M1.(a) (i) Appreciates *pV* should be constant for isothermal change (by working or statement) $W = p\Delta V$ is TO

Allow only products seen where are approximately 150 for 1 mark
Penalise J as unit here

M1

Demonstrates *pV* = constant using 2 points (on the line) set equal to each other or conclusion made or **shows** that for V doubling that *p* halves (worth 2 marks)
need to see values for p and V

Products should equal 150 to 2 sf
Accept statement that products are slightly different so not quite isothermal

A1

Demonstrates *pV* = constant using 3 points (on the line) <u>with conclusion</u>
Need to see values for p and V

Products should equal 150 to 2 sf
Accept statement that products are slightly different so not quite isothermal

A1

3

(ii) Adiabatic <u>therefore</u> no heat transfer **or**
Adiabatic <u>therefore</u> *Q* = 0

B1

Work is done <u>by</u> gas <u>therefore</u> *W* is <u>negative</u> **or**
Work is done <u>by</u> gas <u>therefore</u> energy is removed from the system

B1

<u>ΔU</u> is negative <u>therefore</u> internal energy of gas decreases **or** energy is removed from the system <u>therefore</u> internal energy of gas decreases or work done by the gas <u>so</u> internal energy decreases

Allow
$-\Delta U = -W \text{ or } \Delta U = -W$

B1

3

(iii) Uses pV / T = *constant or uses* $pV = nRT$ *or uses* $pV = NkT$
e.g. makes T subject or substitutes into an equation with p_A and V_A or p_C and V_C (condone use of n = 1) or their $\frac{(pV)_A}{(pV)_C}$

V_a read off range
= 2.5 to 2.6 (× 10^{-4})
p_A = 600 × 10^3
V_C read off range
= 8.5 to 8.6 (× 10^{-4})
p_C = 140 × 10^3

C1

Correct substitution of coordinates (inside range) into $\frac{(pV)_A}{(pV)_C}$
With consistent use of powers of 10

$(pV)_A$ range is 150 to 156 and $(pV)_C$ range is 119 to 120.4

C1

1.2(5) Allow range from 1.2 to 1.3

Accept decimal fraction : 1

A1

3

(b) Energy per large square = 10(J) **or** <u>states</u> that work done is equal to area under curve (between A and B)
or energy per small square = 0.4(J)
or square counting seen on correct area

Must be clear that area represents energy either by subject of formula or use of units on 10 or 0.4

Alternative:
W = area of a trapezium (with working)
or** W = $P_{mean} \times \Delta V$ **or
W = 450 × 10^3 × 2.5 × 10^{-4}
***or** W = area of a rectangle + area of a triangle (with working)*

B1

Number of large squares = 10.5 to 11.5 seen <u>and</u> (W) =
number of squares × area of one square (using numbers)
Range = 105 to 115 (J)
Or

Number of small squares = 263 to 287 seen <u>and</u> (W) =
number of squares × area of one square (using numbers)
Range = 105 to 115 (J)

States that actual work done would be lower because of curvature of line

B1

2

(c) (Total energy removed per s =) 4560 (J)
or number of cycles per s = 40
or (Mass per second =) 114 ÷ 68400 in rearranged form
or their energy ÷ (c ΔT) **or** their energy ÷ 68400

C1

0.067 (kg) seen Allow 0.066 (kg) here
or allow V / t = 1.67 × 10^{-3} ÷ 1100
or ($\frac{V}{t}$) = $\frac{E}{\rho c \Delta\theta}$ and correct **substitution** seen

Condone E = 114 (J) **or** temperature = 291(K)

C1

= 0.061 × 10^{-3} or 6.06 × 10^{-5} (m^3)

A1

3

[14]

M2.(a) (i) Clear statement that for isothermal pV =constant or $p_1V_1 = p_2V_2$ ✓
Applies this to any 2 points on the curve AB ✓
e.g. 1.0 × 10^5 ×1.2 × 10^{-3} = 4.8 × 10^5 × 0.25 × 10^{-3} 120 = 120

Allow pV = c applied to intermediate points ***estimated*** *from graph e.g. V = 0.39 × 10^{-3}, p = 3 × 10^5*

2

(ii) $W = p\,\Delta v$

$= 4.8 \times 10^5 \times (0.39 - 0.25) \times 10^{-3}$

$= 67$ J ✓

1

(b)

	Q / J	W / J	ΔU / J	
process A → B	−188	−188	0	✓
process B → C	+235	(+)67	(+)168	✓
process C → A	0	+168	−168	✓
whole cycle	+47	+47	0	✓

Any horiz line correct up to max 3
Give CE in B → C if ans to ii used for W
If no sign take as +ve

max 3

(c) $\eta_{overall} = 47 / 235 = 0.20$ or 20% ✓

1

(d) Isothermal process would require engine to run very slowly / be made of material of high heat conductivity ✓
Adiabatic process has to occur very rapidly / require perfectly insulating container / has no heat transfer ✓
Very difficult to meet both requirements in the same device ✓
Very difficult to arrange for heating to stop exactly in the right place (C) so that at end of expansion the curve meets the isothermal at A ✓

Do not credit bald statement to effect adiabatic / isothermal process not possible - must give reason
Ignore mention of valves opening / closing, rounded corners, friction, induction / exhaust strokes
wtte

max 2

[9]

M3. (a) (i) *Indicated work per cylinder = area of loop ✓ [either stated explicitly or shown on the Figure e.g. by shading or ticking squares or subsequent correct working.]*

appropriate method for finding area e.g. counting squares ✓

correct scaling factor used [to give answer of 470 J ± 50 J] ✓

indicated power = 4 × 0.5 × (4100/60) × 470

= 64 kW ✓

4

(ii) *(Fuel flow rate = 0.376/100 = 0.00376 litre* s^{-1} *)*

Input power (= c.v. × fuel flow rate)

= $38.6 \times 10^{6} \times 0.00376$ ✓

(= 145 kW)

$\eta_{overall}$ *= brake power/input power ✓ seen or implied from correct subsequent working*

= 55.0/145 = 0.38 or 38% ✓

3

(b) *Power expended in overcoming friction*

in (all) the bearings / between piston & cylinder ✓

and / or in circulating oil / cooling water ✓

and / or driving auxiliaries (e.g. fuel injection pump) ✓

1

(c) *Represents the induction and exhaust (strokes) (which take place at nearly atmospheric pressure). ✓*

1

[9]

M4. (a) (i) *work done (per kg) = area enclosed (by loop)* **(1)**
suitable method of finding area (e.g. counting squares) **(1)**

correct scaling factor ***(1)***
(to give answer ≈ 500 kJ)

(ii) *P (= work done per kg x fuel flow rate)*
= 500 (kJ) × 9.9 (kgs^{-1}) = 5000kW ***(1)***
(4950kW)

(iii) *(output power = indicated power – friction power)*
P_{out} = 4950 – 430 = 45(20) kW ***(1)***
(use of P = 5000 gives P_{out} = 45(70)kW)
(allow C.E. for values of P in (ii))

5

(b) *(i)* *P_{in} (= fuel flow rate × calorific value)*
= 0.30 × 44 × 10^6 = 13(.2) × 10^6W ***(1)***

efficiency = $\frac{4520 \times 10^3}{13.2 \times 10^6} = 34\%$ ***(1)***
(allow C.E. for value of P_{out} in (a) (iii) and P_{in} in (b) (i))

2

[7]

M5. *(a)* *T_H = 273 + 820 = 1093 (K), T_C = 273 + 77 = 350 (K)* ***(1)***

efficiency = $\frac{T_H - T_C}{T_H} = \frac{1093 - 350}{1093}$ *= 0.68 or 68%* ***(1)***

2

(b) *rotational speed of output shaft =* $\frac{1800}{2 \times 60}$ *= 15 rev s^{-1}* ***(1)***

(work output each cycle = 380 J, 2 rev ≡ 1 cycle in a 4 stroke engine)

indicated power = 15 × 190 = 5.7 kW ***(1)***

2

(c) *power lost (= indicated power –actual power) = 5.7 – 4.7 = 1.0 kW* ***(1)***
(allow C.E. for incorrect value from (b))

1

(d) *energy supplied per sec (= fuel flow rate x calorific value)*

$= \frac{2.1 \times 10^{-2}}{60} \times 45 \times 10^{6}$ *= 16 kW (15.8 kW)* ***(1)***

1

(e) *efficiency =* $\frac{\text{net power output}}{\text{power input}} = \frac{4.7}{16}$ *= 0.29 or 29 %*

$\frac{4.7}{15.8} = 0.30 \text{ or } 30\%$

(allow C.E. for value from (d))

1

[7]