THERMODYNAMICS

TUTORIAL No. 1 – BASIC CONCEPTS and PROPERTIES OF FLUIDS

This is set at the level QCF 3

Contents

1. Introduction

This tutorial provides the basic knowledge needed to get started with your studies. In particular you need to understand the thermodynamic properties of fluids. Gas is covered here but vapours are covered in tutorial 2. We will start with a list of symbols needed in thermodynamics.

2. Symbols

These are the main S. I. Symbols appropriate to these studies.

Quantity	**units**	**Derived Unit**	**S.I. symbol**
Length	m		various
Mass	kg		m
Time	s		t
Volume	m^3		V or Q
Specific Volume	m^3/kg		*v*
Volume Flow Rate	m^3/s		
Density	kg/m^3		ρ
Force	$kg\ m/s^2$	N	F
Weight	$kg\ m/s^2$	N	W
Pressure Head	m		h
Altitude	m		z
Area	m^2		A
Speed of Sound	m/s		a
Specific Heat Cap.	N m/kg K	Joule/kg K	c
Energy	N m	Joule	
Enthalpy	N m	Joule	H
Internal Energy	N m	Joule	U
Specific Enthalpy	N m/kg	J/kg	h
Specific Int. Energy	N m/kg	J/kg	u
Mass flow rate	kg/s		
Polytropic Index			n
Adiabatic Index			γ
Pressure	N/m^2	Pascal	p
Heat Transfer	N m	Joule	Q
Work	N m	Joule	W
Heat Transfer Rate	N m/s	Watt	Φ
Work Rate (power)	N m/s	Watt	P
Char. Gas Const	N m/kg K	J/kg K	R
Universal Gas Constant	J/kmol K		R_o
Absolute Temperature	K		T
Celsius Temperature	^oC		θ
Velocity	m/s^2		v or u

3. Basic Concepts

3.1 Extensive and Intensive Properties

Throughout these tutorials you will use properties which are either ***Extensive or Intensive***.

An extensive property is one which is divisible. For example Volume when divided by a number becomes smaller. Other examples are mass and energy.

An intensive property is a property of a mass which remains the same value when the mass is divided into smaller parts. For example the temperature and density of a substance is unchanged if it is divided into smaller masses.

3.2 Total and Specific Properties

Throughout the tutorials you will use ***Total and Specific*** quantities which relate only to extensive properties. A total quantity is always denoted by a higher case letter such as V for volume (m^3) and H for enthalpy (J). A specific quantity represents the quantity per kg and is obtained by dividing the property by the mass. Such properties are always designated by lower case letters such as v for specific volume (m^3/kg) and h for specific enthalpy (J/kg).

Specific volume is mainly used for gas and vapours. The inverse of specific volume is density (ρ) (kg/m^3) and this is mainly used for liquids and solids but also for gases. Note $\rho=1/v$.

Because the same letters are used to designate more than one property, often alternative letters are used. For example v for specific volume may occur in the same work as v for velocity so often u or c is used for velocity. h is used for height, head and specific enthalpy so z is often used for height instead.

The unit of Force and Weight is the kg m/s^2. This comes from Newton's Second Law of Motion (Force = mass $\times$ acceleration). The derived name for the unit is the Newton. In the case of Weight, the acceleration is that of gravity and in order to convert mass in kg into weight in Newtons, you must use $W = mg$ where g is normally 9.81 m/s^2.

3.3 Two Properties Rule

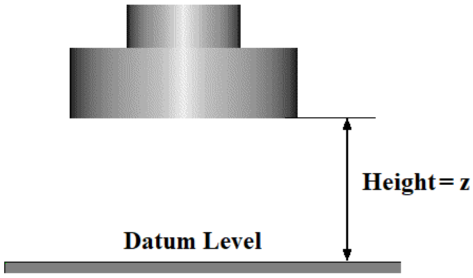
In the following work it is essential to be able to find and use the many properties of fluids. The two property rule is simply that if we know two independent properties of a substance then the other properties may be determined. For example if we know the pressure and temperature of a gas then the volume may be found. This rule does not apply if the substance changes state such as evaporating.

Now we will examine forms of energy a fluid may have.

4. *Energy Forms*

You may have studies energy forms in other studies. Here we are concerned with the enrgy involved in thermo-fluids. Fluids may possess several forms of energy. All fluids possess energy due to their temperature and this is called ***Internal Energy***. All possess ***Gravitational*** or ***Potential Energy*** due to their elevation relative to some datum level. If the fluid is moving it will possess ***Kinetic Energy*** due to its velocity. If it has pressure then it will possess ***Flow Energy***. Often pressure and temperature are the main two governing factors and we add internal energy to flow energy in order to produce a single entity called ***Enthalpy***. Let us look at each in more detail.

4.1. Gravitational or Potential Energy



In order to raise a mass m kg a height z metres, a lifting force is required which must be at least equal to the weight mg.

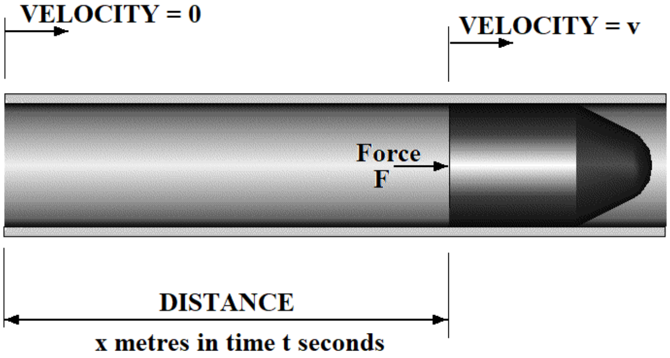
The work done raising the mass is as always, force x distance moved so Work = m g z

Since energy has been used to do this work and energy cannot be destroyed, it follows that the energy must be stored in the mass and we call this gravitational energy or potential energy P.E. There are many examples showing how this energy may be got back, e.g. a hydro-electric power station.

$$\textbf{P.E.} = \mathbf{m\,g\,z}$$

4.2 Kinetic Energy

When a mass m kg is accelerated from rest to a velocity of v m/s, a force is needed to accelerate it.



This is given by Newton's 2nd Law of Motion F= ma.

After time t seconds the mass travels x metres and reaches a velocity v m/s. The laws relating these quantities are:

$$a = \frac{v}{t} \text{ and } x = \frac{v\,t}{2}$$

The work done is:

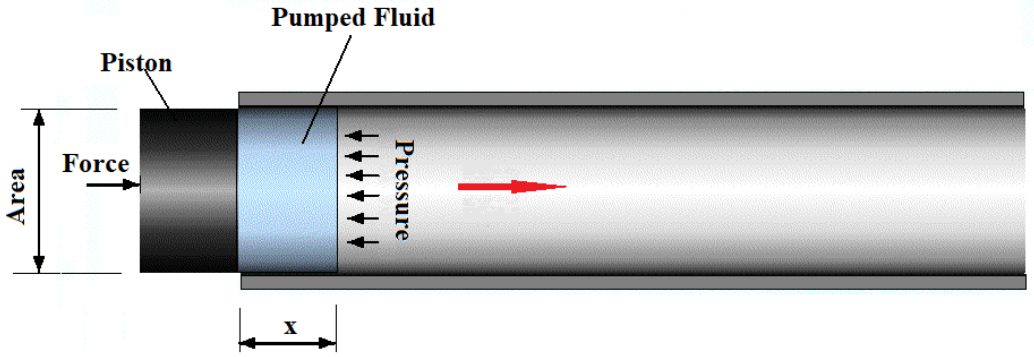
$$W = F\,x = m\,a\,x = \frac{mv^2}{2}$$

Energy has been used to do this work and this must be stored in the mass and carried along with it. This is ***Kinetic Energy***.

$$\mathbf{K.E.} = \frac{\mathbf{mv^2}}{\mathbf{2}}$$

4.3 Flow Energy

When fluid is pumped along a pipe, energy is used to do the pumping. This energy is carried along in the fluid and may be recovered (as for example with an air tool or a hydraulic motor). Consider a piston pushing fluid into a cylinder.



The fluid pressure is p N/m^2. The force needed on the piston is: F= pA

The piston moves a distance x metres. The work done is: W = Fx = pAx

Since Ax =V and is the volume pumped into the cylinder the work done is

W = pV

Since energy has been used doing this work, it must now be stored in the fluid and carried along with it as ***Flow Energy***.

F. E. = p V

4.4 Internal Energy

This is covered in more detail later. The molecules of a fluid possess kinetic energy and potential energy relative to some internal datum. Usually this is regarded simply as the energy due to the temperature and very often the change in internal energy in a fluid which undergoes a change in temperature is given by

$$\Delta U = m\,c\,\Delta T$$

The symbol for internal energy is U kJ or u kJ/kg. Note that a change in temperature is the same in degrees Celsius or Kelvin. The law which states internal energy is a function of temperature only is known as ***Joule's Law.***

4.5 Enthalpy

When a fluid has pressure and temperature, it must possess both flow and internal energy. It is often convenient to add them together and the result is ***Enthalpy***. The symbol is H kJ or h kJ/kg.

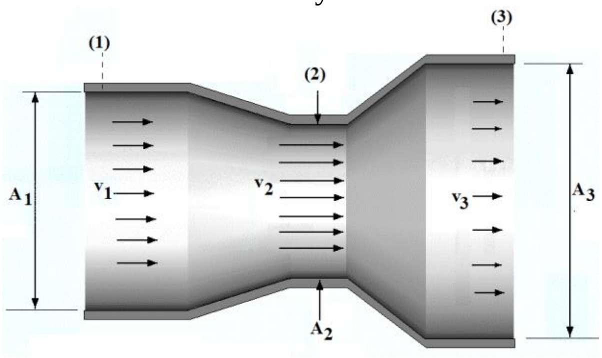
H = F. E. + U

Next you need to study the properties of fluids and the laws relating them.

5. *Continuity of Flow*

When a fluid flows in a pipe the volumetric flow rate is the product of mean velocity and area such that

Volume/s = Area × velocity $\qquad V = A\,v$



The mass flow rate is obtained by multiplying the volume by density so **m = ρAv**

If the area changes, the mass stays constant so the velocity must change. In the case of liquids, the density is constant but not in the case of vapours or gases.

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 = \rho_3 A_3 v_3$$

This equation will be needed to enable you to calculate the velocity and hence kinetic energy.

WORKED EXAMPLE No. 1

A pipe 50 mm bore diameter, carries water with a mean velocity of 4 m/s and a pressure of 200 kPa. The pipe reduces to 25 mm bore diameter. The density of water ρ is 1 000 kg/m^3

i. The volumetric and mass flow rate in the first section
ii. The kinetic energy per second in the first section
iii. The flow energy per second in the first section
iv. The velocity in the second section

SOLUTION

$$A_1 = \frac{\pi d^2}{4} = \frac{\pi \times 0.05^2}{4} = 1.9635 \times 10^{-3}\,\mathrm{m}^2$$

$$\text{Volume flow rate} = Q = A_1\,v_1 = 1.9635 \times 10^{-3} \times 4 = 7.854 \times 10^{-3}\,\mathrm{m^3/s}$$

$$\text{Mass flow rate} = \dot{m} = \rho Q = 1\,000 \times 7.854 \times 10^{-3} = 7.854\ \mathrm{kg/s}$$

$$\mathrm{KE/s} = \frac{\dot{m}v_1^2}{2} = \frac{7.854 \times 4^2}{2} = 493.5\ \mathrm{W}$$

$$\text{Flow Energy} = \mathrm{FE/s} = pQ = 200\,000 \times 7.854 \times 10^{-3} = 1\,571\ \mathrm{W}$$

$$A_2 = \frac{\pi d^2}{4} = \frac{\pi \times 0.025^2}{4} = 490.87 \times 10^{-6}\,\mathrm{m}^2$$

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \quad v_2 = \frac{\rho_1 A_1 v_1}{\rho_2 A_2} = \frac{1\,000 \times 1.9635 \times 10^{-3} \times 4}{1\,000 \times 490.87 \times 10^{-6}} = 16\ \mathrm{m/s}$$

SELF ASSESSMENT EXERCISE No. 1

1. 3 kg/s of a fluid flows in a pipe with a mean velocity of 5 m/s. Calculate the kinetic energy conveyed per second.

2. 4 m^3/s of a fluid flows in a duct with a pressure of 2 MPa. Calculate the flow energy being conveyed per second.

3. 400 kg of fluid is pumped from one lake to another 400 m higher in altitude. What is the increase in energy?

4. 0.128 m^3/s of gas flows at 12 m/s velocity and 2 MPa pressure and 25^oC temperature. Calculate :

   a. the kinetic energy being transported per second.

   b. the flow energy being transported per second.

5. A duct has a cross sectional area of 0.08 m^2 and carries gas at a velocity of 9 m/s. The duct reduces to a cross sectional area of 0.03 m^2. Assuming the density is constant, calculate the velocity in the smaller section.

6. A liquid flows in a pipe at a rate of 1.7 kg/s and a pressure of 0.5 Mpa. The pipe has a bore 20 mm diameter. The liquid has a density of 800 kg/m^3. Calculate the following.

   i. The velocity of the liquid.
   ii. The kinetic energy per second.
   iii. The flow energy per second.

6. Gas Laws

A gas is made of molecules which move around with random motion. In a perfect gas, the molecules may collide but they have no tendency at all to stick together or repel each other. In other words, a perfect gas is completely inviscid. In reality there is a slight force of attraction between gas molecules but this is so small that gas laws formulated for an ideal gas work quite well for real gas. Each molecule in the gas has an instantaneous velocity and hence has kinetic energy. The sum of this energy is the internal energy U. The velocity of the molecules depends upon the temperature.

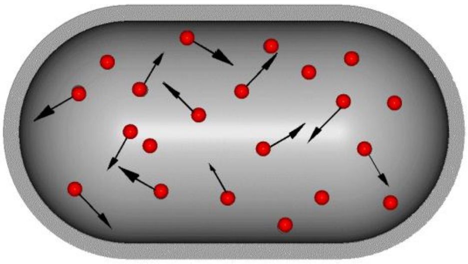
When the temperature changes, so does the internal energy. The internal energy is for all intents and purposes zero at - 273^o C. This is the absolute zero of temperature.

Remember that to convert from Celsius to absolute, add on 273.

For example 40^{o}C is 40 + 273= 313 Kelvins.

6.1 Pressure

If a gas is compressed it obtains pressure. This is best explained by considering a gas inside a vessel as shown.



The molecules bombard the inside of the container. Each produces a momentum force when it bounces. The force per unit area is the pressure of the gas. Remember that pressure = Force/area

$$p = \frac{F}{A}\ N/m^2 \text{or Pascals}$$

Note that 10^3 Pa = 1 kPa 10^6 Pa = 1 MPa 10^5 Pa = 1 bar

The pressure used in gas laws must always be ***Absolute Pressure***. In practical situations, pressure is measured with a gauge that indicates the pressure relative to that of the atmosphere. On such a gauge it is possible to get negative readings if the pressure is less than the surrounding atmosphere. These are called ***Gauge Pressures*** and if you have a gauge pressure you should convert it to absolute pressure by adding on the atmospheric pressure at the time (barometric pressure). Absolute

Pressure = Gauge Pressure + Atmospheric Pressure

In this tutorial, pressures are always absolute unless otherwise stated.

6.2 Constant Volume Law

When a gas is heated the molecules move with greater velocity. If the container is rigid, then the molecules will hit the surface more often and with greater force so we expect the pressure to rise proportional to temperature.

p = c T when V is constant.

WORKED EXAMPLE No. 2

A mass of gas has a pressure of 500 kPa and temperature of 150°C. The pressure is changed to 900 kPa but the volume is unchanged. Determine the new temperature.

SOLUTION

Using constant volume law find:

$$\frac{p_1}{T_1} = c = \frac{p_2}{T_2}$$

T_1 =150 + 273 = 423 K p_1 = 500 000 p_2 =900 000

$$T_2 = \frac{p_2 T_1}{p_1} = \frac{900\ 000 \text{ x } 423}{500\ 000} = 761.4 \text{ K}$$

6.3 Charles' Law

If we kept the pressure constant and increased the temperature, then we would have to make the volume bigger in order to stop the pressure rising. This gives us Charle's Law:

$$\mathbf{V = c\,T \quad \text{when } p \text{ is constant}}$$

WORKED EXAMPLE No. 3

A mass of gas has a temperature of 150^{o}C and volume of 0.2 m^3. The temperature is changed to 50^{o}C but the pressure is unchanged. Determine the new volume.

SOLUTION

Using Charles's law we find:

$$\frac{V_1}{T_1} = c = \frac{V_2}{T_2}$$

T_1 =150 + 273 = 423 K

V_1 = 0.2

T_2 = 50 + 273 = 323 K

$$V_2 = \frac{T_2V_1}{T_1} = \frac{323 \times 0.2}{523} = 0.123 \text{ m}^3$$

6.4 Boyle's Law

If we keep the temperature constant and increase the volume, then the molecules will hit the surface less often so the pressure goes down. This gives Boyle's Law:

$$\mathbf{p = \frac{c}{V} \text{ when } T \text{ is constant}}$$

WORKED EXAMPLE No. 4

A mass of gas has a pressure of 800 kPa and volume of 0.3 m^3. The pressure is changed to 100 kPa but the temperature is unchanged. Determine the new volume.

SOLUTION

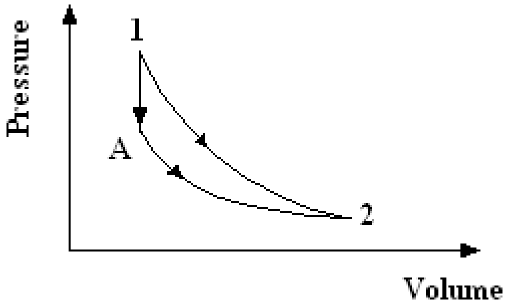
Using Boyle's law we find p_1V_1= c = p_2 V_2

p_1 = 800 ×10^3 V1 = 0.3 p_2 = 100 ×10^3

$$V_2 = \frac{p_1V_1}{p_2} = \frac{800 \times 10^3 \times 0.3}{100 \times\ 10^3} = 2.4 \text{ m}^3$$

6.5 General Gas Law

Consider a gas which undergoes a change in pV and T from point (1) to point (2) as shown. It could have gone from (1) to (A) and then from (A)to (2) as shown.



Process (1) to (A) is constant volume

$$\frac{p_A}{T_A} = \frac{p_1}{T_1}$$

Process (A) to (2) is constant temperature $T_2 = T_A$

Hence

$$\frac{p_A}{T_2} = \frac{p_1}{T_1} \text{and } p_A = \frac{p_1 T_2}{T_1} \dots \dots (1)$$

For the process (A) to (2) Boyle's Law applies so $p_A V_A = p_2 V_2$

Since $V_A = V_1$ then we can write $p_A V_1 = p_2 V_2$

So:

$$p_A = \frac{p_2 V_2}{V_1} \dots \dots (2)$$

Equating (1) and (2) we get:

$$\mathbf{\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} = constant}$$

This is the ***General Gas Law*** to be used to calculate one unknown when a gas changes from one condition to another.

WORKED EXAMPLE No. 2

A mass of gas has a pressure of 1.2 MPa, volume of 0.03 m^3 and temperature of 100^oC.
The pressure is changed to 400 kPa and the volume is changed to 0.06 m^3. Determine the new temperature.

SOLUTION

Using the general gas law we find $p_1V_1/T_1 = p_2V_2/T_2$ where

$p_1 = 1.2 \times 10^6$

$V_1 = 0.03$

$p_2 = 400 \times 10^3$

$T_1 = 100 + 273 = 373$ K

$$T_2 = \frac{p_2 V_2 T_1}{p_1 V_1} = \frac{400 \times 10^3 \times 0.06 \times 373}{1.2 \times 10^6 \times 0.03} = 248.7 \text{ K}$$

6.6 Characteristic Gas Law

The general gas law tells us that when a gas changes from one pressure, volume and temperature to another, then:

$$\frac{pV}{T} = \text{constant}$$

Thinking of the gas in the rigid vessel again, if the number of molecules was doubled, keeping the volume and temperature the same, then there would be twice as many impacts with the surface and hence twice the pressure. To keep the pressure the same, the volume would have to be doubled or the temperature halved. It follows that the constant must contain the mass of the gas in order to reflect the number of molecules. The gas law can then be written as:

$$\frac{pV}{T} = mR$$

Where m is the mass in kg and R is the remaining constant which must be unique for each gas and is called the ***Characteristic Gas Constant***.

If we examine the units of R they are J/kg K.

The equation is usually written as:

$$\mathbf{pV = mRT}$$

Since m/V is the density ρ, it follows that:

$$\boldsymbol{\rho} = \frac{\mathbf{p}}{\mathbf{RT}}$$

Since V/m is the specific volume *v*, then:

$$\boldsymbol{\upsilon} = \frac{\mathbf{RT}}{\mathbf{p}}$$

WORKED EXAMPLE No. 6

A mass of gas has a pressure of 1.2 MPa, volume of 0.03 m^3 and temperature of 100^oC. Given the characteristic gas constant is 300 J/kg K find the mass.

SOLUTION

From the characteristic gas law we have pV = mRT

$p = 1.2 \times 10^6$ N/m^2 V = 0.03 m^3 T = 100 + 273 = 373 K

$$m = \frac{pV}{RT} = \frac{1.2 \times 10^6 \times 0.03}{300 \times 373} = 0.322 \text{ kg}$$

SELF ASSESSMENT EXERCISE No. 2

All pressures are absolute.

1. Calculate the density of air at 1.013 bar and 15 ^oC if R = 287 J/kg K. (1.226 kg/m^3)

2. Air in a vessel has a pressure of 25 bar, volume 0.2 m^3 and temperature 20^oC. It is connected to another empty vessel so that the volume increases to 0.5 m^3 but the temperature stays the same. Taking R = 287 J/kg K. Calculate
   i. the final pressure. (10 bar)
   ii. the final density. (11.892 kg/m^3)

3. 1 dm^3 of air at 20^oC is heated at constant pressure of 300 kPa until the volume is doubled. Calculate i. the final temperature. (586 K)
   ii. the mass. (3.56 g)

4. Air is heated from 20^oC and 400 kPa in a fixed volume of 1 m^3. The final pressure is 900 kPa. Calculate i. the final temperature.(659 K)
   ii. the mass. (4.747 kg)

5. 1.2 dm^3 of gas is compressed from 1 bar and 20^oC to 7 bar and 90^oC.
   Taking R = 287 J/kg K calculate i. the new volume. (212 cm^3)
   ii. the mass. (1.427 g)

The Universal Gas Law

The Characteristic Gas Law states $pV = mRT$
R is the characteristic constant for the gas.
This law can be made universal for any gas because $R = R_o/M_m$.
M_m is the mean molecular mass of the gas (numerically equal to the relative molecular mass). The formula becomes:

$$\mathbf{pV = \frac{mR_oT}{M_m}}$$

R_o is a universal constant with value 8 314.3 J/kmol K. It is worth noting that in an exam, this value along with other useful data may be found in the back of your fluids tables.

The kmol is defined as the number of kg of substance numerically equal to the mean molecular mass. Typical values are:

GAS	Symbol	M_m.
Hydrogen	H_2	2
Oxygen	O_2	32
Carbon Dioxide	CO_2	44
Methane	CH_4	16
Nitrogen	N_2	28
Dry Air		28.96

Hence 1 kmol of hydrogen (H_2) is 2 kg
1 kmol of oxygen (O_2) is 32 kg
1 kmol of Nitrogen is 28 kg and so on.

For example if you had 3 kmol of nitrogen (N_2) you would have $3 \times 28 = 84$ kg

It follows that the M_m must have units of kg/kmol
In order to calculate the characteristic gas constant we use:

$$\mathbf{R = \frac{R_o}{M_m}}$$

For example the characteristic gas constant for air is $R = 8\,314.3/28.96 = 287$

Examine the units

$$\mathrm{R = \frac{R_o}{M_m} = \frac{J/kmol\ K}{kg/kmol} = J/kg\ K}$$

WORKED EXAMPLE No. 7

A vessel contains 0.2 m^3 of methane at 60°C and 500 kPa pressure. Calculate the mass of Methane.

SOLUTION

$$pV = \frac{mR_oT}{M_m}$$

For Methane you should be able to find that M_m = 16

$$500\ 000 \times 0.2 = \frac{m \times 8314.4 \times (273 + 60)}{16}$$

$$m = \frac{500\ 000 \times 0.2 \times 16}{8314.4 \times 333} = 0.578 \text{ kg}$$

SELF ASSESSMENT EXERCISE No. 3

1. A gas compressor draws in 0.5 m^3/min of Nitrogen at 10°C and 100 kPa pressure. Calculate the mass flow rate. (0.595 kg/min)

2. A vessel contains 0.5 m^3 of Oxygen at 40°C and 10 bar pressure. Calculate the mass. (6.148 kg)

7. *Heat Transfer and Specific Heat Capacities*

Specific Heat Capacities

The specific heat capacity of a fluid is defined in two principal ways as follows:

7.1 Constant Volume

The specific heat which relates change in specific internal energy 'u' and change in temperature 'T' is defined as:

$$c_v = \frac{du}{dT}$$

If the value of the specific heat capacity c_v is constant over a temperature range ΔT then we may go from the differential form to the finite form:

$$c_v = \frac{\Delta u}{\Delta T} \quad J/kg$$

Hence

$$\Delta u = c_v \Delta T \quad J/kg$$

For a mass m kg the change is $\mathbf{\Delta U = mc_v \Delta T}$ Joules

This law indicates that the internal energy of a gas is dependant only on its temperature. This was first stated by Joule and is called ***Joule's Law***.

7.2 Constant Pressure

The specific heat which relates change in specific enthalpy 'h' and change in temperature 'T' is defined as:

$$c_p = \frac{dh}{dT}$$

If the value of the specific heat capacity c_p is constant over a temperature range ΔT then we may go from the differential form to the finite form

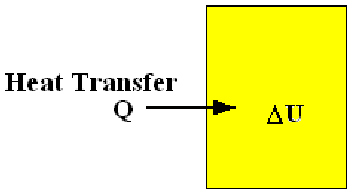
$$c_p = \frac{\Delta h}{\Delta T} J/K \text{ hence } \Delta h = c_p \Delta T \; J/kg$$

For a mass m kg the change is $\mathbf{\Delta H = m\, c_p \Delta T}$ Joules

The reasons why the two specific heats are given the symbols c_v and c_p will be explained next. They are called the ***Principal Specific Heats***.

Constant Volume Heating

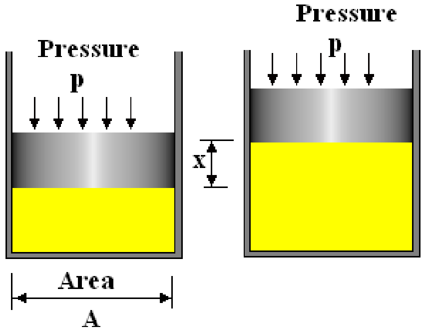
When a fluid is heated at constant volume, the heat transfer 'Q' must be the same as the increase in internal energy of the fluid ΔU since no other energy is involved. It follows that



$$Q = \Delta U = mc_v \Delta T \quad \text{Joules}$$

The change in internal energy is the same as the heat transfer at constant volume so the symbol c_v should be remembered as applying to constant volume processes as well as internal energy.

Constant Pressure Heating



When a fluid is heated at constant pressure, the volume must increase against a surrounding pressure equal and opposite to the fluid pressure p.

The force exerted on the surroundings must be

$$F = pA \quad \text{Newton}$$

The work done is force x distance moved hence:

Work Done = F x = pAx = p ΔV where ΔV is the volume change.

The heat transfer Q must be equal to the increase in internal energy plus the work done against the external pressure. The work done has the same formula as flow energy (p ΔV). Enthalpy is defined as

$$\Delta H = \Delta U + p\Delta V$$

The heat transfer at constant pressure is also

$$Q = \Delta U + p\Delta V$$

Since specific heats are used to calculate heat transfers, then in this case the heat transfer is by definition:

$$Q = m\, c_p\, \Delta T$$

It follows that

$$\Delta H = Q = m\, c_p\, \Delta T$$

For the same temperature change ΔT it follows that the heat transfer at constant pressure must be larger than that at constant volume. The specific heat capacity c_p is remembered as linked to constant pressure.

8. *Link Between c_v c_p and R.*

From the above work it is apparent that

$$\Delta H = mc_p\Delta T = \Delta U + p\Delta V$$

We have already defined

$$\Delta U = mc_v\Delta T$$

Furthermore for a gas only

$$p\Delta V = mR\Delta T$$

Hence

$$mc_p\Delta T = mc_v\Delta T + mR\Delta T$$

Hence

$$\mathbf{c_p = c_v + R} \text{ and } \mathbf{R = c_p - c_v} \text{ (the difference)}$$

9. *Application to Liquids and Vapour*

Liquids are regarded as incompressible because the volume of a liquid does not change much when heated or cooled, very little work is done against the surrounding pressure so it follows that c_v and c_p are for all intents and purposes the same and usually the heat transfer to a liquid is given as:

$$Q = m\,c\,\Delta T \qquad \text{c is the specific heat capacity}$$

Vapour is defined as a gaseous substance close to the temperature at which it will condense back into a liquid. In this state it cannot be considered as a perfect gas and great care should be taken applying specific heats to them. We should use tables and charts to determine the properties of vapours and this is covered in the next tutorial.

WORKED EXAMPLE No. 8

Calculate the change in enthalpy and internal energy when 3 kg of gas is heated from 20°C to 200°C

The specific heat at constant pressure is 1.2 kJ/kg K and at constant volume is 0.8 kJ/kg K. Also determine the change in flow energy.

SOLUTION

i. Change in enthalpy.

$$\Delta H = mc_p\Delta T = 3 \times 1.2 \times 180 = 648 \text{ kJ}$$

ii. Change in internal energy.

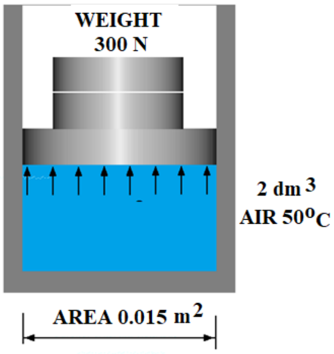
$$\Delta H = mc_v\Delta T = 3 \times 0.8 \times 180 = 432 \text{ kJ}$$

iii. Change in flow energy

$$\Delta FE = \Delta H - \Delta U = 216 \text{ kJ}$$

WORKED EXAMPLE No. 5

A vertical cylinder contains 2 dm^3 of air at 50°C. One end of the cylinder is closed and the other end has a frictionless piston which may move under the action of weights placed on it. The weight of the piston and load is 300 N. The cylinder has a cross sectional area of 0.015 m^2. The outside is at atmospheric conditions.



Determine
i. the gas pressure
ii. the gas mass
iii. the distance moved by the piston when the gas is heated to 150°C

For air take c_p= 1 005 J/kg K and c_v = 718 J/kg K. Atmospheric pressure = 100 kPa

SOLUTION

The pressure of the gas is constant and always just sufficient to support the piston so

p = Weight/Area + atmospheric pressure

p = 300/0.015 + 100 kPa = 20 kPa + 100 kPa = 120 kPa

T_1 = 50 + 273 = 323 K $\qquad$ V_1 = 0.002 m^3

R = c_p - c_v = 1005 - 718 = 213 J/kg K

$$m = \frac{pV}{RT} = \frac{120\ 000 \times 0.002}{213 \times 323} = 0.00348 \text{ kg}$$

T_2 = 150 + 273 = 423 K

$$V_2 = \frac{p_1 V_1 T_2}{p_2 T_1}$$

$p_1 = p_2$

$$V_2 = \frac{V_1 T_2}{T_1} = \frac{0.02 \times 423}{323} = 0.0263 \text{ m}^3$$

Distance moved x = Volume change/Area

$$x = \frac{0.0262 - 0.02}{0.015} = 0.412 \text{ m}$$

SELF ASSESSMENT EXERCISE No. 4

For air take c_p = 1 005 J/kg K and c_v = 718 J/kg K unless otherwise stated.

1. 0.2 kg of air is heated at constant volume from 40°C to 120°C. Calculate the heat transfer and change in internal energy. (11.49 kJ for both)

2. 0.5 kg of air is cooled from 200°C to 80°C at a constant pressure of 5 bar. Calculate the change in internal energy, the change in enthalpy, the heat transfer and change in flow energy. (-43 kJ), (-60.3 kJ), (-17.3 kJ)

3. Air is heated from 20°C to 50°C at constant pressure. Using your fluid tables (pages 16 and 17) determine the average value of c_p and calculate the heat transfer per kg of air. (30.15 kJ)

4. The diagram shows a cylinder fitted with a frictionless piston. The air inside is heated to 200°C at constant pressure causing the piston to rise. Atmospheric pressure outside is 100 kPa. Determine :

   i. the mass of air. (11.9 g)

   ii. the change in internal energy. (1.537 kJ)

   iii. the change in enthalpy. (2.1553 kJ)

   iv. the pressure throughout. (500 kPa)

   v. the change in volume. (1.22 dm^3)