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PCEE4010 – Pneumatics and Hydraulics

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Pembrokeshire College, on behalf of The University of Wales Trinity Saint David



25/01/2024

Lecturer – Jake Mowbray

Programme title would be useful -

HNC Instrumentation Engineering.

Relevant photo always good too.

1 Prime Movers and Conditioning

- 1.1 Operating Principles of Hydraulic and Pneumatic systems
- 1.2 Air compression in a temperature controlled Pneumatic process
- 1.3 Positive displacement pumps in Hydraulic systems
- 1.4 Pressure control in Hydraulic and Pneumatic systems

2 Calculations

- 2.1 Compressor
- 2.2 Pipe losses
- 2.3 Air receiver

Appendix

Bibliography

References

*— No table of contents, figure list,
introduction or page numbers.*

+ Clear sections used.

1 | Prime Movers and Conditioning

1.1 | Operating principles of Hydraulic and Pneumatic systems

Hydraulic and Pneumatic systems are both methods of transmitting energy via the use of a fluid and thus referred to as fluid power systems, where the term fluid refers to *"a substance that has no fixed shape and yields easily to external pressure; a gas or (especially) a liquid"* (Oxford English Dictionary). Where gaseous fluids are used withing Pneumatic systems (commonly air or, in some cases, Nitrogen), and liquidous fluids being used within Hydraulic systems (commonly Hydraulic Oil). The operation of both variants rely on the concept of applying a pressure to an enclosed fluid to *"convey energy from one location to another"* with the purpose of *"to produce rotary or linear motion or apply a force"* (Parr, 2011). The energy in question being that of kinetic and potential fluid energy being utilised to operate external, mechanical pieces of equipment such as pneumatically operated actuators being used to operate valves, and hydraulically operated pistons being used to push or pull objects that require exceptional force (such as a telescopic 'boom' on construction lifting equipment).

Although the fundamental use and operation of both systems are similar, they have differing approaches to how the fluids are pressurised and transmitted through the system. This is heavily influenced by the different properties of a fluid and gas which effects their compressive ability, where *"Gases are readily compressible"* and *"Liquids are only slightly compressible"* (Mott & Untener, 2015). An elaboration on this would be to consider that the volume of a gaseous fluid will reduce as an increasing pressure is applied to it, as opposed to a liquidous fluid which does not (or rather, can with very little change) possess the ability of such manipulation, instead reserving its volume until the system in which it is contained can no longer sustain the forces being applied by the liquid.

Due to the previously described characteristics of both fluid mediums, the systems both feature separate advantages and disadvantages when compared to each other. For example, Andrew Parr states that due to these compression characteristics pneumatic systems *"tends to have a 'softer' action than a hydraulic system which can be prone to producing noisy and wear-inducing shocks in the pipeline"* however, this does not mean that pneumatics are in any way a preferable alternative to hydraulic systems, as Parr later goes on to state that hydraulic systems *"can operate at far higher pressures than a pneumatic system and, consequently, can be used to provide a large force"*. These statements provide a better understanding for why it is only seen that hydraulic systems are used within systems in the construction industry, as it is proven that hydraulics are far more reliable and better suited to the application of lifting and moving loads of extreme weight. The statements also provide explanation as to why pneumatics are often used within the operation of engineering plant equipment such as valves, as the 'softer' transmission of fluid allows for the equipment to be slowly opened or closed to prevent large pressure changes that may cause damage to pipelines or machinery downstream of the process line.

Moving on from the principles of their operation. Unfortunately, both system present various hazards when used within a field of engineering. One shared hazard is that of an unexpected leak of pressurised fluid that can cause serious harm to any person(s) that may be nearby, it is widely considered that relatively low pressures of approximately 5psi is enough to cause serious injuries to exposed orifices such as eyes and ears, whilst higher pressures can cause

A diagram would aid your description.

* page number?

Brief mention of valves, limited discussion of any other fluid power components.

↳ what range of operating pressures?

+linked to workplace pipelines.

No page numbers.

fluids to penetrate through unbroken skin. ✓ As well as this, if there were to be an uncontrolled release of Nitrogen gas within a pneumatic system, there is a risk of asphyxiation ✓ due to the deprivation of Oxygen in the surrounding area. Although hydraulic systems do not possess this potentially fatal risk, the release of hydraulic oil would render the surrounding area(s) covered in a slippery film, increasing the risk of personnel slipping, potentially causing serious harm when walking near the breached pipeline. ✓ It is also good practice to wear the appropriate PPE when handling such a fluid due to the common risk that oils can cause possibly severe dryness and irritation of the skin around the exposed area. ✓

Some consideration for H&S and environmental factors but no expansion into H&S legislation and regulation.

1.2 | Air compression in a temperature controlled Pneumatic process

This section will detail the operation of a Rotary Screw Compressor and the necessary air conditioning methods used alongside within a temperature controlled (Heat Exchanger) Pneumatic process.

A screw compressor features two rotors placed side by side which rotate in opposite directions which draws in air before compressing it by means of 'Positive Displacement'. Atlas Copco describe the operation of screw compressors as *"Each screw element has a fixed, built-in pressure ratio dependent on the length and pitch of the screw. As well as the form of the discharge port"* (Atlas Copco, Working Principle of a Screw Compressor)*. The two screw elements are referred to as male and female, where the male rotor acts as the driver being powered by an electric motor (available in fixed or variable speed options) and drives the female rotor (driven) by means of a timing belt to ensure the synchronous rotation of the elements. ✓

Date?

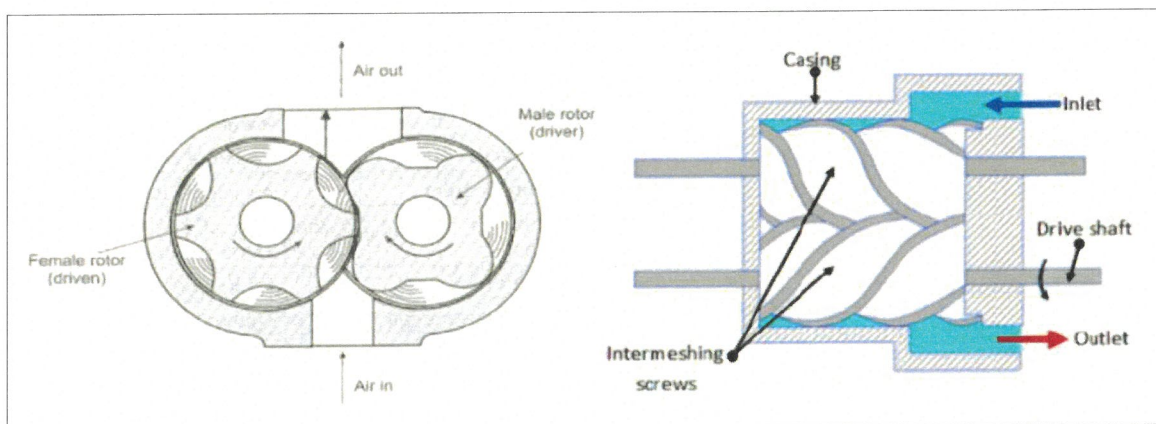


Figure 1: Screw Compressor Diagram (S.Thorat, 2020, Screw Compressor)

As the compressor elements rotate, air is naturally drawn into the compressor via the inlet port (found either vertically or horizontally, both variants operate the same) where it is 'trapped' between the lobes (the external lumps or spikes of the rotors) and the housing of the compressor. As the lobes become intermeshed, the volume between them decreases along the length of the rotors, causing the air trapped between them to gradually compress exponentially as the volume lowers, before exiting the compressor through the outlet port. As mentioned by Atlas Copco, the pressure in which the air is compressed to depends on the design of the two rotating elements. ✓

Due to the precise synchronisation of the compressor rotors, no mechanical parts come into contact with each other or the internal housing material, rendering there to be no need for lubrication, resulting in this compressor in question to be oil-free (there are oil-lubricated variants). ✓

Of course, this compression process naturally generates a byproduct of heat ✓ as the air is compressed, resulting in a need for an air conditioning method before it can be used within a temperature-controlled environment. For this application, a heat exchanger would be an appropriate means to cool the system. ✓

While all heat exchangers work via the same principle of natural thermal transfer from one medium to another, there are slight variations of how they are designed, such as Shell and Tube, Plate Type, and Air Cooled for example. To elaborate, heat exchangers are implemented in industrial applications to transfer the latent heat energy from one fluid(s) to another by exposing the fluid with a higher temperature to one (others) of a lower temperature (large scale exchangers will combine several process lines into one exchanger). A visual aid of this process can be seen in *figure 2*. ✓

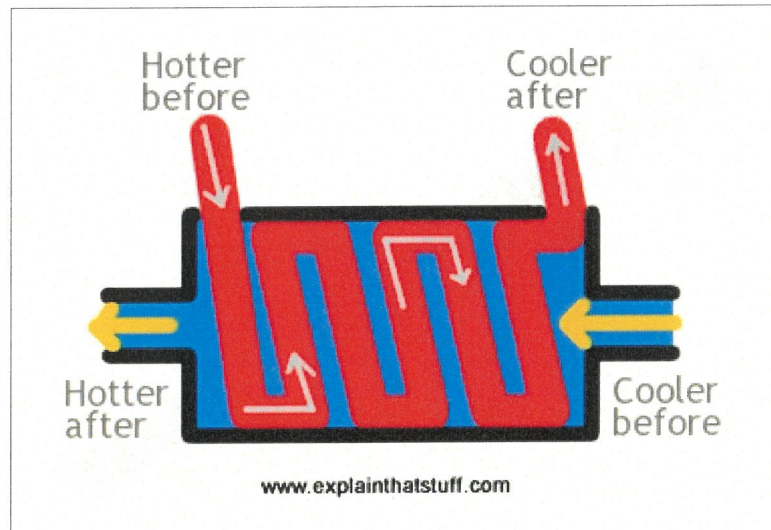


Figure 2: Heat Exchanger Diagram (Woodford, 2023)

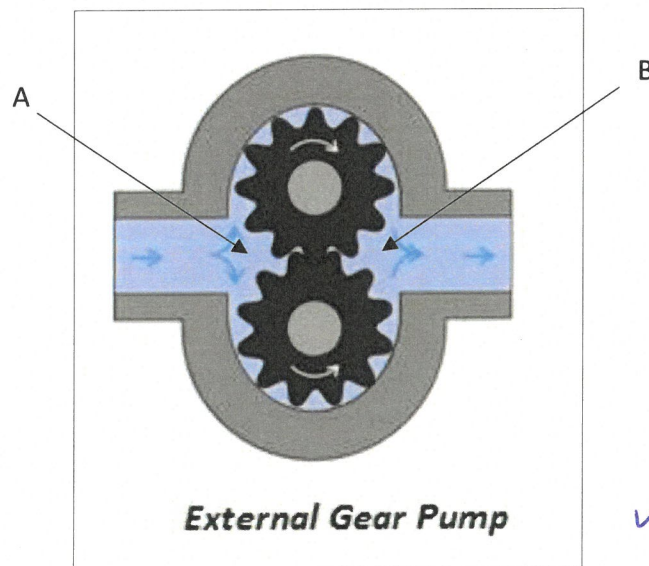
The effectiveness of the heat transfer (the amount of heat transferred, or how much 'cooler' the fluid gets) is altered by the number of 'passes' that one of the fluids makes through the stream of the other. To refer to the diagram in *figure 2*, the process fluid marked in red makes six passes through the stream of the blue fluid, making it a 'six pass heat exchanger'. However, it is considered that the more 'passes' there are in a single exchanger unit decreases the pressure within the system which each continued pass due to the pipelines looping around the unit and increasing the friction applied to the fluid. The UK based manufacturer, Thermex, confirm this by stating "*A greater number of passes increases the amount of heat transfer available, but can also lead to high pressure loss and high velocity*" (Thermex Heat Exchangers). ✓

1.3 | Positive Displacement Pumps in Hydraulic systems

There are two types of pumps used within Hydraulic control systems that operate via the working principle of positive displacement, Gear pumps and Vane pumps. → *Others are available.*

Gear pumps operate in a very similar fashion to that of the previously described 'Rotary Screw Compressor', featuring two counter-rotating gear elements (driver and driven) which interlock to produce the pockets of low pressure at the inlet side of the pump to draw fluid (hydraulic oil) into and around the pump mechanism where it is then forced through the outlet port, under an increased pressure. ✓ However, unlike the screw compressor, the two gear elements within the pump do intermesh tightly with each other and rotate so that the center mesh of the gears move towards the inlet port rather than the outlet. This in turn forces the hydraulic fluid to travel outwards between the spokes of each gear element and the inner casing of the pump, creating a liquid seal (see *figure 3*). ✓ As the liquid is transferred to the outlet side of the pump, the center meshing of the two gears produces a reduced volume within the housing, which in turn creates the increase pressure that the fluid is ejected with. ✓

Another difference of operation is that of how the two gears are driven. Whereas the driver pump transferred the counter rotation via timing belt, the gear pump relies on the mechanical contact between the two gears to transfer the kinetic energy to the driven gear. ✓



A good observation on gear rotation.

Figure 3: Gear Pump Diagram (Michael Smith Engineers Ltd.) * *Date?*

To use *figure 3* as a visual aid, the low-pressure pocket created by the rotation of the gears is located to the left of the center meshing of the gears (seen in location 'A') where the pocket is produced due to the opening of the previously mentioned low volume area. Additionally, the high-pressure pocket created at the outlet (right) side of the pump (location 'B') is created by opposite action. ✓

Rotating vane pumps on the other hand consist of an offset rotating cam block which houses a number of sliding 'vaness' or pushrods which are spring loaded from the center of the cam. ✓ The offset nature of the center block renders one portion of the outside diameter to be in

physical contact with the circular inner diameter of the pump housing, whilst the remainder of the cam diameter is exposed to an 'arcing' or 'crest' open area, the volume of which gradually increases towards the apex of the crest before decreasing again towards the mechanically sealed edge of the housing diameter. As the center block is rotationally driven, the spring-loaded rods extend out of, and compress back into the block as the volume of the exposed space increases and decreases along the crest.

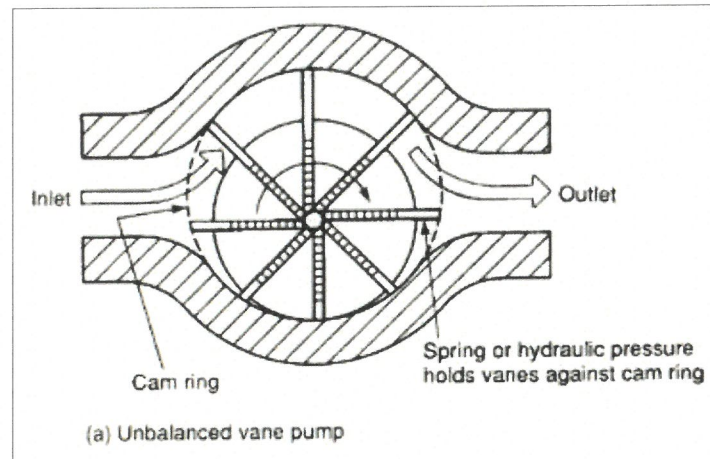


Figure 4: Hydraulic Vane Pump (Parr, 2011)

Like the operating principle of the previously discussed gear pump, the change in volume at the input and output side of the vane pump produce a respective low and high pressure 'pocket' where the spring-loaded rods initially extend and contract at either side of the mechanically sealed edge of the cam diameter, allowing for the transmission and subsequent pressure increase of the hydraulic fluid.

What pressures and efficiency variations are expected with these pumps?

** What page number?*

See comment on References page.

1.4 | Pressure control in Hydraulic and Pneumatic Systems

The most commonly thought of method is that of a Pressure Relief Valve. These components can be found in multiple variants such as dead weight or spring loaded, which operate under the same principle although differ in construction and how the control of pressure is achieved. To elaborate on that factor, relief valves that are implemented into hydraulic systems are often constructed from stonger materials such as steel or brass to withstand the higher pressures associated with pressurised liquids, whereas pneumatic systems will have valves constructed from lighter materials like aluminium which do not require such high strength. The operation of these valves is rather simple, consisting of a spring-loaded stem with a curved, bell-shaped end which sits within a resecced opening (valve 'seat'). The mechanism relies solely on the force exerted by the spring to keep the valve closed. The applied force of the spring is what determines the 'lifting point', meaning the pressure value in which the process fluid must be in order to overcome that of the spring. If a larger pressure were to be applied to the valve, the stem would lift and release the fluid either into the atmosphere (pneumatic) or into a reservoir (hydraulic).

Cracking pressure.

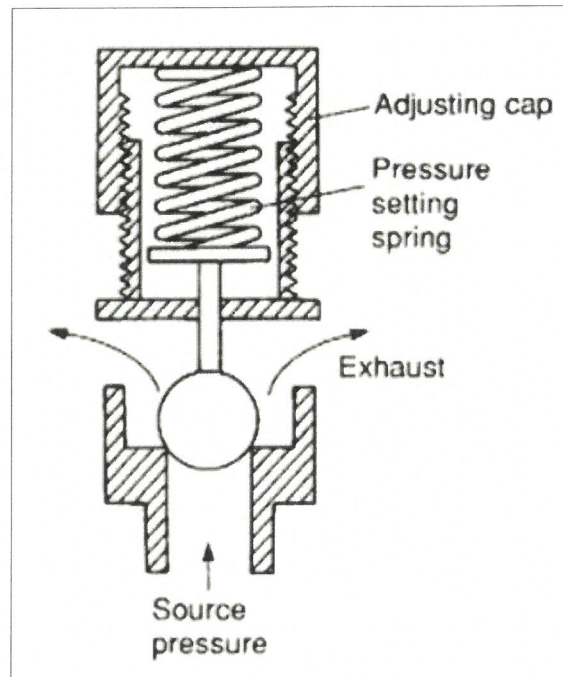


Figure 5: Spring-loaded relief valve (Parr, 2011)

As can be seen in figure 5, the relief valve utilises a spherical ball held against a right angled valve seat to seal the exhaust from the source pressure, which is just a variant of the previously described recessed seat and operates under the same principle. It can also be seen that this valve has an 'Adjusting cap' located above the valve stem, the purpose of which is to implement a means to adjust the set lifting pressure of the valve. This is achieved by either raising or lowering the cap to apply an increased or reduced force against the top side of the spring, further compressing the spring or relieving it. Applying more compressive force against the spring increases its applied pressure to the valve stem, and vice versa. This feature is common

used as a means to calibrate the component and is locked in place after the adjustments are made.

Another method of pressure control is that of a control valve. Similarly to a relief valve they operate under the same working principle for both system applications, with one of the main differences being that of the construction material. The operation will be explained with the use of the diagram in Figure 6.

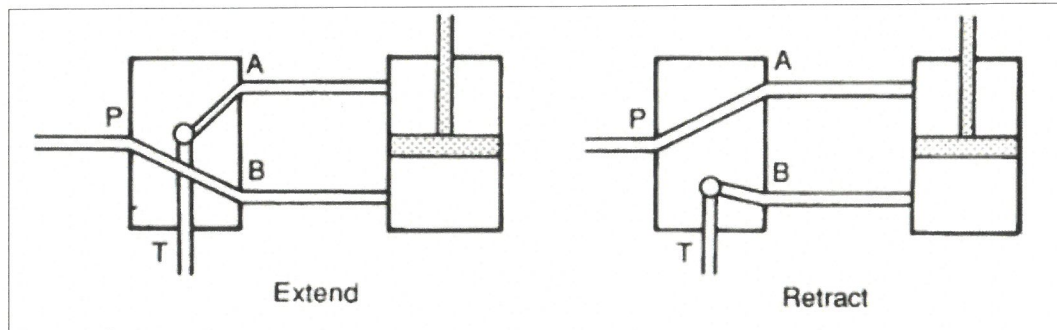


Figure 6: Internal operation of a control valve (Parr, 2011)

The system consists of two block, those being the control valve (left) and a double-acting cylinder (right). In both applications, inlet port 'P' acts as the location where the supply fluid travels into the system, outlet port 'T' is the return or 'dump', while ports 'A' and 'B' connect to either end of the cylinder.

This control valve has two functional configurations, labelled 'Extend' and 'Retract' in the image (note how in one configuration the pipelines are crossing, and in the other they almost run parallel. See Figure 7). The pipelines illustrated in the diagram represent the connected ports within the valve, with the two configurations alternating port 'P' between ports 'A' and 'B' redirect the flow of fluid from either side of the cylinder, to the tank, depending on the desired operation. This change in configuration can be controlled via push button, limit switch, spring, or solenoid to name a few.

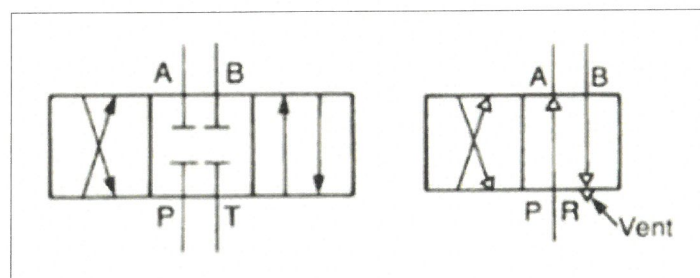


Figure 7: Control Valve graphic Symbol (Parr, 2011)

* This is controlling flow in this scenario rather than pressure directly. The control valve setup can be used in this instance but would require being attached to the flow lines on a tee, - to relieve or divert pressure.

2 | Calculations

2.1 | Compressor

The following question was presented to the author, "A two-stage compressor is drawing 25³/min of free air at N.T.P condition. Determine the output flow rate based on the following instrumented values."

1st Stage

Inlet	Output
20 °C	42 °C
101.325 kPa	525 kPa
25 m ³ /min	V ₂ ?

$$P_1 V_1 / T_1 = P_2 V_2 / T_2 \quad \text{Therefore,} \quad P_1 V_1 T_2 / T_1 P_2 = V_2$$

$$K \text{ (Kelvin)} = ^\circ\text{C} + 273$$

$$101.325_{\times 10^3} \times 25 \times (42 + 273) / ((20 + 273) \times 525_{\times 10^3}) = \underline{5.19 \text{ m}^3/\text{min} (V_2)} \quad \checkmark$$

2nd Stage

Inlet	Output
42 °C	70 °C
525 kPa	850 kPa
5.19 m ³ /min	V ₂ ?

$$P_1 V_1 T_2 / T_1 P_2 = V_2$$

$$525_{\times 10^3} \times 5.19 \times (42 + 273) / ((70 + 273) \times 850_{\times 10^3}) = \underline{2.94 \text{ m}^3/\text{min} (V_2)}$$

This V₂ value is too low.

$$\frac{525 \times 10^3 \times 5.19 \times (70 + 273)}{(42 + 273) \times 850 \times 10^3} = 3.49 \text{ m}^3/\text{min}.$$

2.2 | Pipe losses

The following question was presented to the author, "A 20mm diameter flexible air hose is connected to the air receiver outlet. The hose is 62m in length. Determine the available pressure at the end of the pipe by taking the pressure losses at steady flow into account. The flow rate is restricted to 20dm³/s. Also calculate the pneumatic force of the air at the end of the pipe"

Hose is **62m** in length with a diameter of **20mm**. With a supply pressure of 850kPa (8.5 Bar).

The flow rate is **20dm³/s**

Using the pressure nomogram (below in Table 1), it is decided that 6.5 mbar/m is lost. Therefore, 6.5 x 62 = 403 mbar is lost throughout the entirety of the pipeline.

So, 8.5 bar – 403mbar = **8.097 bar** (809.7 kPa) is the outlet pressure.

Clear method.

$$F = P \times A \text{ and } A = \frac{\pi \times D^2}{4}$$

$$A = \frac{\pi \times 0.02^2}{4} = 0.314 \text{ mm}^2$$

$$\text{So, } F = 809.7 \times 10^3 \times 0.314 \times 10^{-3} = \mathbf{254.2 \text{ N}}$$

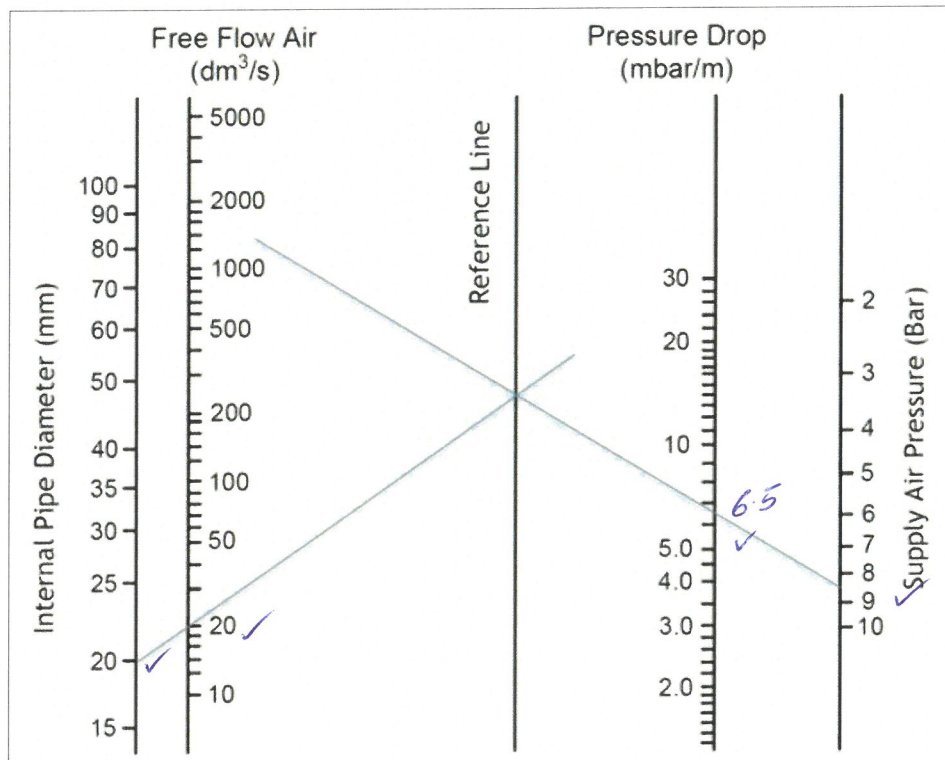


Table 1: Pressure Nomogram

2.3 | Air receiver

The following question was presented to the author, "The flexible pipe [from the previous question] is connected to a single acting, vertically positioned pneumatic cylinder of 76mm internal bore diameter. Determine the maximum mass which could be lifted by this system."

Previous supply force of **254.2 N** at a pressure of **809.7 kPa**.

Internal bore diameter of **76mm**.

$$\text{Again, } F = P \times A \text{ and } A = \frac{\pi \times D^2}{4}$$

$$A = \frac{\pi \times 0.076^2}{4} = 4.54 \text{ mm}^2$$

$$\text{So, } F = 809.7 \times 10^3 \times 4.54 \times 10^{-3} = \mathbf{3676 \text{ N}} \text{ exerted against the cylinder piston.} \checkmark$$

$$\text{As } F = m \times a, \text{ then } m = \frac{F}{a} \text{ where } a = 8.91 \text{ m/s}^2 \text{ (gravitational pull)}$$

$$m = \frac{3676}{8.91} = \mathbf{412.57 \text{ kg}} \text{ total mass lifted.}$$

*Incorrect value for gravity. 9.81 m/s^2 **

Correct method but final Kg value too high.

$$\underline{\underline{374.43 \text{ kg}}}$$

— metres per second squared are the correct units.

They convert out in the formula due to Newtons actually being represented as $1 \text{ N} = 1 \text{ kg} \cdot \text{m/s}^2$

A Newton is defined as the force needed to accelerate a 1kg mass at a rate of 1 m/s^2 .

$$\text{Kg} = \frac{3676 \text{ kg} \cdot \text{m/s}^2}{9.81 \text{ m/s}^2}$$

Leaving 374.43 kg .

Appendix

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↳ These page numbers should be within
your in-text citations e.g.

Figure 4. Hydraulic vane pump (Parr, 2011, pp 40).