LECTURE – 2

THE CONTENTS OF THIS LECTURE ARE AS FOLLOWS:

1.0 DETERMINATION OF NATURAL VENTILATION PRESSURE FROM THERMODYNAMIC PRINCIPLE

2.0 NATURAL VENTILATION ALONG WITH MECHANICAL VENTILATION

3.0 NVP DETERMINATION FROM PV- DIAGRAM

REFERENCES

1.0 DETERMINATION OF NATURAL VENTILATION PRESSURE FROM THERMODYNAMIC PRINCIPLE

When air moves down the downcast shaft, it undergoes auto-compression. Because of auto-compression, its pressure and temperature increase whereas there is a decrease in the specific volume as PV = Constant. Specific volume is defined as the volume per unit of mass.

As this hot (high temperature) and compressed (high pressure) air moves in the mine workings, heat is further added from the rocks thus further increasing the air temperature. Because of this, its specific volume increases but there is a decrease in its pressure as PV = Constant.

Auto-expansion of air takes place in the upcast shaft. This results in an increase in its specific volume and decrease in the pressure and temperature.

The rejection of heat by the air at low temperature to the atmosphere takes place which acts like a sink. Here the air again returns to the atmospheric condition of pressure, specific volume and temperature, thus completing the cycle.

Let there be a unit mass of dry air which enters the downcast shaft. This unit mass of air undergoes auto-compression in the downcast shaft. Let us assume that there is no exchange of heat or moisture between the walls of the shaft and the air. This process of auto-compression is a adiabatic process which can be represented as shown in Fig. 1.

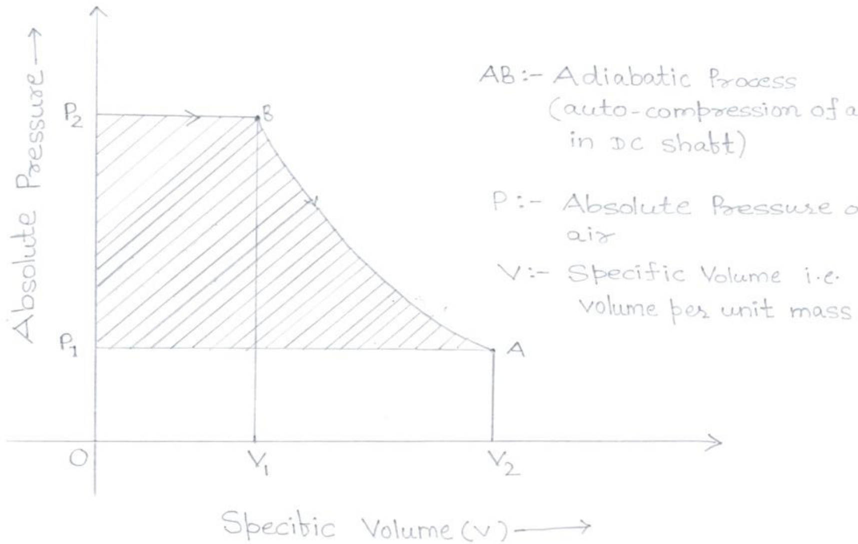

Fig. 1

The work associated with Kinetic energy at the entrance of the downcast shaft

W_{KEI} = P_1V_1 = Area OV_1AP_1

Work done on the air by auto-compression

W_{ac} = $\int_1^2 PdV$ = Area V_1ABV_2

The work associated with Kinetic Energy when the air is leaving the shaft

W_{KEO} = - P_2V_2 = Area OV_2BP_2

Therefore, Gross work done on the air in the downcast shaft

W_{DC} = W_{KEI} + W_{ac} + W_{KEO}

= P_1V_1 + $\int_1^2 PdV$ - P_2V_2

Now,

$$\int d(PV) = \int PdV + \int VdP$$

$\int dPV$ is also equal to $P_2V_2 - P_1V_1$

Therefore

$\int PdV + \int VdP$ = $P_2V_2 - P_1V_1$

$P_1V_1 + \int PdV - P_2V_2 = - \int VdP$

Subscripts 1 and 2 represent conditions at the downcast shaft top and downcast shaft bottom respectively.

Please note that

P = Absolute pressure of air

V = Specific volume i.e., volume per unit mass

Therefore,

$W_{dc} = - \int_1^2 VdP$ = Area P_2BAP_1

Similarly, the work done on the air in the mine workings

$W_w = - \int_2^3 VdP$ = Area P_2BCP_3

In similar lines, the work done on the air in the upcast shaft

$W_{uc} = - \int_3^4 VdP$ = Area P_3CDP_4

Here subscripts 3 and 4 give conditions at the upcast shaft bottom and top respectively.

Now, the total work done on the air in the mine

$W_t = W_{dc} + W_w + W_{uc} = - \int_1^2 VdP - \int_2^3 VdP - \int_3^4 VdP$ = Area ABCD

P_1 is taken equal to P_4 since the upcast and downcast shaft tops are assumed at the same elevation.

The PV diagram for a mine which is naturally ventilated is shown in Fig. 2.

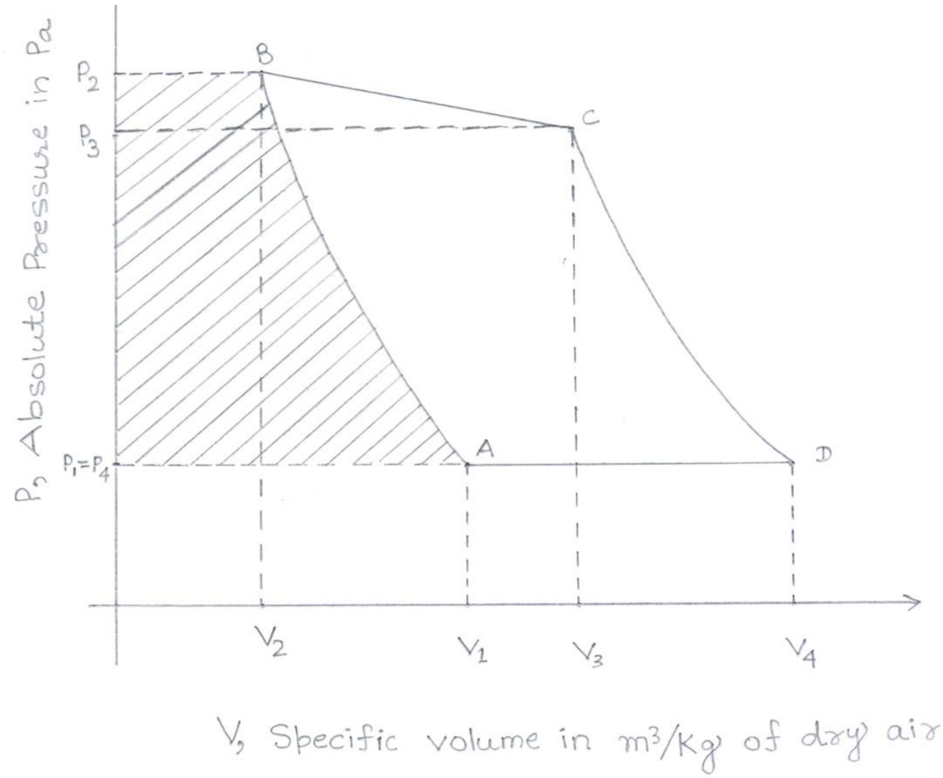

Fig. 2

When there is no external work done on the air or in other words, there is no fan in the ventilation system, the above work is the work of natural ventilation due to the addition of heat in the mine workings and it can be equated to changes in the potential and kinetic energy of air and the frictional work.

From the principle of general energy balance,

$$-\int_1^2 VdP = (h_2 - h_1)\,g + \frac{V_2^2 - V_1^2}{2} + F_{1\text{-}2} \text{ -----------------------(1)}$$

$$-\int_2^3 VdP = (h_3 - h_2)\,g + \frac{V_3^2 - V_2^2}{2} + F_{2\text{-}3} \text{ -----------------------(2)}$$

$$-\int_3^4 VdP = (h_4 - h_3)\,g + \frac{V_4^2 - V_3^2}{2} + F_{3\text{-}4} \text{ ----------------------(3)}$$

Where,

h = Elevation above a certain datum

V = Velocity of air

F = Frictional work

g = Acceleration due to gravity

When we combine equations (1), (2) and (3), we get,

$F_{1-2} + F_{2-3} + F_{3-4}$

$= (h_1 - h_2)\, g - \frac{V_2^2 - V_1^2}{2} - \int_1^2 VdP + (h_2 - h_3)\, g - \frac{V_3^2 - V_2^2}{2} - \int_2^3 VdP + (h_3 - h_4)\, g - \frac{V_4^2 - V_3^2}{2} - \int_3^4 VdP$ ------------------------------------(4)

Neglecting the kinetic energy terms in equation (4) and assuming

$h_2 = h_3$ and $h_1 = h_4$ we get

$F_{1-4} = - \int_1^2 VdP - \int_2^3 VdP - \int_3^4 VdP = W_t$ -------------(5)

Till now we have considered flow of dry air. If in the mine airway, moisture is added, the energy balance equation has to be modified to take into account the changes in potential energy of moisture in addition to the changes in potential and kinetic energy of air and the frictional work. Thus we can write,

$- \int_1^2 VdP = (h_2 - h_1)\, g + g\int_1^2 0.001\, mdh + \frac{V_2^2 - V_1^2}{2} + F_{1-2}$ ------------------------(6)

$- \int_2^3 VdP = (h_3 - h_2)\, g + g\int_2^3 0.001\, mdh + \frac{V_3^2 - V_2^2}{2} + F_{2-3}$ ------------------------(7)

$- \int_3^4 VdP = (h_4 - h_3)\, g + g\int_3^4 0.001\, mdh + \frac{V_4^2 - V_3^2}{2} + F_{3-4}$ -----------------------(8)

Therefore,

$F_{1-4} = - \int_1^2 VdP - \int_2^3 VdP - \int_3^4 VdP - g\int_1^2 0.001\, mdh - g\int_3^4 0.001\, mdh$

Since $g\int_2^3 0.001\, mdh = 0$ for $h_2 = h_3$

In the above equation,

m = Mixing ratio in g/kg of dry air

V = Apparent specific volume of moise air i.e., volume of moist air per unit mass of dry air

2.0 NATURAL VENTILATION ALONG WITH MECHANICAL VENTILATION

If natural ventilation is aiding mechanical ventilation, the PV – diagram takes the shape as shown in Fig. 3. Now let us consider the case with an exhaust fan located at the top of the upcast shaft. In this case, the expansion curve CD extends down to E. In other words we can say that, the pressure of air at the top of the upcast shaft P_4 is not equal to P_1. In fact it is less than P_1. The depression created by the fan is $P_1 - P_4$.

The air is compressed back by the fan to P_1 i.e., atmospheric pressure. This compression is indicated by the curve EF. It is important to note that EF is slightly steeper than CE because of the extra work done against the internal friction of the fan.

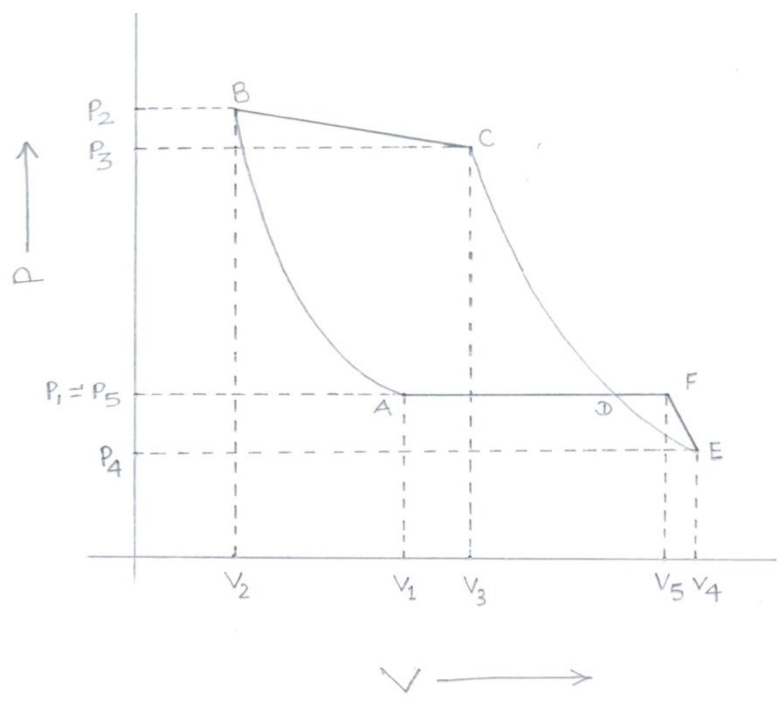

Fig. 3

From Fig. 3 we observe that,

The total work done by natural ventilation as well as fan

$= -\int_1^2 VdP - \int_2^3 VdP - \int_3^4 VdP$ = Area $P_1ABCDEP_4$

The total work done by the fan alone =$-\int_4^5 VdP$ = Area P_1FEP_4

Therefore the work done by NVP = Area (ABCD – DEF)

DEF being very small can be neglected.

Therefore, NVP = Work done as represented by the area ABCD

Energy equation for the compression of air in the fan

$-W_f = \int_4^5 VdP$ --------------------------------------(9)

The above equation has been arrived by neglecting the frictional work in the fan and change in potential and kinetic energy of air across the fan.

Equation (9) can be added to equations (6), (7) and (8) to get the general energy equation for the whole process (neglecting changes in kinetic energy) which can be written as

$F_{1-4} = -\int_1^2 VdP - \int_2^3 VdP - \int_3^4 VdP - \int_4^5 VdP - g\int_1^2 0.001\, mdh - g\int_3^4 0.001\, mdh - W_f$ -----(10)

3.0 NVP DETERMINATION FROM PV – DIAGRAM

Accurate determination of NVP from PV diagram of a mine depends on how accurately, the PV diagram is plotted. In case of existing mines, an exact plot of PV diagram can be made:

- By actual measurement of the absolute pressure by an aneroid barometer

- From estimation of apparent specific volume through barometric and hygrometric readings

In case of significant addition of gases in the mine, the apparent specific volume should take into consideration the partial pressure of these added gases also. In general, addition of lighter gases (e.g., methane) increases the specific volume where as that of heavier gases (like CO_2) decreases the specific volume. An extra work is done in lifting the additional amount of gas in the upcast shaft and equation (10) can be modified to take this into account.

$F_{1\text{-}4}$ =

$$- \int_1^2 VdP - \int_2^3 VdP - \int_3^4 VdP - \int_4^5 VdP - g\int_1^2 0.001\, mdh - g\int_3^4 0.001\, mdh - W_f - m'g\,(h_4 - h_3)$$

In the above equation, m' = mass of gas added in kg/kg of dry air

Power of natural ventilation = Area of indicator loop on the PV – diagram

$$\text{Natural ventilating Pressure} = \frac{\text{Area of indicator loop on the PV – diagram}}{Reference\ specific\ volume\ of\ air\ (usually\ at\ fan\ inlet)}$$

The PV – diagrams discussed earlier are the usual shape of the PV – diagram in case of level workings. However, this may not always be the case. There may be dip and rise workings in the mine too. With dip and rise workings, the curve BC does not drop uniformly but forms a loop as shown in Fig. 4. In this figure, BXC is for dip workings and BYC is for rise workings. Because of additional generation of natural ventilation power in dip workings, the area of the indicator loop increases while it decreases in the case of rise workings.

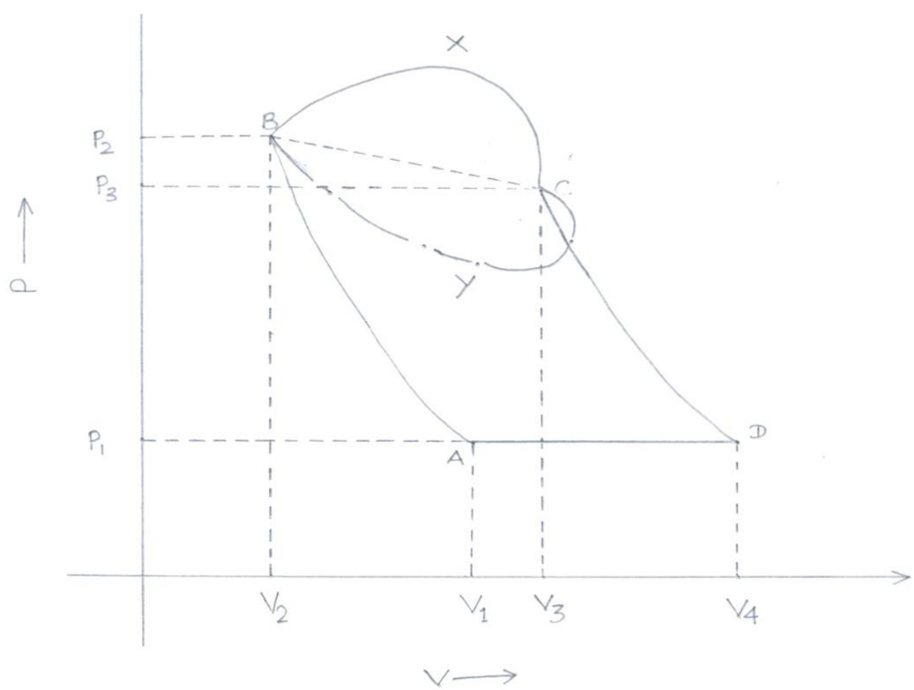

Fig. 4 Effect of dip and rise workings on natural ventilation

With change in air pressure sharply at any point in a mine like, across a regulator or a booster fan, there is also a change in the shape of the curve BC as shown in Fig. 5. The curve BMNC indicates a boosted district with MN representing the booster pressure. The curve BXYC indicates a regulated district with XY representing the pressure drop across the regulator.

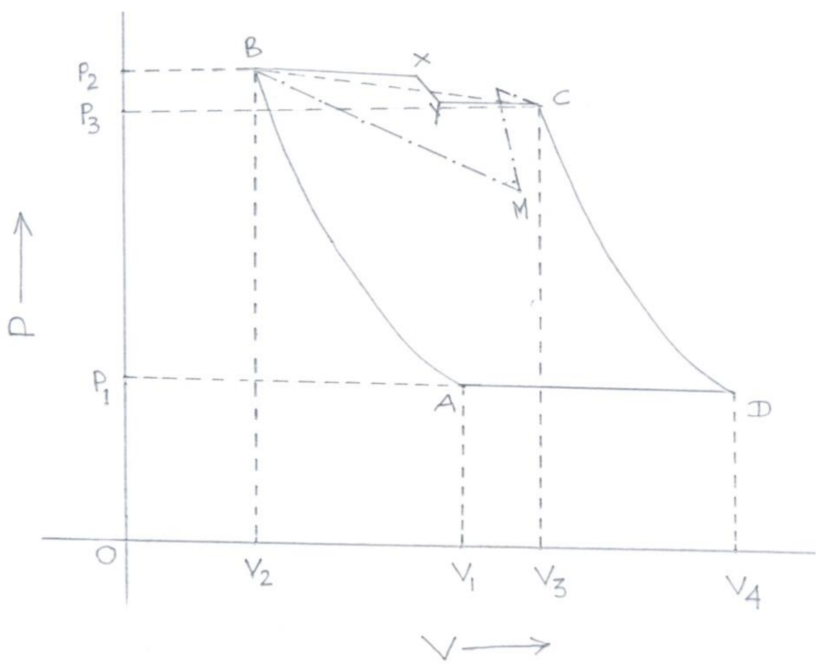

Fig. 5 Effect of regulators and boosters on natural ventilation

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