Research Note

MATHEMATICAL MODEL FOR SEPARATION OF SUBMICRON PARTICLES FROM GAS STREAM IN A CONDUIT TYPE SCRUBBER

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Abstract A mathematical model has been developed for the prediction of the collection efficiency of submicron particles in the conduit type scrubber. The model has been tested with the data in the literature [1, 3].

چکیده   یك مدل ریاضی برای پیش‌بینی راندمان جذب ذرات زیر میکرونی در یك شوینده کانالی ارائه گردیده است. مقایسه مدل
اطلاعات موجود در منابع (۱ و ۳) کارآیی مدل را بخوبی نشان می‌دهد.

Because of the simplicity, high collection efficiency and low cost, atomizing scrubbers have been widely used for small particle removal from gas and are very important types of air pollution control devices. The inertial impaction is the force effective in scrubbers. In this mechanism particles are collected because of large difference between gas (particles) and droplets velocities.

MATHEMATICAL MODEL

To develope a mathematical model for the prediction of collection efficiency of conduit type scrubber, material balance for dust over the differential element of Figure 1 provides:

$$V_g C A - V_g (C + \Delta C) A = \frac{3 V_r Q_w C \eta_D}{2 D V_D} \Delta Z \qquad (1)$$

This equation can be rearranged to give:

$$\frac{dC}{C} = - \frac{Q_w}{Q_g} \frac{V_r}{V_D} \frac{\eta_D}{D} dZ \qquad (2)$$

where η_D is the collection efficiency on single drop as given by [1, 8]:

$$\eta_D = \left[\frac{k}{\quad}\right]^2 \ \& \ k = \frac{c' \rho_P d_P^2 V_r}{9 \mu_g D} \qquad (3)$$

In the previous works which have been published by Calvert [1], Calvert et al. [2], and Boll [6] drop diameters have been calculated from empirical correlation of Nukiyama and Tanasawa. [4] and it is assumed that this diameter is constant through the height of scrubber. Also they have assumed that: $|V_r| = f V_g$

In this work, the model takes into account the variation in the diameter of the drops due to the evaporation by using mass transfer correlations given by Bird et al. [12] which is:

$$\frac{dD}{\quad} = \frac{kg^* (Y_b - Y_D)}{\rho_s V_D} \qquad (4)$$

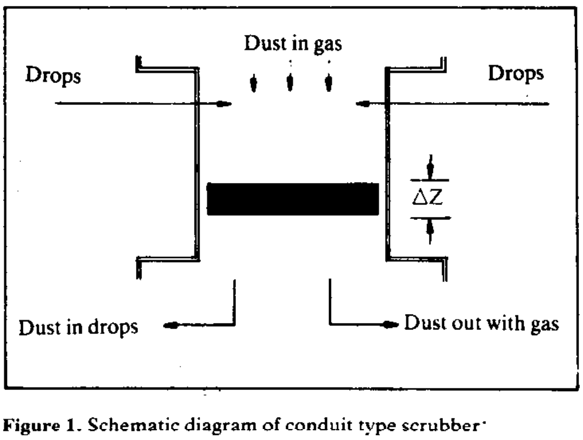

Figure 1. Schematic diagram of conduit type scrubber

where k_g^* is the mass transfer coefficient at high flux rate and is determined from analogy of heat and mass transfer correlations. V_D, the drop velocity, has been calculated from the force balance around a droplet.

$$\frac{dV_D}{dZ} = -\frac{165}{} \frac{\mu_D}{\rho_D D^2} \frac{V_r}{} \quad (5)$$

Substituting equation 5, 4 and 3 in equation 2 and rearrenging gives:

$$\frac{dC}{C} = -\frac{2}{55} \frac{Q_w}{Q_g} \frac{\rho_D D}{\mu_D} \left[\frac{\rho_p d^2 V_r}{(\rho_p d^2 V_r + 6.3 \mu_g D)} \right]^2 \cdot dV_D \quad (6)$$

The profile of penetration defined as the ratio of the outlet concentration to the inlet concentration of the particles can be obtained by solving equation 6, using experimental values of Q_W, Q_g and physical properties of the gas and liquid. The most convenient way of comparing experimental data with predicted values can be accomplished by plotting collection efficiency of scrubber($\eta = 1 - C_o/C_{in}$) versus gas and liquid flow rates.

CALCULATION PROCEDURE

For calculation of penetration profile for collection of submicron particles by the above equations, the scrubber was divided to several increments. In any differential element the drop diameter and drop velocity were calculated by equations 4 and 5, respectively and then equation 6 was solved by numerical integration to obtain penetration in terms of these parameteres and physical situation of the scrubber.

RESULTS AND DISCUSSION

The above equations have been solved for various conditions of water flow rate, gas velocity, particle diameter and height of scrubber. The effect of gas velocity at constant ratio of water to gas flow rate L (Gall/MCF) and the effect of this ratio at constant gas velocity for 0.1 - 1μm particles on the penetration at several heights of scrubber has been studied. The effect of change of drop diameter due to evaporation on the drop velocity and penetration has been investigated at several gas and water flow rates and psycrometric conditions of the gas.

Figure 2 represents the change in drop diameter due to the change of gas velocity. Inspection of this figure reveals that at a fixed gas velocity, the diameter of drop will decrease a significant amount for low values of L (liquid to gas flow rate). The effect of gas velocity on penetration at different values of L are shown in Figure 3 for 0.5 μm particles. The result shows that the low penetration which corresponds to higher efficiency will be obtained at higher gas velocities and higher values of L. The predicted values of efficiency from mathematical model are compared with the experimental data of Ekman and Johnstone [3] in Figure 4 and with theoretical model of Calvert [1] in Figure 5. As observed from these figures, the results of this model are in good agreement with experimental and other theoretical models.

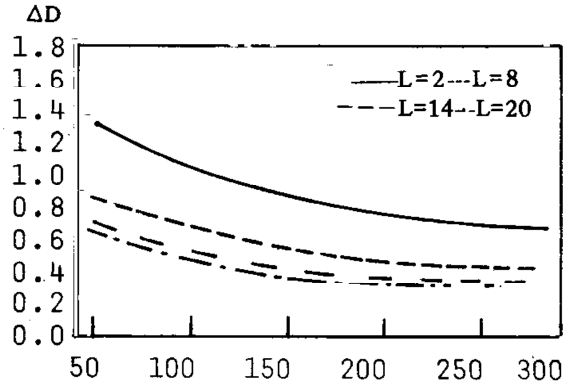

Figure 2. Evaporation of liquid phase, change of drop diameter

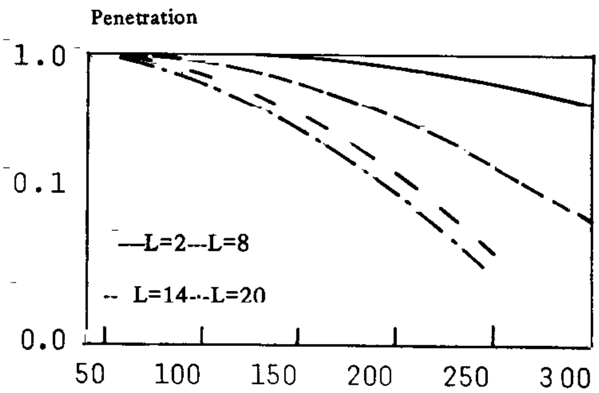

Figure 3. Penetration of 0.5 μm particles, Z = 10 cm

NOMENCLATURE

A = Area of scrubber (cm^2)
C = Concentration of pollutants in gas phase (gr/cm^3)
D = Drop diameter (μm)
d = Particle diameter (μm)
K = Inertial impaction parameter (dimensionless)
K_g^* = Mass transfer coefficient at high flux rate ($gr-mole/cm^2.sec$)

L = Ratio of water to gas flow rates (Gall/MCF)
V = Velocity (m/sec)
$V_r = V_g - V_D$
Y = Mole fraction of water vapor
Z = Height of scrubber (cm)

Greek symbols:

μ = Viscosity (gr/cm. sec), ρ = Density (gr/cm^3),
η = Efficiency

Subscripts

b = Bulk, D = Drop, d = Particle, g = Gas phase,
s = Spray, w = Water phase.

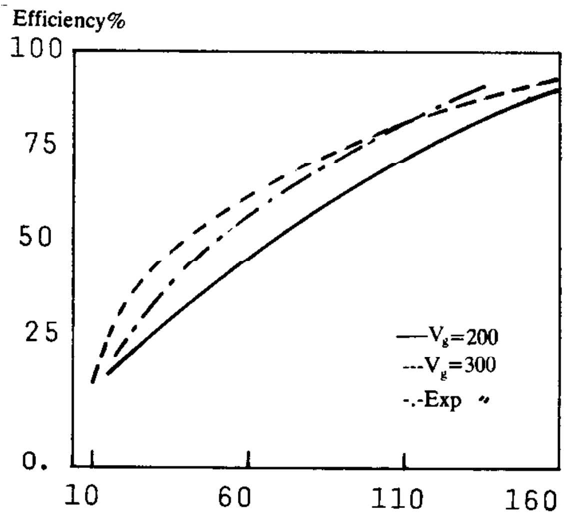

Figure 4. Gas velocity effect collection of 0.5 μm particles

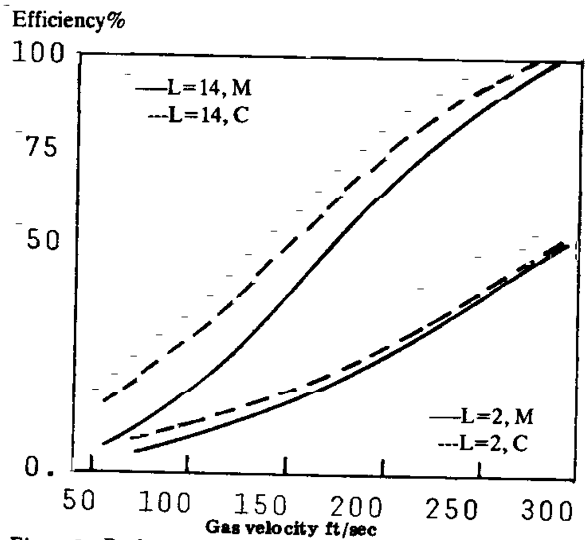

Figure 5. Performance of model M, this model & C, Calvert

REFERENCES

1- Calvert, S, *AIChE. J.* Vol. 16, No. 3, May (1970)

2- Calvert et. al, *J. Air. Poll. Cont. Assoc.* 22, 529 (1972)

3- Ekman and Johnstone, *Ind. Eng. Chem.*, 43, 1358 (1960)

4- Nukiyama and Tanasawa, *Trans. Soc. Mech. Eng.* (Tokyo) 43, 1358 (1938).

5- Hesketh, H. E. *J. Aerosol. Science.*, Vol. 24, No. 1, Oct (1974)

6- Boll, R, *Ind. Eng. Chem. Fundam.* Vol. 12, No. 1, (1973)

7- Dickinson R. D and W. R. Marshall. J. R,. *AIChE. J.* 14, 541 (1968)

8- Calvert, et. al, *J. Air. Poll. Cont. Assoc.* 27, 348 (1977)

9- Ranz and Marshall *Chem. Eng. Prog*, 48, 141 (1952)

10- Rowe, Claxton and Lewis, *Trans. Inst. Chem. Eng.* 43, T14 (1960)

11- Walton and Woolcock. *Intern. J. Air. Pollution*, 3, 129 (1960)

12- Bird, et. al, *John Wily and sons, Inc. New York* (1966)