Distance learning

Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 30: Operations and Plant Management

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Fundamental Thermodynamic Systems

Rev3: April 2020

Contents

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.

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.

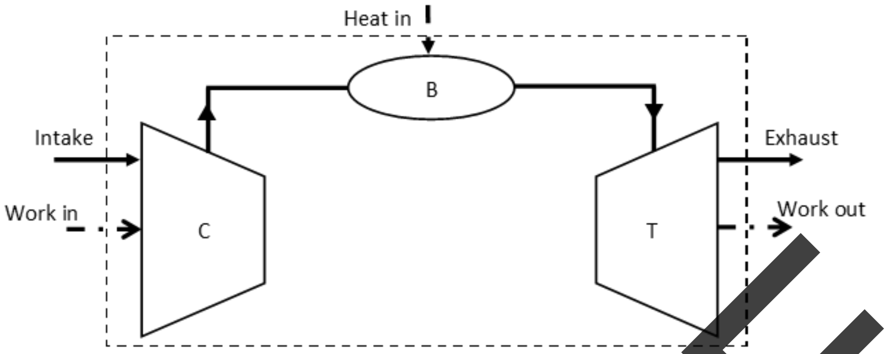

Fig1.3: An open system and its boundaries

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.

$$\Delta E = E_2 - E_1 = U_2 - U_1 + \mathrm{KE}_2 - \mathrm{KE}_1 + \mathrm{PE}_2 - \mathrm{PE}_1 \qquad \text{(Eq.1.2)}$$

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.

$$Q - W = U_2 - U_1 + \mathrm{KE}_2 - \mathrm{KE}_1 + \mathrm{PE}_2 - \mathrm{PE}_1 \qquad \text{(Eq.1.5)}$$

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

The ratio of the specific heats, γ, is also important in calculations which will be discussed in Section.1.2.6. But the equation for finding γ is Eq.1.15.

$$\frac{c_p}{c_v} = \gamma \qquad \text{(Eq.1.15)}$$

1.2.6 Pressure-Volume Diagrams

Theory

When analysing the thermodynamics of a system, one of the first steps is to develop its pressure-volume (P-V) diagram. With volume on the x-axis and pressure on the y-axis, Fig.1.4 shows the P-V diagram of a standard air heat engine. The area enclosed by the graph is the work done by the system.

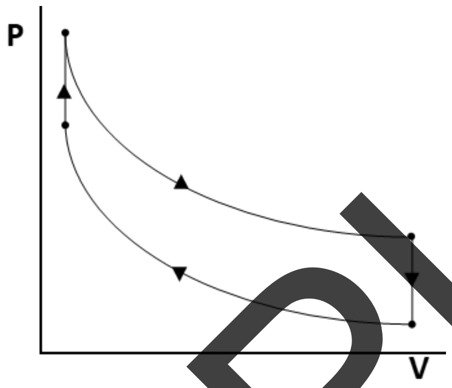

Fig.1.4: P-V diagram of a heat engine, discussed in more detail in workbook 4

P-V diagrams can also help show the work output of the system. The work is the useful energy used to create movement, such as the drive shaft of a generator or car. The area enclosed within the graph is the work done by the system. Work can be calculated using Eq.1.16.

$$W = \int P \, dV \qquad \text{(Eq.1.16)}$$

Knowing the overall net work done by the system will give the efficiency of the system in Eq.1.17.

$$\eta = \frac{W_{net}}{Q_{IN}} \qquad \text{(Eq.1.17)}$$

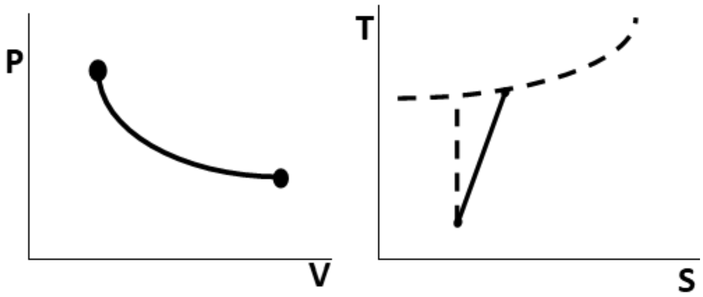

Fig.1.10: Adiabatic on a P-V diagram (left) and T-S diagram (right).

Example 2

A polytropic process features the following parameters;

$P_1 = 8\ kPa$

$P_2 = 0.5\ kPa$

$V_2 = 20\ m^3$

$V_1 = 5\ m^3$

Determine the index of compression for this process.

ANSWER

$$PV^n = constant \quad \therefore \quad P_1V_1{}^n = P_2V_2{}^n \quad \therefore \quad \frac{P_1}{P_2} = \frac{V_2{}^n}{V_1{}^n} \quad \therefore \quad \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n$$

Take logs of both sides …

$$log\left(\frac{P_1}{P_2}\right) = log\left(\left(\frac{V_2}{V_1}\right)^n\right) = n\ log\left(\frac{V_2}{V_1}\right)$$

$$\therefore \quad log\left(\frac{P_1}{P_2}\right) = n\ log\left(\frac{V_2}{V_1}\right)$$

$$\boldsymbol{n} = \frac{log\left(\frac{P_1}{P_2}\right)}{log\left(\frac{V_2}{V_1}\right)} = \frac{log\left(\frac{8}{0.5}\right)}{log\left(\frac{20}{5}\right)} = \frac{log(16)}{log(4)} = \frac{1.204}{0.602} = \mathbf{2}$$