Letter To The Editor

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REMOVAL OF SOLUBLE GASEOUS AIR POLLUTANTS BY FOG

1. Introduction

It is recognised that air pollutants are removed by rain and thus air gets cleaned. But it appears from the literature on the subject that fog is not recognised as a remover of pollution. Just as falling rain washes out some soluble as well as insoluble matter from air, settling fog particles may also be regarded as doing similar work. But as the trajectory of a settling fog droplet is uncertain, no quantitative equation regarding such a process can be developed as done for washing out process by the falling raindrops (Mukherjee 1956). However, soluble gaseous pollutants appear to dissolve more due to the hitting of gas molecules (because of their kinetic motion) with the fog droplets rather than due to sweeping out of the molecules by them. The purpose of the present note is to consider theoretically the removal of soluble gaseous pollutants by fog droplets.

2. Concentration and particle size

It is well known that the rate of condensation on a droplet of radius r is given by—

$$\frac{dm_r}{dt} = 4\pi k_1 r \triangle p \tag{1}$$

(assuming the density of water to be unity), where

m_r = the mass of the droplet,

k_1 = Diffusion coefficient of water vapour, and

$\triangle p$ = Difference between ambient vapour pressure and that over the droplet.

Rate of dissolution of a gaseous pollutant is proportional to the surface area of the droplet in which it dissolves and the mass μ of gas striking unit area,

$$\text{Thus} \quad \frac{dS_r}{dt} = A\mu \, 4\pi r^2 \tag{2}$$

where, A = or < 1

$$\text{Now,} \quad m_r = \frac{4}{3}\pi r^3 \tag{3}$$

The concentration, of the dissolved gas in the droplet is given by

$$C_r = S_r / m_r \tag{4}$$

Therefore,

$$\frac{dC_r}{dr} = \frac{d}{dr}\left(\frac{S_r}{m_r}\right)$$

$$= \frac{1}{m_r} \cdot \frac{dS_r}{dr} - \frac{S_r}{m_r^2} \cdot \frac{dm_r}{dr}$$

$$= \frac{1}{m_r}\left\{\frac{dS_r}{dt} \cdot \frac{dt}{dm_r} \cdot \frac{dm_r}{dr} - \frac{S_r}{m_r} \cdot \frac{dm_r}{dr}\right\}$$

Substituting the values from equations (1) to (4) in the above formula we get,

$$\frac{dC_r}{dr} = \frac{1}{m_r}\left\{\frac{A\mu \, 4\pi r^2}{4\pi k_1 r \triangle p} - C_r\right\}\frac{dm_r}{dr}$$

$$= \frac{3}{r}\left\{\frac{A\mu r}{k_1 \triangle p} - C_r\right\}$$

$$= \frac{3A\mu}{k_1 \triangle p} - \frac{3C_r}{r} \tag{5}$$

In the initial condition the concentration of pollutants in air is large and so far the value of μ is high. Again we know that in the presence of sufficiently high concentration of nuclei, condensation takes place even before the attainment of 100 per cent humidity. Under such conditions, the value of $\triangle p$ may be assumed to be very small. Thus in the initial condition of the formation of fog particles, the first term on the right hand side of equation (5) will be much greater than the second which, as an approximation, may be neglected.

Then $$\frac{dC_r}{dr} \approx \frac{3A\mu}{k_1\triangle p} \qquad (6)$$

or $$C_r = \frac{3A\mu r}{k_1\triangle p} + a \qquad (7)$$

where a is a constant.

The equation (7) shows that when the fog starts forming, the bigger particles become concentrated and smaller particles dilute.

3. Calculation of concentration

Let us assume that a fog is formed when the atmospheric pressure is 1000 mb, the air temperature is 10°C and the sulphur dioxide content is 2 parts per million. Let us also assume that the liquid water content of the fog is 0·3 gm per cubic metre and that the drops are of uniform size of 10 micron radius.

The mass of any gas striking unit area is given by the formula (Mukherjee 1957)

$$\mu = \frac{3}{13}\,\rho\sqrt{\frac{8RT}{\pi M}} \qquad (8)$$

Where ρ is the density of the gas at absolute temperature T, and M is its molecular weight. On calculation it is found that 0·194 gm of sulphur dioxide should strike the particles in a cubic metre whereas the actual amount of the gas is only $0 \cdot 472 \times 10^{-2}$ gm per cubic metre. As sulphur dioxide is readily soluble, even at 10 per cent collection efficiency we get that the whole of the gas should dissolve in the fog particles almost instantaneously. Thus we conclude that the whole of the sulphur dioxide in air goes to solution from the gaseous state probably at the time of formation. The concentration of the gas will be 0·157 gm per kgm of water.

4. Removal of pollutant

The fog particles are heavy and, therefore, should settle down under the action of gravity. The decrease in number of droplets of radius r due to gravity settling is given by Sinclair (1952) as

$$-dn_r = n_r \cdot \frac{v_r}{h}\,dt \qquad (9)$$

where n_r is the number of the particles, v_r the fall velocity and h the height of fall in time dt. Again v_r is given by Stokes' law as

$$v_r = 1 \cdot 20 \times 10^6\,\rho_1\,r^2 \qquad (10)$$

where ρ_1 is the particle density. Thus the rate of settling due to gravity is proportional to the square of radius of the fog particles.

We see from equation (7) that the bigger droplets are concentrated and from equations (9) and (10) that they settle much more quickly than the smaller ones. Thus, it is seen that fog settles down a good part of soluble air pollutant from the lower atmosphere.

It is a common experience in the industrial areas of Calcutta that after the formation of fog the smell of sulphur dioxide increases. This may be due to the fact that sulphur dioxide gas remains stratified at all levels and when fog is formed, the bigger and concentrated particles settle down quickly towards the ground due to gravity. Thus the concentration of sulphur dioxide (now in dissolved state no doubt) increases rapidly near the ground. Inhabitants, who reside near the ground, thus experience an increase in sulphur dioxide concentration.

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