ICE
Chapter 3
Fuel Air and Actual Cycles
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3-1: Fuel Air Cycle: theoretical cycle based on the actual properties of the cylinder contents is called the fuel – air cycle. The fuel – air cycle take into consideration the following:

1- The actual composition of the cylinder contents.

2- The variation in the specific heat of the gases in the cylinder.

3- The dissociation effect.

4- The variation in the number of moles present in the cylinder as the pressure and temperature change.

5- No chemical changes in either fuel or air prior to combustion.

6- Combustion takes place instantaneously at top dead center.

7- All processes are adiabatic.

8- The fuel is mixed well with air.

Comparison of P-V Diagram of Air-standard and Fuel – Air cycle for SI engine:

- **Variation of specific heats:**
- **Dissociation effect:**

1- Losses due to variation of specific heats with temperature.

All gases, except mono-atomic gases, show an increase in specific heat as temperature increase. The specific heat may be written in the form:

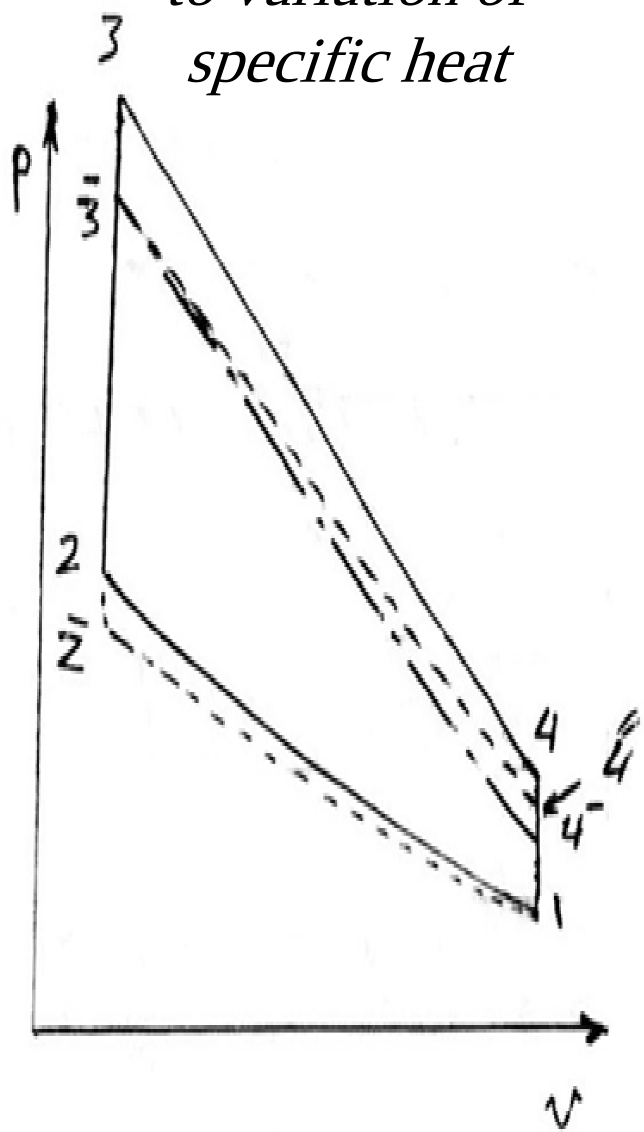
$$C = a + bT + cT^2$$

where T is the absolute temperature and a, b and c are constants for any specific gas. C_v and C_p increase with temperature but:

$(\gamma = \frac{c_p}{c_v})$, decrease as the temperature increase.

➡ There are special tables and charts which gives the specific heat of different gases at different temperatures. Specific heats of a mixture of gases can be calculated, if the constituents of the mixture are known, using the gas mixture relations. If the variation of specific is taken into account during the compression stroke, the final pressure and temperature would be lower if constant value o specific heats is used ($\bar{2}$) as show in Figure (1).When taking variabl specific heat, end of combustion wil be ($\bar{3}$) instead of 3. Expansio process would be $\bar{3}\bar{4}$ when assume isentropic, but expansion takin variable specific heats into account is above$\bar{3}\bar{4}$ and represented by $\bar{3}\bar{\bar{4}}$ Thus it is seen that the effect o variation of specific heats is t deliver less work. The final cycle is ($12\bar{3}\bar{\bar{4}}$).

Figure (1): *Loss due to variation of specific heat*



2- **Losses due to dissociation**.

The effect of **dissociation** is much smaller than that of change of ⇨ **specific heats**. The effect of dissociation on combustion temperature is as shown in figure (2), the dotted line represents the maximum combustion

Effect of dissociation: is to reduce the temperature of the products after combustion by 300 C. This, in turn, reduces the amount of energy that can be drawn from the combustion process and reduces the work output of engines.

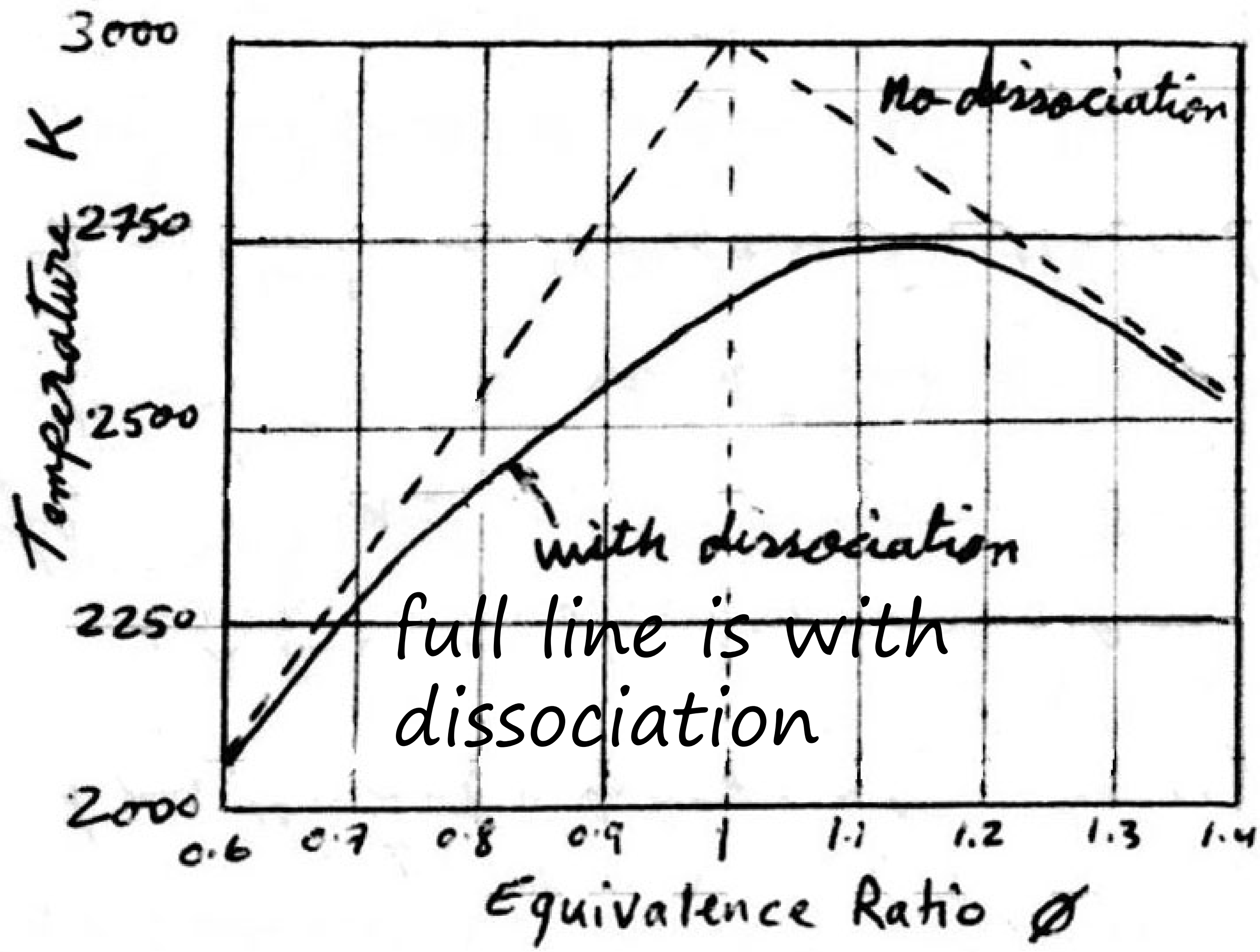


Figure (2): Effect of dissociation temperature at different ϕ

Pollutants: The other effect of dissociation is to form pollutants. This is particularly true in combustion in engines, when carbon monoxide (CO) can be formed even when the mixture is weak (excess air over that of Stoichiometric) - that is, there is more than sufficient oxygen in the air to oxidize completely both the carbon and hydrogen in the fuel

3-2: The Actual Cycle

The actual cycle (see Fig. (3) experienced by internal combustion engines is an open cycle with changing composition, actual cycle efficiency is much lower than the air standard efficiency due to various losses occurring in the actual engine.

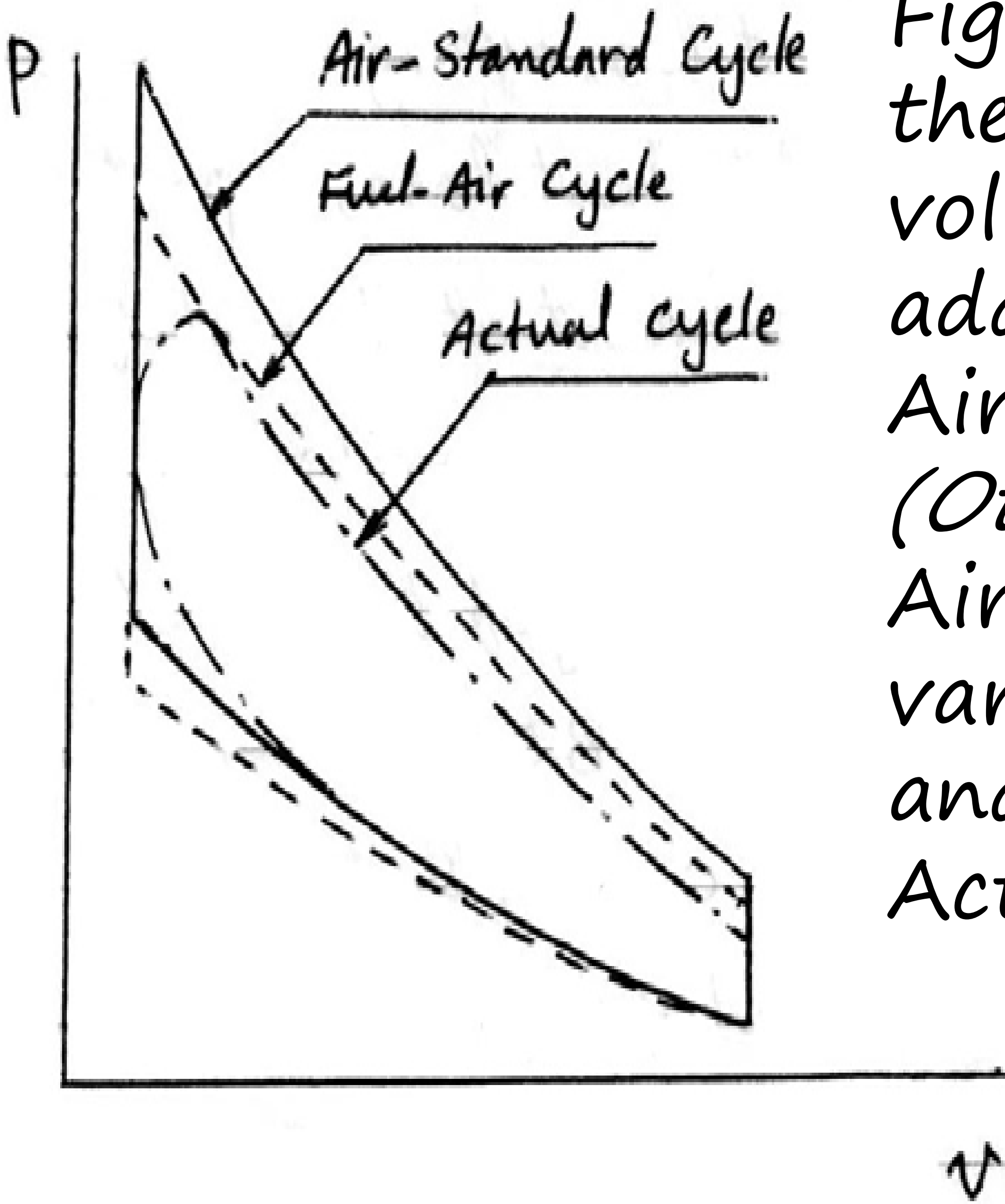


Figure (3) shows (1) the two constant volume cycles (heat added and rejected) Air – Standard cycle (Otto). (2) Fuel – Air cycle with variable specific heat and dissociation. (3) Actual cycle.

These losses are as follows:

1- Losses due to variation of specific heats with temperature:.

2- Losses due to dissociation.

3- time losses, effect of spark timing

4- incomplete combustion loss.

5- direct heat loss.

6- exhaust blow down loss.

7- pumping losses.

8- Friction losses.

9- Effect of throttle opening

3- time losses:

In theoretical cycles the burning is assumed to be instantaneous. Whereas, in actual cycle, burning is completed in a definite interval of time. The effect of this time is that the maximum pressure will not be produced when the volume is minimum; but sometime after T.D.C., causes a reduction in the work produced.

the time at which burning starts is varied by varying the spark timing (spark advance).

4- incomplete combustion loss:

Fuel vapor, air, and residual gas are present in the cylinder, this makes it impossible to obtain perfect homogeneous mixture. Therefore some fuel does not burn to CO_2 or partially burns to CO, and O_2 will appear in the exhaust. Energy release in actual engine is about 90 to 93% of fuel energy input.

5- direct heat loss:

During combustion process and subsequent expansion stroke, the heat flows from cylinder gases through cylinder walls and cylinder head into the water jacket or cooling fins. Some heat enters the piston head and flows through piston rings into the walls of the cylinder or carried away by the engine oil. The heat loss during combustion and expansion does not represent a complete heat loss; a part of the heat loss would be rejected in the exhaust at the end of the expansion stroke.

6- exhaust blow down loss:

The opening of the exhaust value before B.D.C. reducing cylinder pressure, causing the roundness of the end of the P-V diagram, as shown in figure (4), this means a reduction in the work done per cycle.

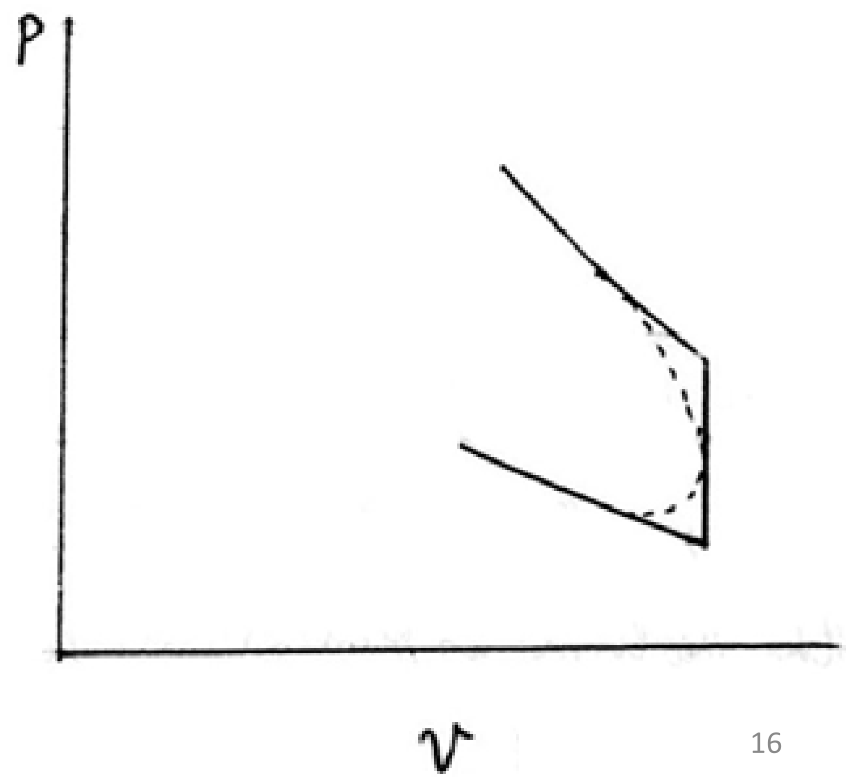


Figure (4): *Effect of exhaust valve opening time*

7- pumping losses:

Pumping loss is due to expelling the exhaust gases and the induction of the fresh charge. In naturally aspirated engine this would be a negative work.

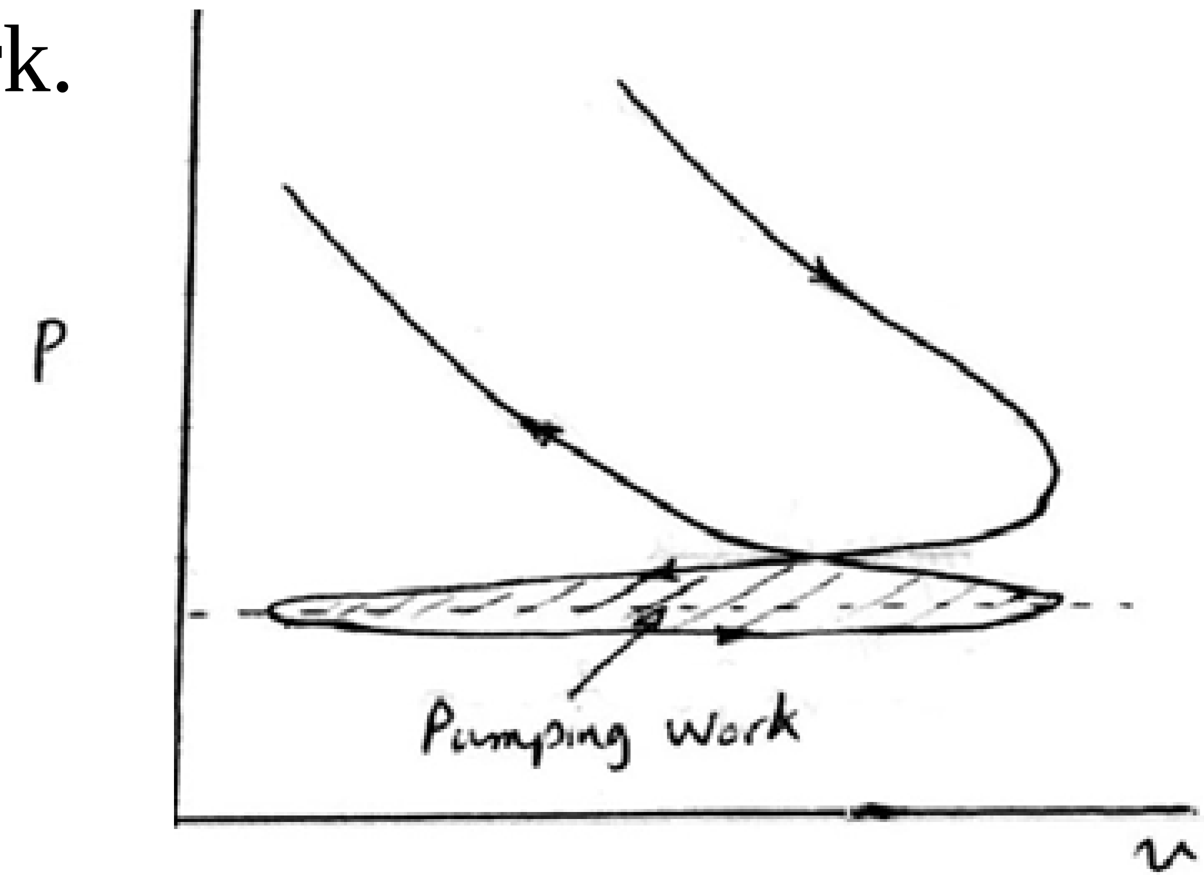


Figure (4): *Effect of pumping*

The upper loop represent positive work output (A) while the lower loop consisting of the exhaust and intake strokes is negative work (B). The more closed the throttle position, the lower will be the pressure during the intake stroke and the greater the negative pumping work.

8- Friction losses:

These losses are due to the friction between the piston and cylinder walls, the various bearings, and the friction in the auxiliary equipment, such as pumps, fans, etc…

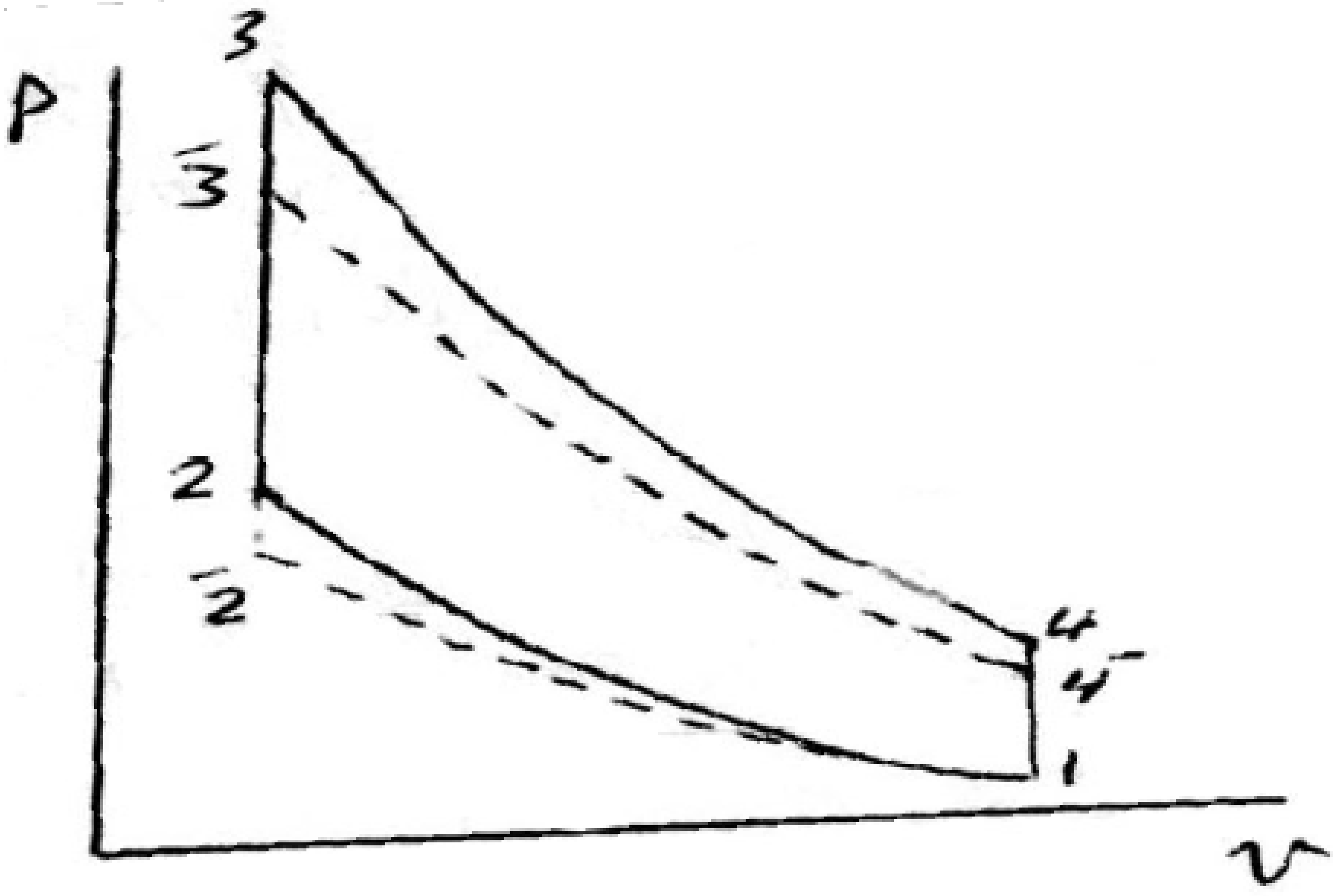
Effect of throttle opening

When a four- stroke SI engine is run at partially closed throttle, (throttle is a butterfly valve in the intake system), fuel supplied to the engine is reduced, and this would lead to less power output at part throttle opening.

Effect of spark timing:

The effect of spark timing is shown in figure (8), $\phi = 0$ means spark timing at T.D.C, in this case the peak pressure is low and occurs nearly 40° after T.D.C., as spark timing is advanced to achieve combustion at TDC, additional work is required to compress the burning gases. Figure (8) shows the power loss by retarded ignition timing optimum loss in power. In actual practice a deliberate retard in spark from optimum may be done to avoid knocking and reduce exhaust emissions of H, C and CO.

Example (4-2): A petrol engine of compression ratio 6 uses a fuel of calorific value 43950kJ/kg. The air – fuel ratio is 15:1. The temperature and pressure of the charge at the charge at the end of the suction stroke are 60°C and 1 bar state (1). Determine the maximum pressure in the cylinder if the index of compression is 1.32 and the specific heat at constant volume is expressed by the expression; $C_v = 0.71 + 19 \times 10^{-5}$ T kJ/kg K, where T is the temperature in K. Compare this value with that when constant specific heat C_v= 0.72 is used.


P
3
3̄
2
2̄
4
4̄
1
v

Solution:

$$p_1 v_1^n = p_2 v_2^n$$

$$p_2 = p_1 \left(\frac{v_1}{v_2} \right)^n = 1 \times 6^{1.32} = 10.645 \ bar$$

$$T_2 = T_1 \left(\frac{p_2 v_2}{p_1 v_1} \right) = 333 \times \frac{10.645}{6}$$

$$= 590.8\text{K}$$

Mean specific heat $C_{v_{mean}} = 0.71 + 19 \times 10^{-5} \left[\frac{T_2 + T_3}{2} \right]$

Assume 1 kg of air in the cylinder, heat added per kg air $= \frac{43950}{15}$

$$Q = C_v \times \text{mass of charge} \times (T_3 - T_2)$$

$$2930 = [0.71 + 19 \times 10^{-5} (T_3 + 590.8)/2] \times \frac{16}{15} \times (T_3 - 590.8)$$

Solving we get T_3=3090 K

$$P_3 = P_2 \frac{T_3}{T_2} = 10.645 \times \frac{3090}{590} = 55.75 \text{bar}$$

For constant specific heat, $2930 = 0.72 \times \frac{16}{15} (T_3 - 590)$

Solving we get T_3=4405 K

$$P_3 = 10.645 \times \frac{4405}{590} = 79.5 \text{ bar}$$

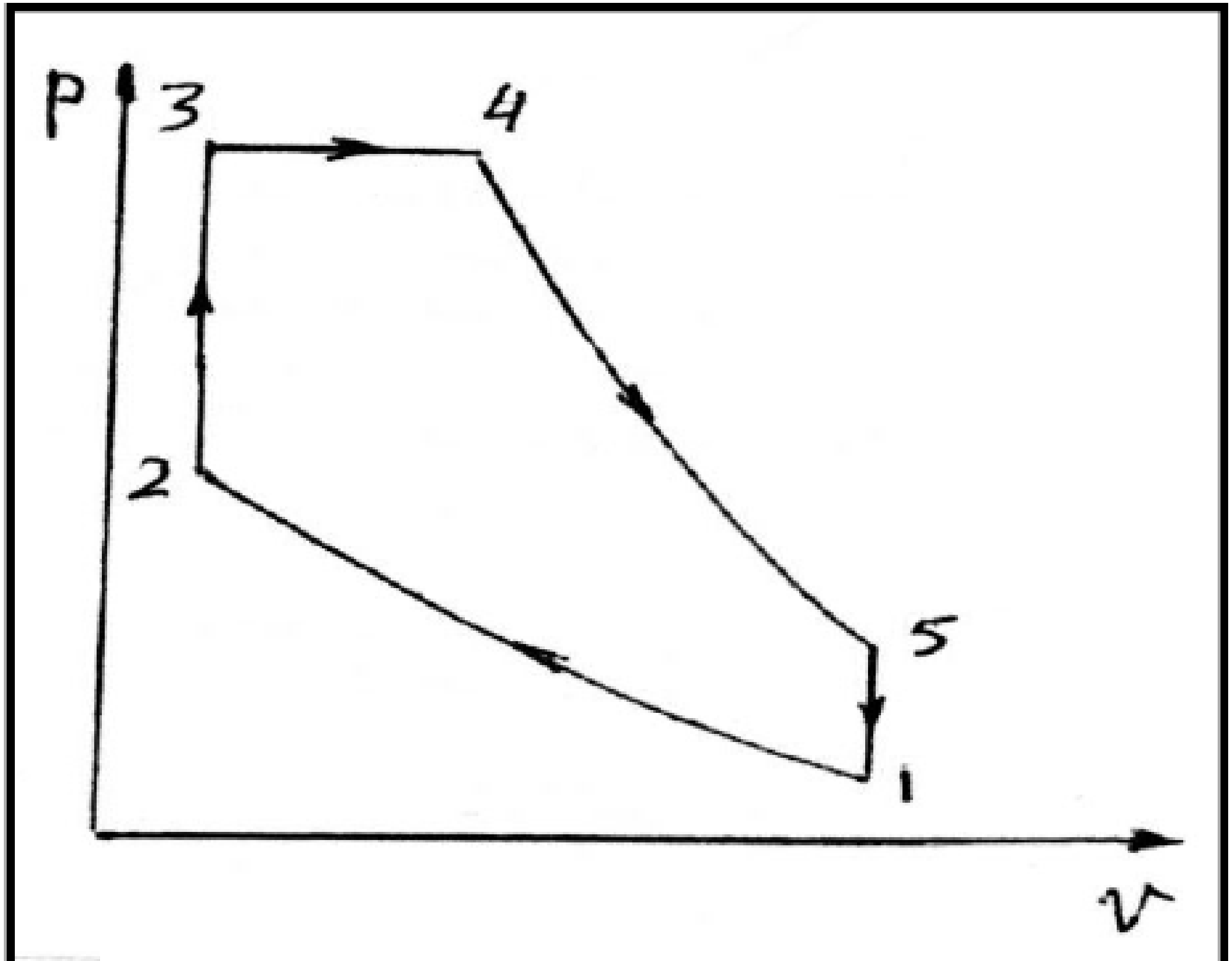
Example (3 - 3):

In an oil engine, working on dual combustion cycle, the temperature and pressure at the beginning of compression are 90 °C and 1 bar. The compression ratio is 13:1. The heat supplied per kg of air is 1674 kJ, half of which is supplied at constant volume and half at constant pressure. Calculate (i) the maximum pressure in the cycle (ii) the percentage of stroke at which cut-off occurs. Take γ for compression 1.4, R= 0.293 kJ/kg K and C_v for products of combustion (0.71+12 $\times 10^{-5}$T)

$$(i)\ \ P_2 = P_1\left(\frac{v_1}{v_2}\right) = 1\times(13)^{1.4} = 36.3\ \ \text{bar}$$

$$\mathrm{T}_2 = T_1\left(\frac{v_1}{v_2}\right)^{\gamma-1} = 363(13)^{0.4} = 1013K$$

$$\mathrm{Q}_{12} = m\int_{T_2}^{T_3} C_v\,dT = m\int_{T_2}^{T_3}(0.71 + 12\times10^{-5}T)\,dT$$



Neglect mass of fuel;

$$837 = 1\left[0.71T + 12\times10^{-5}\frac{T^2}{2}\right]_{T_2}^{T_3}$$

$$= 0.71(\mathrm{T}_3 - 1013) + \frac{12\times10^{-5}}{2}(T_3^2 - 1013^2)$$

$$= 0.00006\,\mathrm{T}_3^2 + 0.71\,\mathrm{T}_3 - 1617.8$$

Solving we get T_3=1955.6 K

$$\therefore \text{Maximum pressure} = 36.3 \times \frac{1955.6}{1013} = 70.1 \text{ bar}$$

(ii) $\mathrm{C}_\mathrm{p} = C_v + R = 1.003 + 12\times10^{-5}T$

$$\mathrm{Q}_{34} = m\int_{T_3}^{T_4} C_p\,dT = m\int_{T_3}^{T_4}(1.003 + 12\times10^{-5}T)\,dT$$

$$837 = 1\left[1.003\,\mathrm{T} + 12\times10^{-5}\frac{T^2}{2}\right]_{1864}^{T_4}$$

$$837 = 1.003(T_4 - 1864) + 0.00006(T_4^2 - 1955.6^2)$$

$$= 1.003\,T_4 + 0.00006\,T_4^2 - 3028$$

$$0.00006\,T_4^2 + 1.003\,T_4 - 3865 = 0$$

Solving we get, T_4=2611 K

$$\frac{v_4}{v_3} = \frac{T_4}{T_3} = \frac{2611}{1955.6} = 1.335$$

$$\text{Cut-off} = v_4 - v_3 \qquad , \frac{V_1}{V_2} = 13$$

% of stroke at which cut off occurs $= \dfrac{v_4 - v_3}{v_1 - v_2}$

$$= \frac{1.335\,v_3 - v_3}{13\,v_2 - v_2} = \frac{(1.335 - 1)v_2}{12\,v_2} = 2.793\%, \qquad (V_3 = V_2)$$