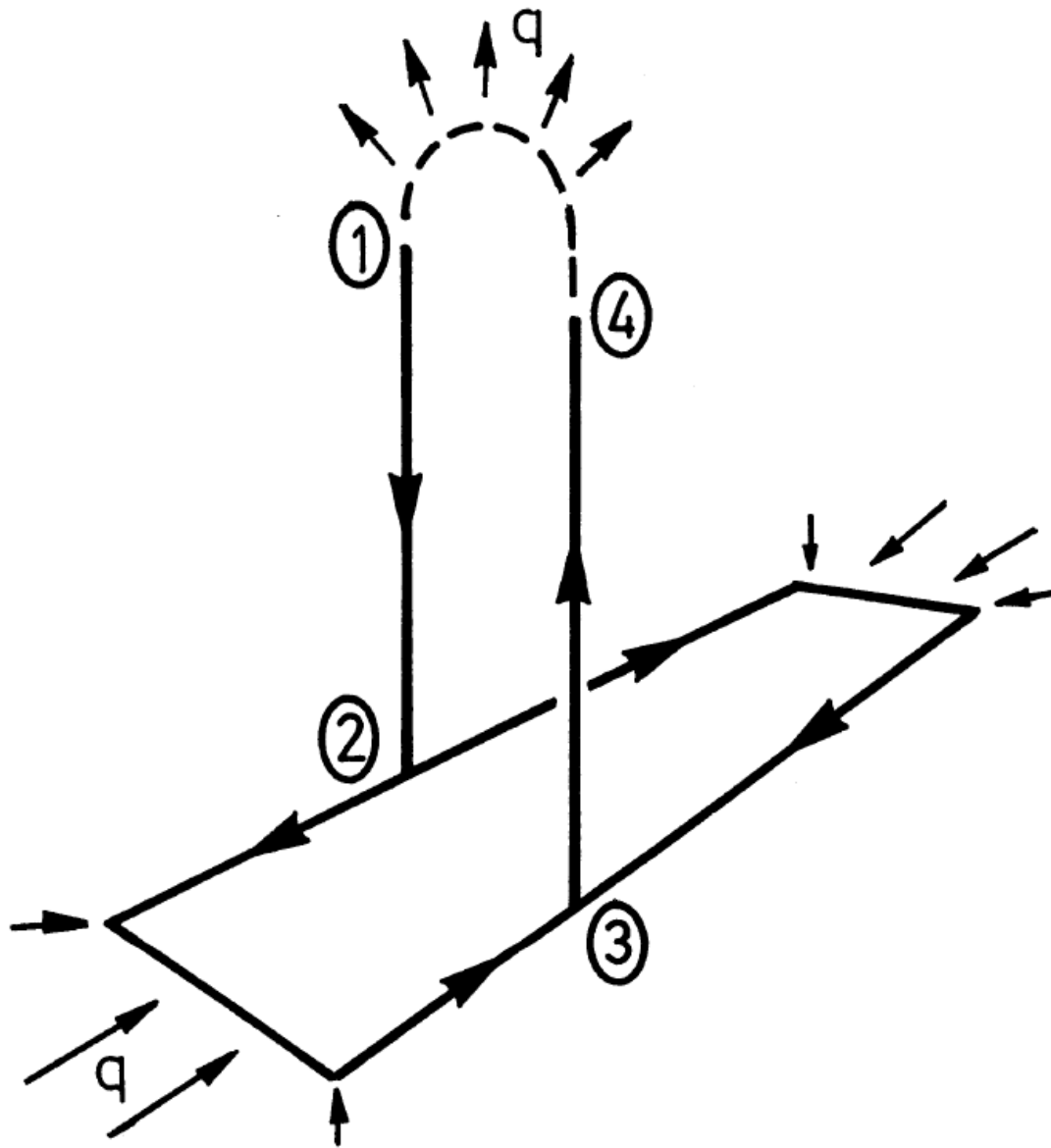# MINE VENTILATION THERMODYNAMICS

Thermodynamic considerations of mine ventilation

- The thermodynamic approach developed by Baden Hinsley (1950-51).

- **The mine-ventilation system can be compared to a gigantic heat engine with the following cycle:**

a. Air descending the downcast shaft undergoes auto-compression, as a result of which its pressure and temperature increase and specific vol. decreases.

b. As air travels through the mine workings, heat is added from rocks to the hot and compressed air, thus increasing its temperature. As a result, its specific vol. increases, but pressure decreases.

c. In upcast shaft, auto-expansion leads to increase in its specific vol., but pressure and temp. fall.

d. Finally, heat is rejected by the air to the atmosphere and the air returns to the atmospheric condition of pressure, specific volume and temperature thus completing the cycle.

Elements of closed cycle of thermodynamic processes of underground mine ventilation

Baden Hinsley (1900-1988)
Realized that mine ventilation system is indeed a gigantic heat engine consisting of following cycles:

Downcast shaft: Air enters the system/mine and is compressed and heated by gravitational energy.

Mine workings: More heat is added to the air from the strata, machines, and other sources.

Upcast shaft: Air expands during its ascent.

Surface: Exhaust air cools to the original entry temp. & press. condition, closing the cycle

- **Adiabatic processes occur in the shafts, and expansion occurs at constant pressure through the workings.**

  [Adiabatic process is a thermodynamic process where no heat is exchanged between a system and its surroundings. This can occur due to rapid changes (like a sudden compression or expansion) or because the system is perfectly insulated. Changes in internal energy are solely due to work done on or by the system, not heat transfer.]

- **An indicator diagram can be plotted for the mine ventilation system on *P-V* (pressure-specific vol.) coordinates.**
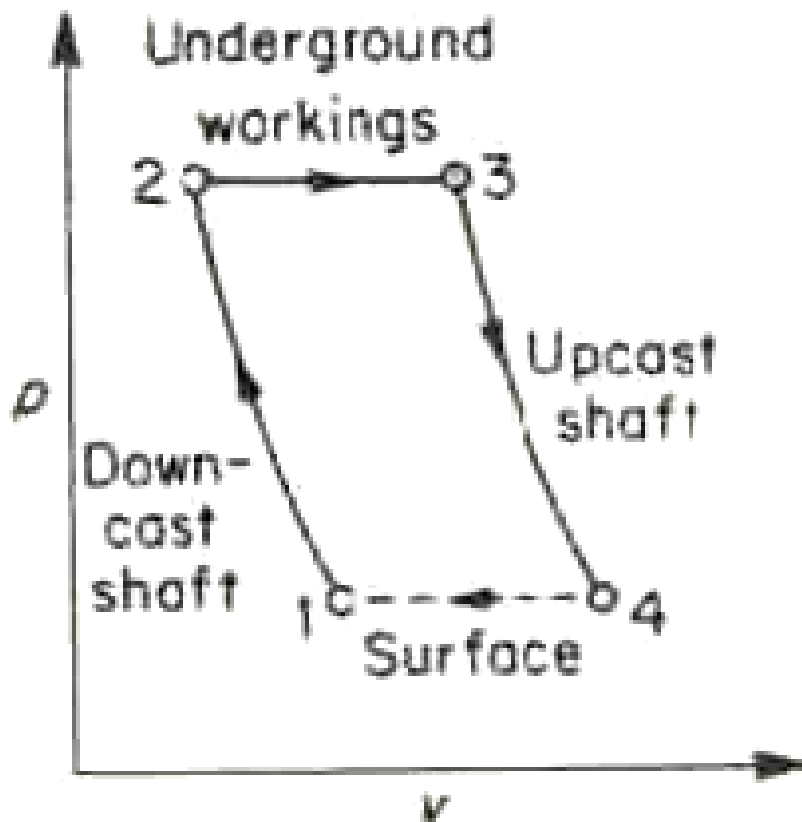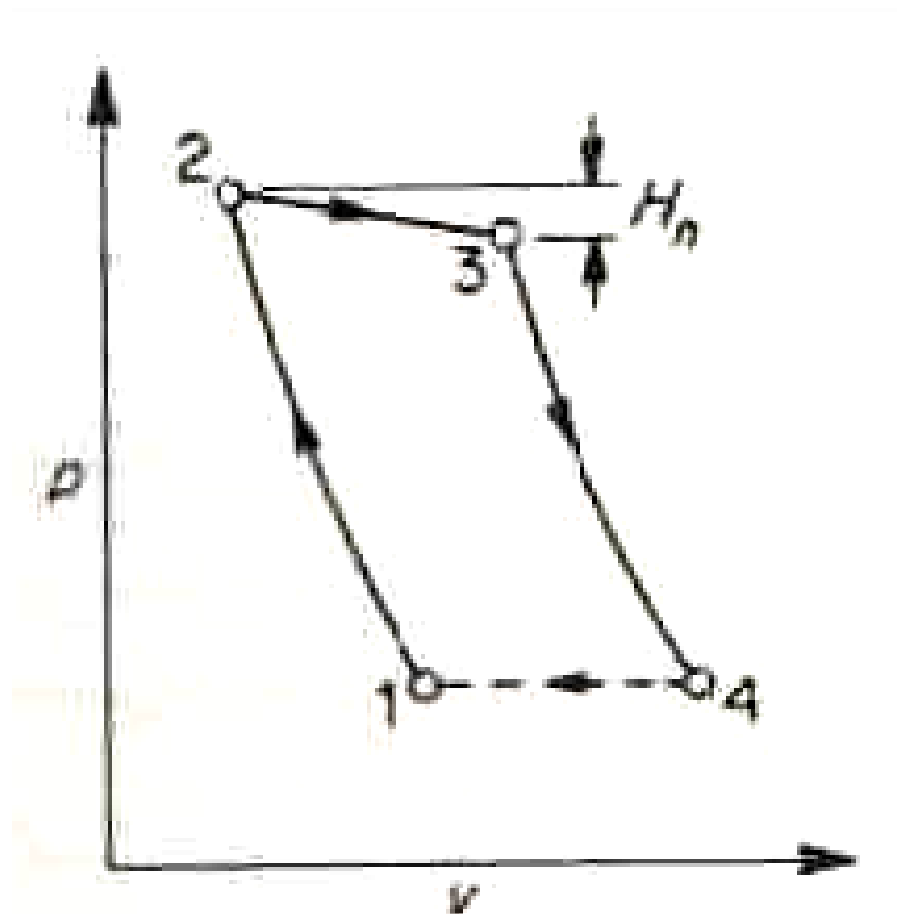

Fig. Indicator diagram for mine ventilation system
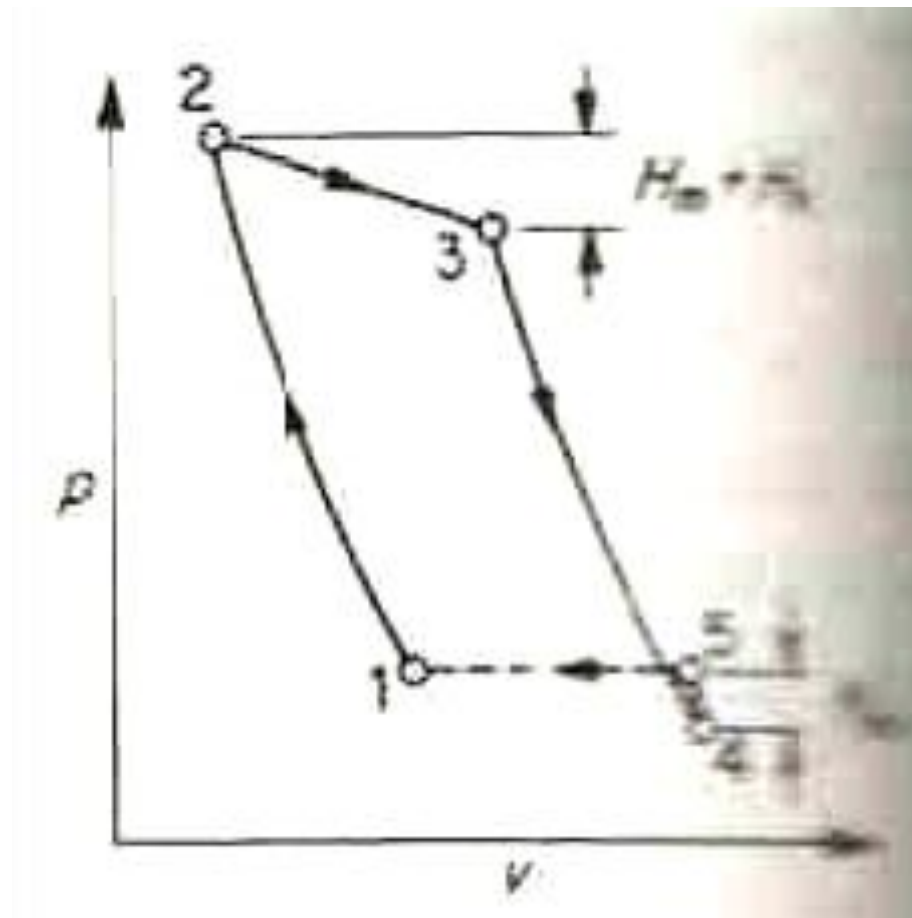
Case I: Mine ventilated by natural means only

- The actual cycle for a mine with natural ventilation only shown in Fig.

- The pressure difference between points 2 and 3 is equal to the natural ventilation head Hn, neglecting head loss in shafts.

Case II: Mine ventilated by fan plus natural means

Diagram for a mine with combined fan and natural ventilation is shown in figure.

In this case, the natural ventilation head is equal to the pressure difference between points 2 and 3 less the fan head Hm.

The work of natural ventilation

Fig. *P-V* indicator diagram for a naturally ventilated mine

Consider a unit mass of dry air entering the downcast shaft and undergoes auto-compression.

Assuming no heat or moisture exchange between the shaft wall and air, the process of auto-compression is a frictional adiabatic (Curve AB).
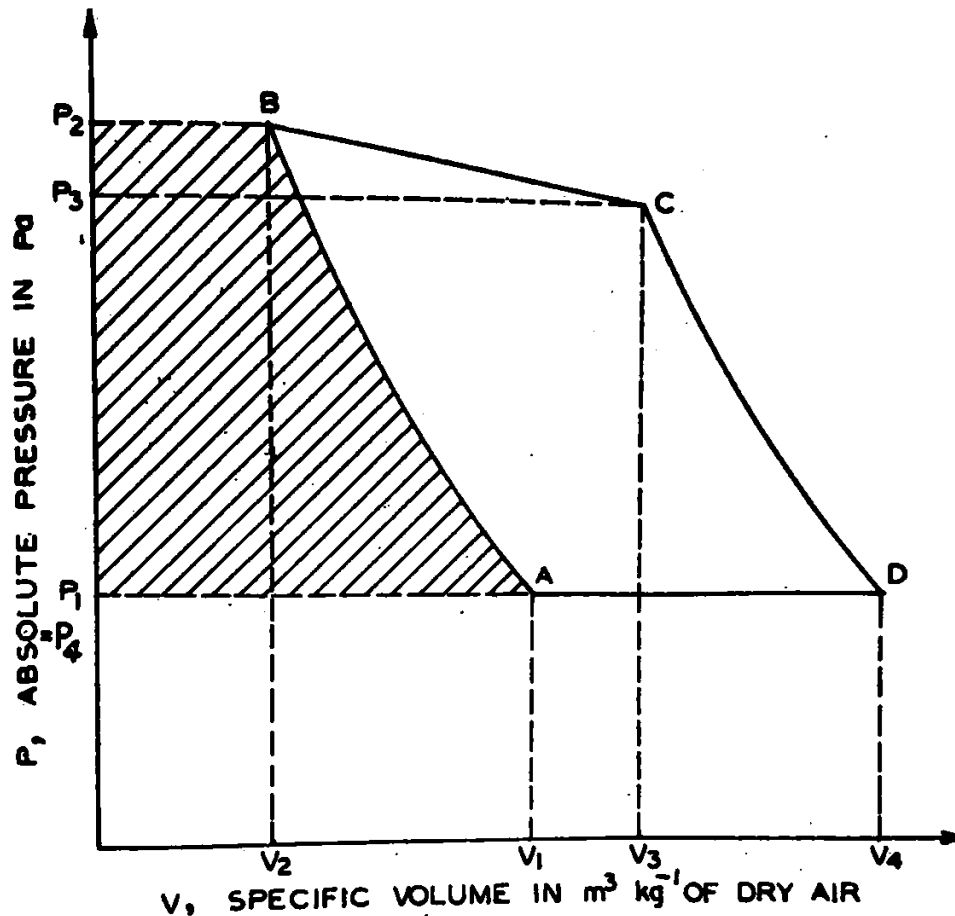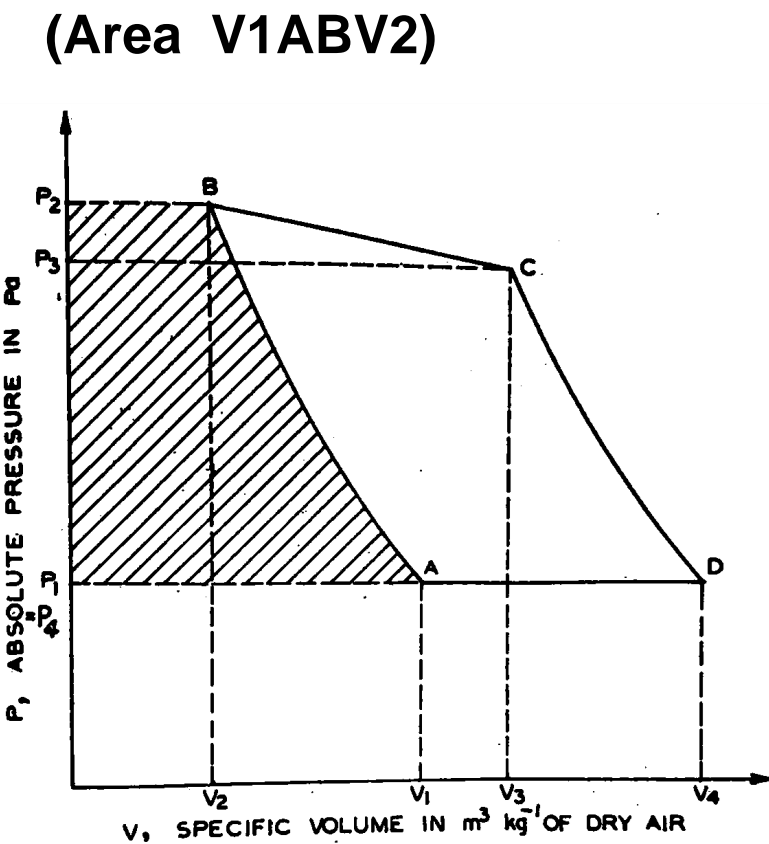
- The flow work of air entering the shaft

$$W_{fli} = P1V1 \qquad \text{(area OV1AP1)}$$

- The work done on the air by auto-compression

$$W_c = \int_{1}^{2} P \, dV \qquad \text{(Area V1ABV2)}$$

- The flow work out of the shaft

$$W_{flo} = - P2V2 \qquad \text{(area OV2BP2)}$$

- **The total work done on the air in downcast shaft**

$$W_{dc} = W_{fli} + W_c + W_{flo} = P1V1 + \int_1^2 PdV - P2V2 = - \int_1^2 V.dP \quad \text{(area P2BAP1)}$$

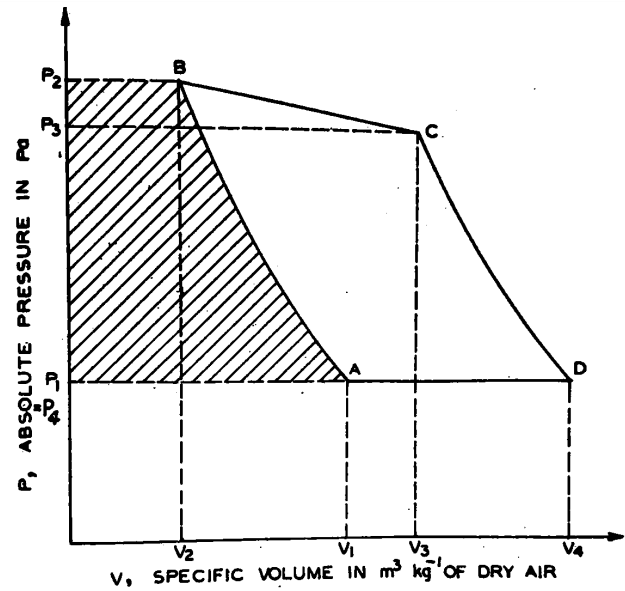Note: since the work is one of compression done on the air it is –ve

∫d(PV) = ∫PdV + ∫VdP ,   Also   ∫d(PV) = P2V2 – P1V1

Hence ∫PdV + ∫VdP = P2V2 – P1V1

Or   P1V1 + ∫PdV – P2V2 = - ∫VdP

Where
P = absolute pressure of air
V = specific vol. (vol. per unit mass)

- **Similarly, work done on the air in mine workings**
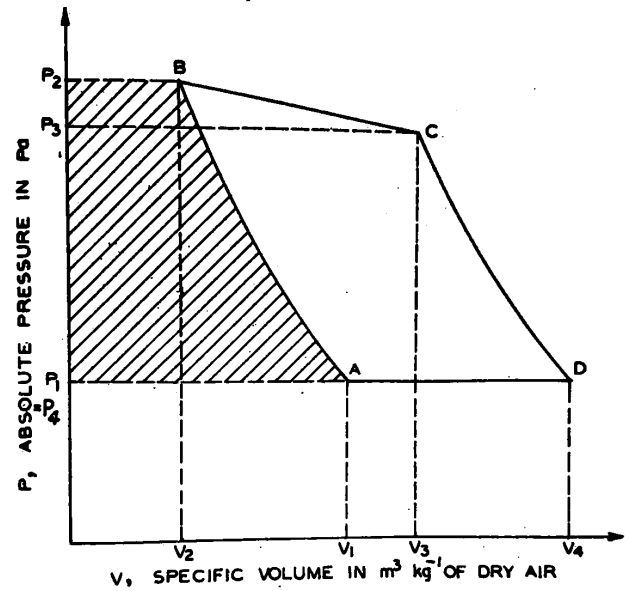
$$W_w = - \int_2^3 V.dP \qquad \text{(area P2BCP3)}$$

- **Work done on the air in upcast shaft**

$$W_{uc} = - \int_3^4 V.dP \qquad \text{(area P3CDP4)}$$

P, ABSOLUTE PRESSURE IN Pa

V, SPECIFIC VOLUME IN m³ kg⁻¹ OF DRY AIR

- **Total work done on the air in the mine**

$$Wt = Wdc + Ww + Wuc = -\int_{1}^{2} V.dP \quad -\int_{2}^{3} V.dP \quad -\int_{3}^{4} V.dP$$
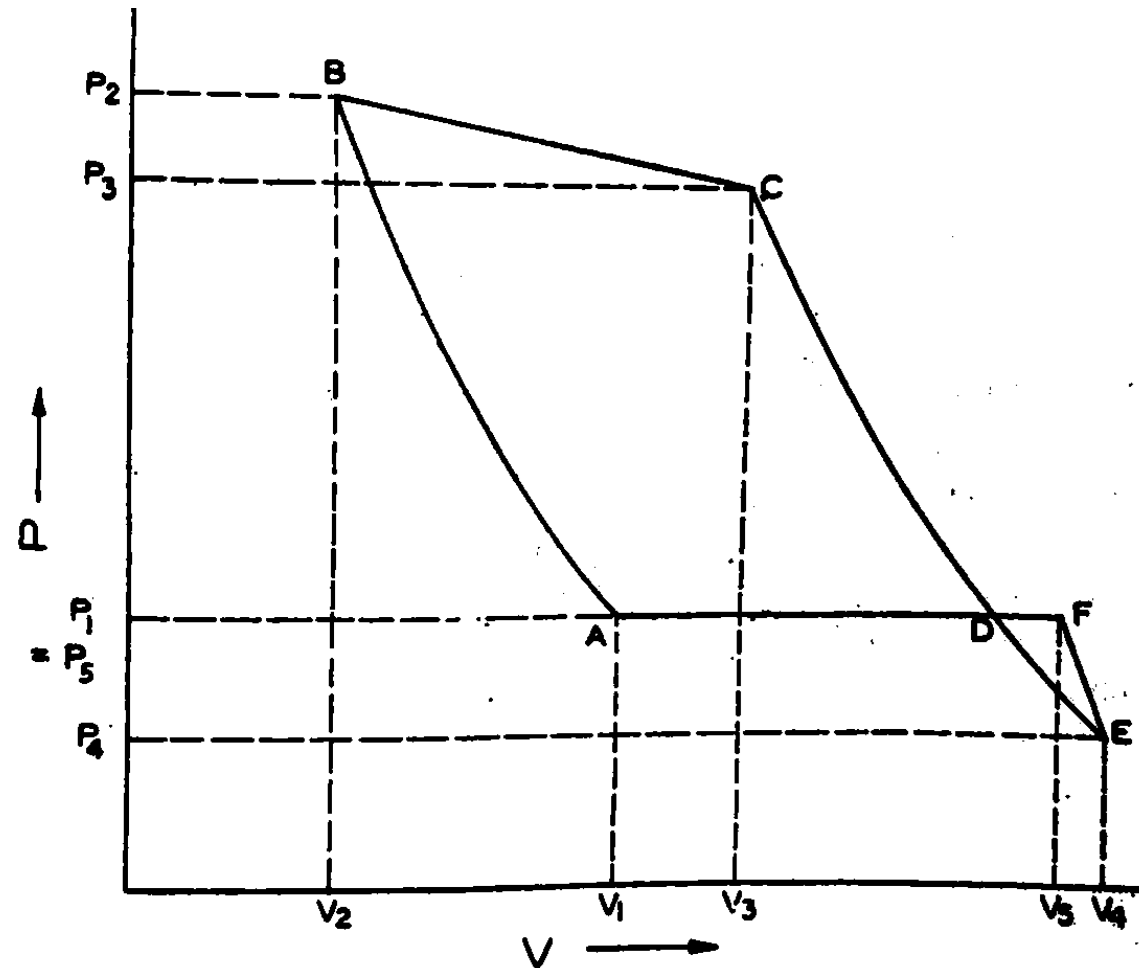
(area ABCD)

P1 is taken equal to P4 since the upcast and downcast shaft-tops are assumed at the same elevation.

When there is no external work done on the air (i.e. there is no fan in the ventilation system), the above work is the work of natural ventilation due to addition of heat in the mine workings

Work of natural ventilation with mechanical ventilation

- When mechanical ventilation aiding natural ventilation, the P-V diagram becomes as in Fig.

- Considering the exhaust fan at the top of the upcast shaft, the expansion curve CD extends down to E.

- In other words, the pressure of air at the top of the upcast shaft P4 is no longer equal to P1 but less than P1.

- P1 – P4 = the depression created by the fan

- The air is however, compressed back by the fan to P1, the atmospheric pressure, the compression following the curve EF.

Fig. *P-V* indicator diagram with fan ventilation

- The total work done by natural agency as well as the fan

$$= -\int_{1}^{2} V.dP \ - \int_{2}^{3} V.dP \ - \int_{3}^{4} V.dP \qquad \text{[given by area P1ABCDEP4]}$$

- Out of which work done by the fan alone Wf $= -\int_{4}^{5} V.dP$

[given by area P1FEP4]

- So the work done by N.V.P. is given by the area ABCD – DEF

- But since the area DEF is very small, it can be neglected and the N.V.P. will then be calculated from the work done as represented by the area ABCD only.

Determination of N.V.P from P-V diagram

- Accuracy of determination of NVP from P-V diagram of the mine depends on how accurately the P-V diagram is plotted.

- An exact plot of P-V diagram can be made

  – from actual measurement of the absolute pressure by an aneroid barometer and

  – estimation of apparent specific vol. of air from barometric and hygrometric readings using the following equation:

$$V = 287.1 \, T \, / \, [1000 \, (B - e)] \ m^3/kg$$

Where

B = barometric pressure, kPa

e = vapour pressure, kPa

T = temp. in K

- The area of indicator loop on the P-V diagram gives the power of natural ventilation.

- Dividing it by a reference specific vol. of air (usually at the fan inlet) gives the N.V.P.