Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 29: Electro, Pneumatic and Hydraulic Systems

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Parameters of Pneumatic and Hydraulic Systems

INTRODUCTION

LO1 Calculate the parameters of pneumatic and hydraulic systems

Pneumatic and hydraulic theory:

Combined and ideal gas laws: Boyle's Law, Charles' Law and Gay-Lussac's Law

Fluid flow, calculation of pressure and velocity using Bernoulli's Equation for Newtonian fluids

System performance, volumetric operational and isothermal efficiency

Contents

Pneumatic and hydraulic theory:

Combined and ideal gas laws: Boyle's Law, Charles' Law and Gay-Lussac's Law

Boyle's Law

Boyle's Law describes, quite simply, how gas pressure is inversely proportional to the volume of the container which it occupies. Put mathematically…

$$P \propto \frac{1}{V}$$

where P is gas pressure and V is volume of the container. Temperature must remain constant (isothermal process)

This is a very intuitive relationship. If you blow up a balloon and then sit on it, well, you are squashing (reducing the volume) of the balloon and therefore expect the air pressure inside to increase. The balloon is very likely to burst as a result.

Let's take away the proportionality term in the middle and form our first equation…

$$PV = k \quad [1]$$

k is a constant, so it represents the product of pressure and volume.

If we have the same mass of gas (air in this case, same number of molecules) but place it into a second much larger balloon, we will still have the same product of pressure and volume…

$$P_1V_1 = P_2V_2 \quad [2]$$

There could be a gas supply feeding your home via a large pipe (subscript 1 in equation 2). As the gas enters the property it is usual for it to enter a gas meter and then exit the meter via a gas pipe of smaller radius (subscript 2 in equation 2). Boyle's law (equation 1) tells us that the product of pressure and volume in the larger pipe is equal to the product of the pressure and volume in the smaller pipe. The smaller pipe has lower volume; therefore, the smaller pipe has a larger gas pressure.

Worked Example 1

A gas in a piston occupies a volume of 0.2 m^3 at a pressure of 1.6 MPa. Determine;

a) The gas pressure if the volume is changed to 0.08 m^3 at constant temperature.
b) The volume if the gas pressure is changed to 3.2 MPa at constant temperature.

ANSWERS

a)

$$P_1V_1 = P_2V_2$$

$$P_1 = 1.6 \times 10^6;\ V_1 = 0.2;\ P_2 = ?;\ V_2 = 0.08$$

$$P_2 = \frac{P_1V_1}{V_2} = \frac{(1.6 \times 10^6)(0.2)}{(0.08)} = \mathbf{4\ MPa}$$

b)

$$P_1V_1 = P_2V_2$$

$$P_1 = 1.6 \times 10^6;\ V_1 = 0.2;\ P_2 = 3.2\ MPa;\ V_2 = ?$$

$$V_2 = \frac{P_1V_1}{P_2} = \frac{(1.6 \times 10^6)(0.2)}{(3.2 \times 10^6)} = \mathbf{0.1\ m^3}$$

Charles' Law

Now that we appreciate Boyle's Law, let's wonder what might happen if we were to heat the gas (air). Well, blow up your balloon and place it in the fridge for a while. Afterwards you will notice that the volume of the balloon has decreased. The opposite applies if you place the balloon in the oven for a while; it increases in volume. What is going on here? Atomically, all of those air molecules become very active when in the oven and bounce off each other like crazy, causing collisions and expansion. This is effectively what Charles' Law says…

$$V \propto T \quad [3]$$

This says that the volume of a gas is proportional to its temperature. OK, let's strip away the constant of proportionality again and write down Charles' Law…

$$\frac{V}{T} \propto k \quad [4]$$

This tells us that gas volume divided by temperature is constant. For the same mass of gas (air) this relationship holds good under different conditions. We can now write Charles' Law…

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad or, more\ simply: V_1 T_2 = V_2 T_1 \quad [5]$$

Gay-Lussac's Law

This law is analogous to Charles' Law, but says that the pressure of a gas is proportional to the gas temperature – **IF** we hold the volume and mass of the gas constant.

$$P \propto T \quad [6]$$

Now we strip-away the constant of proportionality once more…

$$\frac{P}{T} = k \quad [7]$$

We now use previous analogies to arrive at…

$$P_1 T_2 = P_2 T_1 \quad [8]$$