Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 13: Fundamentals of Thermodynamics and Heat Engines

Unit Workbook 4

in a series of 4 for this unit

Learning Outcome 4

Internal Combustion Engines

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Approved Centre

Contents

INTRODUCTION

Determine the performance of internal combustion engines.

- Application of the second law of thermodynamics to heat engines.
- Comparison of theoretical and practical heat engine cycles, including Otto, Diesel and Carnot.
- Explanations of practical applications of heat engine cycles, such as compression ignition (CI) and spark ignition engines, including their relative mechanical and thermodynamic efficiencies.
- Describe possible efficiency improvements to heat engines.

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.

4.1 Ideal Heat Engine Cycles

4.1.1 Second Law of Thermodynamics with Heat Engines

The second law of thermodynamics is a series of observations that concerns the way things flow as time progresses forward. Typical observations are “water flows from high to low”, and “heat flows from hot to cold”. In the context of heat engines, however, the second law can be summed up as: **“No heat engine can be 100% efficient”**.

4.1.2 Carnot Cycle

Theory

The Carnot cycle is a theoretical heat engine design, intended to be the ideal operating system of a heat engine. It consists of four closed processes:

1-2: Fig.4.1 shows the first stage of the Carnot cycle, and its effect on the T-S and P-V diagram. As an isentropic system $\Delta Q = \Delta S = 0$.

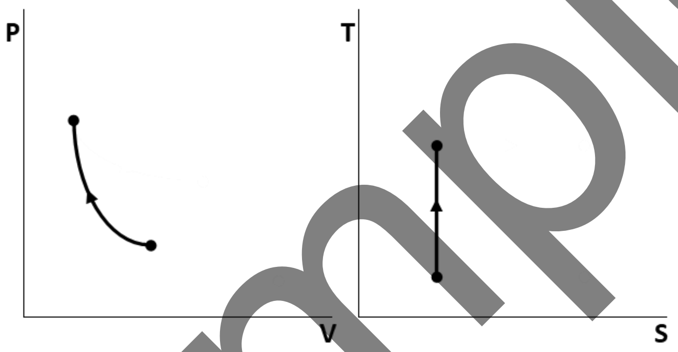

Fig 4.1: Stage 1-2 of the Carnot cycle

2-3: Fig. 4.2 represents the second stage, the isothermal process means that there is a heat input, but the process also produces a work output.

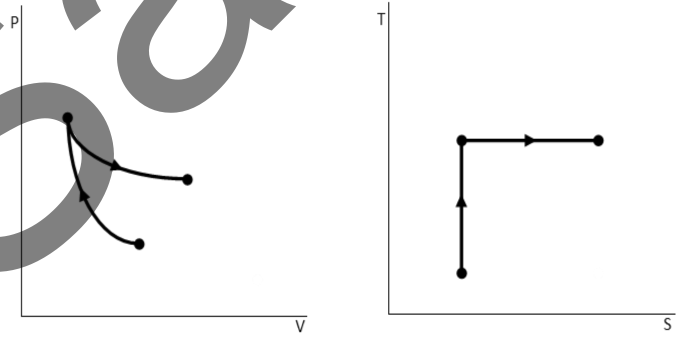

Fig.4.2: Stages 1-2-3 of the Carnot cycle

3-4: Fig. 4.3 shows the isentropic expansion of the system, as with stage 1-2, $\Delta Q = \Delta S = 0$.

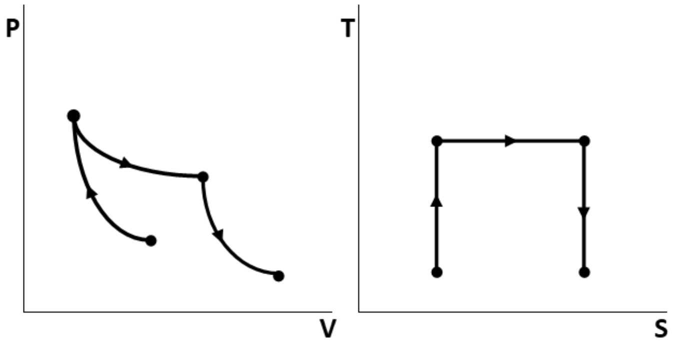

Fig. 4.3: Stages 1-2-3-4 of the Carnot cycle

4-1: The final stage, isothermal compression, completes the Carnot cycle, illustrated by Fig. 4.4

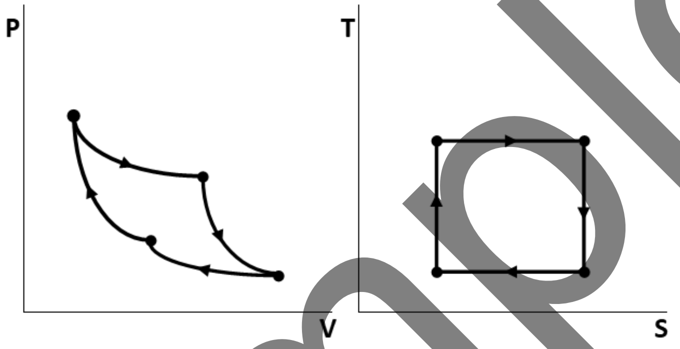

Fig. 4.4: The complete Carnot cycle

We know, from the previous learning objectives, that $Q_{net} = W_{net}$, we can calculate the thermal efficiency of the system as Eq. 4.1:

$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}} = 1 - \frac{T_{cold}\Delta s_{cold}}{T_{hot}\Delta s_{hot}} \qquad \text{(Eq. 4.1)}$$

Since $\Delta s_{cold} = \Delta s_{hot}$, then thermal efficiency can be reduced to Eq. 4.2:

$$\eta_{th} = 1 - \frac{T_{cold}}{T_{hot}} \qquad \text{(Eq. 4.2)}$$

This gives the **Carnot efficiency**, the ideal efficiency of an engine that cannot be attained in practical systems.

Example 1

What is the maximum possible efficiency of an engine where $T_{cold} = 50\ K$ and $T_{hot} = 320\ K$?

$$\eta_{th} = 1 - \frac{50}{320} = 0.844$$

Example 2

A claim that a new engine has been developed with a thermal efficiency of 75%. It draws in air at $10^{\circ}C$ and its exhaust releases gas at $680^{\circ}C$. Comment on whether a system such as this is possible.

Answer: Remembering to convert the temperatures to K

$$\eta_{th} = 1 - \frac{273 + 10}{273 + 680} = 0.703 = 70.3\%$$

The maximum possible efficiency is 70.3%, the claim cannot possible be true.

4.1.3 Otto Cycle

Theory

The Otto cycle is built to represent a more realistic engine system. This process is more commonly associated with a spark ignition (SI) engine, which will be discussed in Section 4.2. The complete P-V and T-S diagrams of the cycle are shown in Fig. 4.8 below. The defining feature of the Otto cycle is its constant pressure heat addition in the system. The point marked r_c on Fig. 4.5 is known as the compression ratio of the system, it is the ratio of volumes between the top dead centre (TDC) of the piston, relative to the bottom dead centre (BDC) of the piston, given by Eq. 4.3.

$$r_c = \frac{V_{BDC}}{V_{TDC}} \qquad \text{(Eq. 4.3)}$$

The Otto cycle can be broken down into four stages:

1-2: Isentropic compression, Fig. 4.5 shows the first stage of the system on the P-V and T-S diagram.

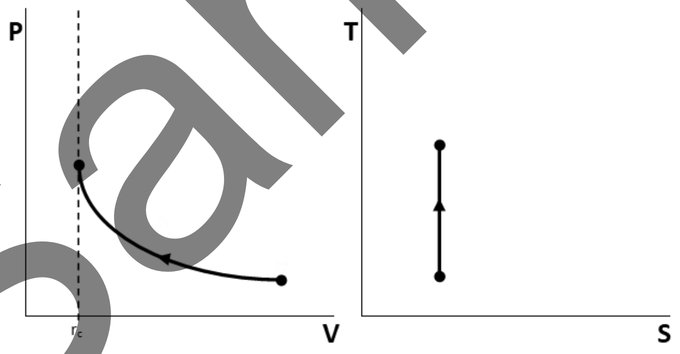

Fig. 4.5: Stage 1-2 of the Otto cycle

2-3: Constant volume heat addition, Fig. 4.6 shows the second stage in the cycle.

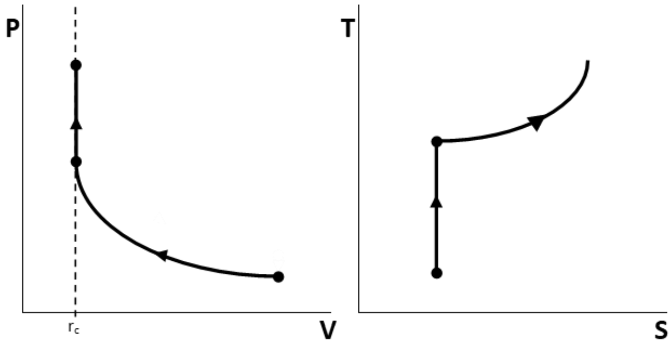

Fig.4.6: Stages 1-2-3 of the Otto cycle

3-4: Isentropic expansion back to $V = V_1$, Fig. 4.7 shows the next stage of the Otto cycle.

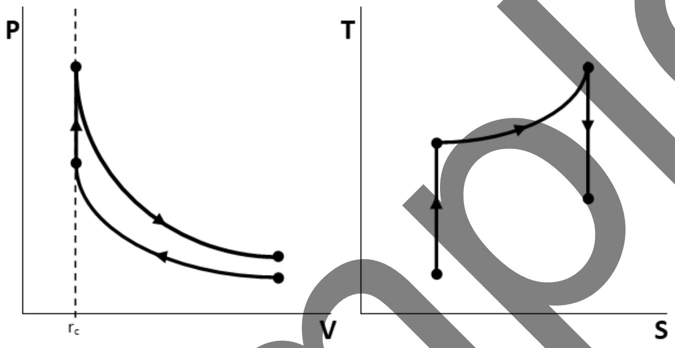

Fig. 4.7: Stages 1-2-3-4 of the Otto cycle.

4-1: Constant pressure heat rejection, the cycle is completed, and the working fluid returns to the original conditions at point 1.

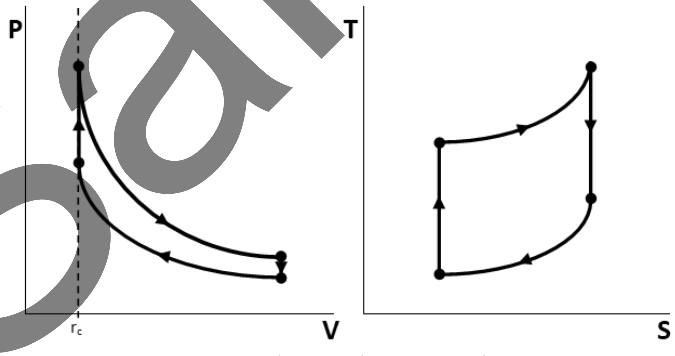

Fig. 4.8: The complete Otto cycle

The thermal efficiency of the Otto cycle, $\eta_{th,O}$, is given as Eq.4.4. **The derivation of the Eq.4.4 is not required but can be found in "Other Resources" on Moodle.**

$$\eta_{th,OTTO} = 1 - \frac{1}{r_c^{\gamma-1}} \qquad \text{(Eq. 4.4)}$$

4.1.4 Diesel Cycle

Theory

The Diesel cycle is used to represent realistic compression ignition (CI) engines, which will be discussed in more detail later in Section 4.2, we can break it down into four stages:

1-2: Isentropic compression, Fig. 4.9 shows the effect on the P-V and T-S diagrams.

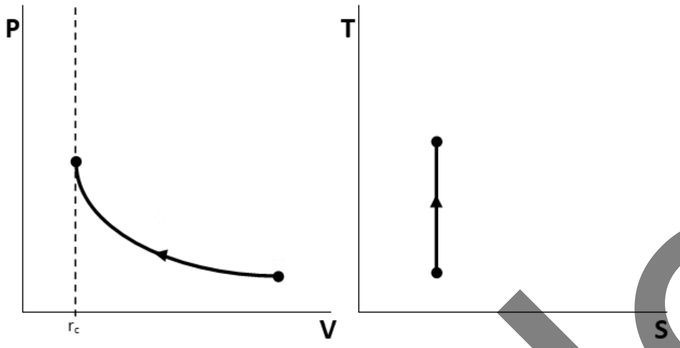

Fig. 4.9: Stage 1-2 of the Diesel cycle

2-3: Constant pressure heat addition. The point α is the cut-off ratio, given as V_3/V_2, shown in Fig. 4.10

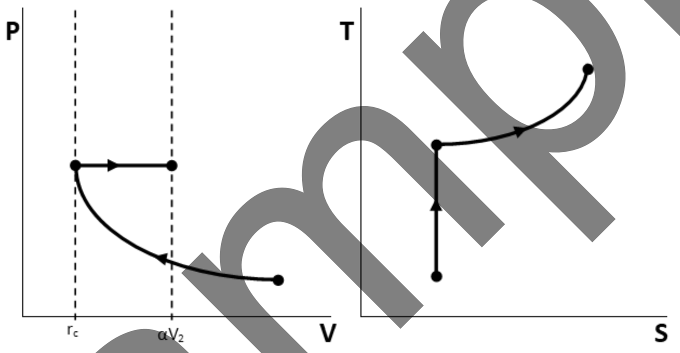

Fig. 4.10: Stages 1-2-3 of the Diesel cycle

3-4: Isentropic expansion back to V_1, shown on a P-V and T-S diagram by Fig. 4.11.

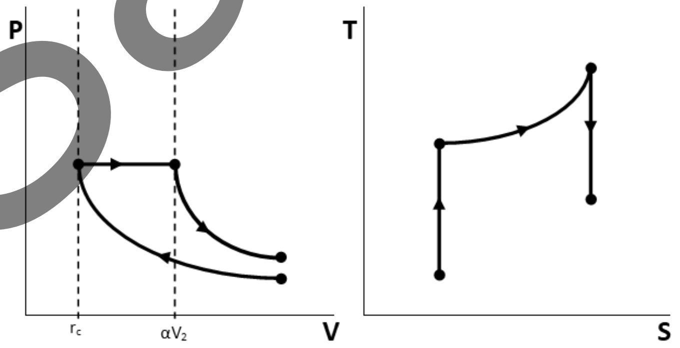

Fig. 4.11: Stages 1-2-3-4 of the Diesel cycle