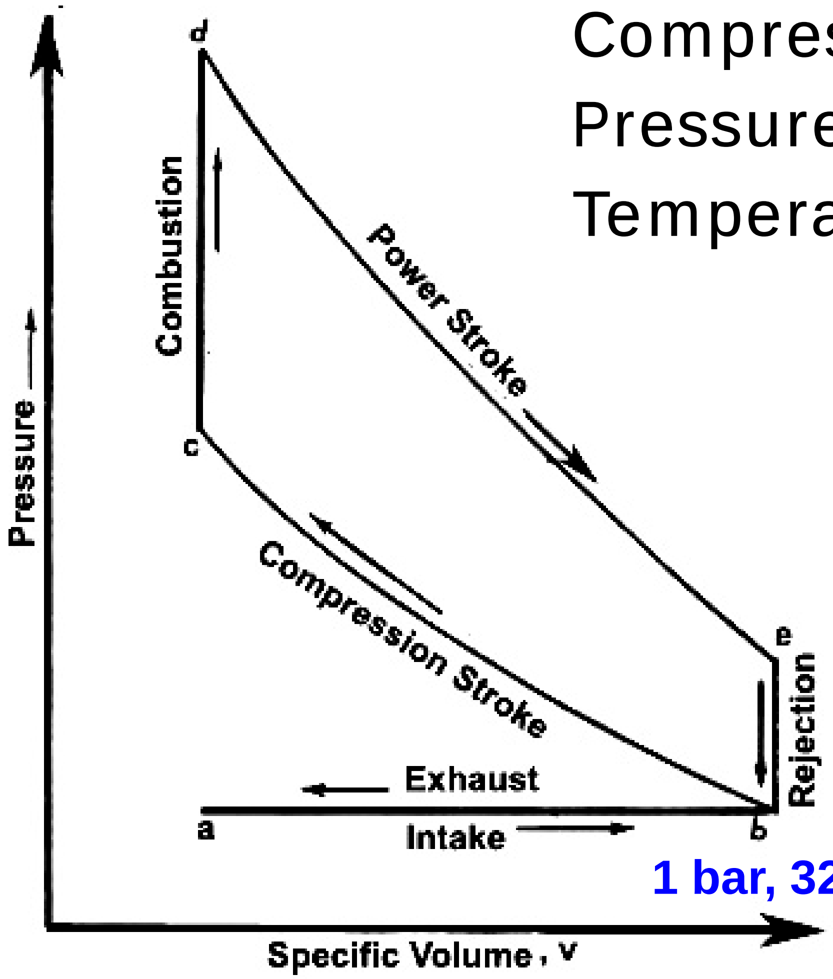
Tutorial on IC Engines
for
Aircraft

1) For an ideal cycle of a reciprocating IC engine , in which heat is added to the working medium, air, at constant volume, the following working conditions are given : P_a= 1 bar, $T_{a=}$320K, Compression ratio =4.0, gas constant of air, R=287 J/kg.deg; Pressure ratio= 4.0 adiabatic exponent, k = 1.4.

For 1 kg of working medium find out :

a) Amounts of heat added and heat rejected
b) Thermal efficiency of a Carnot cycle for the given working conditions
c) Thermal efficiency of the cycle
d) The Indicated mean effective pressure (IMEP)



1 bar, 320K

Compression ratio : $\varepsilon = v_b / v_c = 4$

Pressure Ratio : $\pi = p_d / p_c = 4$

Temperature Ratio: $\tau = T_d / T_b = ?$

$v_b = R.T_b / P_b = 287 x 320 / 10^5$

$= \mathbf{0.92\ m^3 / kg}$

$v_c = v_b / \varepsilon = 0.92 / 4.0$

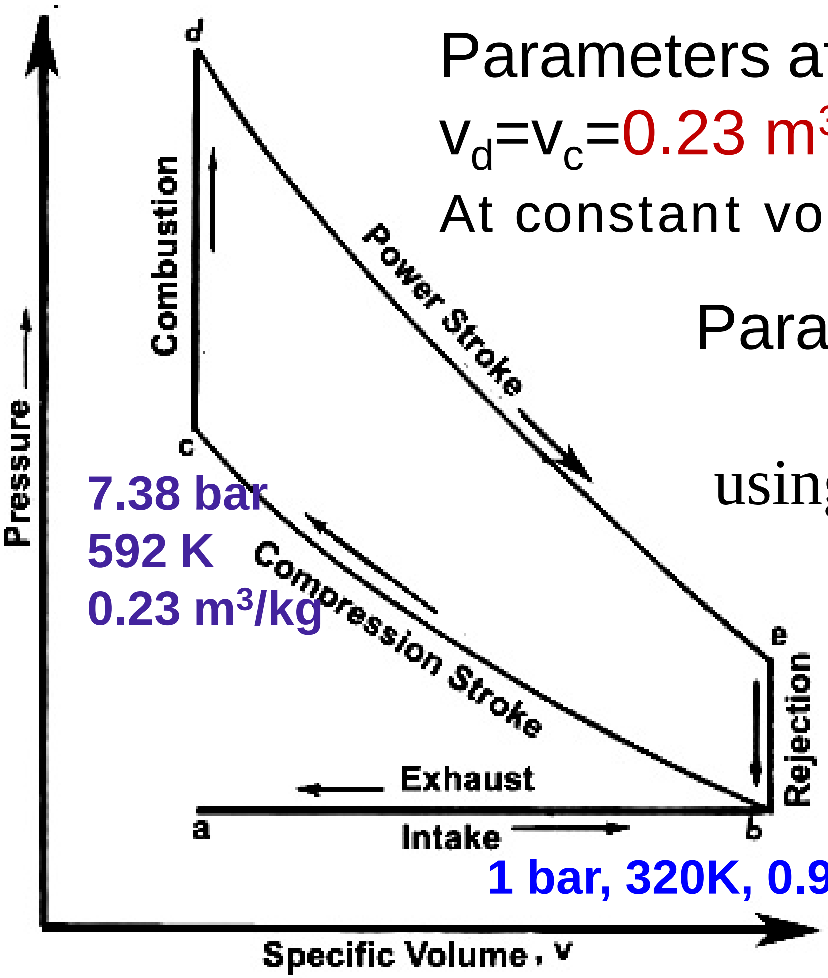
$= \mathbf{0.23\ m^3 / kg}$

$p_c = p_b . \varepsilon^\kappa = 1 x 4^{1.4} = \mathbf{7.38}$ bar

$T_c = p_c . v_c / R$

$= 7.38 x 10^5 x 0.23 / 287$

$= \mathbf{592\ K}$



Parameters at point d shall be computed from :

$v_d = v_c = 0.23\ m^3/kg$; & $p_d = p_c x \pi = 7.38 \text{ x } 4 = 29.6$ bar

At constant vol., $T_d = T_c \text{ x } \pi = 592 \text{ x } 4 = 2368$ K

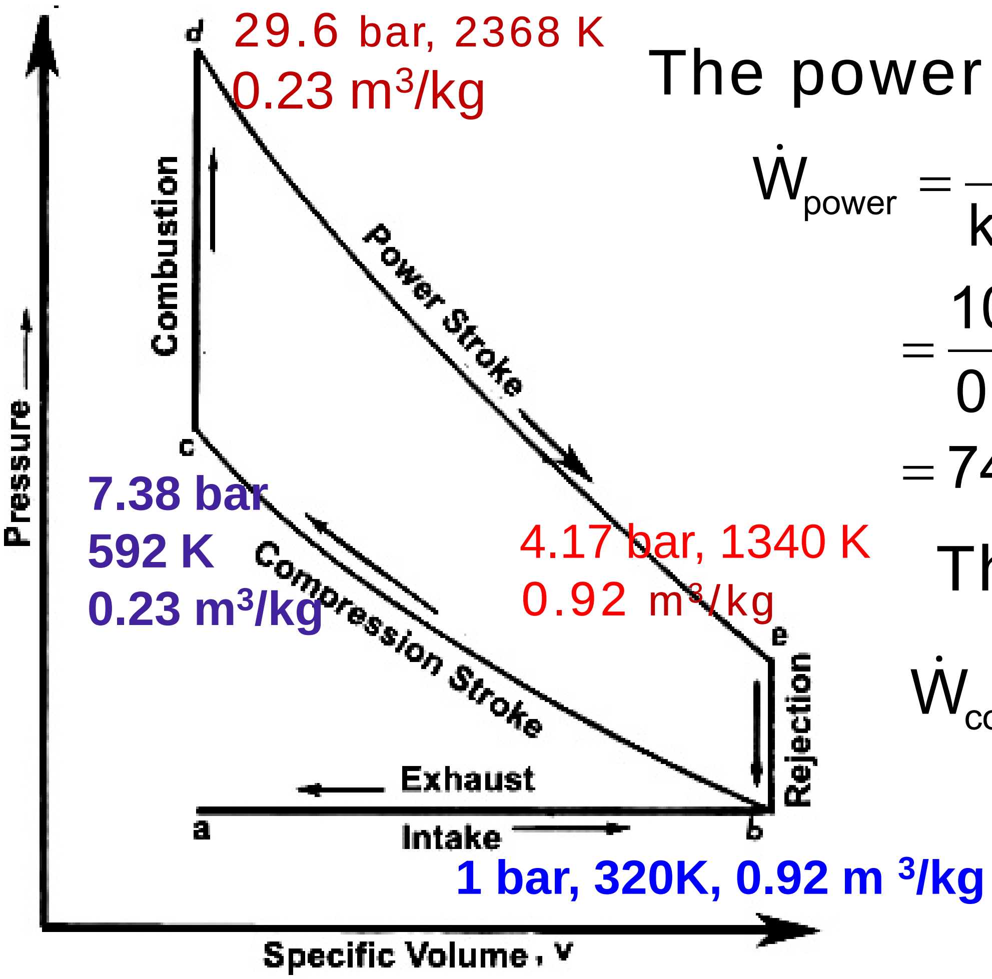
Parameters at point e may be found :

$$\text{using } \frac{T_e}{T_d} = \left(\frac{v_d}{v_e}\right)^{k-1} = \left(\frac{v_b}{v_c}\right)^{k-1} = \frac{1}{\varepsilon^{k-1}}$$

$$T_e = T_d/\varepsilon^{\kappa-1} = 2368/4^{0.4} = 1340 \text{ K}$$

$$v_e = v_b = 0.92\ m^3/kg$$

$$P_e = RT_e/v_e$$
$$= 287x1340/0.92x10^5$$
$$= 4.17 \text{ bar}$$



The power stroke work is given as :

$$\dot{W}_{power} = \frac{1}{k-1}\left(p_d v_d - p_e v_e\right)$$

$$= \frac{10^5}{0.4}\left(29.6 \times 0.23 - 4.17 \times 0.92\right)$$

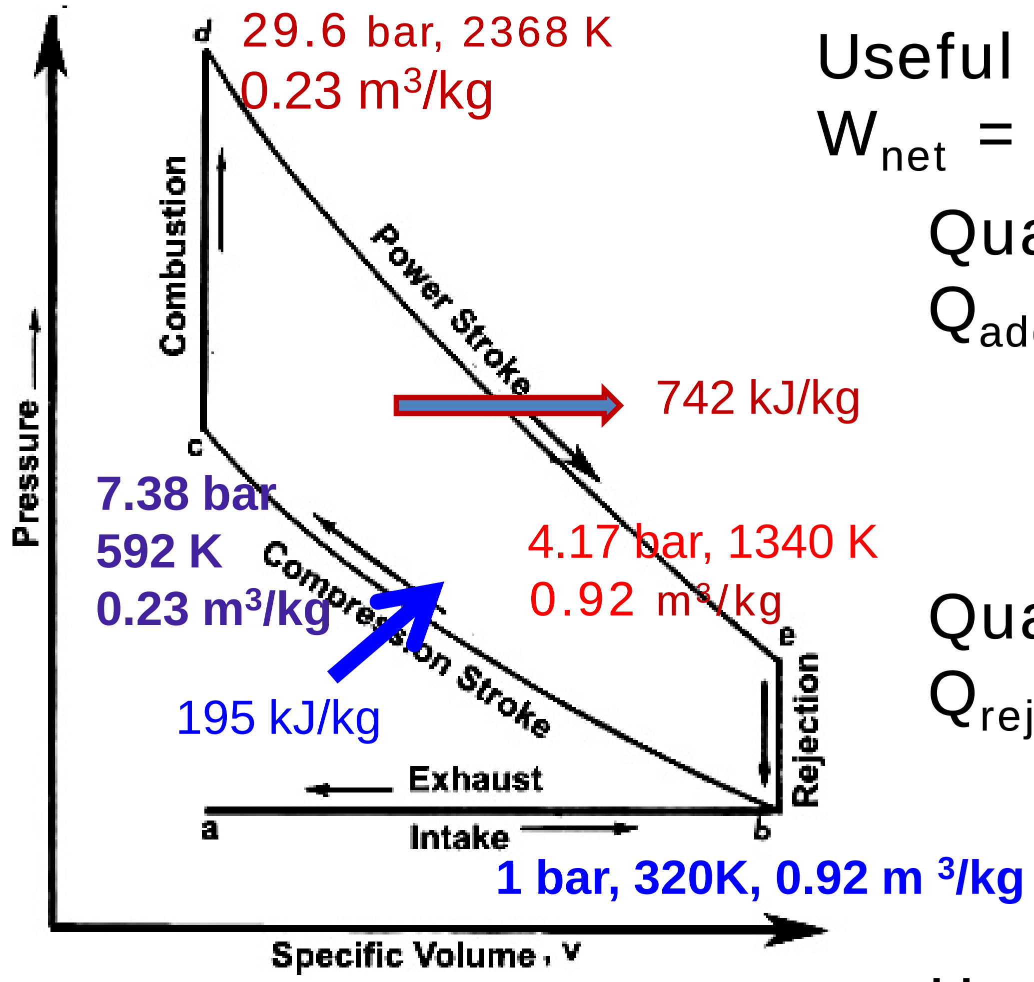
$$= 742.0 \text{ kJ/kg}$$

The compression work is :

$$\dot{W}_{compr} = \frac{1}{k-1}\left(p_b v_b - p_c v_c\right)$$

$$= \frac{10^5}{0.4}\left(1 \times 0.92 - 7.38 \times 0.23\right)$$

$$= -195 \text{ kJ/kg}$$



Useful work is thus :

W_{net} = 743-195 = **547 kJ/kg**

Quantity of heat added is :

$Q_{add} = C_v(T_d - T_c)$

$= 0.72(2368 – 592)$

$= 1280$ kJ/kg

Quantity of heat rejected

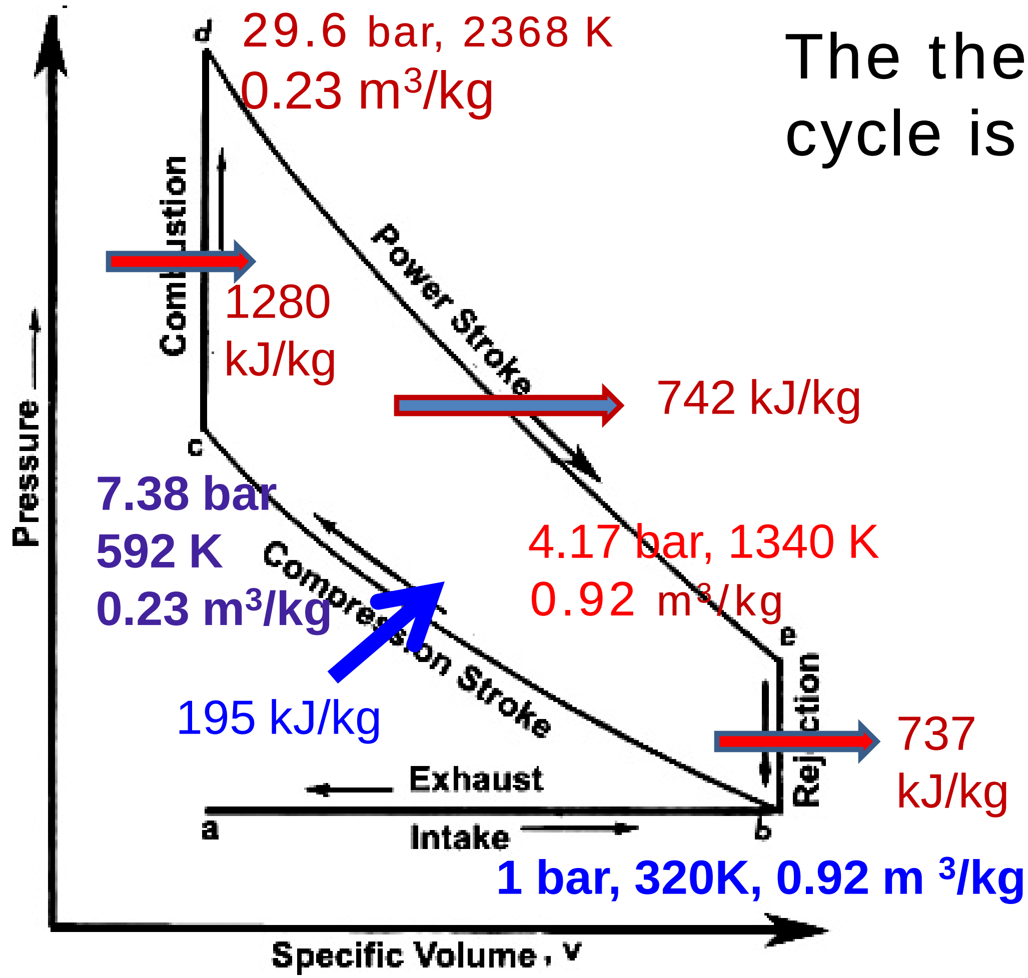
$Q_{rej} = C_v(T_e - T_f)$

$= 0.72\ (1340 – 320)$

$= 737$ kJ/kg

Heat utilised: 1280 – 737

Q_{net} = **543 kJ/kg**



The thermal efficiency of the cycle is :

$$\eta_{th} = Q_{net} / Q_{add}$$

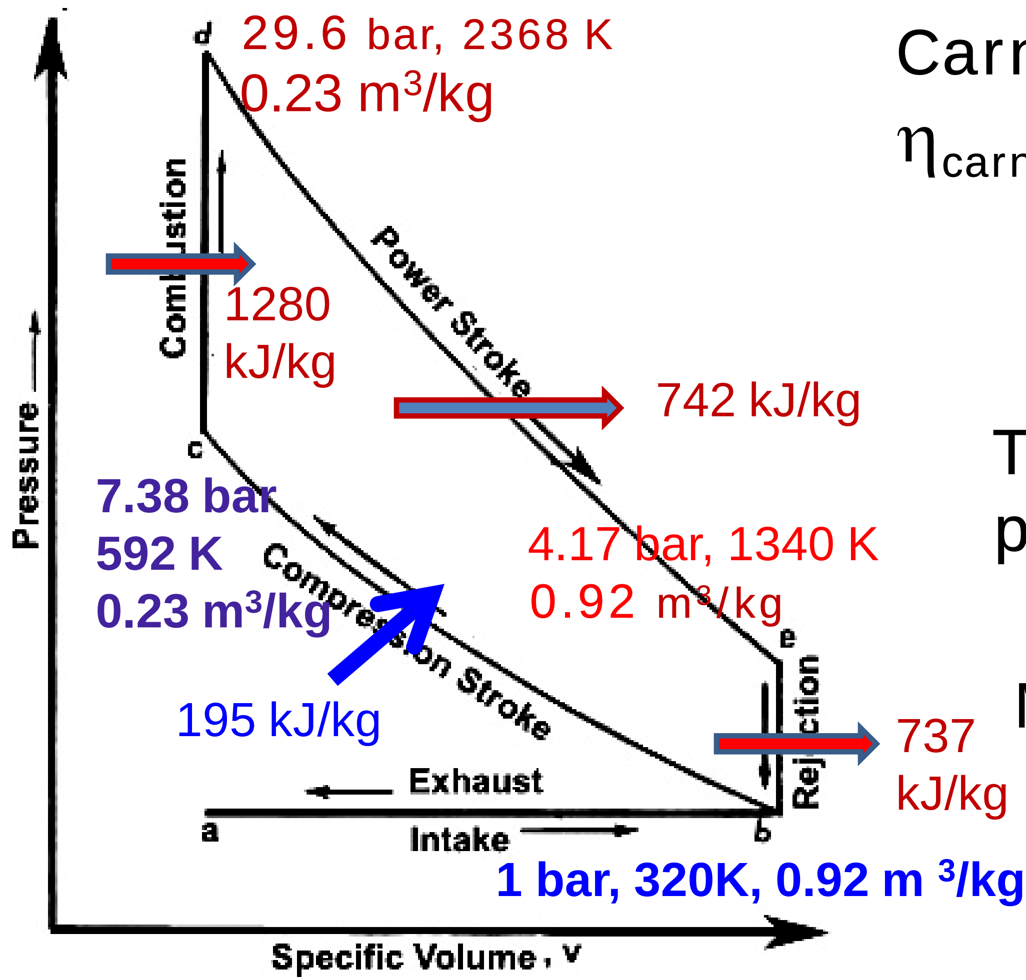
$$= 543 / 1280$$

$$= 0.425$$

Thermodynamically , thermal eff.

$$\eta_{th} = 1 - \frac{1}{r^{k-1}} = 1 - \frac{1}{4^{0.4}}$$

$$= 0.426$$

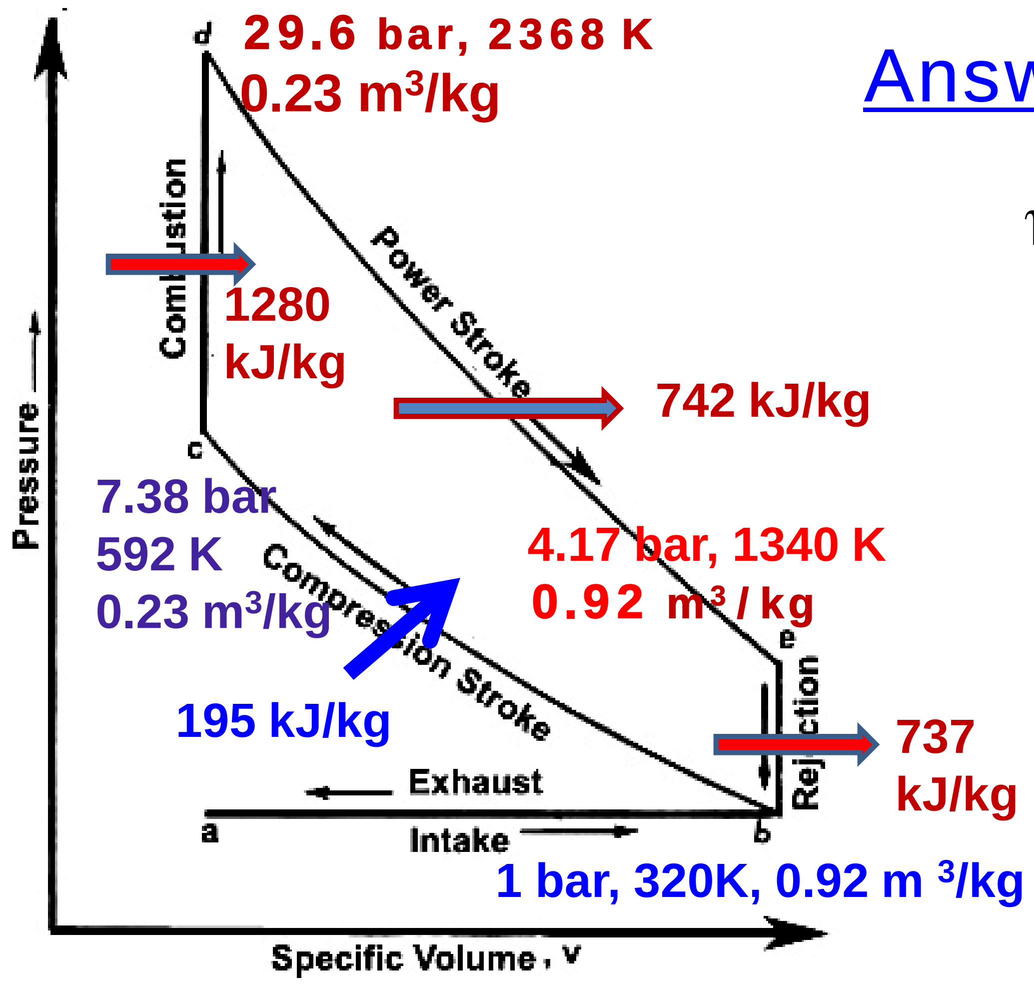


Carnot cycle efficiency is :

$$\eta_{carnot} = 1 - T_b / T_d$$
$$= 1 - 320/2368$$
$$= 0.865 \text{ or } 86.5\%$$

The mean effective pressure is :

$$MEP = W_{net} / (v_b - v_c)$$
$$= 547{,}000/69000$$
$$= 7.9 \text{ bar}$$



Answers

$\eta_{carnot} = 86.5\%$

MEP = 7.9 bar

$\eta_{th} = 0.425$

2) For an ideal IC engine operating with combustion at constant pressure, given that it is operating with p_a= 1 bar, T_a=350 K, compression ratio = 20, isobaric expansion ratio = 2.0. The working medium is air (k=1.4 and R = 287 kJ/kg). For 1 kg of air calculate :

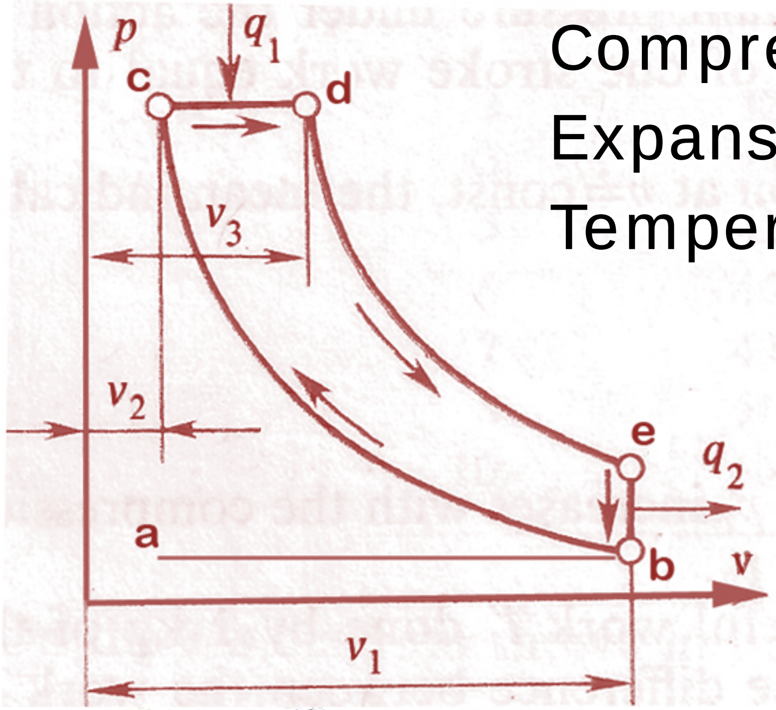
(i) Pressure and temperature at all cycle points

(ii) Work done under various cycle legs

(iii) Heat added or rejected during various cycle legs

(iv) Carnot cycle efficiency

(v) Indicated mean effective pressure



Compression ratio : $\varepsilon = v_b / v_c = 20$

Expansion Ratio (c-d): $\delta = v_d / v_c = 2$

Temperature Ratio: $\tau = T_d / T_b = ?$

$v_b = R.T_b / P_b = 287 \times 350 / 10^5$

$= \mathbf{1.0\ m^3 / kg}$

$v_c = v_b / \varepsilon = 1.0 / 20.0$

$= \mathbf{0.05\ m^3 / kg}$

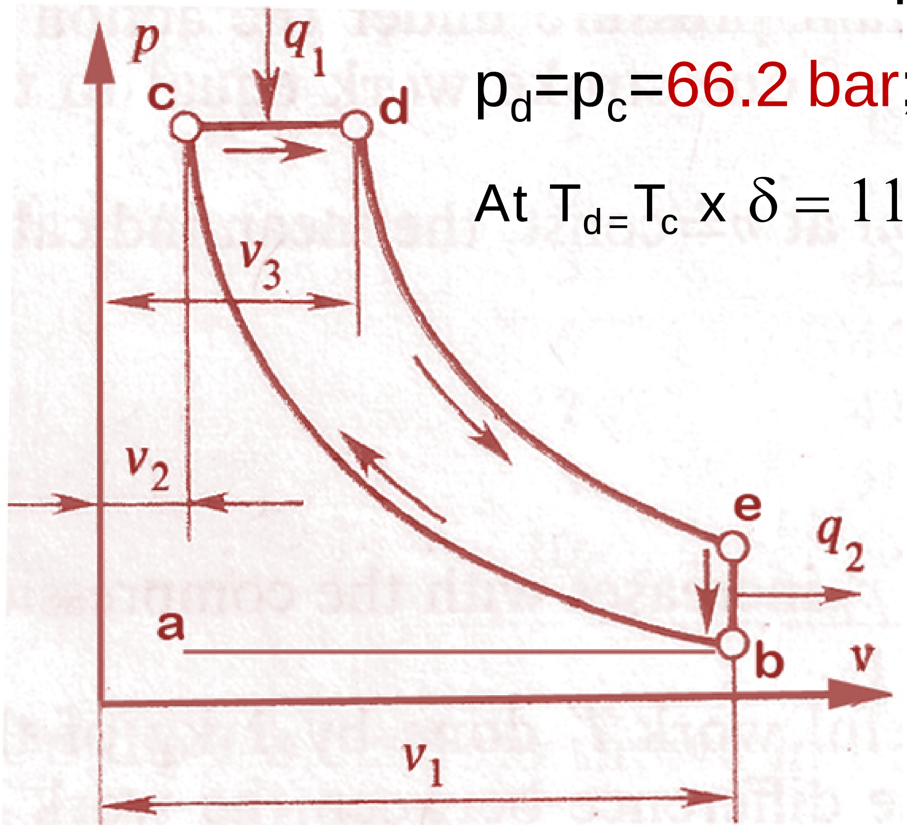
$p_c = p_b.\ \varepsilon^k = 1 \times 20^{1.4} = \mathbf{66.2\ bar}$

$T_c = p_c.v_c / R$

$= 66.2 \times 10^5 \times 0.05 / 287$

$= \mathbf{1155\ K}$

Parameters at point d shall be computed from :



$p_d = p_c = 66.2$ bar; & $v_d = v_c x \delta = 0.05 \times 2 = 0.1\ m^3/kg$

At $T_d = T_c \times \delta = 1155 \times 2 = 2310$ K

Now,

$v_e = v_b = 1.0\ m^3/kg$

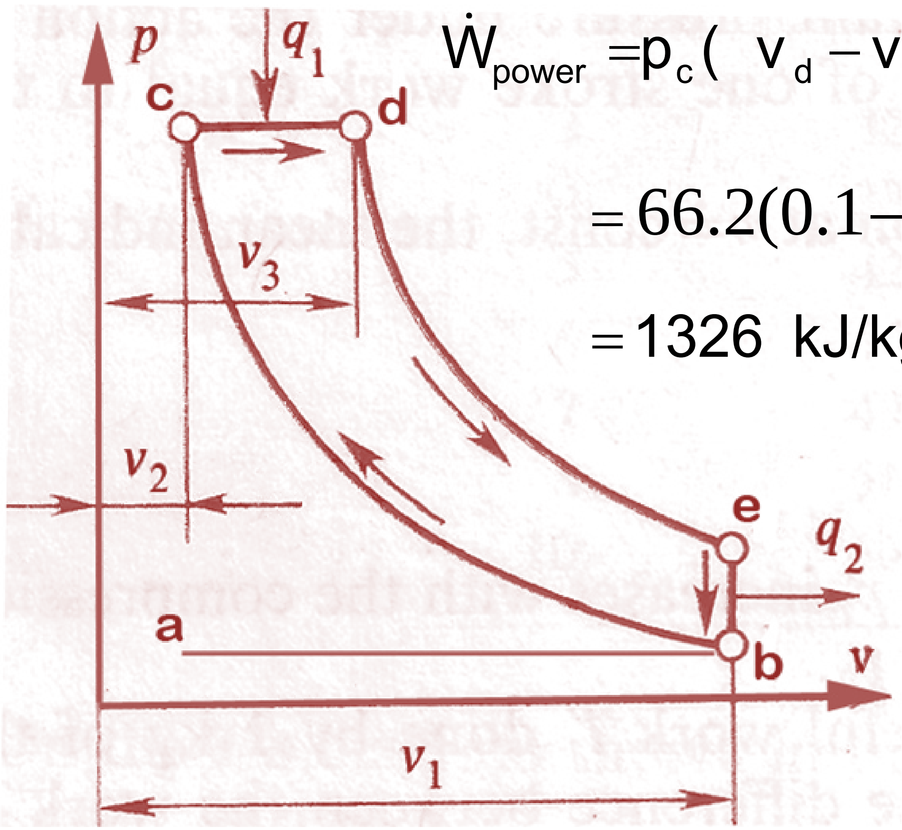
using $\frac{T_e}{T_d} = \left(\frac{v_d}{v_e}\right)^{k-1}$

$T_e = 920$ K

$P_e = R.T_e / v_e$

$= 287 \times 927 / 1 \times 10^5$

$= 2.64$ bar



$$\dot{W}_{power} = p_c(v_d - v_c) + \frac{1}{k-1}(p_d v_d - p_e v_e)$$

$$= 66.2(0.1 - 0.05) + \frac{10^5}{0.4}(66.2 \times 0.01 - 2.64 \times 1.0)$$

$$= 1326 \text{ kJ/kg}$$

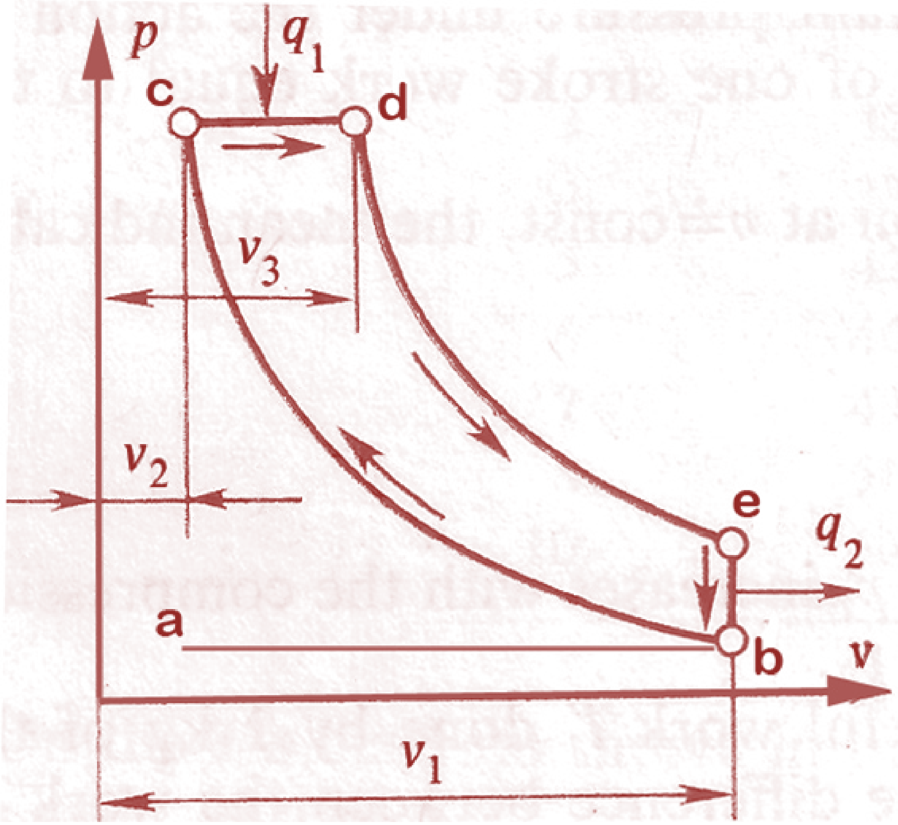
Compression work

$$\dot{W}_{compr} = \frac{1}{k-1}(p_b v_b - p_c v_c)$$

$$= \frac{10^5}{0.4}(1 - 66.2 \times 0.05)$$

$$= -578 \text{ kJ/kg}$$

Net work output = 1326 – 578 = 748 kJ/kg



Quantity of heat added is :

$q_1 = C_p(T_d - T_c)$

$= 1.005(2310 – 1155)$

$=$ 1162 kJ/kg

Quantity of heat rejected

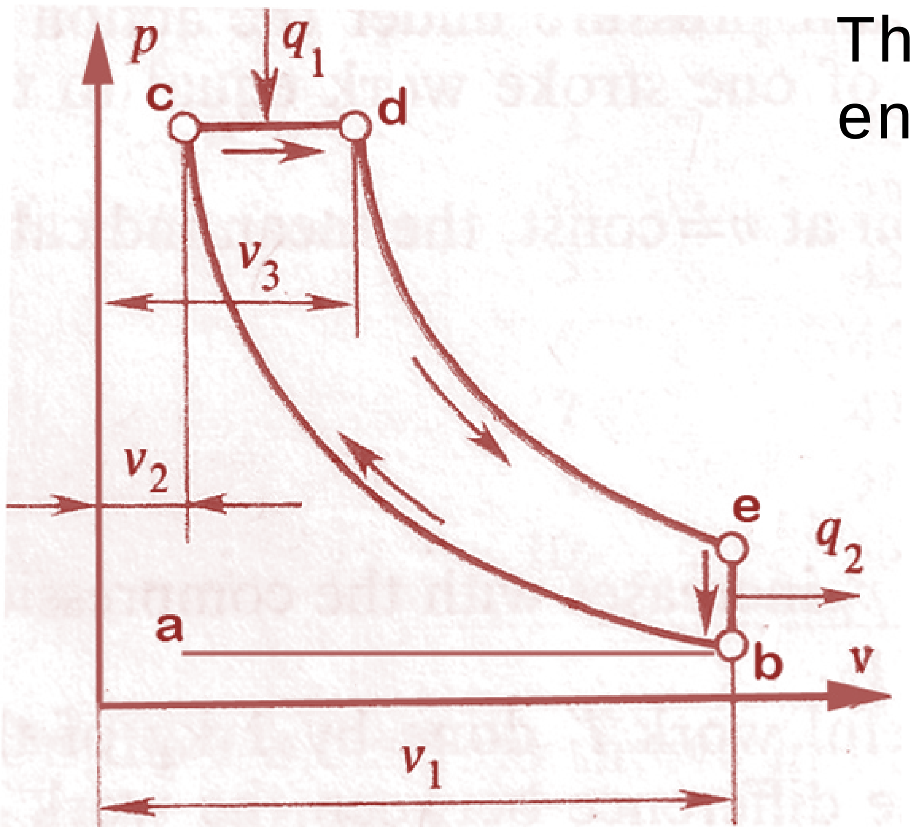
$q_2 = C_v(T_e - T_b)$

$= 0.72\ (920 – 350)$

$=$ 410 kJ/kg

Heat utilised: 1162 – 410

$Q_{net} =$ **752 kJ/kg**



The thermal efficiency of the engine is :

$$\eta_{th} = Q_{net} / Q_{add}$$

$$= 752 / 1162$$

$$= 0.648$$

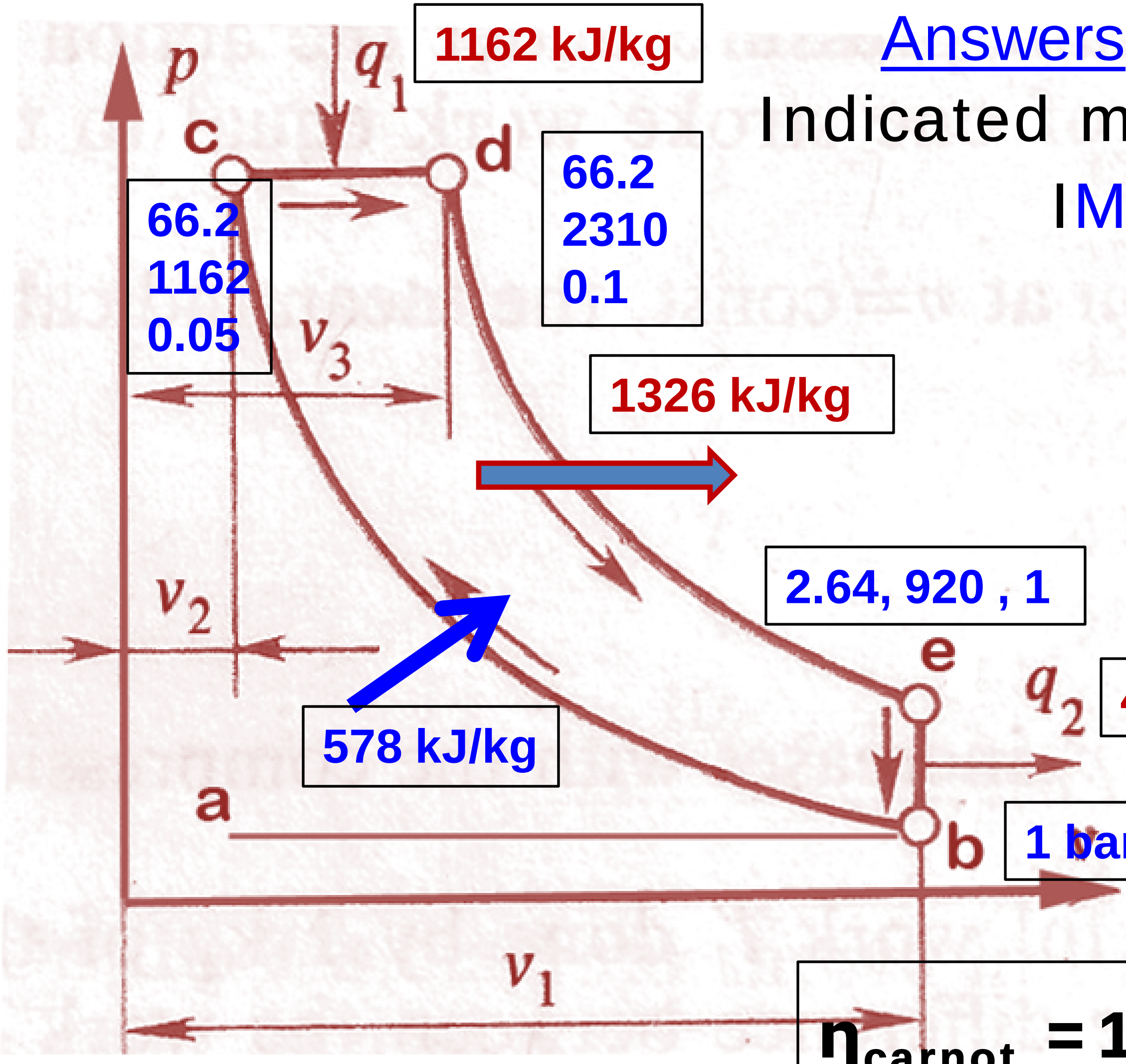
Cycle efficiency is:

$$\eta_{th} = 1 - \frac{\delta^k - 1}{k.\varepsilon^{k-1}}(\delta - 1)$$

$$= 1 - \frac{2^{1.4} - 1}{1.4x20^{0.4}}$$

$$= 0.65$$

This is derived for ideal diesel cycle



Answers

Indicated mean effective pressure

$$IMEP = W_{net} / (v_b - v_c)$$

$$= 748,000/95,000$$

$$= 7.88 \text{ bar}$$

$$\eta_{th} = 0.648$$

$$\eta_{carnot} = 1 - 350/2310 = 0.85$$

Quiz questions - I

1) Which is more important : (i) Air charge per cycle , or (ii) Air charge per minute - for engine power performance estimation ?

2) Does Volumetric efficiency matter any more once supercharging is used in aircraft engines?

3) If High torque production coincides with high BMEP, what is the other operational requirements?

4) In IC engine parlance - what is the difference between (i) compression ratio, and (ii) pressure ratio?

5) Does a turbosupercharger provide higher efficiency of the engine, or that it only provides a continuous control mechanism for the supercharger ?

Quiz questions - II

6) Is very high supercharging beneficial at low altitude flying of aircraft ?

7) Is there is any limit to the degree of supercharging that can be applied to aircraft engines?

8) When does the intake and exhaust valve operation overlap? Does the design and timing of operation of these valve operations affect the engine performance ?

9) When should the engine produce (i) more Power (BHP), and (ii) more Torque – during an aircraft flight ?

10) For typical aircraft engines which fundamental parameter is kept high (design) for maximum power output?

Questions

1) A four-stroke engine produces an output of 420 kW when operating with mechanical efficiency of 87.5%. The fuel consumption is given as 164 kg/hr, when the air consumption is 2780 kg/hr, when the fuel heating value is prescribed as 44200 kJ/kg. Calculate :

(i) IHP; (ii) FHP; (iii) air/fuel ratio;

(iv) Indicated thermal efficiency

(v) Brake thermal efficiency

[**Ans : 600 HP; 75 HP; 15.2 ; 30% ; 26.2%**]

Questions

2) An aircraft engine , equipped with a single stage supercharged engine, is flying at 7.0 km altitude (where ambient pressure is - 41.1. kn/m^2 ; and the ambient temperature is T = 241 K). The carburetor delivery condition is given as pressure = 75 mm H_2O, and the temperature = -24.4^0 C . Assuming ideal air (k=1.4) as working medium and no friction loss or heat loss in the supercharging, Calculate :

(i) The Supercharging pressure ratio

(ii) Corresponding Cylinder intake temperature

[Ans : 2.7 ; 73^o C]

Questions

3) A four-stroke aircraft engine is running at 3600 rpm during the aircraft ground operation. The inlet air temperature is 15.6^0 C and the pressure is 1 bar. The engine has a total displaced volume of 4065.6 cc. The air/fuel ratio is 14:1. The bsfc is 0.377 kg/kW-hr for a power output of 83.5 kW.

Calculate the volumetric efficiency of the engine.

[Ans. 84.5%]

Next Class :

Propeller fundamentals