Air Pollution Control and Design Handbook

(IN TWO PARTS)

PART 2

Edited by

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and

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PREFACE

Air pollution is a result of technological progress, and of human activities, intensified by the demands of twentieth-century life-styles, and given political, legal, and economic impetus by legislation and its enforcement in the last decade. Air pollution has been acknowledged as a disquieting phenomenon, and a widespread commitment has been made to control the problem. To be successful, such a commitment requires application of sound engineering practice, economics, and a spark of creativity. To succeed in controlling air pollution regardless of its source, the engineer needs to be able to manipulate the appropriate technologies.

This book addresses one of the major problems facing industry. Analysis and recommendations are presented in various problem areas by respective experts and stress practical aspects of pollution control engineering as related to air quality. The editors and contributors identify the major elements of the industrial air pollution situation. Adverse environmental impact will, of course, be dependent on the nature of a particular business, its raw materials, products, and processes.

From the large spectrum of technological possibilities, development of techniques to control air pollution from stationary sources has received great impetus and made rapid strides since enactment of federal and state air pollution laws. The threat of fine and plant shutdown in addition to social responsibilities have made manufacturing enterprises not only more cognizant of problems in this area but have goaded them to action.

Recent international events have included sharp increases in the prices of essential fuels, creating the widely perceived "energy crisis" which in turn has additionally exacerbated problems in air pollution control. Cheaper, more abundant fuels such as coal do not burn clean, so use of such fuels presents air pollution problems.

High priority and urgency have been assigned to vigorous programs in air pollution control.

This handbook is intended as a further step in closing the gap between knowledge and practice. Technological progress requires continual reexamination of priorities and experience. It is intended for use by experts and novices; engineers, managers, and students who are interested in learning the language, and as a reference for those who are faced with air pollution problems from stationary sources. The editors extend heartfelt thanks to their many friends in industry who cooperated and helped in the publication of this book.

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Chapter 24

PACKED TOWER AND ABSORPTION DESIGN

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Scrubbers used in air pollution control are available in a wide range of types and sizes. They are used mainly to eliminate one or more objectionable gaseous or particulate components from a gas stream. Their principle of design is based on mass transfer (diffusion), inertial impaction, or electrostatic attraction.

In mass transfer, gaseous components are dissolved in liquid. When gas and liquid are brought into intimate contact, the concentration gradient is established between two phases, and diffusion takes place. Objectionable components, higher in concentration in the gaseous phase, are transferred to the liquid phase, having a lower concentration. During this diffusion process, solute is transferred in liquid with or without chemical reaction.

THEORY

When fluid passes over a solid surface, its velocity at the surface of the solid is zero. The velocity of the fluid thus changes from that in the bulk stream to the solid surface across which it is flowing. The velocity rises sharply in a zone between the interface and a very small distance perpendicular to the solid interface. This small zone is called the laminar region. The fluid in the bulk

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stream can be in the turbulent region. The zone between the laminar and turbulent regions is known as the transition or buffer region.

Intimate contact between gas and liquid is established in the laminar region over solids known as packing. The laminar region consists of stagnant gas and liquid films. As diffusing fluid passes from the main stream, it has to pass through the main stream, buffer zone, and laminar regions.

Diffusion through the laminar film is on a molecular scale and is known as molecular diffusion. Molecules in gases move in random directions, and as they do so, they collide against each other. The resultant distance is, therefore, very small; hence, molecular diffusion is a slow process. If, on the other hand, the temperature of the gas is higher, molecules travel at a higher velocity and can cover larger distances, thereby increasing the rate of diffusion. At lower pressure, there is a greater distance between molecules; this can also increase the rate of diffusion.

The main concentration gradient is established in the laminar region, so the mechanism of gas absorption by diffusion is a molecular diffusion.

RATE OF DIFFUSION

At steady state, gas-gas molecular diffusion of component A from position 1 to position 2 through stagnant nondiffusing component B is given by

$$\frac{D_{AB}P_t}{RTZ_g P_{BM}} (P_{A_1} - P_{A_2}) \qquad (1)$$

where

D_{AB} = diffusivity (cm^2/sec or ft^2/hr)
R = gas constant (82.06 cm^3 atm/g mole) or 0.729 ft^3 atm/lb mole)
P_t = total pressure (atm)

T = temperature (K or R)
P_{BM} = log mean pressure of nondiffusing component B (atm)
Z_g = distance in direction of diffusion (cm or ft)
P_A, P_B = partial pressure of A or B (atm)
Subscripts 1, 2 indicate position

Estimation of D_{AB} for Gases

The Hirschfelder-Bird-Spotz [1] relation to estimate D_{AB} is

$$D_{AB} = \frac{0.0009292\, T^{3/2}[(1/M_A) + (1/M_B)]^{1/2}}{P(\gamma_{AB})^2[f(kT/\epsilon_{AB})]} \tag{2}$$

In this formula, D_{AB} is in square centimeters per second and T is in degrees Kelvin; γ_{AB} is the molecular separation at collision in angstroms [$= (\gamma_A + \gamma_B)/2$]; M_A and M_B are the molecular weights of components A and B, respectively; ϵ_{AB} is the energy of molecular interaction in ergs [$= (\epsilon_A \epsilon_B)^{1/2}$]; k is Boltzmann's constant (1.38×10^{-16} ergs/K); and $f(kT/\epsilon_{AB})$ is the collision function given in Fig. 24-1. Values of ϵ/k (K) and γ (Å) for common components are given in Table 24-1.

For components for which values of ϵ/k and γ are not given, the following empirical relations are recommended:

$$\frac{\epsilon}{k} = 0.77T_c \tag{3}$$

$$\frac{\epsilon}{k} = 1.15T_b \tag{4}$$

$$\frac{\epsilon}{k} = 1.92T_m \tag{5}$$

where T_c, T_b, and T_m are the critical temperature, boiling point temperature, and melting temperature, respectively, in degrees Kelvin; and

$$\gamma = 1.18V_o^{1/3} \tag{6}$$

where V_o is the molal volume given in cubic centimeters per gram mole of liquid at the normal boiling point.

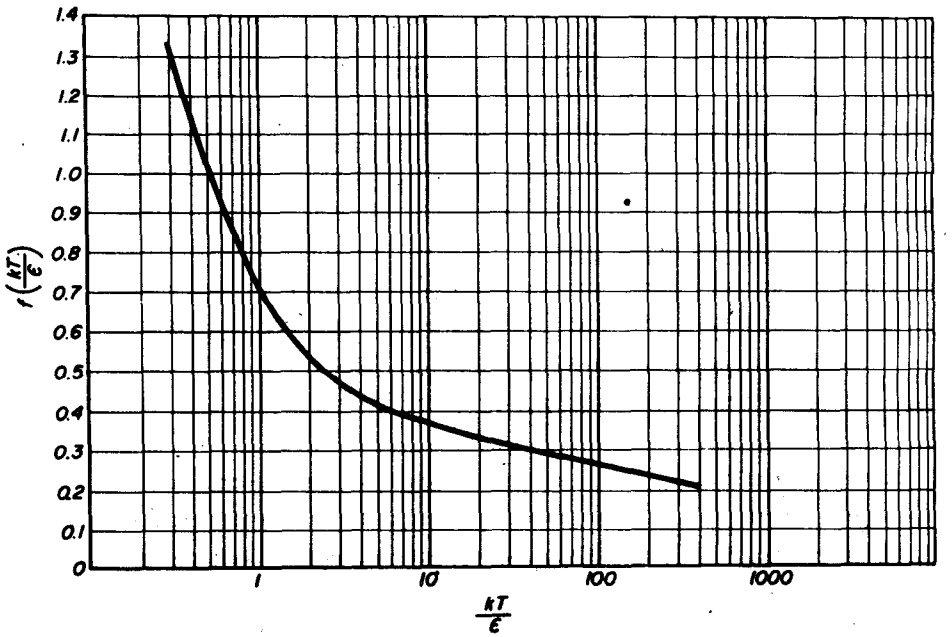

FIG. 24-1. Collision function $f(kT/\epsilon_{AB})$.

For larger molecules, molal volume can be determined as a summation of atomic volumes. Values of atomic volumes can be obtained from the literature, such as Perry's Chemical Engineer's Handbook [4].

Diffusivity Coefficient in Liquids

By the Wilke correlation [2], diffusivity of components in liquids is given by

$$D_{AB} = \frac{T}{\mu_B F} \tag{7}$$

where

T = temperature (°K)

μ_B = viscosity of solvent (cps)

TABLE 24-1

Force Constants and Collision Diameters [2]

Gas	ϵ/k (K) (from viscosity)	Y_o (angstroms) (from viscosity)
Air	97.0	3.617
Ammonia	315	2.624
Argon	124.0	3.418
Benzene	440	5.270
CO_2	190	3.996
CO	110.3	3.590
CCl_4	327	5.881
Diphenyl	600	6.223
Ethane	230	4.418
Ethanol	391	4.455
Ethyl ether	350	5.424
Ethylene	205	4.232
Fluorocarbon F-12	288	5.110
Helium	6.03	2.70
n-Heptadecane	800	7.923
Hydrogen	33.3	2.968
HCl	360	3.305
Iodine	550	4.982
Methane	136.5	3.882
Neon	35.7	2.80
Nitrobenzene	539	4.931
NO	119	3.47
Nitrogen	91.5	3.681
N_2O	220	3.879
n-Octadecane	820	7.963
n-Octane	320	7.451
Oxygen	113.2	3.433
Propane	254	5.061
SO_2	252	4.290
Water	363	2.655

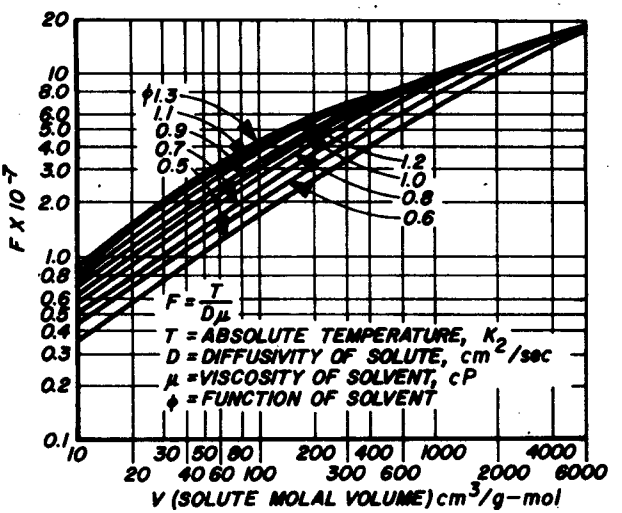

FIG. 24-2. (From Ref. 3, with permission of McGraw-Hill Book Company.)

D_{AB} = diffusivity of component A through solvent B

F = a function of the molecular volume of the solute

φ, as shown in Fig. 24-2, is a solvent characteristic, used as parameter in Fig. 24-2, and is equal to 1.0, 0.82, and 0.70 for water, methanol, and benzene, respectively. For other solvents where data are unavailable, φ may be assumed to be 0.9 [3].

Example 1

Estimate the diffusion coefficient between SO_2 and air at 15 psia and 25°C (gas absorption of SO_2 by water is controlled by resistances both in gas film and liquid film).

$$T = 25 + 273 = 298°K$$

$$P = \frac{15}{14.7} = 1.020 \text{ atm}$$

$$\frac{\epsilon_{SO_2\text{-air}}}{kT} = (0.326 \times 0.846)^{1/2} = 0.525$$

From Fig. 24-1,

	Air	SO_2	
ϵ/k	97.0	252	(Table 24-1)
ϵ/kT	0.326	0.846	
r (Å)	3.617	4.290	(Table 24-1)
M	29	64	

For $\frac{\epsilon}{kT} = 0.525$, $f(\frac{\epsilon}{kT}) = 1.0$ (See Fig. 24-1.)

$$r_{SO_2\text{-air}} = \frac{3.617 + 4.290}{2} = 3.953$$

Using Eq. (2),

$$D_{SO_2\text{-air}} = \frac{0.0009292 \times 298^{3/2}[(1/29) + (1/64)]^{1/2}}{1.02(3.953)^2(1.0)}$$

$$= 0.067 \text{ cm}^2/\text{sec}$$

Example 2

Estimate diffusivity of chlorine in water at 25°C and 1 atm pressure.

$T = 273 + 25 = 298$ K

$\mu_{H_2O} = 0.8937$ cps

φ = molal volume of solute, Cl_2 is 48.2 (from Table 24-2), solute characteristic for $H_2O = 1.0$

Using Fig. 24-2,

$F = 2.1 \times 10^7$

Using Eq. (7),

$$D = \frac{T}{\mu F} = 1.58 \times 10^{-5} \text{ cm}^2/\text{sec}$$

TABLE 24-2

Atomic and Molecular Volumes [3]

Atomic volume		Molecular volume	
Carbon	14.8	H_2	14.3
Hydrogen	3.7	O_2	25.6
Chlorine	24.6	N_2	31.2
Bromine	27.0	Air	29.9

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