Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 13: Fundamentals of Thermodynamics and Heat Engines

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Fundamental Thermodynamic Systems

rev2: May 2019

edexcel
Approved Centre

Contents

INTRODUCTION

Investigate fundamental thermodynamic systems and their properties. Forms of energy and basic definitions.

- Definitions of systems (open and closed) and surroundings.
- First law of thermodynamics.
- The gas laws: Charles' Law, Boyle's Law, general gas law and the Characteristic Gas Equation.
- The importance and applications of pressure/volume diagrams and the concept of work done.
- Polytropic processes: constant pressure, constant volume, adiabatic and isothermal systems.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose	Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.
Theory	Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.
Example	The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.
Question	Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.
Challenge	You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.
Video	Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

rev2: May 2019

edexcel
Approved Centre

1.1 Fundamental Systems:

1.1.1 First Law of Thermodynamics

Purpose Thermodynamics studies the behaviour and dynamics of energy. The first law of thermodynamics is simple: "energy cannot be created or destroyed, it can only be transferred from one form to another".

1.1.2 Forms of energy and basic definitions.

Theory Energy comes in a wide variety of forms, for example; if your lightbulb was powered by a gas power station, the energy changes several times before coming out of the bulb as light and heat, shown by Fig.1.1. None of the processes will be 100% efficient, and realistically will lose a lot of energy as heat.

Fig.1.1: An energy flow chart from gas to a lightbulb.

Fig.1.1 shows several different energies, but energy can be categorised into larger groups:

- Kinetic energy is the energy of a moving object; in Fig.1.1 this would be the generator's shaft spinning to generate electrical energy.
- Potential energy is the energy that an object has due to its position relative to others, for example, electrical energy moves from high charge to low charge. Or an object on a table has more potential energy than an object on the floor (the potential energy would be converted to kinetic when it drops).
- Internal energy is the energy that is holding the bonds of the molecules together, such as the chemical energy holding a fuel's molecules together.

1.1.3 Definitions of Systems and Surroundings

Theory A system is defined as either open or closed, and where the system meets its surroundings is called the boundary. A closed system is one that only has an input or output of energy in some form, shown by Fig.1.2, the boundary encloses the entire system, a closed system is typically used when modelling an engine's cylinder. Mass cannot enter or leave a closed system.
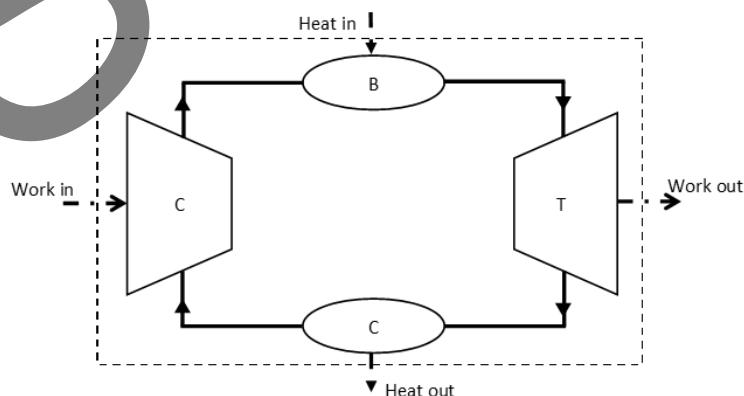

Fig.1.2: A diagram of a closed system, the labels on the system will be explained in Section.1.1.6

rev2: May 2019

edexcel
Approved Centre

An open system can have a mass flow, the boundary will surround the equipment, but will also have an intake and exhaust of mass through the boundary. Most thermodynamic systems will use an open system, such as heat pumps and refrigeration cycles.
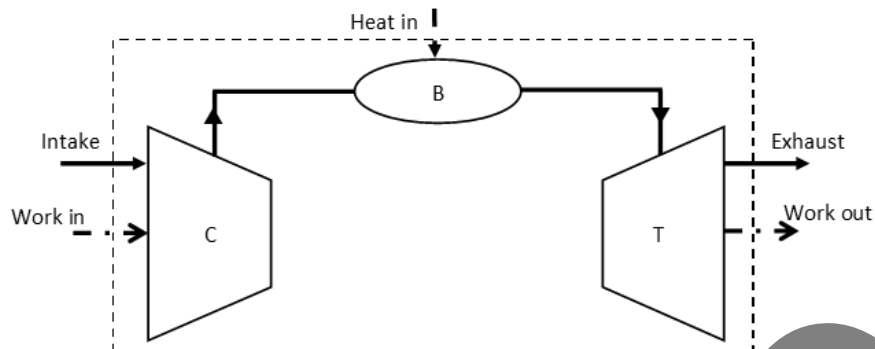

Fig1.3: An open system and its boundaries

1.2 Fundamental Equations

1.2.1 Applying the First Law to Systems

Theory   The first law of the system can be calculated by Eq.1.1 as simply the summation (Σ) of energies, where U is the internal energy of the molecules, PE is the potential energy, and KE is the kinetic energy.

$$E = U + \sum PE + \sum KE \qquad \text{(Eq.1.1)}$$

Meaning a change (Δ) in energy is modelled as Eq.1.2.

$$\Delta E = E_2 - E_1 = U_2 - U_1 + KE_2 - KE_1 + PE_2 - PE_1 \qquad \text{(Eq.1.2)}$$

For a closed system it can be assumed that there is no flow in the system, meaning that $KE = PE = 0$. And so, the change of energies between two points can be shown as Eq.1.3, where Q is the heat transferred, and W is the work transferred.

$$U_1 + Q = U_2 + W \qquad \text{(Eq.1.3)}$$

Which turns into the standard thermodynamic equation that is Eq.1.4.

$$Q - W = U_2 - U_1 \qquad \text{(Eq.1.4)}$$

For an open system however, the equation is Eq.1.5.

$$Q - W = U_2 - U_1 + KE_2 - KE_1 + PE_2 - PE_1 \qquad \text{(Eq.1.5)}$$

1.2.2 Moles

Theory

Before moving onto gas laws, a brief explanation of the term "moles" is required. Moles define the number of atoms or molecules that are present in a material. The equation to calculate the number of moles, n, is given by Eq.1.6, where m is the overall mass of the substance, and M_r is the molecular mass of the substance.

$$n = \frac{m}{M_r} \qquad \text{(Eq.1.6)}$$

For example, one mole of Helium (atomic mass 4) would weigh 4 grams. To find the number of atoms or molecules present in the substance, the number of moles is multiplied by Avogadro's constant ($N_A = 6.022 \times 10^{23} mol^{-1}$).

Example 1

Find the number of molecules present in:

a) $3.5g$ of methane
b) $80g$ of Sodium Chloride

Answers:

a) Methane's chemical formula is CH_4, meaning there are 4 Hydrogens ($M_r = 1$) to every Carbon ($M_r = 12$), so the total molecular mass is $(4 \times 1) + 12 = 16$.

   The number of moles is therefore $n = \frac{3.5}{16} = 0.2188 mol$

   Which then gives the number of atoms as $0.2188 \times 6.022 \times 10^{23} = 1.32 \times 10^{23}\ atoms$

b) Sodium Chloride's chemical formula is $NaCl$. One chlorine atom ($M_r = 35.5$) for every sodium atom ($M_r = 23$), the total molecular mass is $35.5 + 23 = 58.5$

   The number of moles is therefore $n = \frac{80}{58.5} = 1.3675$

   Which gives the number of molecules as $1.3675 \times 6.022 \times 10^{23} = 8.24 \times 10^{23} molecules$

1.2.3 The Ideal Gas Equation

Theory

When the working fluid is modelled as a gas, it is useful to model it as an "ideal gas". An ideal gas is an imaginary substance that obeys the relationship in Eq.1.7, where P is the pressure, V is the volume, n is the number of moles, R_u is the universal gas constant ($8.314 J \cdot mol^{-1} \cdot K^{-1}$) and T is the temperature in Kelvin.

$$PV = nR_u T \qquad \text{(Eq.1.7)}$$

rev2: May 2019

edexcel
Approved Centre