STEPS FOR DESIGNING A HYDRAULIC SYSTEM

1. Determine cylinder area

$$Cylinder\ Area = \frac{\{\,Tons\ x\ 1000\ x\ 9{,}81\ x\ 1{,}2\}}{MPa\ (Working\ Pressure)}$$

Area = Cylinder/Piston Area in mm^2.
Tons will be the load on the cylinder.
1000 is bringing the tons to kilogram.
9,81 is bringing the load to Newton's.
1,2 is a safety figure increasing the cylinder area by 20% to overcome seal friction.

2. Cylinder Diameter

$$Diameter = \sqrt{\left\{\frac{Area\ \times 4}{\pi}\right\}}$$

The method below to use with a **DAL** calculator. (**D**irect **A**lgebraic **L**ogic)

$$\left(\frac{Area \times 4}{\pi}\right) = \sqrt{\ }$$

Diameter = Cylinder diameter in millimetres
Area = The cylinder area from Step 1.

3. Cylinder Wall Thickness. LAMÉ'S FORMULA

$$t = \left(\frac{D}{2}\right)\left[\sqrt{\left\{\frac{(S+P)}{(S-P)}\right\}} - 1\right]$$

The method below to use with a **DAL** calculator. (**D**irect **A**lgebraic **L**ogic)

$$(\sqrt{((S+P)/(S-P))} - 1) \times D/2 =$$

t = Cylinder wall thickness in mm
D = Cylinder bore diameter in mm.
S = Yield Stress of ST 52 Steel. Using a Safety Factor of 3, S = 98 N/mm^2.
P = Relief valve press setting in MPa, or any pressure higher than the relief valve pressure setting, which may be the result of pressure intensification.

4. Piston Rod Diameter.

$$Diameter = \left[\left\{\sqrt[4]{\frac{(Force \times 64 \times L^2 \times 5)}{(\pi^3 \times 0{,}86 \times 10^{11})}}\right\}\right] \times 1000$$

Rod Diameter = mm.
Force = Newton's.
$64/\pi^3$ = Moment of inertia of a solid Bar.
L = Rod length in metres.
5 = Safety Factor, or a higher safety factor which one may deem necessary.
$0{,}86 \times 10^{11}$ = E for mild steel

The abbreviated formula below for the above, may be used, it includes the safety factor of 5.

$$Piston\ Rod\ Diameter = \left\{\sqrt[4]{Tons \times L^2}\right\} \times 33$$

The method below to use with a **DAL** calculator. (**D**irect **A**lgebraic **L**ogic)

$$((\sqrt{}\sqrt{}(Tons \times L^2)) \times 33 =$$

$$\left(\left((Tons \times L^2)\right)Y^{0{,}25}\right) \times 33 =$$

Tons = Load on the cylinder.
L = Rod Length in metres.

5. Pump Flow Rate.

$$Q = A\ \times V \times 10^{-6}$$

Q = Pump flow rate in litres/min.
A = Piston area in mm^2
V = Cylinder Velocity or speed in mm/min.

6. Prime Mover. - (Electric motor or internal combustion engine). Always remember engines are rated at sea level, where the atmospheric pressure is taken at 100kPa. The atmospheric pressure in Johannesburg is close to 80kPa, approximately 20% less than at sea level. Therefore, when one has to use an engine at altitude, if is not turbo charged, one must multiply by 1,2.

   Regarding electric motors - Electric motors being used at high altitude, as in Johannesburg, should be fitted with high altitude cooling fans and the relevant fan cowlings.

Determine prime mover power requirement.

$$kW = \frac{(MPa \times l/min \times 1{,}2)}{60}$$

kW = Prime mover kilowatt rating.
MPa = Pressures relief valve pressure setting.
Litre/min = Pump flow rate in litres/minute.
1,2 = 20% extra power to overcome hydraulic losses.

7. Amperage.

$$Amps = \frac{(kW \times 1000)}{\left(Volts \times 0{,}8 \times \sqrt{3}\right)}$$

kW = Kilowatt.
Volts = Electric motor supply voltage.
0,8 = Power factor.
$\sqrt{3}$ = 1,73 - The third root factor for three phase systems.

8. Pump intake line diameter.

$$Dia = \sqrt{\frac{(Q \times 21{,}22)}{V}}$$

The method below to use with a **DAL** calculator. (**D**irect **A**lgebraic **L**ogic)

$$Q \times 21{,}22 \div V = \sqrt{}$$

Dia. = Pipe inside diameter in millimetres.
Q = Pump flow rate in litres/minute.
V = the recommended fluid velocity in metres/second. The recommended fluid velocity in pump intake lines is 0,7m/sec.

Vane and Gear pumps may be mounted above the oil level, but never higher than 500mm above the fluid. The vacuum reading in pump suction lines, at the pump intake port, should not be greater than -10kPa, (90 kPa absolute). If water based fluids or Phosphate Ester fluids area used, as these fluids have a higher specific gravity, the pumps must be installed below the fluid level - flooded suction.

Remember, Piston pumps must always be mounted below the fluid level, except if the pump intake line is boosted with an auxiliary pump, sometimes referred to as a charge pump.

If pump intake lines are at a distance horizontally from the pump, between 1m to 3m, the fluid velocity must be reduced from 0,7m/sec to 0,2m/sec. This will ensure lower frictional losses in the line.

In the worst case scenario, if the intake line is longer than 3m, then the pipe diameter that one would have determined using the 0,2 m/sec velocity will be used, but the area must be determined and multiplied by 5, to determine the diameter of the long intake line. Pump intake lines are much cheaper than pumps.

As an example, say an intake line that was determined using a fluid velocity of 0,2 m/sec, has an inside diameter 125mm. We will then take the area of the diameter of 125mm and multiply it by 5 to determine the larger area, we will then use the new area to find the diameter of the larger pipe.

$$Area = \pi \times \frac{D^2}{4}$$

$$= \pi \times \frac{125^2}{4}$$

$$\underline{\mathbf{= 12271,85mm^2}}$$

$$The\ area\ will\ be\ multiplied\ by\ 5 = 12271,85 \times 5$$

$$\underline{\mathbf{= 61359,25mm^2}}$$

$$Therefore\ the\ larger\ diameter = \sqrt{61359,25 \times \frac{4}{\pi}}$$

$$\underline{\mathbf{= 279,51mm}}$$

The pipe inside diameter may be rounded off to 300mm.

9. Pressure line Diameter.

$$Dia = \sqrt{\frac{(Q \times 21,22)}{V}}$$

The method below to use with a **DAL** calculator. (**D**irect **A**lgebraic **L**ogic)

$$Q \times 21,22 \div V = \surd$$

Dia. = Pipe bore diameter in millimetres.
Q = Pump flow rate in litres/min.
V = Recommended fluid velocity in the pipe.

The fluid velocity is flexible, as it has to be compared to the Reynold's number. To obtain a laminar flow rate in the pipes the Reynold's number must remain below 2500, for most applications. Reynold's numbers higher than 2500 will result in turbulent flow rates in the piping, causing high frequency sounds and vibration.

10. Check Reynold's Number.

$$Re = \frac{(V \times D \times 10^3)}{cSt}$$

Re = Reynold's Number
V = Fluid Velocity.
D = Pipe bore diameter in millimetres.
cSt = Centistoke. Use a fluid viscosity of 46 cSt. Assuming one uses a 68 cSt oil viscosity and it warms up to a viscosity of 46 cSt, as mentioned above.

11. Determine Cylinder Area Ratio.

$$Ratio = \frac{D^2}{\{(D^2) - (d^2)\}}$$

The method below to use with a **DAL** calculator. (**D**irect **A**lgebraic **L**ogic)

$$D^2 \div \{(D^2) - (d^2)\} =$$

D = Piston Diameter in millimetres.
d = Rod Diameters in millimetres.

12. Return Line Flow Rate.

$$Litres\ per\ min = Ratio\ \times Pump\ Flow/Rate$$

Ratio = The ratio is determined in Step 11.
Pump flow rate determined in Step 5.

13. Return Line Diameter.

$$Diameter = \sqrt{\frac{(Q \times 21{,}22)}{V}}$$

The method below to use with a **DAL** calculator. (**D**irect **A**lgebraic **L**ogic)

$$Q \times 21{,}22 \div V = \surd$$

Diameter = Pipe inside diameter in millimetres.
Q = Return line flow rate from step 11, i.e. Ratio x Pump flow rate.
V = Recommended fluid velocity, starting with 3m/second. (Depending on the Reynold's Number, which will be checked in step 14 below).

14. Check the Reynold's Number.

$$Re = \frac{(V \times D \times 10^3)}{cSt}$$

Re = Reynold's Number
V = Fluid Velocity.
D = Pipe bore diameter in millimetres.
cSt = Centistoke. Use a fluid viscosity of 46 cSt. Assuming one uses a 68 cSt oil viscosity and it warms up to a viscosity of 46 cSt, as mentioned above.

15. Determine the flow rate required for the pressure line filter.

$$Litres\ per\ minute = 1{,}5 \times Pump\ Flow\ Rate$$

Pump flow rate from Step 5.

16. Determine the flow rate required for the return line filter.

$$Litres\ per\ minute = Cylinder\ area\ ratio \times 1{,}5 \times Pump\ Flow\ Rate$$

Cylinder area ratio from Step 11 above
Pump flow rate from Step 5.

17. Determine the flow rate for the directional control valve.

$$Litres\ per\ minute = Cylinder\ Area\ Ratio \times Pump\ Flow\ Rate$$

Cylinder area ratio from Step 11.
Pump flow rate from Step 5.

18. Relief valve size.
    The flow rate that the relief valve must be sized to is **at least the pump flow rate.**

19. Determine if a decompression system is required. A decompression system must be fitted if more than 0,5 litres is compressed in the cylinder. In practice one would have to determine the volume of oil that may be compressed in the piping between the directional control valve and the cylinder as well.

$$Litres = \left\{\frac{(\pi \times D^2)}{4} \times L \times \frac{MPa}{14} \times 0{,}00001\right\}$$

    Litres = Compressed volume.
    D = Cylinder bore diameter in millimetres.
    L= Cylinder stroke in metres.
    MPa = Relief valve pressure setting.

20. If a decompression is required, the time in seconds to decompress must be determined.

$$Seconds = \frac{(Volume\ of\ Compressed\ Oil\ \times 60)}{(Directional\ Valve\ Flow\ Rate)}$$

    Volume of compressed oil from Step 19.

    Directional valve flow rate.
    There are generally three directional valves that one may normally choose. NG6, NG10 or the NG16. The NG6 valve, according to hydraulic manufactures, may be used up to 50 litres/min. It is more practical to reduce the flow rate to 20 litres/min. NG10 valves are rated up to 100 litres/min, but again, try and restrict the flow rate to 40 litres/min. The NG16 valve is rated up to 300 litres/min, here again, it is better to use the valve at a lower flow rate. The reasoning behind reducing the flow rate through the valves is to try and lower the possibility of heat build across the valves.

    Remember, larger flow rate valves may be used if one has to decompress a large volume of oil in a relatively short time. The time to decompress is approximately 3 seconds. Where large volumes of oil have been compressed, anything more than around 3 litres, one may want to decompress in 10 seconds plus. Unfortunately there is no set rule for a decompression time, one must ensure that there is no shock in the hydraulic system during the decompression cycle.

21. Reservoir capacity.
Reservoirs are generally sized to between 1 to 4 times the flow rate of the pump. Remember, where possible always err on the larger size for a reservoir. The larger the reservoir the greater the surface cooling area.

A salient point to also remember, compensation must be taken into account on systems where the cylinder may need a large volume of oil as it extends. It is not good practice to have the fluid in the reservoir almost drained when a cylinder reaches the end of its stroke, especially, as in single acting rams.

$$Reservoir\ Fluid\ Volume = Pump\ flow\ rate\ \times 4$$