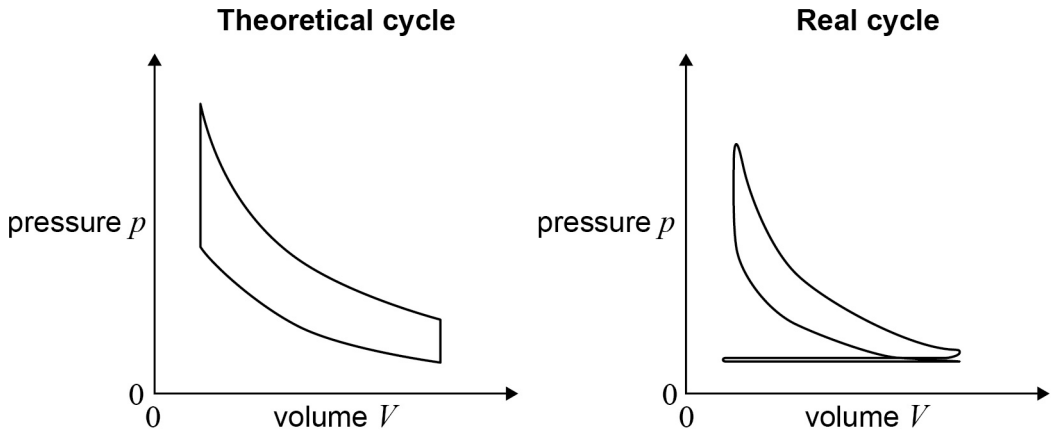
Do not write outside the box

0 1 **Figure 5** shows the $p-V$ diagram for a theoretical petrol engine cycle compared to the indicator diagram for a real four-stroke petrol engine with the same maximum and minimum volumes.

Figure 5



Compare the theoretical and real engine cycles. In your answer you should:

- state and explain the differences between the cycles
- explain why the work output per cycle of the real engine is less than that predicted by an analysis of the theoretical cycle.

[6 marks]

Total			**9**

1	**The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer.** **Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.**	The following statements are likely to be present. **First bullet: differences between cycles** • Real engine needs induction and exhaust strokes/ pumping loop • Ideal cycle needs no pumping loop/same air used repeatedly • Corners rounded on real cycle • Reason: valves take finite time to open and close/combustion not instantaneous • Heating/cooling cannot occur at constant volume in real cycle • Reason: piston would have to stop • In real cycle expansion & compression are not adiabatic • Reason: heat transfer takes place to cooling medium during these strokes • In ideal cycle air only is taken through cycle (repeatedly)/gas is ideal • In real engine some exhaust gas/fuel vapour is present/gas is not ideal • Max pressure is lower in real engine • Fuel may not be completely burnt • Ideal cycle makes no reference to any mechanism • In real engine a mechanism is necessary e.g. for	6

Mark	Criteria	QoWC
6	Both bullets in question are answered. Answer includes 9 or more points taken from both lists opposite with reasons mainly matching differences Allow for answers which state the events in both cycles, provided points alongside are covered and some reasons given for differences.	The student presents relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.
5	A fair attempt to answer both bullets. Answer includes 7or 8 points taken from both lists, including at least two matching reasons for differences. Answers will not be as full as for 6 marks.	
4	Comparisons are less complete but good understanding is shown of the differences between the diagrams. Answer includes 5 or 6 of the points opposite with at least one taken from each part.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.
3	The student will address 4 or 5 of the points listed but reasons may not be given with confidence or reasons may not match the differences	

	2	Fewer than 4 points are covered. The student is more likely to state the differences rather than explain them. The answer addresses one or both bullets in the question but with limited scope. They are likely to refer to 'heat losses' or 'friction' without detail.	The student presents some relevant information in a simple form. The text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.	valve operation, generation of spark **Second bullet: why work output less** ▪ Area of loop is smaller for real engine, so less work done per cycle ▪ Area of pumping loop has to be subtracted from main loop, reducing work done ▪ Friction between moving surfaces/between piston & cylinder/in bearings has to be overcome ▪ energy is expended in driving oil and water pumps, opening and closing valves overcoming fluid viscosity etc Accept other reasonable answers in lieu. (eg variation in γ during expansion and compression)	
	1	Some attempt is made to compare the cycles.			
	0	No relevant analysis.	The student's presentation, SP&G seriously obstruct understanding.		

Do not write outside the box

0 2 . 1 An ideal heat pump and an ideal refrigerator operate between the same hot and cold spaces.

Which statement relating to the coefficient of performance (COP) is correct?
Tick (✓) the correct answer.

[1 mark]

The COP of the refrigerator must be < 1. ☐

The COP of the heat pump must be greater than the COP of the refrigerator. ☐

The COP of the heat pump will increase if the temperature of the hot space is increased. ☐

The COP of the refrigerator will decrease if the cold space temperature increases. ☐

0 2 . 2 An ideal refrigerator operates between a cold space at a temperature of $-1\ °C$ and a hot space at a temperature of $70\ °C$.

Calculate the input power to the refrigerator if the rate of transfer of energy to the hot space is $100\ W$.

[3 marks]

input power = _____ W

4

Question	Answer	Additional Comments/Guidance	Mark
02.1	Tick against answer **B** ✓	Auto marked	1
02.2	COPref $= \frac{272}{343-272}$ (= 3.8 (3.83)) ✓ 3.8 = $Q_C/(100 - Q_C)$ giving Q_C = 79 (W) (79.3W) ✓ P_{IN} = 79/3.8 = 21 (W) (20.7 W) ✓ **OR** for 2nd and 3rd marks COPref = Q_C/W and $Q_C + W = Q_H = 100$ ✓ 3.8 $W + W = 100$ So W = 21 (W) ✓ **OR** for 2nd and 3rd marks COPhp = COPref + 1 ✓ W = Q_H/4.8= 100/4.8 = 21 (W) ✓		3
Total			**4**

0 3 The National Grid is supplied mainly from power stations which have overall efficiencies of up to about 40%

Table 1 shows the average power requirements of a large paper-manufacturing business (a paper mill).

Table 1

Requirement	**Average power / MW**
for driving electric motors for wood grinders, pumps, fans, etc.	49
for heating, ie boiling and drying in the paper-making process and for heating the paper mill	141
for running electrical office equipment, lighting, etc.	8

The paper mill can either

- take all of its energy from the National Grid, or
- install an electrical generator of output 60 MW driven by a gas turbine of efficiency 36% as part of a combined heat and power (CHP) scheme. The hot exhaust gases from the turbine are used to produce steam at high temperature and pressure for heating.

The owners of the paper mill are considering the CHP option.

Explain, with reference to the data above and any other factors, the advice you would give them.

In your answer you should

- explain why the maximum theoretical efficiency of a heat engine is much less than 100%
- use the information above, including the numerical data, to compare the two options.

[6 marks]

<table>
<tr><th>Question</th><th>Answers</th><th>Additional Comments/Guidelines</th><th>Mark</th></tr>
<tr><td>03</td><td>
The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist marking this question.
<table>
<tr><th>Mark</th><th>Criteria</th><th>QoWC</th></tr>
<tr><td>6</td><td>Both bullets in question are answered. Answer includes 8 or more points taken from both lists opposite and table below including use of data. Comes to a conclusion or advice given..</td><td rowspan="2">The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.</td></tr>
<tr><td>5</td><td>A fair attempt to answer both bullets. Answer includes 7 points taken from both lists opposite and table below including use of data. Answers will not be as full as for 6 marks. Comes to a conclusion or advice given.</td></tr>
</table>
</td><td>
Likely answer points:

First bullet

1. All heat engines must obey 2nd Law of thermodynamics

2. They must reject energy to a sink/surroundings (at low temperature)

3. Maximum efficiency determined by source and sink temperatures / formula quoted
$\eta = T_H - T_C/T_H$

4. 100% efficiency would require $T_C = 0\ K$ and/or a small difference between T_H and T_C gives low efficiency

5. Allow: inefficiencies from nature of working cycle, friction, incomplete combustion etc.

Second bullet

6. 60 MW will cover electrical need (but not much margin for expansion)

7. input power = 57/0.36 = 158 MW (or 167 MW at 60 MW output)

8. max heat available for heat requirement = 101 MW (or 107 MW at 60 MW output)

9. and likely to/will be less than this
</td><td>6</td></tr>
</table>

	4	Makes some attempt to use the numerical data correctly. Answer includes any 5 or 6 of the points opposite or in table below.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.	10. this is not enough for heating requirement 11. (at least) 34 MW will need to come from National Grid. 12. power station input to give 198 MW to mill = 495 MW 13. Energy <u>that would otherwise be wasted</u> is utilised. Other answer points (other factors) for 2nd bullet are in the table below; credit sensible alternatives		
	3	Any 4 of the answer points opposite or in table below are given May not make use of numerical data.				
	2	2 or 3 answer points opposite or in table below are covered. May not make use of the numerical data.	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.			
	1	Any one pertinent statement.				
	0	No sensible statements made.	The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.			

0 4 In an ideal heat-engine cycle a fixed mass of air is taken through the following four processes.

A → B isothermal compression from an initial pressure of 1.0×10^5 Pa and a volume of 9.0×10^{-2} m^3 to a pressure of 2.2×10^5 Pa. The work done on the air is 7100 J.

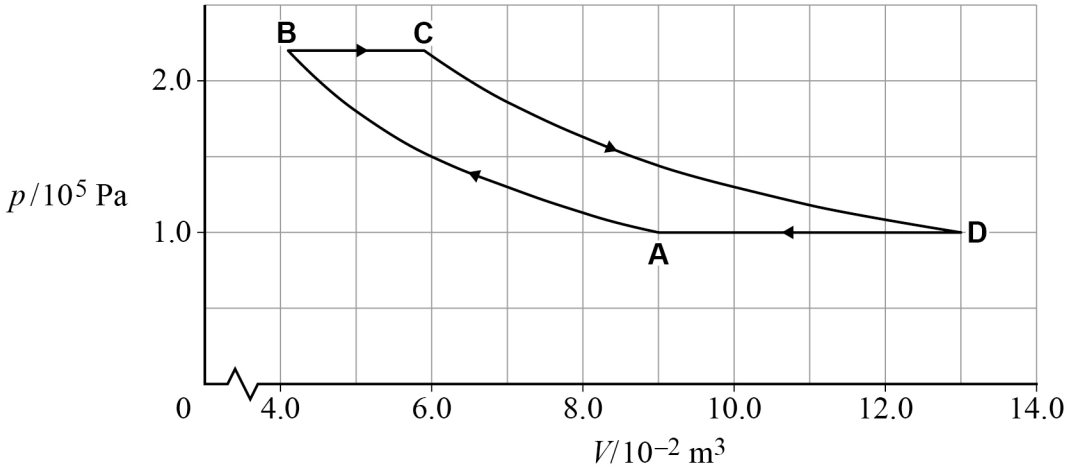
B → C increase in volume at constant pressure to a volume of 5.9×10^{-2} m^3.

C → D isothermal expansion to a pressure of 1.0×10^5 Pa and a volume of 13×10^{-2} m^3. The work done by the air is 10 300 J.

D → A reduction in volume at constant pressure to the original volume.

Figure 3 shows the cycle.

Figure 3



0 4 . 1 Show, by calculation, that the volume at **B** is 4.1×10^{-2} m^3.

[1 mark]

0 4 . 2 The temperature of the air between **A** and **B** is $295\ \text{K}$.

Show that the temperature of the air at **C** is about $420\ \text{K}$.

[2 marks]

0 4 . 3 An ideal engine based on this cycle uses a device called an economiser. The economiser stores **all** the energy transferred in the cooling process **D** → **A** and gives up **all** this energy to the air in process **B** → **C**.
This means that an external source supplies energy to the air by heating only in process **C** → **D**.

Complete **Table 1** to show the values of work done W and energy transfer Q in each of the four processes.
Use the space below **Table 1** for any calculations.
Use a consistent sign convention.

[2 marks]

Table 1

Process	Work done W / J	Energy transfer Q / J
A → B	-7100	-7100
B → C	4000	
C → D	10 300	10 300
D → A		$-14\ 000$

0 4 . 4 Explain why W is equal to Q in process **A** → **B** and in process **C** → **D**.

[2 marks]

0 4 . 5 It is claimed that the efficiency of this engine cycle is the same as the maximum theoretical efficiency of a heat engine operating between the same temperatures.

Deduce whether this claim is true.

[3 marks]

0 4 . 6 Discuss **one** problem that would be faced by an engineer designing a real engine based on this cycle.

[2 marks]

12

Total			**7**

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.1	$p_A V_A = p_B V_B$ $V_B = \frac{1.0 \times 10^5 \times 9.0 \times 10^{-2}}{2.2 \times 10^5}$ ✓ (= 4.1×10^{-2} m^3)	The mark is for attempt to use Boyle's Law with correct numbers substituted.	1	1.1b × 1 ? or 2.1f × 1 L2M × 1
04.2	Use of $\frac{V_B}{T_B} = \frac{V_C}{T_C}$ ✓ OR Use of $\frac{p_A V_A}{T_A} = \frac{p_C V_C}{T_C}$ ✓ Leading to T_C = 425 K ✓	Allow ECF from **03.1** Accept any correct application of pV/T = constant 426 K if 4.09×10^{-2} m^3 used for V_B At least 3 sig fig answer must be seen	2	1.1b × 2 ? or 2.1f × 1 L2M × 2
04.3	**Process** / **Work *W*/J** / **Heat transfer *Q*/J** **A → B** / -7100 / -7100 **B → C** / 4000 / *14000* ✓ **C → D** / 10 300 / 10 300 **D → A** / - *4000* ✓ / -14 000	1st mark for either italicised answer correct including sign 2nd mark for both italicised answers correct including sign Calculations might show *W* for **D → A** = $p\Delta V = 1.0 \times 10^5 \times (13.0 - 9.0) \times 10^{-2}$ J = 4000 J	2	2.1b × 2
04.4	1st Law applies/must be obeyed OR $Q = \Delta U + W$ ✓ (for isothermal process) $\Delta U = 0$ so $Q = W$ ✓	1st mark for any reference to First Law in words or equation. 2nd mark for stating $\Delta U = 0$ (in isothermal process) and showing $Q = W$	2	2.1f × 2

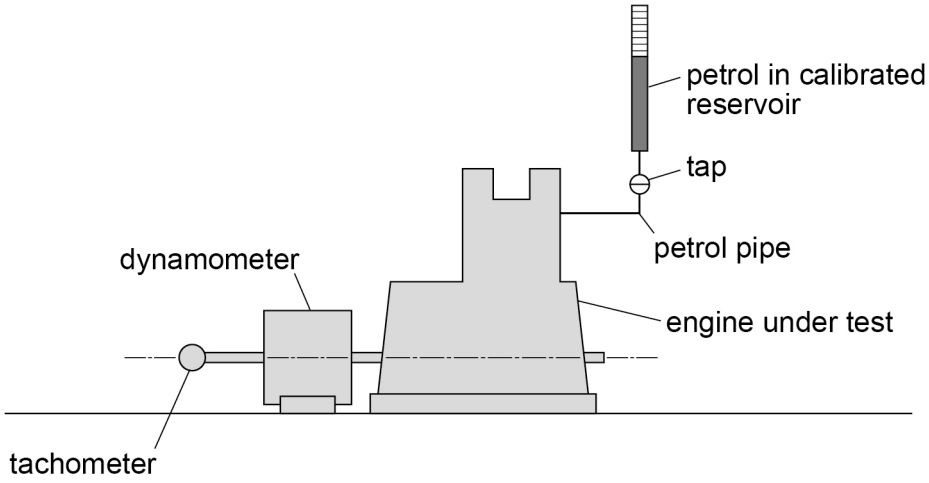
04.5	Claim is correct as Net work = 3200 J ✓$_1$ η = 3200/ 10300 = 0.31 or 31% ✓$_2$ ηmax $=$ $\frac{425-295}{425}$ = 0.31 or 31% ✓$_3$ OR ηmax $=$ $\frac{420-295}{420}$ = 0.30 or 30%	Alternative for 1st mark: Net work = area of loop in Fig 3 = 6.5 squares × 500 J = 3250 J allow ± 250 J If student tots up their *W* column in Table 1 correctly for their values, award the 1st mark point ✓$_1$ (or if they use the area of the cycle correctly calculated) Also award ✓$_1$ for 3200 J even if it does not agree with their Table 1. If they have been awarded ✓$_1$ for net work, and divide this value by 10300, give the 2nd mark point ✓$_2$ If they calculate the max theoretical efficiency correctly give ✓$_3$ **Then if they have ✓$_1$, ✓$_2$ and ✓$_3$:** If there is no concluding statement award 2 marks If the concluding statement is incorrect for their efficiencies award 2 marks If their concluding statement is correct for their efficiencies award 3 marks If they only get the max theoretical efficiency, award 1 mark. If 420 K has been used allow argument that efficiencies are not (quite) the same	3	3.1b ×1 3.1a × 2

04.6	Isothermal processes are impossible/difficult to achieve ✓ Because engine would have to run (very) slowly **Or** perfect conducting material used ✓ OR Economiser will not store/transfer energy effectively ✓ because it will lose heat to surroundings ✓ **Or** unless it has large/have large surface area **Or** because it will not be perfectly insulated Accept other sensible suggestions and corresponding reasons	Answer should relate to the real engine based on 'this cycle'. Do not allow problems common to all heat engines e.g. ignore 'friction' and simple statements relating to 'heat loss to surroundings'. Give 1 mark if student spots that Work/power output is very small for size of engine 1 mark if they back this up.	2	3.1a × 2

Total			**12**

0 5 **Figure 4** shows some of the equipment used to investigate the thermal and mechanical efficiencies of a single-cylinder four-stroke petrol engine.

Figure 4



- Petrol is supplied to the engine from a calibrated reservoir.
- Sensors are used to measure the volume V and pressure p above the piston inside the cylinder.
- The dynamometer applies a load to the output shaft and measures the output torque of the engine.
- The tachometer measures the rotational speed of the engine in revolutions per second.

In one test the air intake valve (throttle) setting remains fixed and the load provided by the dynamometer is kept constant.

Describe how you would determine the input power, the indicated power, the brake power, the thermal efficiency and the mechanical efficiency.

In your answer you should
- describe the measurements that you would take
- show how you would use the measurements and any other necessary data.

[6 marks]

<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td>05</td><td>The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist marking this question.
<table>
<tr><th>Mark</th><th>Criteria</th></tr>
<tr><td>6</td><td>There is a response to both bullet points in the question. Student quotes or uses points A B C 11 and 12 in words or symbols and have 7 or more of detail points 1-10 covering all three powers.</td></tr>
<tr><td>5</td><td>There is a response to both bullet points in the question. Mark as for 6 above. Answers will not be as confident or detailed as for 6 marks, or answers may not be expressed using scientific terminology.</td></tr>
<tr><td>4</td><td>The student describes how to determine at least 2 of powers A, B, C with detail points for each. They may be able to give one of the efficiencies. They should have at least 7 of points 1 to 12. Answers show more confidence than for 3 marks.</td></tr>
<tr><td>3</td><td>Student describes how to determine at least 2 powers. They will have 5 points or more from 1 to 12 .They may miss out efficiency formulae altogether,or get them wrong.</td></tr>
<tr><td>2</td><td>Student includes 3 or 4 of points 1 to12, relating detail points 1 to 10 to the appropriate power formula.</td></tr>
<tr><td>1</td><td>Makes any 2 of points 1 to 12.</td></tr>
<tr><td>0</td><td>No sensible statements made.</td></tr>
</table>
Marks not awarded for simply quoting formulae from Data booklet.</td><td>Likely answer points:

<u>1st bullet</u>
Measurements/info needed and how obtained
A input power from c.v. × fuel flow rate
1. measure volume of fuel used in given time
2. by using reservoir/measuring cylinder and stopclock
3. find/look up calorific value of fuel; accept c.v. is known

B indicated power from area of indicator diagram x cycles s^{-1}
4. need cylinder pressures and corresponding volumes
5. take an indicator diagram / $p-V$ diagram
6. using sensors (data logger + computer + software)
7. determine area of indicator diagram with method
8. measure speed from tachometer <u>and</u> × ½

C brake (output) power from $P = T\omega$
9. torque on output shaft using dynamometer and engine speed using tachometer
10. multiply tachometer reading by 2π

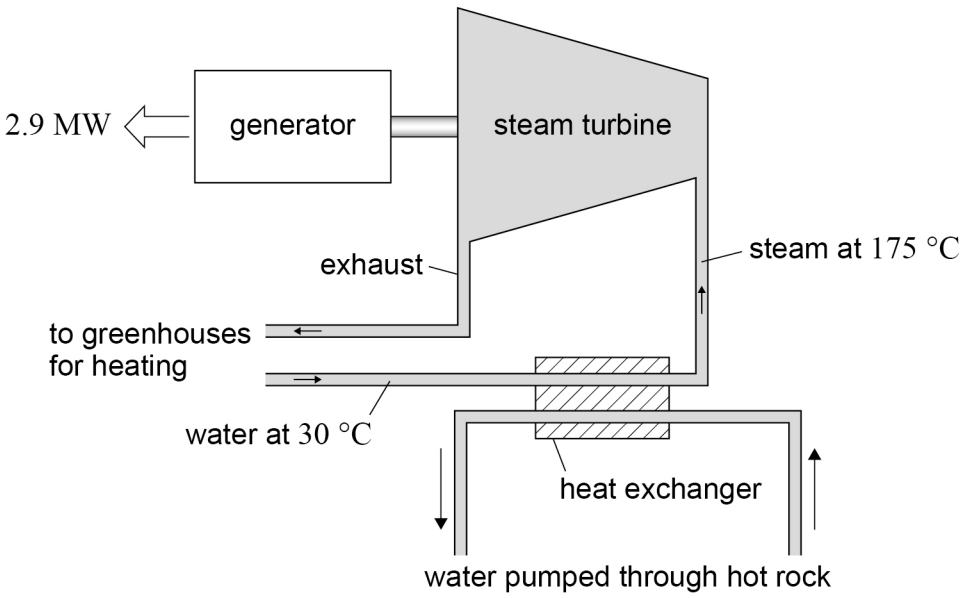
Note: no credit for formulae simply stated as they are in formulae booklet.
<u>2nd bullet</u>
11. thermal efficiency = indicated power/input power
12. mechanical efficiency = brake power/indicated power
(Note: these formulae are not in the formulae booklet)</td><td>6</td><td>AO1.1a ×3
AO2.1g ×1
AO3.2b ×2</td></tr>
<tr><td>Total</td><td></td><td></td><td>6</td><td></td></tr>
</table>

0 6 . 1 Explain how the second law of thermodynamics predicts that a heat engine can never be 100% efficient.

[2 marks]

0 6 . 2 A company plans to build a geothermal power station in a region where there is hot rock deep below the surface. The scheme is shown in **Figure 7**.

Figure 7



In the heat exchanger, energy from the hot rock is used to produce steam at $175\ °C$.
The steam passes through a turbine that drives an electric generator.
The exhaust steam is used to heat nearby greenhouses where it condenses before returning to the heat exchanger.

The lowest temperature in the turbine cycle is $30\ °C$.

The company claims that when the electrical power output is $2.9\ MW$, the power station will provide $6.4\ MW$ for heating the greenhouses.

Deduce whether this claim is likely to be true.
Treat the power station as an ideal heat engine which obeys the second law of thermodynamics.

[4 marks]

6

Total			**8**

Question	Answers	Additional comments/Guidance	Mark	AO
06.1	(For 2nd law of thermodynamics to apply...) Engine must operate between hot and cold reservoirs ✓ And must reject some energy to cold reservoir ✓ (Meaning W cannot equal Q_H)	accept hot and cold spaces / hot source and cold sink / high and low temperatures Accept for 2nd mark: For 100% efficiency T_C would have to be 0 K (which is impossible)	2	AO1.1a ×2
06.2	$175\ ^{o}C = 448$ K and $30\ ^{o}C = 303$ K and ✓1 $\eta = \frac{T_H - T_C}{T_H}$ ✓1 $= \frac{448 - 303}{448} = 0.32$ ✓2 $(\eta = \frac{W}{Q_C + W}$ so $Q_C = \frac{W}{\eta} - W)$ $Q_C = \frac{2.9}{0.32} - 2.9 = 6.2$ MW ✓3 6.2 MW < 6.4 MW so claim is not true ✓4 Alternatives for 3rd and 4th marks: For $Q_C = 6.4$ MW, $\eta = \frac{2.9}{2.9+6.4} = 0.31$ ✓3 Actual $\eta > 0.31$ so Q_C has to be < 6.4 MW so claim not true ✓4 OR	1st mark for converting to K and giving thermal efficiency equation 2nd mark for calculating efficiency 3rd mark for another relevant calculation 4th mark for a comparison leading to a conclusion regarding claim. This is not an independent mark. e.g. 4th mark: claim is not true (based on ideal engine) because 6.2 MW < 6.4 MW ✓4 OR accept: claim is true; for real engine η will be (considerably) less, so energy available for greenhouse heating will be/is likely to be higher than 6.4 MW If temperatures <u>not</u> changed to K condone giving ECF for marks ✓3 and ✓4 : $\eta = \frac{175 - 30}{175} = 0.83$ $Q_C = \frac{2.9}{0.83} - 2.9 = 0.6$ MW ✓3 0.6 < 6.4 so claim not true ✓4	4	AO1.1b ×1 AO3.1b ×3 L2M ×3

	input power = $\frac{2.9}{0.32}$ = 9.1 MW input power needed for company claim = 2.9 + 6.4 = 9.3 MW ✓3 9.1 < 9.3 so claim not true ✓4			

Total			**6**

0 7 **Figure 4** shows the results of a test on an internal combustion engine which uses purified biogas.

Figure 4

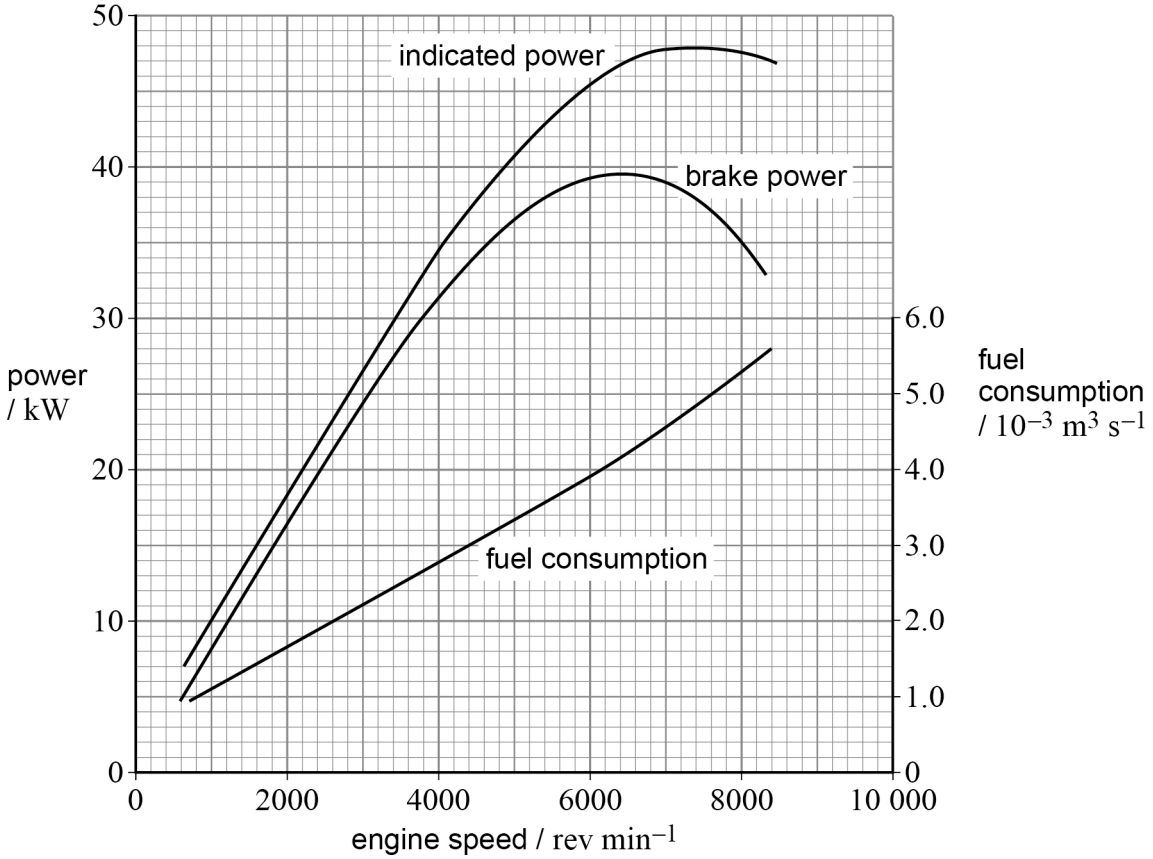


Figure 4 shows how the indicated power, brake (or output) power and fuel consumption of the engine vary with the engine speed. The scale on the left-hand axis is power and the scale on the right-hand axis is fuel consumption.

0 7 . 1 **Figure 4** can be used to analyse the performance of the engine.

Determine, for the speed at which the engine develops its maximum brake power:

- the overall efficiency
- the thermal efficiency
- the mechanical efficiency.

Go on to explain how knowledge of these efficiencies can be useful to an engineer.

calorific value of biogas used in the test = 32.3×10^6 J m^{-3}

[6 marks]

0 7 . 2 Explain why it is **not** advisable to run this engine at speeds above $7000 \text{ rev min}^{-1}$.
Refer to **Figure 4** in your answer.

[2 marks]

8

Question	Answers	Additional comments/Guidelines	Mark	AO
07.1	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (**L1**), 3 or 4 mark (**L2**) and 5 or 6 mark (**L3**) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question **Level 3 (5–6 marks)** 6 marks: both areas of the question are covered (i.e. calculations and explanations) with all efficiencies calculated correctly and at least two of points 7,8,9. 5 marks: both areas covered but with one or two minor errors in calculations or explanations. **Level 2 (3–4 marks)** 4 marks: all efficiencies calculated correctly with no explanation of usefulness of efficiencies OR a good attempt at calculating efficiencies and some explanation given of usefulness of efficiencies. 3 marks: Both areas covered partially or one area covered reasonably well but not fully. E.g may only be able to calculate correctly 2 of the three required efficiencies and give no explanation of their usefulness. **Level 1 (1–2 marks)** Student is likely to make one or two calculations (e.g input power and one efficiency) at any speed, but not likely to be able to explain the usefulness of efficiency. **0 marks** The student shows inadequate understanding of the graphs. Formulae may be quoted from the Formulae Booklet or from memory, but the student is unable to apply their meaning to the question.	Numerical answers: 1. Peak brake power occurs at (6200 to 6600) rev min^{-1} 2. Input power = 136 kW 3. Overall efficiency = 0.29 4. Thermal efficiency = 0.35 5. Mechanical efficiency = 0.84 6. Friction power = 7.5 kW General points: 7. Relates thermal efficiency to how well the calorific value of fuel is converted into work/power inside the engine. 8. Relates mechanical efficiency to work/power used in overcoming friction/viscosity inside engine and work/power to operate valves, water/oil pumps etc. 9. Overall efficiency gives an idea of how well energy in fuel is converted into useful work output. If student uses peak <u>indicated</u> power points 1 to 5 become 1. Peak power occurs at (7200 to 7600) rev min^{-1} 2. Input power = 150 kW 3. Overall efficiency = 0.26 4. Thermal efficiency = 0.32 5. Mechanical efficiency = 0.80 Do not allow marks at Level 3.	6	AO3.1a ×1 AO1.1a × 3 AO2.1h × 2

Question	Answers	Additional comments/Guidance	Mark	AO
07.2	Links two quantities from Figure 4 at speeds above 7000 rev min^{-1} ✓ Gives reason for not running engine at speeds above 7000 rev min^{-1} ✓	Examples of points expected for MP1: • brake power drops whilst input power continues to increase (as shown by fuel consumption curve) • brake power drops whilst indicated power flattens off • indicated power flattens off while fuel consumption increases Do not accept: the brake power gets less with no reference to other power(s). MP2: any of overall, thermal or mechanical efficiency decreases, or efficiency decreases. friction or friction power increases at high engine speeds breakdown of lubrication and/or greater work done against viscosity at high engine speeds. Do not accept: damage to engine may occur - unless backed up by reason relating to friction/friction power. .	Max 2	AO3.1b ×1 AO2.1g ×1
Total			**8**	

0 8 . 1 Which is a correct statement about an ideal heat engine?
Tick (✓) **one** box.

[1 mark]

The efficiency is increased when the kelvin temperatures of the hot source and the cold sink are increased by equal amounts. ☐

The maximum efficiency depends on the p–V cycle. ☐

The efficiency is 50% when the kelvin temperature of the hot source is twice the kelvin temperature of the cold sink. ☐

0 8 . 2 An ideal heat engine has an efficiency of 0.33
The same engine works in reverse as an ideal refrigerator between the same hot and cold spaces.

Determine the coefficient of performance COP_{ref} of the refrigerator.

[2 marks]

$COP_{ref} =$ _____

3

Question	Answers	Additional comments/Guidance	Mark	AO
08.1	The efficiency is 50% when the kelvin temperature of the hot source is twice the kelvin temperature of the cold sink. ✓		1	AO1.1a × 1

Question	Answers	Additional comments/Guidance	Mark	AO
08.2	Identifies $Q_H = 3 \times W$ and $Q_C = Q_H - W$ ✓ In reverse $COP_{ref} = Q_C / W$ Leading to $COP_{ref} = 2$ ✓	MP1 can be awarded for $Q_H - Q_C = 0.33Q_H$ or $Q_C = 0.67Q_H$ Give credit for substituting numbers in equations eg $W = 1$ $Q_H = 3$, $Q_C = 2$ OR $W = 33$ $Q_H = 100$, $Q_C = 67$ Accept working shown on a diagram Accept working using temperatures T_H T_C with numbers substituted eg $T_H = 300$ (K), $T_C = 200$ (K) No credit for simply quoting formulae from Formulae Booklet.	2	AO1.1b × 2
Total			**3**	

0 9 **Figure 6** shows a low-voltage solid-state thermoelectric cooling element.
The element is a square of side $40\ \text{mm}$ and is $4\ \text{mm}$ thick.

Figure 6

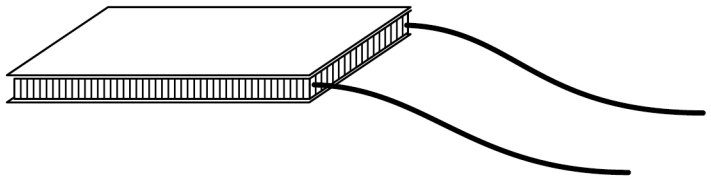
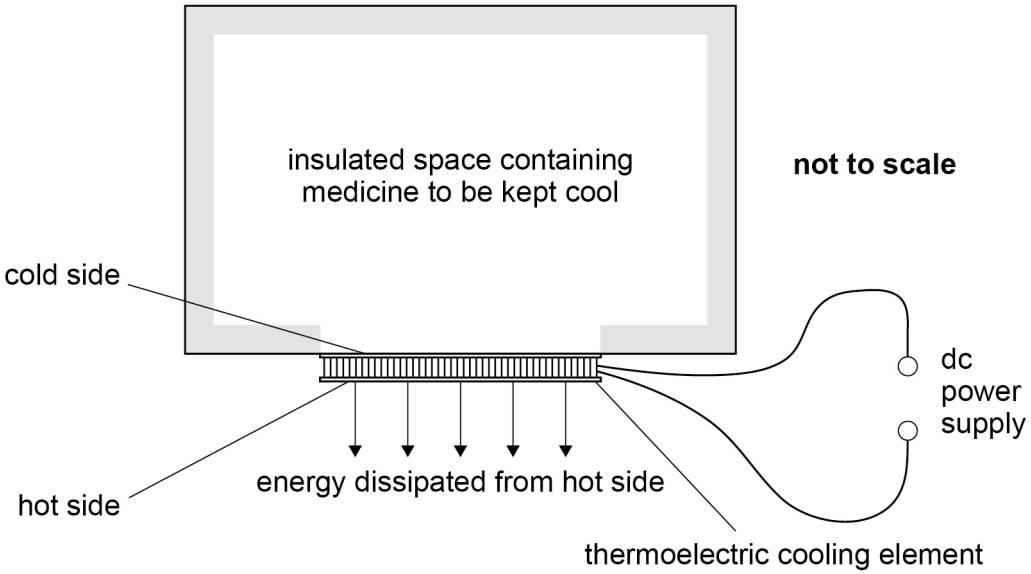


Figure 7 shows how the element is used as part of a thermoelectric refrigerator to keep small quantities of medicine at a low temperature.

Figure 7



The manufacturer's data for the element show that when the temperature of the hot side is $35\ °\text{C}$ and the temperature of the cold side is $5\ °\text{C}$:

- the rate at which energy is dissipated from the hot side is $65\ \text{W}$
- the electrical power supplied is $28\ \text{W}$.

Do not write outside the box

0 9 . 1 It is claimed that the coefficient of performance (COP) of a thermoelectric refrigerator is much less than the COP of an ideal refrigerator.

Discuss whether the claim is valid for the thermoelectric refrigerator in this question.

[4 marks]

0 9 . 2 Suggest why a small value of the COP might be acceptable for this particular application of a thermoelectric cooling element.

[2 marks]

6

Question	Answers	Additional comments/Guidance	Mark	AO
09.1	$Q_C = Q_H - W = 65 - 28 = 37$ W ✓1 COPref = 37/28 = 1.32 ✓2 COPref for ideal refrigerator = 278/(308 − 278) = 9.3 ✓3 Actual COP is very low compared to ideal so claim is valid ✓4	If temperature not changed to K do not award marks ✓3 and ✓4 Condone consistent use of Celsius in the denominator. No ECF for ✓4 from incorrect values of COP, unless from arithmetic error.	4	4 x AO3

Question	Answers	Additional comments/Guidance	Mark	AO
09.2	One factor from ✓1 • Thermoelectric cooler is small/convenient/of simple construction/(highly) portable • can run off batteries/solar panel • has no moving parts • requires low maintenance • no risk of leaking fluids • temperature is about 5 °C, not cooler • low energy/power consumption (28W) For ✓2 • convenience outweighs poor COP • any COP >1 means cooling power > power supplied • waste of electrical energy from having low COP is acceptable	✓1 for advantage from bullet point list For ✓1 accept application, eg use in hot countries, by campers, climbers, walkers etc. ✓2 mark for relating answer to COP	2	2 x AO3
Total			**6**	

1 0 **Figure 7** shows the p–V diagram for a theoretical diesel engine cycle.
Figure 8 shows the indicator diagram for a real four-stroke diesel engine working between the same maximum and minimum volumes.

Figure 7

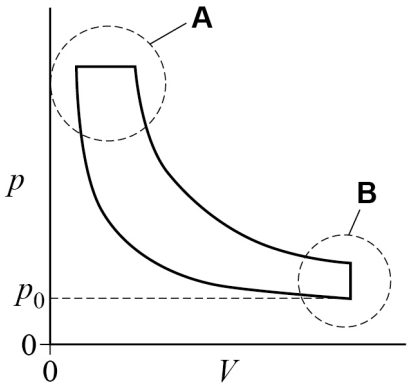
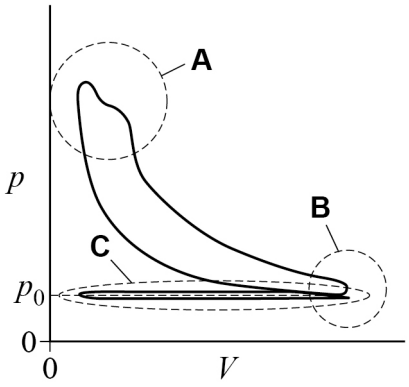


Figure 8



p_0 is atmospheric pressure.

Compare the indicator diagram with the theoretical diesel cycle.
In your answer, explain:

- the differences between region **A** on **Figure 7** and region **A** on **Figure 8**
- the differences between region **B** on **Figure 7** and region **B** on **Figure 8**
- why the features shown in region **C** appear only on the indicator diagram
- why the efficiency of the real engine will always be less than the efficiency predicted by an analysis of the theoretical cycle.

[6 marks]

<table>
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<tr>
<td>10</td>
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<table>
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<tr><td>6</td><td>All three areas (as outlined alongside) covered with at least two aspects covered in some detail.
6 marks can be awarded even if there is an error and/or parts of one aspect missing.</td></tr>
<tr><td>5</td><td>A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.</td></tr>
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<td>The following points are likely to be present.

First two bullets: differences at A and B
1. Corners rounded at B on real cycle. Reason: valves take finite time to open and close.
2. Cooling cannot occur at constant volume in real cycle. Reason: piston would have to stop/cooling takes finite time.
3. Heating cannot occur at constant pressure in real cycle. Reason: heating cannot be (precisely) controlled.
4. Max pressure is lower in real engine. Reason: e.g. incomplete combustion

Third bullet: region C
5. Real engine needs induction and exhaust strokes/ pumping loop.
6. In theoretical cycle same air used repeatedly (so needs no pumping loop).
7. In ideal cycle air only is taken through cycle (repeatedly)/gas is ideal.
8. Upper line is exhaust, lower line is induction.

Fourth bullet: why efficiency less
9. Area of loop is smaller for real engine, so less work done per cycle/indicated power.
10. Area of pumping loop has to be subtracted from main loop, reducing work done.
11. Friction between moving surfaces/between piston & cylinder/in bearings has to be overcome.</td>
<td>6</td>
<td>5 × AO1

1 × AO2</td>
</tr>
</table>

		12. Energy is expended in driving oil and water pumps, opening and closing valves, overcoming fluid viscosity etc. 13. In real cycle expansion & compression are not adiabatic. Reason: heat transfer takes place to cooling medium during these strokes 14. Calorific value of fuel cannot be completely released/ Fuel may not be completely burnt. Accept other reasonable answers in lieu (eg variation in γ during expansion and compression).		

Total			**6**

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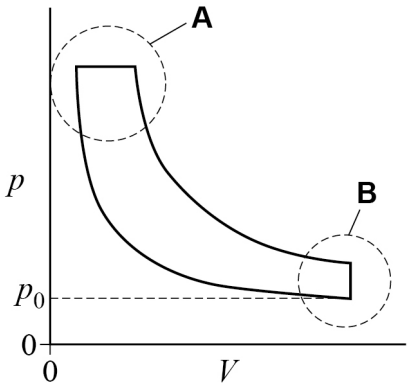
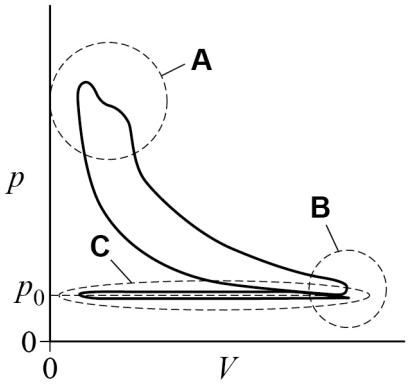


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[6 marks]

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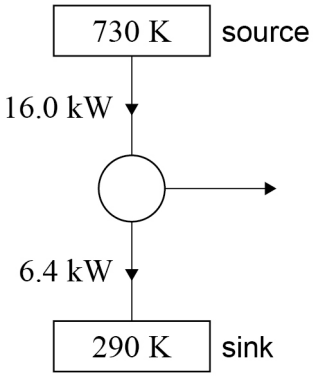
1 × AO2</td>
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		12. Energy is expended in driving oil and water pumps, opening and closing valves, overcoming fluid viscosity etc. 13. In real cycle expansion & compression are not adiabatic. Reason: heat transfer takes place to cooling medium during these strokes 14. Calorific value of fuel cannot be completely released/ Fuel may not be completely burnt. Accept other reasonable answers in lieu (eg variation in γ during expansion and compression).		

Total			**6**

1 2 **Figure 9** shows an ideal heat engine.

Figure 9



The engine operates between a source at a temperature of $730\ \text{K}$ and a sink at a temperature of $290\ \text{K}$.
The input power is $16.0\ \text{kW}$ and the power rejected to the sink is $6.4\ \text{kW}$.

1 2 . 1 Calculate the efficiency of this engine.

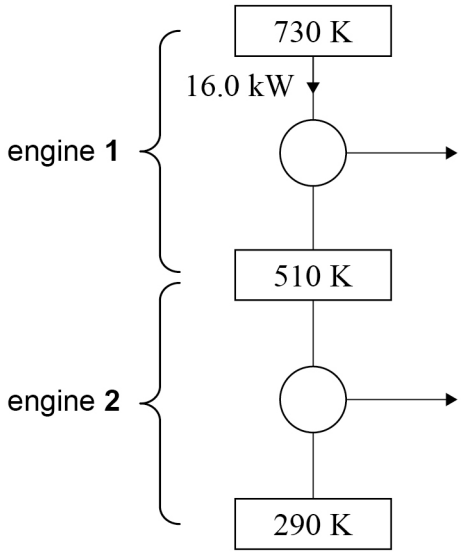
[1 mark]

efficiency = _____

Do not write outside the box

1 2 . 2 **Figure 10** shows another system operating between the same overall temperatures and with the same input power as the engine in **Figure 9**. This system consists of two ideal engines.

Figure 10



The sink for engine **1** forms the source for engine **2**. The temperature of the intermediate reservoir is 510 K.
All the energy rejected by heat transfer in engine **1** provides the input energy to engine **2**.
A student suggests that the system in **Figure 10** can provide more output power and be more efficient than the engine in **Figure 9**.

Deduce whether the student's suggestions are correct.
You may annotate **Figures 9** and **10**.

[3 marks]

4

Question	Answers	Additional comments/Guidelines	Mark	AO
12.1	0.60 OR 60%✓	Condone 0.6 (1 sf) $\eta = \frac{(730-290)}{730} = 0.60$ $\eta = \frac{16.0-6.4}{16.0} = 0.60$	1	1 × AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
12.2	Calculates P_{OUT} from engine 1 and calculates Q_C ✓ Uses Q_C from engine 1 as Q_H for engine 2 and calculates P_{OUT} from engine 2 ✓ Compares total output power and overall efficiency of **Figure 9** and **Figure 10** engines and concludes that they are the same so student is not correct ✓	$\eta_1 = 220 \div 730 = 0.30$ $P_{OUT1} = 0.30 \times 16.0 = 4.8$ kW $Q_C = 11.2$ kW $\eta_2 = 220 \div 510 = 0.43$ $P_{OUT2} = 0.43 \times 11.2 = 4.8$ kW Allow ECF for MP2 from MP1 Total $P_{OUT} = 9.6$ kW Overall η for 2 stages = $9.6 \div 16 = 0.60$ Do not allow an ecf for MP3 Evidence can be seen on **Figure 9** and **Figure 10** but answer must make clear comparisons. If calculations are correct, but more than 2 sf is used, then answers will be slightly greater than 9.6 kW and greater than 0.60. Do not accept a comment that the student claim is correct as this answer arises from conclusions drawn from poor sf considerations.	3	3 × AO3
Total			**4**	

1 3 The Lenoir engine was the first successful internal combustion engine.

Figure 6 shows the basic form of the Lenoir engine. The piston rod drives a crankshaft which is not shown. The fuel is a mixture of gas and air.

Figure 6

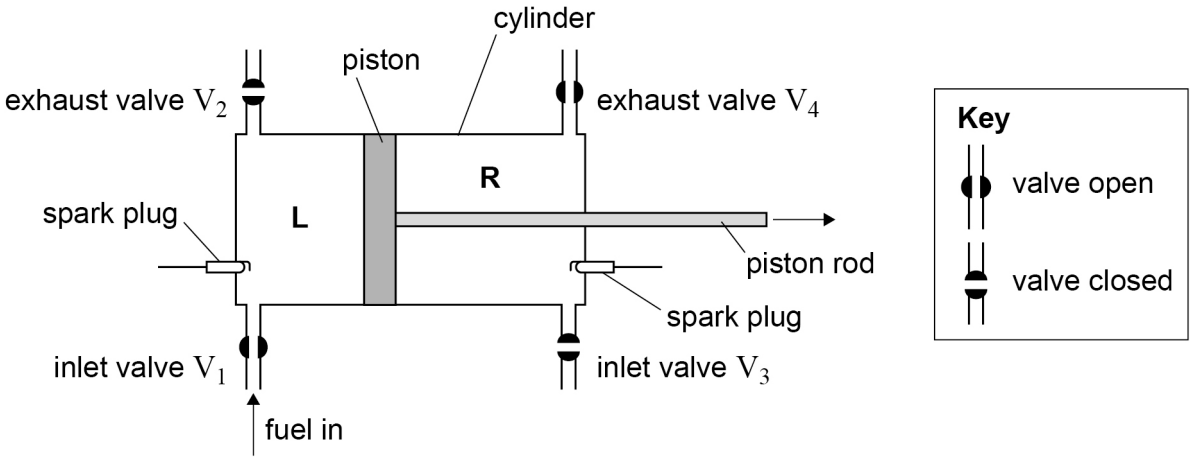
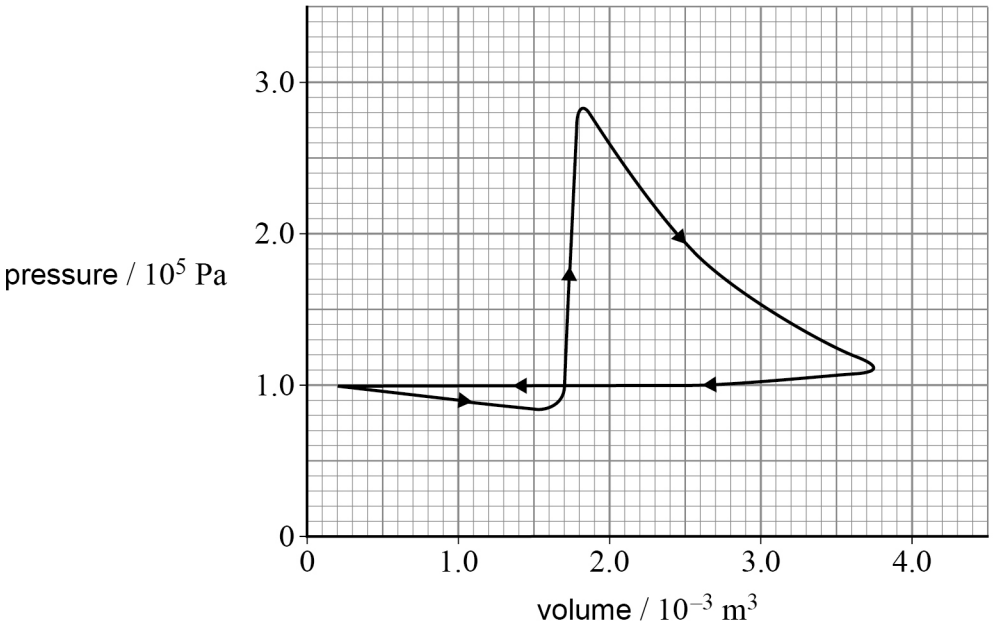


Figure 7 shows an indicator diagram for the space **L**, taken during a test on a Lenoir engine.

Figure 7



In one cycle the following changes occur in **L**.

- **Induction**. The piston starts at the left-hand end of the cylinder. It moves to the right and fuel passes through the open inlet valve V_1 into **L**. **Figure 6** shows the piston during this induction process, with V_1 open.
- **Ignition**. When the piston is nearly halfway along the cylinder, V_1 is closed. A spark ignites the fuel causing a sudden rise in pressure.
- **Expansion**. The hot gases expand and the piston moves to the end of the stroke.
- **Exhaust**. The exhaust valve V_2 opens. The piston moves to the left. The exhaust gases are expelled at atmospheric pressure.

The same processes are repeated in space **R** one half of a revolution of the crankshaft later than in **L**. So when the piston is moving to the left, induction, ignition and expansion occur in **R** at the same time as the exhaust process occurs in **L**.

1 3 . 1 The indicator diagram is for a rotational speed of the crankshaft of 120 rev min^{-1}.

Determine, using **Figure 7**, the indicated power of the engine.
Assume that the indicator diagram for **R** is identical to the indicator diagram for **L**.

[5 marks]

indicated power = _____ W

Question 13 continues on the next page

1 3 . 2 The following data are taken during the test on the engine:

fuel consumption = $6.44 \times 10^{-4}\ \text{m}^3\ \text{s}^{-1}$
calorific value of fuel = $18.0 \times 10^{6}\ \text{J m}^{-3}$
torque at crankshaft = $39.0\ \text{N m}$
rotational speed = $120\ \text{rev min}^{-1}$

Calculate the input power and the output (brake) power of the engine.

[2 marks]

input power = _____ W

output power = _____ W

1 3 . 3 The output power of a four-stroke petrol engine of a similar working volume to that of the Lenoir engine is about $150\ \text{kW}$.

Suggest **two** reasons for the very low output power of the Lenoir engine compared with a four-stroke petrol engine.

[2 marks]

1 _____

_____

_____

_____

2 _____

_____

_____

_____

1 3 . 4 Which statement is correct?

Tick (✓) **one** box.

[1 mark]

Thermal efficiency is a measure of how much of the indicated power is converted into output power. ☐

Overall efficiency is the product of mechanical efficiency and thermal efficiency. ☐

Mechanical efficiency is equal to friction power divided by indicated power. ☐

Input power is equal to indicated power plus friction power. ☐

10

Question	Answers	Additional comments/Guidelines	Mark	AO
13.1	MAX 4 from: • Attempts to find area of large loop • Subtracts area of small loop • Shows suitable scaling factor • Uses 4 cycles s^{-1} • correctly calculates indicated power using their values. 592 W ✓ (cao)	eg counting small squares $157 - 9$ squares $= 148$ squares scaling factor of $0.10 \times 10^{-3} \times 0.1 \times 10^{5} = 1.0$ J per square $148 \text{ J} \times 1.0 = 148 \text{ J}$ If counting 'large' squares: (6.5 - 0.5) squares × $0.50 \times 10^{-3} \times 0.50 \times 10^{5}$ gives 150 J Accept approximating to triangles cycles $s^{-1} = 4$ (as it is double acting at 2 rev s^{-1}) indicated power $= 148 \times 4 = 592 \text{ W} \pm 30 \text{ W}$	5	AO1 ×1 AO3 ×2 AO2 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
13.2	Input power $= 6.44 \times 10^{-4} \times 18.0 \times 10^{6} = 11.6 \times 10^{3}$ W ✓ Output power $= T\omega = 39.0 \times 2 \times 2\pi = 490$ W ✓	Correct answers only Accept 1.2×10^{4} W or 12000W Condone working not shown provided answers are correct.	2	AO1 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
13.3	MAX 2 from: • Power is developed for only about half of the stroke $_1$✓ • Maximum pressure is very much lower than in a petrol engine $_2$✓ • The fuel is not compressed before ignition $_3$✓ • Pumping loop/negative work is large compared to work output loop $_4$✓ • The speed of the engine is very low $_5$✓ • Difficulty in lubricating cylinder so friction likely to be high $_6$✓ • Calorific value of fuel is low $_7$✓	Allow for other sensible reasons eg efficiency from 03.2 is only about 4% Do not accept simple references to 'low efficiency' or 'less efficient' For $_6$✓ Do not accept 'more friction' without a reason	2	AO3 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
13.4	Tick in 2nd box ✓ Overall efficiency is the product of mechanical efficiency and thermal efficiency.		1	AO1 ×1

Total			**10**