

SCHEME OF VALUATION

(Scoring indicators)

Revision: 2015		Course Code: 4024		
Course Title: THERMAL ENGINEERING				
Q.No	Scoring indicator	Split up score	Sub Total	To
I.1	<div style="border: 1px solid black; display: inline-block; padding: 2px;">PART - A</div> <p>THERMODYNAMIC SYSTEM : The region in the space that contained matter whose behaviour is to be investigated is called <i>thermodynamic system</i> and will be referred to simply as the <i>system</i>.</p>	2	2	10
I.2	<p>Thermal efficiency of a cycle may be defined as the ratio of the work done to the heat supplied during the cycle. The thermal efficiency obtained with air as the working fluid is known as air standard efficiency.</p>	2	2	
I.3	<p>Relative Efficiency (η_R) : It is the ratio of actual efficiency obtained from the engine to the theoretical or air standard efficiency of that engine.</p> $\eta_R = \frac{\eta_{\text{Th}}}{\eta_{\text{air std}}}$	2	2	
I.4	<p>Dryness Fraction : This term refers to quality of wet steam. It is defined as the ratio of the weight of dry steam actually presents to the weight of total wet steam which contains it. It is denoted by x. Thus</p> $x = \frac{W_d}{W_d + W}$ <p>Where W_d = Weight of dry steam in 1 kg of wet steam, W = Weight of water in suspension in 1 kg of wet steam</p>	2	2	
I.5	<p>For driving air motors, for use in blast furnace, for use in pneumatic drills, for use in gas turbines, for scavenging and super charging I C engines, for spray painting, For RAC applications, for pneumatic brakes in automobiles etc</p>	0.5x4=2	2	

SCHEME OF VALUATION

PART-B

(Scoring indicators)

<p>II.1</p>	<p>FIRST LAW OF THERMODYNAMICS :</p> <p>First law of thermodynamics (Joule's law of thermo-dynamics) is the special case of law of conservation of energy applied to thermodynamic transaction. The thermodynamic transactions are described in terms of heat and work.</p> <p>The first law confirms that <i>heat and work are mutually convertible, and the creation of energy from nothing cannot be achieved.</i></p> <p>First law of thermodynamics may be expressed as follows.</p> <p>If a system is operated through a closed cycle, then the net heat transfer is directly proportional to the net work transfer. Mathematically, it may be expressed with cyclic integrals as</p> $\oint dQ \propto \oint dW$ $\oint dQ = \frac{1}{J} \oint dW$ <p>Where J = Proportionality constant</p> <p>If $\oint dQ = 1$ Joules, then $\oint dW = 1Nm$</p> <p>Since $1 Nm = 1$ joules, the constant is unity.</p> <p>\therefore The law may be expressed as $\oint dQ = \oint dW$</p> <p>Where $\oint dQ =$ Net heat transfer $\oint dW =$ Net work transfer.</p> <div data-bbox="734 750 1021 817" style="text-align: center;"> </div>	<p>Statement/ Definition - 3 marks</p> <p>Explanation - 3 marks</p>	<p>6 marks.</p>
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SCHEME OF VALUATION

(Scoring indicators)

II.2	S. I. Engine (or) Petrol Engine	C. I. Engine (or) Diesel Engine		
	<ol style="list-style-type: none"> 1. Charge comprises air and fuel which is admitted into cylinder during suction stroke. 2. Carburettor is used to supply the charge. 3. Spark-plug is used to ignite the charge. 4. Compression ratio varies from 6 : 1 to 9 : 1. 5. It works on Otto cycle (constant volume cycle). 6. Initial cost is less but maintenance is costly. 7. For a given output, it is lighter in weight. 8. Easy and quick starting. 9. Engine is almost vibration free at idle or slow speeds. 10. Lighter flywheel is requires as fluctuation of speed is minimum. 11. Thermal Efficiency is less (about 26%) 12. Output is controlled by a throttle valve which regulates mass of charge. 13. Generally used for light duty such as scooters, motor cycles, sprayers, cars etc. 	<ol style="list-style-type: none"> 1. Charge comprises only air. 2. Fuel injector injects fuel oil as a spray into compressed air. 3. Due to very high compression of air, fuel gets automatically ignited. 4. Compression ratio is high and varies from 12 : 1 to 22 : 1. 5. It works on Diesel cycle (modified constant pressure cycle). 6. Initial cost is high and maintenance is cheap. 7. Due to high C.R engine is heavier. 8. Starting is not so quick. 9. Engine vibrates considerably. 10. Heavier flywheel is essential. 11. Thermal Efficiency is high (about 40%) 12. Output is controlled by regulating supply of oil injected. 13. Used in heavy duty vehicles such as buses, trucks, tractors etc. 	<p style="font-size: 1.2em;">Any Six from Each Sum = 6 marks</p>	<p style="font-size: 1.2em;">6 marks</p>

SCHEME OF VALUATION

(Scoring indicators)

II.3

This cycle is a combination of Otto and Diesel cycles. It is sometimes called *semi-diesel cycle*, because semi-diesel engines work on this cycle. In this cycle, heat is absorbed partly at a constant volume and partly at a constant pressure.

The ideal dual combustion cycle consists of two reversible adiabatic or isentropic, two constant volume and a constant pressure processes. These processes are represented on $p-v$ and $T-S$ diagram as shown in Fig. 6.15 (a) and (b).

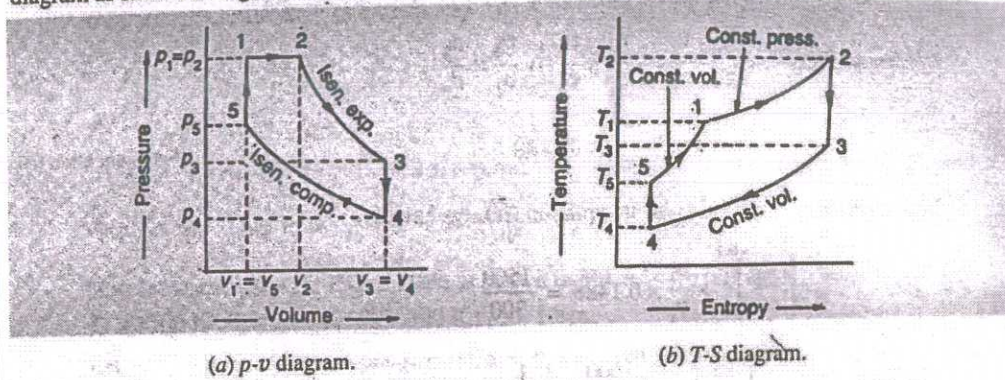


Fig. 6.15. Dual combustion cycle.

Let the engine cylinder* contain m kg of air at point 1. At this point, let p_1 , T_1 and v_1 be the pressure, temperature and volume of the air. Following are the five stages of an ideal dual combustion cycle.

1. **First stage (Constant pressure heating).** The air is heated at constant pressure from initial temperature T_1 to a temperature T_2 represented by the curve 1-2 in Fig. 6.15 (a) and (b).

$$\therefore \text{Heat absorbed by the air, } Q_{1-2} = m c_p (T_2 - T_1)$$

2. **Second stage (Reversible adiabatic or isentropic expansion).** The air is expanded reversibly and adiabatically from temperature T_2 to a temperature T_3 as shown by the curve 2-3 in Fig. 6.15 (a) and (b). In this process, no heat is absorbed or rejected by the air.

3. **Third stage (Constant volume cooling).** The air is now cooled at constant volume from temperature T_3 to temperature T_4 as shown by the curve 3-4 in Fig. 6.15 (a) and (b).

$$\therefore \text{Heat rejected by the air, } Q_{3-4} = m c_v (T_3 - T_4)$$

4. **Fourth stage (Reversible adiabatic or isentropic compression).** The air is compressed reversibly and adiabatically from temperature T_4 to a temperature T_5 as shown by the curve 4-5 in Fig. 6.15 (a) and (b). In this process, no heat is absorbed or rejected by the air.

5. **Fifth stage (Constant volume heating).** The air is finally heated at constant volume from temperature T_5 to a temperature T_1 as shown by the curve 5-1 in Fig. 6.15 (a) and (b).

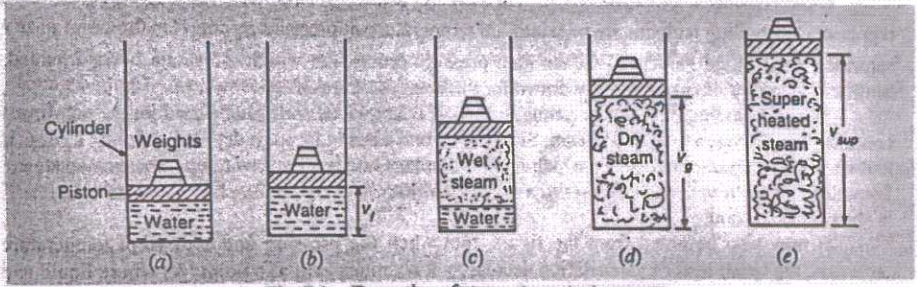
$$\therefore \text{Heat absorbed by the air, } Q_{5-1} = m c_v (T_1 - T_5)$$

Figure - P-V → 3 mark
 T-S → 3 mark
 Explanation - 3 marks.

6 mark.

SCHEME OF VALUATION

(Scoring indicators)

II.4	<p>Theory :</p> <p>Morse Test is conducted on a multi-cylinder engine mainly to find the I.P of the engine. In this test, B.P is found as usual while all the cylinders are working (by brake load test etc.). Then one cylinder is cut out by short circuiting the supply to spark plug in petrol engines (or by cutting-off supply to injector of one cylinder in case of Diesel engines). Now b.p of engine with 3-cylinders working is found by load test. Again this cylinder is given supply of current to spark plug and another cylinder is cut out. Since frictional power loss is same though a cylinder is cut out.</p> <p>$(\Sigma i.p)_1 - f.p = (b.p)_1$ when all cylinders working</p> <p>$(\Sigma i.p)_2 - f.p = (b.p)_2$ when one cylinder is cut out</p> <p>Subtracting : $(\Sigma i.p)_1 - (\Sigma i.p)_2 = (b.p)_1 - (b.p)_2$</p>	Brief Explanation only	6 marks
II.5	 <p style="text-align: center;">Fig. 7.1. Formation of steam at constant pressure.</p> <p>Consider 1 kg of water at 0° C contained in the piston-cylinder arrangement as shown in Fig. 7.1 (a). The piston and weights maintain a constant pressure in the cylinder. If we heat the water contained in the cylinder, it will be converted into steam as discussed below :</p> <ol style="list-style-type: none"> 1. The volume of water will increase slightly with the increase in temperature as shown in Fig. 7.1 (b). It will cause the piston to move slightly upwards and hence work is obtained. This increase in volume of water (or work) is generally, neglected for all types of calculations. 2. On further heating, temperature reaches boiling point. The boiling point of water, at normal atmospheric pressure of 1.013 bar is 100° C, but it increases with the increase in pressure. When the boiling point is reached, the temperature remains constant and the water evaporates, thus pushing the piston up against the constant pressure. Consequently, the specific volume of steam increases as shown in Fig. 7.1 (c). At this stage, the steam will have some particles of water in suspension, and is termed as <i>wet steam</i>. This process will continue till the whole water is converted into wet steam. 3. On further heating, the water particles in suspension will be converted into steam. The entire steam, in such a state, is termed as <i>dry steam</i> or <i>saturated steam</i> as shown in Fig. 7.1 (d). Practically, the dry steam behaves like a perfect gas. 4. On further heating, the temperature of the steam starts rising. The steam, in such a state, is termed as <i>superheated steam</i> as shown in Fig. 7.1 (e). 	Explanation - 3, Figure - 3 marks	6 marks.
II.6	<p>MODES OF HEAT TRANSFER :</p> <p>There are three modes of heat transfer namely conduction, convection and radiation.</p> <p>In fact 'conduction' and 'radiation' are said to be basic modes of heat transfer. As a result of conduction and/or radiation occurring in a fluid media, heat transfer by 'convection' occurs.</p> <p>THERMAL CONDUCTION :</p> <p>This is the form of heat transfer which takes place through any substance, solid, liquid or gas due to energy exchange in the molecules and by virtue of temperature difference.</p>	2 marks.	

SCHEME OF VALUATION

(Scoring indicators)

	<p>THERMAL CONVECTION :</p> <p>The term thermal convection refers to the heat exchanged between a surface and a fluid moving over the surface.</p> <p>When a fluid (liquid or gas) flows over a solid, and the temperatures are different, heat transfer takes place between the fluid and the solid surface as a result of the motion of the fluid. This mechanism of heat flow is called convection, since</p> <p>THERMAL RADIATION :</p> <p>A heated body when placed in vacuum loses heat. In the absence of material medium heat cannot be lost by conduction or convection. Here heat is said to be transferred by radiation.</p> <p>Radiation is that mode of heat transfer which requires no material medium.</p>	<p>2 marks</p> <p>2 marks</p>	<p>6 marks</p>
<p>II.7</p>	<p>PARALLEL FLOW HEAT EXCHANGER :</p> <p>In this type of heat exchanger hot and cold fluids enter at the same end of the exchanger, flow through in the same direction and leave together at the other end. The principle is illustrated in fig.</p> <div style="text-align: center;"> <p>PARALLEL FLOW HEAT EXCHANGER</p> </div> <p>For a parallel flow of fluids the temperature of the two fluids approaches each other at the exit. The longer the flow passage, the closer together the temperature of the two fluids will be at the exit.</p> <p>COUNTER FLOW HEAT EXCHANGERS :</p> <p>In this type of heat exchanger hot and cold fluids enter at the opposite ends of the heat exchanger and flow through in the opposite directions.</p> <p>Fig. shows the principle of counter flow heat exchanger.</p> <div style="text-align: center;"> <p>Fig.</p> </div> <p>In this exchanger, as the flow passage is lengthened, the temperature difference between two fluids at any point in the flow passage becomes smaller and smaller. Thus, with a very long flow passage, the temperature of hot fluid at its exit approaches the temperature of coolant at its entrance. Likewise the temperature of coolant at its exit approaches that of hot fluid as it enters.</p>	<p>Fig - 1 mark Explanation - 2 mark</p> <p>Fig: 1 mark Explanation - 2 mark</p>	<p>6 marks.</p>

SCHEME OF VALUATION

PART-C

(Scoring indicators)

III.a

(b) Constant pressure (isobaric) process

Consider 'm' kg of gas being heated at constant pressure from state 1 to 2. The heating of the gas under constant pressure causes an increase in the volume and temperature. There will be some external work done due to the increase in the volume. This process, represented on a p-V diagram is as shown in Fig. 1.24. Fig. 1.25 shows the process represented on a T-S diagram. The horizontal line 1-2 in Fig. 1.24 represents the process in pV diagram. The curve 1-2 in Fig. 1.25 represents the process in T-S diagram. A part of heat supplied during the process is utilised to increase the internal energy and the remaining part is utilised to do external work.

(i) p - V - T relationship

For a perfect gas,

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

Since $p_1 = p_2$,

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

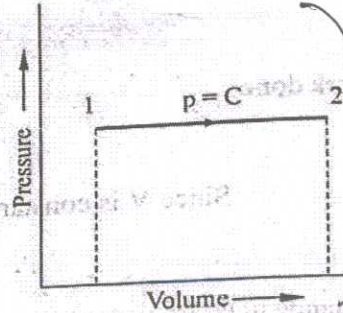


Fig. 1.24

(ii) Work done

$${}_1W_2 = \int_1^2 p dV$$

$$= p \{V\}_{V_1}^{V_2}$$

$${}_1W_2 = p(V_2 - V_1)$$

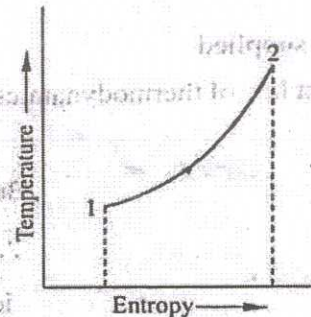


Fig. 1.25

(iii) Change in internal energy

Since there is a temperature rise from T_1 to T_2

$$\Delta U = m C_v (T_2 - T_1)$$

(iv) Heat supplied

From first law of thermodynamics,

$${}_1Q_2 = \Delta U + {}_1W_2$$

$$= m C_v (T_2 - T_1) + p(V_2 - V_1)$$

For a constant pressure process, $p_1 = p_2$

$${}_1Q_2 = m C_v (T_2 - T_1) + (p_2 V_2 - p_1 V_1)$$

For a perfect gas

$$pV = mRT$$

$$\therefore {}_1Q_2 = m C_v (T_2 - T_1) + (mRT_2 - mRT_1)$$

$$= m C_v (T_2 - T_1) + mR (T_2 - T_1)$$

$$= m (T_2 - T_1) (C_v + R)$$

But, $C_v + R = C_p$

$${}_1Q_2 = m C_p (T_2 - T_1)$$

About Process - 1 mark.

P-V-T Relation with Fig - 2 mark.

Work done with Fig - 1 mark.

Heat Supplied - 2 mark.

8 marks.

SCHEME OF VALUATION

(Scoring indicators)

III.b	<p>Solution :</p> <p>Initial conditions :</p> $p_1 = 1.5 \text{ MPa} = 1500 \text{ kPa}$ $T_1 = 1500 + 273 = 1773 \text{ K}$ $V_1 = 0.12 \text{ m}^3$ <p>Final conditions :</p> $p_2 = 175 \text{ kPa}$ $T_2 = ?$ <p>Adiabatic index, $\gamma = \frac{C_p}{C_v} = \frac{1.0035}{0.7165} = 1.4$</p> <p>For adiabatic process,</p> $\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}} = \left[\frac{1500}{175}\right]^{\frac{1.4-1}{1.4}}$ $= (8.5714)^{\frac{0.4}{1.4}} = 1.8474$ <p>(i) Final temperature, $T_2 = \frac{T_1}{1.8474} = \frac{1773}{1.8474} = 959.72 \text{ K}$ $= 959.72 - 273 = 686.72^\circ\text{C}$</p> <p>Also, $\frac{V_2}{V_1} = \left(\frac{p_1}{p_2}\right)^{\frac{1}{\gamma}} = \left(\frac{1500}{175}\right)^{\frac{1}{1.4}} = 4.639$ $\therefore V_2 = 4.639 \times 0.12 = 0.5567 \text{ m}^3$</p> <p>(ii) Work done, $W = \frac{p_1 V_1 - p_2 V_2}{\gamma - 1}$ $= \frac{1500 \times 0.12 - 175 \times 0.5567}{1.4 - 1} = 206.44 \text{ kJ}$</p>	1 mark.	
	}	2 marks.	
	}	2 marks.	
	}	2 marks.	7 marks.

SCHEME OF VALUATION

(Scoring indicators)

IV.a

Consider a certain quantity of gas at an initial pressure and temperature of p_1 and T_1 respectively. V_1 being initial volume point (1) on p-V diagram (Fig. 9.5) represents this state. To change this state of gas to p_2 , V_2 and T_2 i.e., point (2) on diagram, let us choose an intermediate state (A).

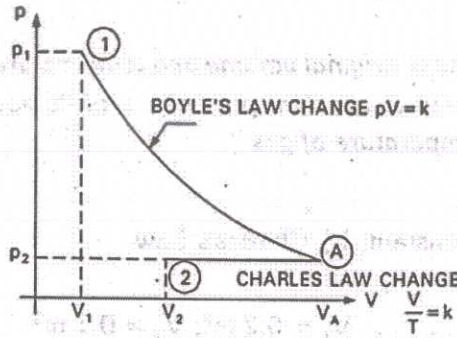


Fig.

1st Process : T_1 being constant, for a change of state from (1) to (A), we have, by Boyle's Law.

$$p_1 V_1 = p_2 V_A \text{ i.e., } V_A = \frac{V_1 \times p_1}{p_2} \quad \dots \dots \dots (i)$$

2nd Process : $p_A = p_2$ being constant, for a change of state from (A) to (2), we have, by Charles's Law.

$$\frac{V_A}{T_1} = \frac{V_2}{T_2} \text{ i.e., } V_A = \frac{V_2 \times T_1}{T_2} \quad \dots \dots \dots (ii)$$

From (i) and (ii) $\frac{V_1 \times p_1}{p_2} = \frac{V_2 \times T_1}{T_2}$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} \quad \dots \dots \dots (iii)$$

From (iii) it follows that $pV/T = \text{a constant}$ for any fixed mass of gas, changing its state. Denoting this constant on the basis of unit mass by a symbol R , we have $pV/T = mR$ for ' m ' kg of gas. Thus $pV = mRT$ is known as characteristic equation of a perfect gas.

Further, $\rho = \frac{m}{V} R T$ i.e., $p = \rho R T$ $\rho = \text{density in kg/m}^3$.

Fig - 2 marks

2 marks

2 marks

Final Expression - 2 marks.

8 marks.

SCHEME OF VALUATION

(Scoring indicators)

IV.b	<p>Initial condition :</p> <p>Pressure, $p_1 = 1000 \text{ kN/m}^2$</p> <p>Volume, $V_1 = 0.0001 \text{ m}^3$</p> <p>Temperature, $T_1 = 25 + 273 = 298 \text{ K}$</p> <p>Final volume, $V_2 = 0.001 \text{ m}^3$</p> <p>Gas constant, $R = 0.297 \text{ kJ/kg K}$.</p> <p>(a) Mass of air, m</p> $p_1 V_1 = m R T_1$ $\therefore m = \frac{p_1 V_1}{R T_1} = \frac{1000 \times 0.0001}{0.297 \times 298} = 1.13 \times 10^{-3} \text{ kg}$ <p>(b) Final pressure, p_2</p> $p_1 V_1 = p_2 V_2$ <p>or $p_2 = \frac{p_1 \cdot V_1}{V_2} = \frac{1000 \times 0.0001}{0.001} = 100 \text{ kN/m}^2$ <p>(c) Work transfer, W</p> $W = p_1 V_1 \cdot \log_e \frac{V_2}{V_1} = 1000 \times 0.0001 \log_e \left(\frac{0.001}{0.0001} \right)$ $= 0.2303 \text{ kJ}$ </p>	} 1 marks.	} 2 marks	} 2 marks	} 7 marks.
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Scheme of Valuation

(Scoring indicators)

<p>V.a</p>	<p>Fig.</p>	<p>P-V diagram - 2 mark.</p>
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SCHEME OF VALUATION

(Scoring indicators)

<p>Process (1) – (2) : Adiabatic compression of air. Pressure increases from p_1 to p_2; volume decreases from V_1 to V_2. Temperature increases from T_1 to T_2. Entropy remains constant. $\phi_1 = \phi_2$. Heat transfer being zero, work is done on the air at the expense of its internal energy.</p> <p>Process (2) – (3) : Constant volume heat addition by applying hot body to cylinder walls. (In practice it is ignition of fuel resulting combustion). Pressure increases from p_2 to p_3. Temperature increases from T_2 to T_3. T_3 is maximum temperature of cycle. Entropy increases from ϕ_2 to ϕ_3. Work transfer is zero.</p> <p>Process (3) – (4) : Heat source is withdrawn ; Gas expands adiabatically. Pressure decreases from p_3 to p_4. Temperature decreases from T_3 to T_4. Volume increases from V_3 to V_4. Entropy remains constant $\phi_3 = \phi_4$. Heat transfer is zero and work is done by the air.</p> <p>Process (4) – (1) : Constant volume heat rejection by applying a cold body to engine. Pressure decrease from p_4 to p_1. Temperature decreases from T_4 to T_1. Entropy decreases from ϕ_4 to ϕ_1. This process completes the cycle and returns the air to its original state (1).</p> <p>Heat received by air $Q_{2-3} = C_v (T_3 - T_2)$ Heat rejected by air $Q_{4-1} = C_v (T_4 - T_1)$ Work done per cycle, $\oint W = Q_{2-3} - Q_{4-1}$ $= C_v [(T_3 - T_2) - (T_4 - T_1)]$</p> <p>Air standard efficiency of cycle = $\frac{\text{Work done}}{\text{Heat received}}$</p> <p>i.e., $\eta_{\text{Otto}} = \frac{C_v [(T_3 - T_2) - (T_4 - T_1)]}{C_v (T_3 - T_2)}$ $= 1 - \frac{T_4 - T_1}{T_3 - T_2}$</p>	<p style="font-size: 2em; font-weight: bold;">4</p> <p style="font-size: 1.2em; font-weight: bold;">MARKS</p>
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SCHEME OF VALUATION

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<p>From adiabatic compression (1) - (2),</p> $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1}$ $T_2 = T_1 \cdot r^{\gamma-1}$ <p>From adiabatic expansion (3) - (4).</p> $\frac{T_2}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = r^{\gamma-1} \dots \dots \frac{V_4}{V_3} = \frac{V_1}{V_2} = r$ $T_3 = T_4 \cdot r^{\gamma-1}$ <p>r = ratio of expansion = ratio of compression in Otto cycle</p> <p>Expression for η becomes, $\eta_{\text{Otto}} = 1 - \frac{T_4 - T_1}{r^{\gamma-1}(T_4 - T_1)}$</p> $\therefore \eta_{\text{air std}} = \eta_{\text{Otto}} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{r^{\gamma-1}}$		2 marks.		8 marks.
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SCHEME OF VALUATION

(Scoring indicators)

V.b

In the valve timing diagram as shown in Fig. 26.9, we see that the inlet valve opens before the piston reaches *TDC* ; or in other words while the piston is still moving up before the beginning of the suction stroke. Now the piston reaches the *TDC* and the suction stroke starts. The piston reaches the *BDC* and then starts moving up. The inlet valve closes, when the crank has moved a little beyond the

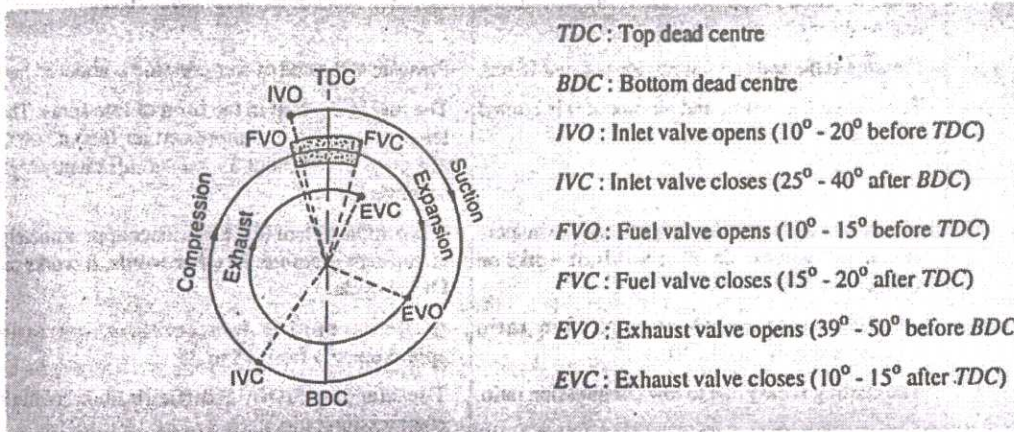


Fig. 26.9. Valve timing diagram for a four stroke cycle diesel engine.

BDC. This is done as the incoming air continues to flow into the cylinder although the piston is moving upwards from *BDC*. Now the air is compressed with both valves closed. Fuel valve opens a little before the piston reaches the *TDC*. Now the fuel is injected in the form of very fine spray, into the engine cylinder, which gets ignited due to high temperature of the compressed air. The fuel valve closes after the piston has come down a little from the *TDC*. This is done as the required quantity of fuel is injected into the engine cylinder. The burnt gases (under high pressure and temperature) push the piston downwards, and the expansion or working stroke takes place. Now the exhaust valve opens before the piston again reaches *BDC* and the burnt gases start leaving the engine cylinder. Now the piston reaches *BDC* and then starts moving up thus performing the exhaust stroke. The inlet valve opens before the piston reaches *TDC* to start suction stroke. This is done as the fresh air helps in pushing out the burnt gases. Now the piston again reaches *TDC*, and the suction starts. The exhaust valve closes when the crank has moved a little beyond the *TDC*. This is done as the burnt gases continue to leave the engine cylinder although the piston is moving downwards.

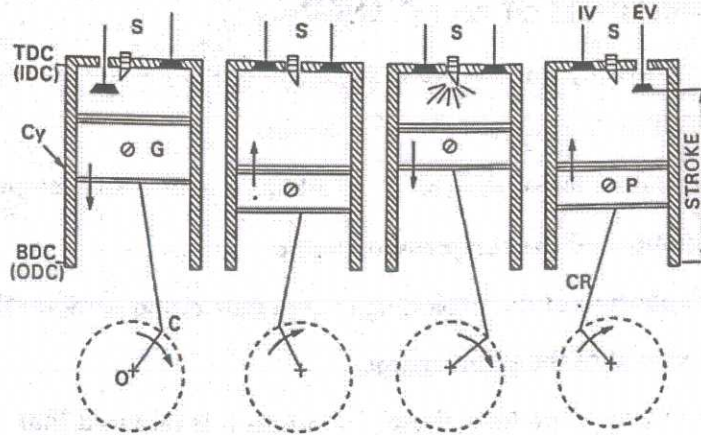
Explanation: 4 mark, Fig: 3 mark

3 marks.

SCHEME OF VALUATION

(Scoring indicators)

VI.a



(a) Suction (b) Compression (c) Power (d) Exhaust
 TDC = Top Dead Centre BDC = Bottom Dead Centre
 IV = Inlet Valve EV = Exhaust Valve
 P = Piston Cy = Cylinder
 CR = Con. rod S = Spark Plug
 G = Gudgeon Pin C = Crank pin
 CO = Crank

Fig. 5.2

1st Stroke :

Suction Stroke (Induction Stroke) : Piston moves down from TDC to BDC. Inlet valve opens. Partial vacuum is created inside the cylinder. Fresh charge of fuel air is admitted through inlet valve. Exhaust valve remains closed. Fig. 5.2 (a).

2nd Stroke :

Compression Stroke : Piston moves up from BDC to TDC. Both the valves remain closed. Charge is compressed inside the cylinder. Its pressure and temperature increase. Fig. 5.2 (b).

At the end of compression a spark is ejected and ignites the charge.

3rd Stroke :

Expansion Stroke (Power Stroke) : Piston moves down from TDC to BDC, as the power is developed in the form of heat energy. Both the valves remain closed. This is also called working stroke. Fig. 5.2 (c).

4th Stroke :

Exhaust Stroke : Piston moves up from BDC to TDC. Exhaust valve opens. Burnt gases are driven out. Inlet valve remains closed Fig. 5.2 (d).

It may be noted that during first two strokes piston's movement is due to momentum of the fly-wheel keyed to the crankshaft. The charge comprising fuel and air mixture comes from a carburettor.

Fig: 3 mark.

Explanation - 4 marks.

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These operations are represented on p-V diagram Fig. . . .

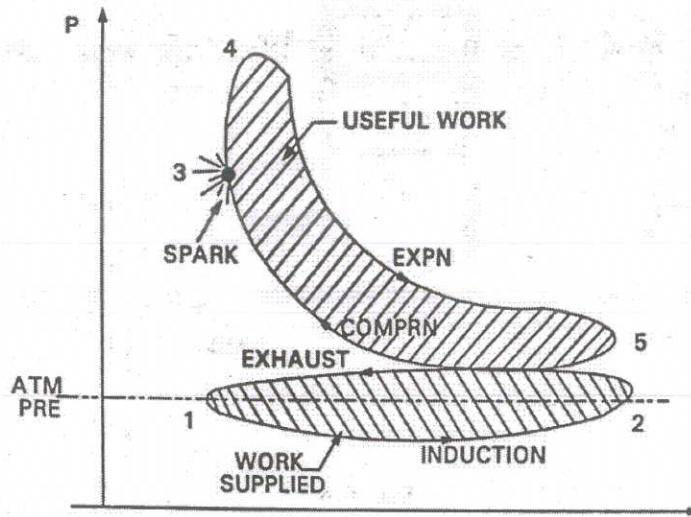


Fig.

P-V diagram - 1 mark.

8 marks.

VI.b

Let clearance volume, $V_2 = V_c = 1$
 $V_s =$ Swept or stroke volume.

Then compression ratio $r = \frac{V_c + V_s}{V_c}$

$$14 = \frac{1 + V_s}{1}$$

$$14 = 1 + V_s \text{ and } V_s = 13$$

2 MARK

SCHEME OF VALUATION

(Scoring indicators)

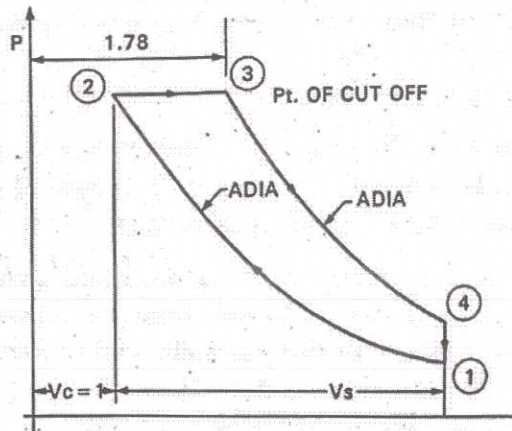


Fig. 4.11

$$(2) - (3) = 6\% \text{ of } V_s = .06 \times 13 = 0.78$$

= Volume of 6% of stroke

$$V_3 = \text{volume at pt. of cut-off} = V_c + 0.78 = 1 + 0.78 = 1.78.$$

$$\text{Cut-off ratio, } \rho = \frac{V_3}{V_2} = \frac{1.78}{1} = 1.78.$$

Now,

$$\eta_{\text{Diesel}} = 1 - \frac{1}{\gamma} \cdot \frac{1}{r^{\gamma-1}} \left(\frac{\rho^{\gamma} - 1}{\rho - 1} \right)$$

$$= 1 - \frac{1}{1.4} \cdot \frac{1}{(14)^{0.4}} \left(\frac{(1.78)^{1.4} - 1}{1.78 - 1} \right)$$

$$= 1 - 0.248 \left(\frac{1.24}{0.78} \right) = 1 - 0.395 = 0.605$$

$$= 60.5\%$$

Fig. 1 mark.

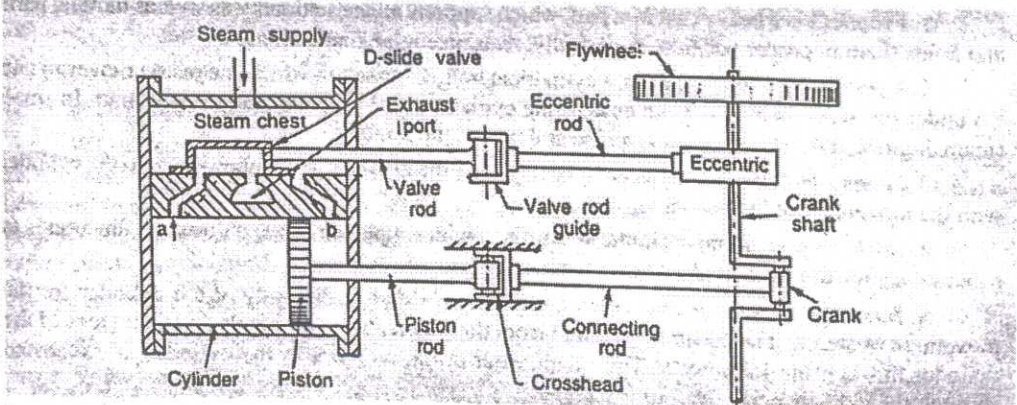
2 mark

7-marks.

2 mark

SCHEME OF VALUATION

(Scoring indicators)

VII.a	<p>The principal parts of a single cylinder, double acting horizontal reciprocating steam engine are shown in Fig. 17.1.</p> <p>The superheated steam at a high pressure (about 20 atmospheres) from the boiler is led into the steam chest. After that the steam makes its way into the cylinder through any of the ports 'a' or 'b' depending upon the position of the D-slide valve. When port 'a' is open, the steam rushes to the left side of the piston and forces it to the right. At this stage, the slide valve covers the exhaust port and the other steam port 'b' as shown in Fig. 17.1. Since the pressure of steam is greater on the left side than that on right side, the piston moves to the right.</p>  <p style="text-align: center;">Fig. 17.1. Single cylinder double acting horizontal reciprocating steam engine.</p> <p>When the piston reaches near the end of the cylinder, it closes the steam port 'a' and exhaust port. The steam port 'b' is now open, and the steam rushes to the right side of the piston. This forces the piston to the left and at the same time the exhaust steam goes out through the exhaust pipe, and thus completes the cycle of operation. The same process is repeated in other cycles of operation, and as such the engine works.</p>	<p style="text-align: center;">Fig - 4 marks</p> <p style="text-align: center;">Explanation - 4 marks</p> <p style="text-align: right;">6 marks</p>	
VII.b	<p>Solution. Given : $p = 8 \text{ bar}$; $x = 0.8$</p> <p><i>Enthalpy of 1 kg of steam</i></p> <p>From steam tables, corresponding to a pressure of 8 bar, we find that</p> $h_f = 720.9 \text{ kJ/kg and } h_{fg} = 2046.5 \text{ kJ/kg}$ <p>We know that enthalpy of 1 kg of wet steam,</p> $h = h_f + x h_{fg} = 720.9 + 0.8 \times 2046.5 = 2358.1 \text{ kJ Ans.}$ <p><i>Heat required to raise 2 kg of this steam from water at 20° C</i></p> <p>We have calculated above the enthalpy or total heat required to raise 1 kg of steam from water at 0° C. Since the water, in this case, is already at 20° C, therefore</p> <p>Heat already in water = $4.2 \times 20 = 84 \text{ kJ}$</p> <p>∴ Heat required per kg of steam</p> $= 2358.1 - 84 = 2274.1 \text{ kJ}$ <p>and heat required for 2 kg of steam</p> $= 2 \times 2274.1 = 4548.2 \text{ kJ Ans.}$	<p style="text-align: right;">3 marks</p> <p style="text-align: right;">7 marks.</p> <p style="text-align: right;">4 marks</p>	

SCHEME OF VALUATION

(Scoring indicators)

VIII.a	<p>Consider a unit mass flow of steam through a nozzle.</p> <p>Let V_1 = Velocity of steam at the entrance of nozzle in m/s V_2 = Velocity of steam at any section considered in m/s, h_1 = Enthalpy or total heat of steam entering the nozzle in kJ/kg, and h_2 = Enthalpy or total heat of steam at the section considered in kJ/kg.</p> <p>We know that for a steady flow process in a nozzle,</p> $h_1 + \frac{1}{1000} \left(\frac{V_1^2}{2} \right) = h_2 + \frac{1}{1000} \left(\frac{V_2^2}{2} \right) + \text{Losses}$ <p>Neglecting losses in a nozzle,</p> $\frac{1}{1000} \left(\frac{V_2^2}{2} - \frac{V_1^2}{2} \right) = h_1 - h_2$ <p>$\therefore V_2 = \sqrt{V_1^2 + 2000(h_1 - h_2)} = \sqrt{V_1^2 + 2000 h_d}$... (i)</p> <p>where h_d = Enthalpy or heat drop during expansion of steam in a nozzle $= h_1 - h_2$</p> <p>Since the entrance velocity or velocity of approach (V_1) is negligible as compared to V_2 therefore from equation (i),</p> $V_2 = \sqrt{2000 h_d} = 44.72 \sqrt{h_d}$... (ii)	<p style="writing-mode: vertical-rl; transform: rotate(180deg);">Basic Steps - 4 marks.</p>	
VIII.b	<p>Solution. Given : $p_1 = 15 \text{ bar}$; $p_2 = 1.5 \text{ bar}$</p> <p><i>Final velocity of the steam</i></p> <p>From steam tables, corresponding to a pressure of 15 bar, we find that enthalpy of dry saturated steam,</p> $h_1 = 2789.9 \text{ kJ/kg}$ <p>and corresponding to a pressure of 1.5 bar, enthalpy of dry saturated steam,</p> $h_2 = 2693.4 \text{ kJ/kg}$ <p>\therefore Heat drop, $h_d = h_1 - h_2 = 2789.9 - 2693.4 = 96.5 \text{ kJ/kg}$</p> <p>We know that final velocity of the steam,</p> $V_2 = 44.72 \sqrt{h_d} = 44.72 \sqrt{96.5} = 439.3 \text{ m/s Ans.}$ <p><i>Percentage reduction in the final velocity</i></p> <p>We know that heat drop lost in friction $= 10\% = 0.1$... (Given)</p> <p>\therefore Nozzle coefficient or nozzle efficiency $K = 1 - 0.1 = 0.9$</p> <p>We know that final velocity of the steam,</p> $V_2 = 44.72 \sqrt{K h_d} = 44.72 \sqrt{0.9 \times 96.5} = 416.8 \text{ m/s}$ <p>\therefore Percentage reduction in final velocity $= \frac{439.3 - 416.8}{439.3} = 0.051 \text{ or } 5.1\% \text{ Ans.}$</p>	<p style="writing-mode: vertical-rl; transform: rotate(180deg);">Final Deviation - 4 marks.</p>	<p style="writing-mode: vertical-rl; transform: rotate(180deg);">8 marks.</p>

SCHEME OF VALUATION

(Scoring indicators)

IX.a

Fourier's Law of Conduction :

The fundamental law of thermal conduction is stated by Fourier.

This is an empirical law based on observation and is stated as : "The rate of flow of heat (Q) through a single homo-genous solid is directly proportional to the area of section (A) at right angles to the direction of heat flow, and to the change of temperature with respect to the length of the path $\left(\frac{dT}{dx}\right)$ of the heat flow."

Mathematically,

$$Q \propto A \cdot \frac{dT}{dx} \quad \text{or} \quad Q = -k A \frac{dT}{dx}$$

where k is constant of proportionality and is known as coefficient of thermal conductivity of the body. It largely depends on type of material.

'-ve' sign of k in the equation takes care of decreasing temperature along with the direction of increasing thickness or the direction of heat flow.

The temperature gradient dT/dx is always negative along positive 'x' direction and hence, the value of Q becomes '+ ve'.

Thus, $Q = k \cdot A \cdot \frac{dT}{dx}$

$$k = \frac{Q}{A} \cdot \frac{dx}{dT}$$

When $Q = 1 \text{ W}$ or 1 J/s , $A = 1 \text{ m}^2$

and $\frac{dx}{dT} = 1 \text{ m}^{\circ}\text{K}$

then $k = \text{W} \times \frac{1}{\text{m}^2} \times \frac{\text{m}}{\text{K}} = \text{W/m}^{\circ}\text{K}$

Newton-Rikhman Equation : The heat transfer per unit time by convection is given by,

$$Q = h A (t_1 - t_2) \text{ watts or J/s}$$

where $h =$ heat transfer coefficient

$=$ convection coefficient

$=$ coefficient of convective heat transfer ($\text{W/m}^2 \text{ K}$) or ($\text{W/m}^2 \cdot ^{\circ}\text{C}$)

$A =$ surface area (m^2)

$(t_1 - t_2) =$ temperature difference between the fluid and the surface

This equation is called Newton-Rikhman formula

4 marks

8 marks

4 marks

SCHEME OF VALUATION

(Scoring indicators)

The quantity, $\frac{Q}{A} = q = h (t_1 - t_2)$ is called the heat flux i.e., heat transferred by convection per unit area per unit time.

From the above relation, we have

$$h = \frac{Q}{A(t_1 - t_2)} \text{ W/m}^2 \text{ K}$$

IX.b

34.8. Heat Transfer by Conduction through a Composite Wall

Consider a composite wall consisting of two different materials through which the heat is being transferred by conduction, as shown in Fig. 34.2.

- Let x_1 = Thickness of first material,
- k_1 = Thermal conductivity of first material,
- x_2, k_2 = Corresponding values for the second material,
- T_1, T_3 = Temperatures of the two outer surfaces,
- T_2 = Temperature at junction point, and
- A = Surface area of the wall.

Now assuming T_1 to be higher than T_2 , the heat will flow from left to right as shown in the figure. Under steady conditions, the rate of heat flow through section 1 is equal to that through section 2. We know that heat flowing through section 1,

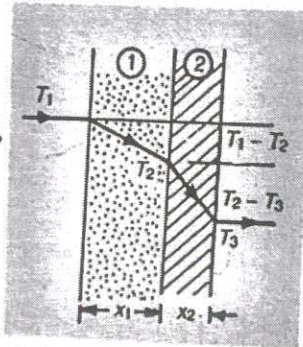


Fig. 34.2. Heat transfer through a composite wall.

$$Q = \frac{k_1 A (T_1 - T_2)}{x_1}$$

or $(T_1 - T_2) = \frac{Q}{A} \times \frac{x_1}{k_1} \dots (i)$

Similarly for section 2,

$$(T_2 - T_3) = \frac{Q}{A} \times \frac{x_2}{k_2} \dots (ii)$$

Adding equations (i) and (ii),

$$(T_1 - T_3) = \frac{Q}{A} \left(\frac{x_1}{k_1} + \frac{x_2}{k_2} \right)$$

or $Q = \frac{A (T_1 - T_3)}{\frac{x_1}{k_1} + \frac{x_2}{k_2}} = \frac{(T_1 - T_3)}{\frac{x_1}{k_1 A} + \frac{x_2}{k_2 A}} = \frac{(T_1 - T_3)}{\sum \frac{x}{kA}}$

Fig - 3 marks

Explanation - 4 marks

7 marks

SCHEME OF VALUATION

(Scoring indicators)

X.a

A single stage reciprocating air compressor, in its simplest form, consists of a cylinder, piston, inlet and discharge valves, as shown in Fig. 28.1. From the geometry of the compressor, we find that when the piston moves downwards (or in other words, during outward or suction stroke), the pressure

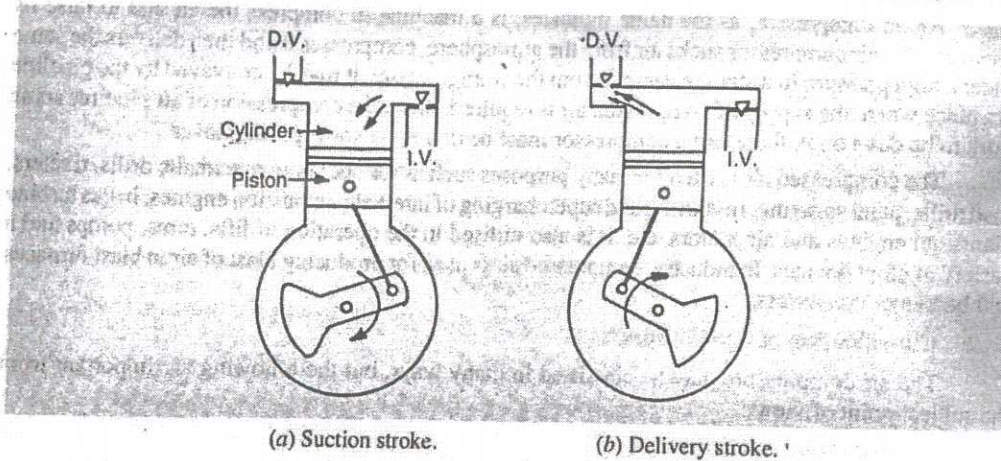


Fig. 28.1. Single stage reciprocating air compressor.

inside the cylinder falls below the atmospheric pressure. Due to this pressure difference, the inlet valve (I.V.) gets opened and air is sucked into the cylinder, at inlet pressure until the piston completes the outward stroke. Now when the piston moves upwards (or in other words, during inward or delivery stroke), the pressure inside the cylinder goes on increasing till it reaches the discharge pressure. At this stage, the discharge valve (D.V.) gets opened and air is delivered to the container. At the end of delivery stroke, a small quantity of air, at high pressure, is left in the clearance space. As the piston starts its suction stroke, the air contained in the clearance space expands till its pressure falls below the atmospheric pressure. At this stage, the inlet valve gets opened as a result of which fresh air is sucked into the cylinder, and the cycle is repeated.

Fig - 1 marks
Explanation - 1 marks

- 2 marks -

SCHEME OF VALUATION

(Scoring indicators)

X.b	<p>Initial pressure, $p_1 = 1 \text{ bar}$</p> <p>Initial temperature, $T_1 = 15 + 273 = 288 \text{ K}$</p> <p>Mass of air, $m = 1 \text{ kg}$</p> <p>Final pressure, $p_3 = 40 \text{ bar}$</p> <p>Law of compression, $pV^{1.25} = \text{constant.}$</p> <p>For minimum work (energy)</p> $p_2 = \sqrt{p_1 \times p_3} = \sqrt{1 \times 40}$ $= 6.324 \text{ bar}$ <p>Then, energy required per cycle.</p> $W = \frac{2.n}{n-1} \cdot mRT_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}} - 1 \right]$ <p>Assume, $R = 0.287 \text{ kJ/kgK}$ for air</p> $W = \frac{2 \times 1.25}{1.25 - 1} \times 1 \times 0.287 \times 288 \left[\left(\frac{6.324}{1} \right)^{\frac{1.25-1}{1.25}} - 1 \right]$ $= 826.56 \times 0.4461$ $= \mathbf{368.73 \text{ kJ}}$	<p style="font-size: 2em;">}</p> <p>1 mark</p>		
	<p style="font-size: 2em;">}</p> <p>2 marks</p>			
	<p style="font-size: 2em;">}</p> <p>2 marks</p>			7 marks
	<p style="font-size: 2em;">}</p> <p>2 marks.</p>			