.609×10^{-2}
9.072×10^{2}	9.072×10^{5}	9.072×10^{-1}	8.896×10^{3}	2000	1

Velocity

Meters/Sec	Kilometers/Hr	Miles/Hr	Feet/Min.	Feet/Sec	Inches/Min.
1	3.6	2.237	1.968×10^{2}	3.281	2.362×10^{3}
1×10^{-1}	1×10^{-4}	6.214×10^{-5}	5.468×10^{-3}	9.113×10^{-5}	6.562×10^{-2}
2.778×10^{-1}	1	6.214×10^{-1}	5.468×10^{1}	9.113×10^{-1}	6.562×10^{2}
4.470×10^{-1}	1.609	1	88	1.467	1.056×10^{3}
5.080×10^{-3}	1.829×10^{-2}	1.136×10^{-2}	1	1.667×10^{-2}	12
3.048×10^{-1}	1.097	6.818×10^{-1}	60	1	7.2×10^{2}
4.233×10^{-4}	1.524×10^{-3}	9.470×10^{-4}	8.333×10^{-2}	1.389×10^{-3}	1

1 decimeter/second = 0.1 meters/second = 0.005468 ft/min = 0.06562 in/min

Unit Pressure (Either Fluid or Mechanical)

Bar	Newton/m^2 (Pascal)	Kilopond/m^2	Atmosphere	Pounds/Ft^2	Pounds/Inch^2
1×10^{-5}	1	1.020×10^{-1}	9.869×10^{-6}	2.088×10^{-2}	1.45×10^{-4}
1	1×10^{5}	1.020×10^{4}	9.869×10^{-1}	2.088×10^{3}	14.5
9.807×10^{-5}	9.807	1	9.678×10^{-5}	2.048×10^{-1}	1.422×10^{-3}
9.807×10^{-1}	9.807×10^{4}	1×10^{4}	9.678×10^{-1}	2.048×10^{3}	14.220
1.013	1.013×10^{5}	1.033×10^{4}	1	2.116×10^{3}	14.693
4.789×10^{-4}	47.893	4.884	4.726×10^{-4}	1	6.944×10^{-3}
6.897×10^{-2}	6.897×10^{3}	7.033×10^{2}	6.806×10^{-2}	1.440×10^{2}	1

1 kilopond/sq cm = 0.9807 bar = 98070 Pascal = 0.9678 atmos = 2048 Lbs/sq ft = 14.22 Lbs/sq inch

Power (Fluid, Electrical, or Mechanical)

Kilowatt	Watt, Joule/s and N-m/s	Foot-Pounds per Minute	Foot-Pounds per Second	BTU/Hr	BTU/Min
1	1000	4.425×10^{4}	7.376×10^{2}	3.412×10^{3}	56.862
1×10^{-3}	1	44.254	7.376×10^{-1}	3.412	5.686×10^{-2}
7.461×10^{-1}	746	3.300×10^{4}	5.500×10^{2}	2.545×10^{3}	42.44
2.260×10^{-5}	2.260×10^{-2}	1	1.667×10^{-2}	7.710×10^{-2}	1.285×10^{-3}
1.356×10^{-3}	1.356	60	1	4.626	7.710×10^{-2}
2.931×10^{-4}	2.931×10^{-1}	12.971	2.162×10^{-1}	1	1.667×10^{-2}
1.759×10^{-2}	17.586	7.783×10^{2}	12.971	60	1

1 U.S. = 1 U.K. Horsepower = 0.7461 kW = 33,000 ft-lbs/min. = 2545 BTU/hr = 42144 BTU/min

Energy or Work

Kilowatt-Hour	Watt-second Joule, or N-m	Horsepower-Hr	Foot-Pound	Inch-Pound	BTU
1	3.6×10^{6}	1.341	2.655×10^{6}	3.187×10^{7}	3.412×10^{3}
2.778×10^{-7}	1	3.725×10^{-7}	7.376×10^{-1}	8.851	9.477×10^{-4}
2.778×10^{-14}	1×10^{-7}	3.725×10^{-14}	7.376×10^{-8}	8.851×10^{-7}	9.477×10^{-11}
7.457×10^{-1}	2.685×10^{6}	1	1.980×10^{6}	2.376×10^{7}	2.544×10^{3}
3.766×10^{-7}	1.356	5.051×10^{-7}	1	12	1.285×10^{3}
3.138×10^{-8}	1.130×10^{-1}	4.209×10^{-8}	8.333×10^{-2}	1	1.071×10^{-4}
2.931×10^{-4}	1.055×10^{3}	3.931×10^{-4}	7.783×10^{2}	9.339×10^{3}	1

Temperature Conversion Chart

Enter the table in the column marked **"Temp"** with the temperature either Fahrenheit or Celsius (Centigrade) that you wish to convert. If converting into Celsius, read the equivalent value in the column to the left. If converting into Fahrenheit, read the equivalent value in the column to the right.

°C	Temp	°F	°C	Temp	°F	°C	Temp	°F
-17.7	**0**	32.0	15.6	**60**	140.0	143	**290**	554
-17.2	**1**	33.8	16.1	**61**	141.8	149	**300**	572
-16.6	**2**	35.6	16.6	**62**	143.6	154	**310**	590
-16.1	**3**	37.4	17.1	**63**	145.4	160	**320**	608
-15.5	**4**	39.2	17.7	**64**	147.2	165	**330**	626
-15.0	**5**	41.0	18.2	**65**	149.0	171	**340**	644
-14.4	**6**	42.8	18.8	**66**	150.8	177	**350**	662
-13.9	**7**	44.6	19.3	**67**	152.6	182	**360**	680
-13.3	**8**	46.4	19.9	**68**	154.4	188	**370**	698
-12.7	**9**	48.2	20.4	**69**	156.2	193	**380**	716
-12.2	**10**	50.0	21.0	**70**	158.0	199	**390**	734
-11.6	**11**	51.8	21.5	**71**	159.8	204	**400**	752
-11.1	**12**	53.6	22.2	**72**	161.6	210	**410**	770
-10.5	**13**	55.4	22.7	**73**	163.4	215	**420**	788
-10.0	**14**	57.2	23.3	**74**	165.2	221	**430**	806
-9.4	**15**	59.0	23.8	**75**	167.0	226	**440**	824
-8.8	**16**	60.8	24.4	**76**	168.8	232	**450**	842
-8.3	**17**	62.6	25.0	**77**	170.6	238	**460**	860
-7.7	**18**	64.4	25.5	**78**	172.4	243	**470**	878
-7.2	**19**	66.2	26.2	**79**	174.2	249	**480**	896
-6.6	**20**	68.0	26.8	**80**	176.0	254	**490**	914
-6.1	**21**	69.8	27.3	**81**	177.8	260	**500**	932
-5.5	**22**	71.6	27.7	**82**	179.6	265	**510**	950
-5.0	**23**	73.4	28.2	**83**	181.4	271	**520**	968
-4.4	**24**	75.2	28.8	**84**	183.2	276	**530**	986
-3.9	**25**	77.0	29.3	**85**	185.0	282	**540**	1004
-3.3	**26**	78.8	29.9	**86**	186.8	288	**550**	1022
-2.8	**27**	80.6	30.4	**87**	188.6	293	**560**	1040
-2.2	**28**	82.4	31.0	**88**	190.4	299	**570**	1058
-1.6	**29**	84.2	31.5	**89**	192.2	304	**580**	1076
-1.1	**30**	86.0	32.1	**90**	194.0	310	**590**	1094
-0.6	**31**	87.8	32.6	**91**	195.8	315	**600**	1112
0	**32**	89.6	33.3	**92**	197.6	321	**610**	1130
0.5	**33**	91.4	33.8	**93**	199.4	326	**620**	1148
1.1	**34**	93.2	34.4	**94**	201.2	332	**630**	1166
1.6	**35**	95.0	34.9	**95**	203.0	338	**640**	1184
2.2	**36**	96.8	35.5	**96**	204.8	343	**650**	1202
2.7	**37**	98.6	36.1	**97**	206.8	349	**660**	1220
3.3	**38**	100.4	36.6	**98**	208.4	354	**670**	1238
3.8	**39**	102.2	37.1	**99**	210.2	360	**680**	1256
4.4	**40**	104.0	38	**100**	212	365	**690**	1274
4.9	**41**	105.8	43	**110**	230	371	**700**	1292
5.5	**42**	107.6	49	**120**	248	376	**710**	1310
6.0	**43**	109.4	54	**130**	266	382	**720**	1328
6.6	**44**	111.2	60	**140**	284	387	**730**	1346
7.1	**45**	113.0	65	**150**	302	393	**740**	1364
7.7	**46**	114.8	71	**160**	320	399	**750**	1382
8.2	**47**	116.6	76	**170**	338	404	**760**	1400
8.8	**48**	118.4	83	**180**	356	410	**770**	1418
9.3	**49**	120.2	88	**190**	374	415	**780**	1436
9.9	**50**	122.0	93	**200**	392	421	**790**	1454
10.4	**51**	123.8	99	**210**	410	426	**800**	1472
11.1	**52**	125.6	100	**212**	413	432	**810**	1490
11.5	**53**	127.4	104	**220**	428	438	**820**	1508
12.1	**54**	129.2	110	**230**	446	443	**830**	1526
12.6	**55**	131.0	115	**240**	464	449	**840**	1544
13.2	**56**	132.8	121	**250**	482	454	**850**	1562
13.7	**57**	134.6	127	**260**	500	460	**860**	1580
14.3	**58**	136.4	132	**270**	518	465	**870**	1598
14.8	**59**	138.2	138	**280**	536	471	**880**	1616

Table of Standard Wire Gauges

Gauge No.	(1) Sheet Metal	(2) Steel Wire	(3) Music Wire	(4) Drill Rod	(5) Copper Wire: Copper Wire Diam.	Circular Mil Area	Ohms per 1000 Feet	Ohms per 1000 Meters
4/0	---	.3938	.006	---	.4600	212,000	.0509	.1670
3/0	---	.3625	.007	---	.4096	168,000	.0642	.2105
2/0	---	.3310	.008	---	.3648	133,000	.0810	.2656
0	---	.3065	.009	---	.3248	106,000	.1019	.3342
1	---	.2830	.010	.227	.2893	83,700	.1290	.4231
2	---	.2625	.011	.219	.2576	66,400	.1618	.5307
3	.2391	.2437	.012	.212	.2294	52,600	.2054	.6737
4	.2242	.2253	.013	.207	.2043	41,700	.2588	.8489
5	.2092	.2070	.014	.204	.1819	33,100	.3253	1.067
6	.1943	.1920	.016	.201	.1620	26,300	.4105	1.346
7	.1793	.1770	.018	.199	.1443	20,800	.5194	1.704
8	.1644	.1620	.020	.197	.1285	16,500	.6574	2.156
9	.1495	.1483	.022	.194	.1144	13,100	.8286	2.718
10	.1345	.1350	.024	.191	.1019	10,400	1.036	3.400
11	.1196	.1205	.026	.188	.0907	8,230	1.309	4.294
12	.1046	.1055	.029	.185	.0808	6,530	1.650	5.414
13	.0897	.0915	.031	.182	.0720	5,180	2.080	6.822
14	.0747	.0800	.033	.180	.0641	4,110	2.621	8.600
15	.0673	.0720	.035	.178	.0571	3,260	3.304	10.84
16	.0598	.0625	.037	.175	.0508	2,580	4.174	13.69
17	.0538	.0540	.039	.172	.0453	2,050	5.249	17.22
18	.0478	.0475	.041	.168	.0403	1,620	6.636	21.77
19	.0418	.0410	.043	.164	.0359	1,290	8.631	28.31
20	.0359	.0348	.045	.161	.0320	1,020	10.52	34.51
21	.0329	.0317	.047	.157	.0285	810	13.26	43.49
22	.0299	.0286	.049	.155	.0253	642	16.83	55.20
23	.0269	.0258	.051	.153	.0226	509	21.09	69.18
24	.0239	.0230	.055	.151	.0201	404	26.66	87.44
25	.0209	.0204	.059	.148	.0179	320	33.63	110.3
26	.0179	.0181	.063	.146	.0159	254	42.57	139.6
27	.0164	.0173	.067	.143	.0142	202	53.45	175.3
28	.0149	.0162	.071	.139	.0126	160	67.84	222.5
29	.0135	.0150	.075	.134	.0113	127	84.35	276.7
30	.0120	.0140	.080	.127	.0100	100	107.8	353.6
31	.0105	.0132	.085	.120	.00893	79.2	136.0	446.1
32	.0097	.0128	.090	.115	.00795	64.0	168.2	551.7
33	.0090	.0118	.095	.112	.00708	50.4	213.6	700.6
34	.0082	.0104	.100	.110	.00630	39.7	271.1	889.2
35	.0075	.0095	.106	.108	.00561	31.4	342.5	1123
36	.0067	.0090	.112	.106	.00500	25.0	431.7	1416
37	.0064	.0085	.118	.103	.00445	20.3	532.1	1745
38	.0060	.0080	.124	.101	.00396	16.0	671.5	2203
39	---	.0075	.130	.099	.00353	12.3	872.8	2861
40	---	.0070	.138	.097	.00314	9.6	1128	3700

(1) Manufacturers standard gauge for hot and cold rolled sheets, based on a weight of 41.82 lbs. per inch of thickness per square foot.

(2) U.S. Steel Wire Gauge. Also known as Washburn and Moen, American Steel and Wire, and Roebling gauges. Used by most of the steel producers in the U.S. and has replaced the Birmingham (Stubs) gauge in most instances.

(3) Special gauge for piano and music wire for mechanical springs.

(4) Stubs Steel Wire Gauge. Used sometimes for carbon steel drill rod. Drill rod may also be called out in other gauges such as Morse Twist Drill Gauge (Manufacturers Standard Gauge for twist drills) or by the American Standard Straight Shank Twist Drill standard dimensions.

(5) Copper wire is measured by the B & S gauge (also called AWG). Resistance values are at 77°F or 25°C. Convert between °C and °F with chart on page 61. To convert chart resistance values to a new °C temperature:

$$[RT = R \times [1 + 0.00385 \times (t - 25)]]$$

RT is resistance at new °C temperature; **t** is new temperature in °C; and **R** is resistance value from chart.

A circular mil is a unit of area that is applied to electrical wires and is equal to the area of a circle 1 mil (0.001 inch) in diameter. The area of any circle is equal to the square of its diameter in mils.

Densities and Specific Gravities of Common Materials

Specific gravity is a number indicating how many times a certain volume of a material is heavier than an equal volume of water. As the density of water differs slightly at different temperatures, the temperature of 62° F is used for comparison. The weight of one cubic inch of pure water at 62° F is 0.0361 pound.

If the specific gravity of any material is known, the weight of a cubic inch of the material can be found by multiplying its specific gravity by 0.0361.

To find the weight per cubic foot of a material, the specific gravity of which is known, multiply the specific gravity by 62.335.

If the weight of a cubic inch of material is known, the specific gravity is found by dividing the weight per cubic inch by 0.0361.

If the weight of a cubic foot of a material is known, the specific gravity is found by multiplying the weight per cubic foot by 0.01604.

Material	Specific Gravity	Weight Per Cubic Inch (Pounds)	Weight Per Cubic Foot (Pounds)
Aluminum	2.70	0.0975	168.50
Brass: 80C., 20Z	8.60	0.3105	536.60
Brass: 70C., 30Z	8.44	0.3048	526.70
Brass: 60C., 40Z	8.36	0.3018	521.70
Brass: 50C., 50Z	8.20	0.2961	511.70
Bronze: 90C., 10T	8.78	0.3171	547.90
Chromium	6.93	0.2502	432.40
Concrete	2.31	0.083	144.00
Copper	8.89	0.3210	554.70
Gold	19.25	0.695	1200.00
Iron, Cast	7.03-7.73	0.254-0.279	438.70-482.40
Iron, Wrought	7.80-7.90	0.282-0.285	486.70-493.00
Lead	11.37	0.470	709.00
Magnesium	1.75	0.062	109.00
Steel, Carbon	7.83-7.87	0.283-0.284	489.00-490.80
Steel, Stainless	7.70	0.278	480.00
Tin	7.29	0.2633	454.90

Mechanical Properties of Common Materials

Material	Ultimate			Modulus of Elasticity Tension or Compression (PSI)	Modulus of Elasticity Shear (PSI)	Weight (lb/in³)
	Tension	Compres-sion	Shear			
Steel, forged-rolled						
0.10-0.20 C	60,000	39,000	48,000	30,000,000	12,000,000	0.28
0.20-0.30 C	67,000	43,000	53,000	30,000,000	12,000,000	0.28
0.30-0.40 C	70,000	46,000	56,000	30,000,000	12,000,000	0.28
0.60-0.80 C	125,000	65,000	75,000	30,000,000	12,000,000	0.28
Cast Iron						
Gray (ASTM 20)	20,000	80,000	27,000	15,000,000	6,000,000	0.26
Gray (ASTM 35)	35,000	125,000	44, 000	———	———	0.26
Gray (ASTM 60)	60,000	145,000	70,000	20,000,000	8,000,000	0.26
Malleable	50,000	120,000	48,000	23,000,000	9,200,000	0.26
Wrought Iron	48,000	25,000	38,000	27,000,000	———	0.28
Steel Cast						
Low C	60,000	———	———	———	0.28	
Medium C	70,000	———	———	———	———	0.28
High C	80,000	45,000	———	———	———	0.28
Brass						
Cast	40,000	———	———	———	———	0.30
Annealed	54,000	18,000	———	———	———	0.30
Cold-drawn	85,000	———	———	15,500,000	6,200,000	0.30
Bronze						
Cast	22,000	———	———	———	———	0.31
Cold-drawn	85,000	———	———	15,000,000	6,000,000	0.31

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