Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 13: Fundamentals of Thermodynamics and Heat Engines

Unit Workbook 2

in a series of 4 for this unit

Learning Outcome 2

Plant Equipment

Contents

INTRODUCTION

Apply the Steady Flow Energy Equation to plant equipment:

- Conventions used when describing the behaviour of heat and work.
- The Non-Flow Energy Equation as it applies to closed systems.
- Assumptions, applications and examples of practical systems.
- Steady Flow Energy Equation as applied to open systems.
- Assumptions made about the conditions around, energy transfer and the calculations for specific plant equipment e.g. boilers, super-heaters, turbines, pumps and condensers.

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.

2.1 Energy equations

2.1.1 Heat and Work

Theory

When calculating heat and work, it's important to know the convention for calculations. Consider Eq.2.1 below.

$$Q - W = U_2 - U_1 \qquad \text{(Eq.2.1)}$$

This is the equation used in a closed system, typically the compression or expansion stroke of a piston. The convention for energy transfer is:

- if heat is transferred from the surroundings into the system, then Q is **positive**
- if heat is released from the system into the surroundings, then Q is **negative**
- If external work is done **by** the fluid or engine, then W is **positive**
- if external work is done **on** the fluid or engine, then W is **negative**

Example 1

Calculate the work of an engine for one stroke if the heat transferred out of the system is 300 kJ/kg and the internal energy has decreased by 900 kJ/kg. State whether work is done on or by the fluid.

$$Q - W = U_2 - U_1$$

Heat is transferred out of the system, so Q is **negative**, and $U_2 - U_1$ is also **negative** since there is a decrease in internal energy.

$$-300 - W = -900$$

$$-W = -900 + 300$$

$$-W = -600$$

$$W = 600\ kJ/kg$$

The work is positive, therefore work is done **by** the fluid

2.2 Closed System

2.2.1 Non-Flow Energy Equation

Theory The Non-Flow Energy Equation is given as Eq.2.1. No flow means that there is no kinetic or potential energy. The assumptions when calculating a closed system are:

- The fluid is compressible
- The system is insulated – meaning that heat is not lost to the environment over time
- The fluid is a "perfect" gas – the implication of this term will be discussed in Section 2.1.3

2.2.2 Applying the Non-Flow Energy Equation

Theory Most problems are simplified into defining one aspect of the system as constant. Table.2.1 shows the equations used to calculate work, internal energy and heat for the Non-Flow Energy Equation. Using the equations defined in workbook 1 will help find the temperature, pressure and volume.

The term C_v seen in the table is the specific heat capacity of the fluid at constant volume. There is also the specific heat capacity at constant pressure, C_p. The ratio $C_v/C_p = \gamma$ is used in the calculations mentioned in workbook 1. The specific heat capacities will change with temperature, and so the assumption of "a perfect gas" is used, which means that C_v, C_p and γ are constant at all temperatures.

Table.2.1: Equations used to calculate heat, work and internal energy for a closed system

Process	P,V,T relationship	W	Δu	Q
Isobaric constant pressure	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$	$P(V_2 - V_1)$	$mc_p(T_2 - T_1)$	$mc_p(T_2 - T_1)$
Isochoric constant volume	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$	0	$mc_v(T_2 - T_1)$	$Q = U_2 - U_1$ $Q = mc_v(T_2 - T_1)$
Isothermal constant temperature	$T = c$ $P_1V_1 = P_2V_2$	$P_1V_1 ln\left(\frac{V_2}{V_1}\right)$	0	$Q = W$ $Q = P_1V_1 ln\left(\frac{V_2}{V_1}\right)$
Polytropic reversible heat and work transfer	$PV^n = constant$ $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{n-1}$ $\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}$	$\frac{P_1V_1 - P_2V_2}{n - 1}$	$mc_v(T_2 - T_1)$	$Q = W + U_2 - U_1$
Adiabatic no heat transfer	$PV^\gamma = constant$ $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$ $\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$	$\frac{P_1V_1 - P_2V_2}{\gamma - 1}$	$mc_v(T_2 - T_1)$	0

Example 2

A closed system has a four-stage process. The working fluid's original state is $293K$ at $0.1MPa$. The system then shrinks from $0.3m^3$ down to $0.15m^3$ through isentropic compression. The fluid then undergoes isobaric heating and expands to $0.18m^3$. The system then undergoes isentropic expansion back to $0.3m^3$, before isochoric cooling to its original state. Calculate:

a) the work, heat and internal energy change of each stage.
b) the overall work, heat and internal energy change of the system.
c) and calculate the overall efficiency of the system.

Assume the working fluid is air acting as a perfect gas, with;

$C_V = 0.718\ kJ \cdot kg^{-1} \cdot K^{-1}$

$C_p = 1.00\ kJ \cdot kg^{-1} \cdot K^{-1}$

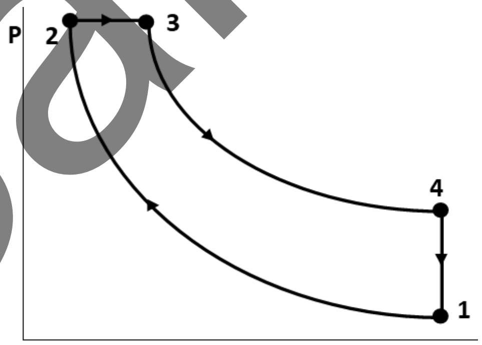
$R = 0.287$

$\gamma = 1.4.$

Answer:

Check your answers with the excellent online OMNICALCULATOR which is very useful for confirming your solutions on many of your course modules.

a) First, we draw the P-V diagram.



Stage 1-2: Isentropic Compression.

Isentropic expansion means no heat transfer (i.e. adiabatic). Therefore;

$$PV^\gamma = constant$$

$$\therefore \quad P_1V_1{}^\gamma = P_2V_2{}^\gamma \quad \therefore \quad \left(\frac{V_2}{V_1}\right)^\gamma = \frac{P_1}{P_2} \quad \therefore \quad \boldsymbol{P_2} = \frac{P_1}{\left(\frac{V_2}{V_1}\right)^\gamma} = \frac{0.1 \times 10^6}{\left(\frac{0.15}{0.3}\right)^{1.4}} = 263.9\ kPa$$