Basic Fluid Power Formulas

Linear Force or Thrust:
- Force (lbs) = Area (in²) x Pressure (psi)
  \[ F_{lb} = \text{AREA} \times \text{PSI} \]
- Force (N) = Area (cm²) x Pressure (bar) x 10
  \[ F_N = (\text{AREA} \times \text{BAR}) \times 10 \]

Power (hydraulic):
- Power (hp) = Pressure (psi) x Flow (gpm) / 1714
  \[ HP = \frac{\text{PSI} \times \text{GPM}}{1714} \]
- Power (kW) = Pressure (bar) x Flow (lpm) / 600
  \[ kW = \frac{\text{BAR} \times \text{LPM}}{600} \]

*When calculating for sizing a system’s prime mover, multiply answer by the pump’s efficiency %.

Power (pneumatic):
- Power (hp) = Pressure (psi) x Flow (cfm) / 229
  \[ HP = \frac{\text{PSI} \times \text{CFM}}{229} \]
- Power (kW) = Pressure (bar) x Flow (dm³/min) / 600
  \[ kW = \frac{\text{BAR} \times \text{dm}^3/\text{MIN}}{600} \]

Power (mechanical):
- Power (hp) = Torque (lb-in) x Speed (rpm) / 63025
  \[ HP = \frac{\text{LB}.IN \times \text{RPM}}{63025} \]
- Power (hp) = Torque (lb-ft) x Speed (rpm) / 5252
  \[ HP = \frac{\text{LB}.FT \times \text{RPM}}{5252} \]
- Power (hp) = Torque (Nm) x Speed (rpm) / 7124
  \[ HP = \frac{\text{Nm} \times \text{RPM}}{7124} \]
- Power (kW) = Torque (Nm) x Speed (rpm) / 9543
  \[ kW = \frac{\text{Nm} \times \text{RPM}}{9543} \]

Fluid Power Motor Torque:
- Torque (lb-in) = Displacement (cir) x Pressure (psi) / 2π
  \[ T_{bin} = \frac{Dp}{2\pi} \]
- Torque (lb-ft) = Displacement (cir) x Pressure (psi) / 24π
  \[ T_{ibft} = \frac{Dp}{24\pi} \]
- Torque (Nm) = Displacement (ccr) x Pressure (bar) / 20π
  \[ T_{Nm} = \frac{Dp}{20\pi} \]

Cylinder Travel Speed:
- Speed (in/min) = Flow (cim) / Area (in²)
  \[ v_{ipm} = \frac{Q}{A} \]
- Speed (cm/min) = Flow (ccm) / Area (cm²)
  \[ v_{cpm} = \frac{Q}{A} \]

Velocity of Oil in Hydraulic Lines:
- Velocity (ft/sec) = Flow (gpm) x 0.3208 / Area (in²)
  \[ v_{fps} = \frac{0.3208Q}{A} \]
- Velocity (m/sec) = Flow (lpm) / Area (cm²) x 6
  \[ v_{mps} = \frac{Q}{6A} \]
### Pump Flow Required for Hydraulic Cylinder (estimate):

<table>
<thead>
<tr>
<th>Flow (gpm)</th>
<th>[ GPM = \frac{2(\text{AREA} \times \text{STROKE}) \times \text{CPM}}{231} ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (lpm)</td>
<td>[ LPM = \frac{2(\text{AREA} \times \text{STROKE}) \times \text{CPM}}{1000} ]</td>
</tr>
</tbody>
</table>

### Converting Free Air to Compressed Air (standard atm. conditions):

<table>
<thead>
<tr>
<th>Compression Ratio</th>
<th>[ C.R. = \frac{\text{PSI} + 14.7}{14.7} ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed Air (scfm)</td>
<td>[ SCFM = \text{CFM} \times \text{C.R.} ]</td>
</tr>
<tr>
<td>Compressed Air (slpm)</td>
<td>[ SLPM = \text{LPM} \times \text{C.R.} ]</td>
</tr>
</tbody>
</table>

Free air is ambient air at a given temperature and pressure, dependent on environmental conditions. The Compression Ratio is the ratio between the absolute discharge air and the absolute suction pressure. It is used to convert to compressed air delivery at standard atmospheric conditions (14.7 psia, 68°F, 36% relative humidity) at sea level.

### Air Consumption for Pneumatic Cylinder (estimate):

| Flow (scfm) | \[ SCFM = C.R. \times \left( \frac{2(\text{AREA} \times \text{STROKE}) \times \text{CPM}}{1728} \right) \] |

### Sizing an Air Compressor:

<table>
<thead>
<tr>
<th>Average System Demand (cfm)</th>
<th>[ \text{CFM} = \frac{\text{SCFM} \times \text{DUTY CYCLE} %}{\text{C.R.} \times 100} ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Time (min)</td>
<td>[ ON TIME = \frac{V_1 \times (\text{PSI}<em>{\text{max}} - \text{PSI}</em>{\text{min}})}{14.7 \times \text{SCFM}} ]</td>
</tr>
<tr>
<td>Min. Pressure (psi)</td>
<td>[ T_{\text{min}} = \frac{V_1}{14.7 \times Q} ]</td>
</tr>
</tbody>
</table>

### Sizing a Hydraulic Accumulator (isothermal conditions):

Combined Gas Law: \[ p_1 V_1 T_2 = p_2 V_2 T_1 \] (*use absolute values*)

Where:
- \( p_1 \) = Precharge Pressure (psia)
- \( p_2 \) = Minimum System Pressure (psia)
- \( p_3 \) = Maximum System Pressure (psia)
- \( V_1 \) = Empty Accumulator Gas Volume (in³)
- \( V_2 \) = Accumulator Gas Volume (in³) @ \( p_2 \)
- \( V_3 \) = Accumulator Gas Volume (in³) @ \( p_3 \)
- \( \Delta V \) = Oil Outlet Flow (in³)

\[ \Delta V = \frac{(V_1 p_1)(p_3 - p_2)}{(p_3 p_2)} \]

\[ V_1 = \frac{\Delta V (p_3 p_2)}{p_1 (p_3 - p_2)} \]

### Sizing a Valve:

Hydraulic Valve; Where:
- \( C_v \) = Velocity Coefficient
- \( Q \) = Flow (gpm)
- \( \Delta p \) = Differential pressure between inlet & outlet (psi)
- \( SG \) = Specific Gravity of Liquid Media

\[ C_v = \frac{Q \sqrt{SG}}{\sqrt{\Delta p}} \]

\[ Q = C_v \frac{\Delta p}{SG} \]

The metric equivalent to \( C_v \) is flow factor, noted as \( K_v \). The equation is identical, though the units of flow used are cubic meters per hour (m³/hr) and units of pressure used are bar.
Pneumatic Valve; Where:

- \( C_v \) = Velocity Coefficient
- \( Q \) = Flow (scfm)
- \( \Delta p \) = Differential pressure between inlet & outlet (psi)
- \( p_1 \) = Absolute Inlet Pressure (psia)
- \( p_2 \) = Absolute Outlet Pressure (psia)
- \( SG \) = Specific Gravity of Gaseous Media

Subsonic Flow:

\[
C_v = \frac{Q\sqrt{SG}}{\sqrt{p_2 \Delta p}}
\]

\[
Q = C_v \sqrt{\frac{p_2 \Delta p}{SG}}
\]

Sonic Flow (choked flow):

\[
C_v = \frac{Q\sqrt{SG}}{\left(\frac{p_1}{2}\right)}
\]

- Critical velocity is reached when absolute downstream (outlet) pressure is less than or equal to 53% of absolute upstream (inlet) pressure.

The metric equivalent to \( C_v \) is flow factor, noted as \( K_v \). The equations are identical, though the units of flow used are normal cubic meters per hour (m³/hr) and units of pressure used are bar/bara.

\[
C_v = \frac{K_v}{0.86}
\]

\[
K_v = 0.86C_v
\]

**General Information and “Rules of Thumb”:**

- Estimating pump drive horsepower: 1 hp of input drive for each 1 gpm at 1,500 psi pump output
- Horsepower when idling a pump: an idle and unloaded pump will require about 5% of its full rate hp
- Reservoir capacity (Gallons) = length (in) x width (in) x height (in) x air gap % / 231
- Oil compressibility: 1/2% approximate volume reduction for every 1,000 psi of pressure
- Wattage to heat hydraulic oil: each 1 watt will raise the temperature of 1 gallon of oil by 1°F per hour
- 1 HP = 0.746 kW = 2545 BTU/hr = 746 Watts = 44,760 Joules/min
- 1 bar = 14.5 psi = 100 kPa = 0.987 atm = 29.603”Hg
- 1 atm = 14.7 psi = 1.013 bar = 29.921”Hg
- 1”Hg = 0.49 psi = 13.609”H_2O
- 1 in = 25.4 mm
- 1 in² = 6.45 cm²
- 1 in³ = 16.387 cm³
- 1 ft² = 144 in² = 929 cm²
- 1 ft³ = 1728 in³ = 28.317 liters = 7.481 gallons
- 1 gallon = 3.785 liters = 231 in³ = 0.134 ft³
- 1 lb-ft = 12 lb-in = 1.356 Nm
- 1 meter/sec = 3.28 ft/sec = 39.36 in/sec
- °C = 5/9(°F -32); *F = °C x 9/5 + 32
- °K = °C + 273.7; °R = °F + 459.7

**Guidelines for flow velocity in hydraulic lines:**

- 2 to 4 ft/sec = suction lines
- 10 to 15 ft/sec = pressure lines up to 500 psi
- 15 to 20 ft/sec = pressure lines 500 – 3,000 psi
- 25 ft/sec = pressure lines over 3,000 psi
- 4 ft/sec = any oil lines in air-over-oil systems