CHAPTER II

LITERATURE REVIEW

Correlation of Mass Transfer Coefficient in Solid-Liquid Agitation

The rate of mass transfer from solid particle is controlled by the relative velocity of solid to liquid and the rate of renewal of liquid layer which may depend on the intensity of turbulence around the solid particle.

2.1 Hixson and Baum's Correlation [1], [2]

Hixson and Baum studied the rate of mass transfer from solid particles 0.25 cm in diameter in liquids agitated by a turbine and by a marine propeller in unbaffled vessels of various diameters and obtained a dimensionless equation.

$$kT/D_v = T/Z = r[T^2 N\rho_l/\mu]^p[\mu/\rho_l D_v]^q \quad \text{......(2.1)}$$

or

$$Sh_T = r\,Re^p_T\,Sc^q \quad \text{.....................(2.2)}$$

The experimental data are correlated in Figure 2.1(a) and 2.1(b) and represented by the following equations:

For Turbine

$$Re_T < 6.7\times10^4 \quad ; \quad Sh_T = 2.7\times10^{-5}\ Re_T^{\ 1.4}\ Sc^{0.5} \quad ....(2.3)$$

$$Re_T > 6.7\times10^4 \quad ; \quad Sh_T = 0.16\ Re_T^{\ 0.62}\ Sc^{0.5} \quad ....(2.4)$$

For Marine Propeller

$$3{,}300 < Re_T < 330{,}000 \ ; \ Sh_T = 3.5\times10^{-4}\ Re_T^{\ 1.0}\ Sc^{0.5} \quad ...(2.5)$$

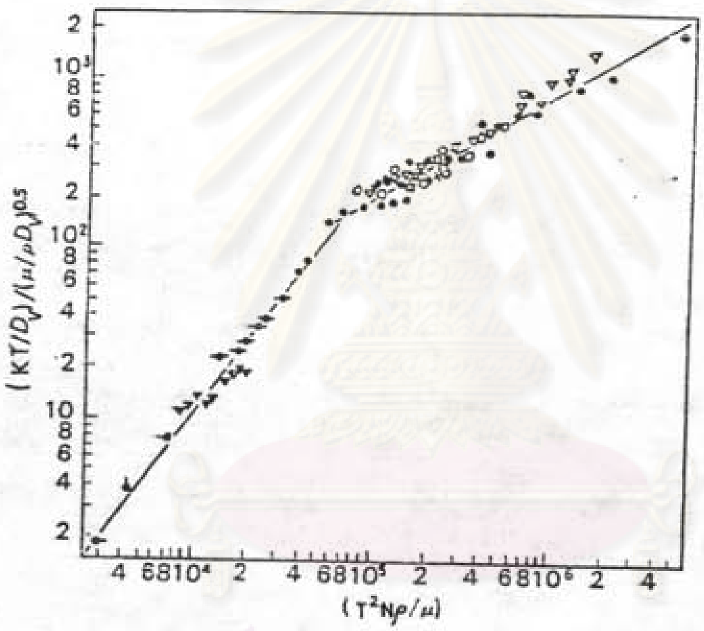

Figure 2.1(a) Correlation of mass transfer coefficients. ●: Benzoic acid-water, O: Benzoic acid-benzene, —●: Benzoic acid-sperm oil, ●: Benzoic acid-cotton seed oil, ●—: Benzoic acid-rapeseed oil, -●-: Benzoic acid-40% sucrose, ▼: Benzoic acid-ethylene glycol, ▽ : Barium chloride-water, □ : Rock salt – water, X: Naphthalene-methanol

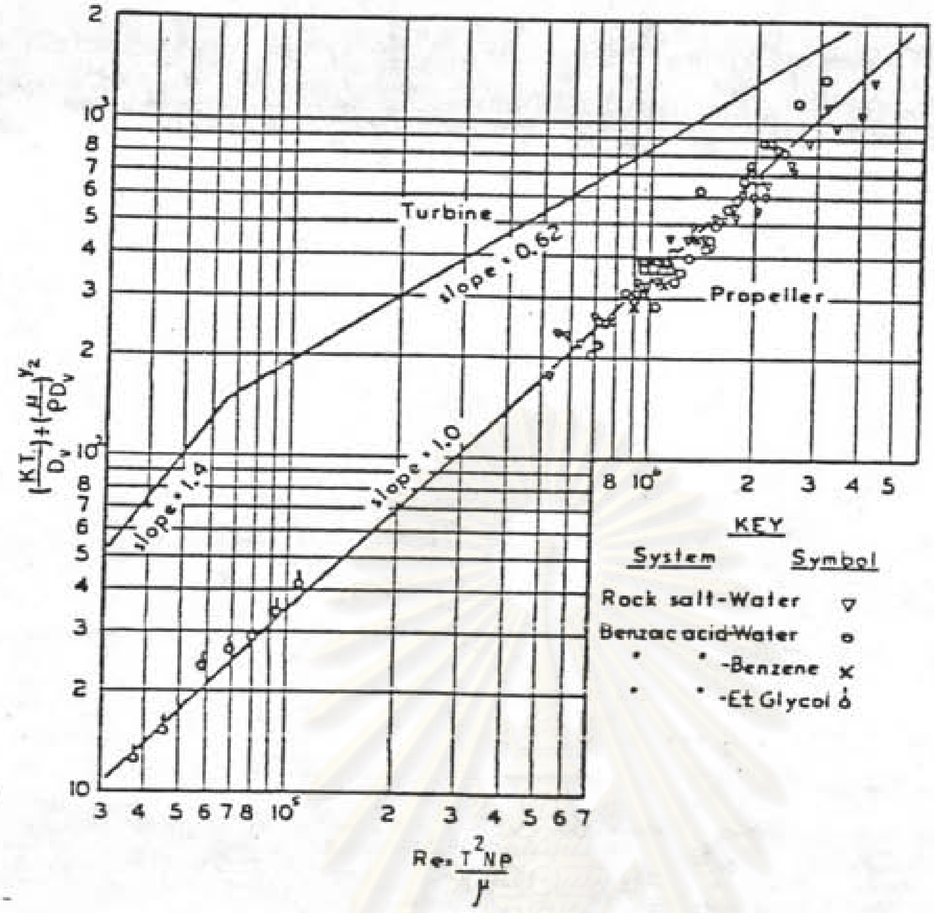

Figure 2.1(b) Graphical determination of constant exponents of general equation for mass transfer

2.2 Nagata's Correlation [4], [5]

More general correlation for geometrically similar, unbaffled vessels, with spherical and granular solids is

$$kT/D_v = 3.60\times10^{12}[T^2N\rho_l/\mu]^p[\mu/\rho_l D_v]^q[D_v^2/T^3g]^{0.627}[d_p/T]^{3.08}[\Delta\rho/\rho_l]^{-2.82} \qquad \text{.................(2.6)}$$

where

$$p = 0.0802[T^3g\rho_l^2/\mu^2]^{0.0772}[\log\{(\Delta\rho/\rho_l)+0.043\}+1.35]10^{-13.52d_p/T}$$

$$q = 14.4\, d_p/T+1.84[\Delta\rho/\rho_l]^{0.116}$$

2.3 Humphrey and Van Ness's Correlation [14]

Humphrey and Van Ness measured the rate of solution of $Na_2S_2O_3 \cdot 5H_2O$ crystal suspended in a flow type agitation vessel. They used a baffled vessel of 1 ft diameter agitated by a 3-bladed marine propeller and 6-bladed turbine. The correlation of mass transfer coefficients is the same as Equation (2.1) and the numerical value of r, p and q are as follows;

				Re range of application
For propeller	$r = 0.13$	$p = 0.58$	$q = 0.5$	63,000 - 330,000
For turbine	$r = 0.0032$	$p = 0.87$	$q = 0.5$	31,000 - 89,000

2.4 Johnson and Chen-Jung Huang's Correlation [15]

They undertook experiments on the dissolution of solids, using a turbine with six straight blades as impeller. The vessel was equipped with four baffles, and they derived the equation.

$$kT/D_v = 0.0924[D_i^2 N\rho_l/\mu]^{0.710}[\mu/\rho_l D_v]^{0.5} \qquad \text{.........(2.7)}$$

2.5 Barker and Treybal's Correlation [6]

Barker and Treybal studied the rate of solution of solid particles suspended in water and 45 % sucrose solution in 2-12 in. baffled vessels agigated by a six-flat-blade turbine. The dissolution rate coefficients of boric acid, rock salt and benzoic acid in several sizes were correlated by the following equation.

$$\ln(10k) = I + 0.85\, V^{0.03875} \ln(Re/10^4) \qquad \text{..........(2.8)}$$

where k is the mass transfer coefficient in (ft/hr), I is a function of V, V is the volume of liquid in the vessel (ft^3) and $Re' = (\pi D_1^2 N\rho_1/\mu)$ is the modified Reynolds number. The effect of Schmidt number and particle size was not significant

By taking 0.833 as an average value for $0.85\ V^{0.02875}$, the following dimensionless equation is obtained

$$kT/D_v = 0.02[\pi D_1^2 N\rho_1/\mu]^{0.833}[\mu/\rho_1 D_v]^{0.5} \quad \text{........(2.9)}$$

or

$$Sh_T = 0.052\ Re_a^{0.833}\ Sc^{0.5} \quad \text{..................(2.10)}$$

A large number of reports have been presented on the rate of mass transfer from suspended solid particles in agitated liquids. This is illustrated in Table 2.1.

As can be seen from Table 2.1 there is a wide divergence of the results and correlations. This is because different approaches have been used to predict mass transfer from suspended solids: dimensional analysis, the slip velocity theory proposed by Harriott [18], the non-steady state model according to Higbie's penetration theory [19] and the Kolmogoroff's theory of local isotropic turbulence [20].

Table 2.1 Dimensionless-type correlations from various references [16], [17]

Systems †	Baffles	Particle form	Schmidt number	Reynolds number	Correlation
Water-barium chloride Water-naphthalene	No	Tablets	$486-2.56\times10^{6}$	$<6.7\times10^{4}$ $>6.7\times10^{4}$	$Sh_T = 2.7\times10^{-5}Re_T^{1.40}Sc^{0.50}$ $Sh_T = 0.16Re_T^{0.62}Sc^{0.50}$
Water-benzoic acid Methyl alc.-benzoic acid	No	Spheres			$Sh_T = a(Re_T)^{p} Sc^{0.5}(d/T)^{g}$ $0.02<p<0.67$ $-0.80<g<-0.32$
HCl-Zn powder Water-$AgNO_3$ Water-urea Water-ammonium chloride	No	Spheres and granulars		$10^{3}-10^{6}$	$Sh_T = 3.60\times10^{13}Re_T^{p} Sc^{q} X$ $X = (D_v^2/T^3g)^{0.537}(d/T)^{3.08}(\Delta\rho/\rho)^{-2.83}$
Water-benzoic acid Water-boric acid Sucrose sin-benzoic acid Sucrose sin-boric acid	Yes	Granulars	$735-55\times10^{3}$	$10^{4}-10^{6}$	$Sh_T = 0.052Re_a^{0.833}Sc^{0.5}$
Water benzoic acid	Yes	Tablets		$24\times10^{3}-12\times10^{4}$	$Sh_T = 3.30Re_a^{0.55}Sc^{0.30}$
Iodine-copper	Yes	Spheres	700-11,300	$0.5\times10^{4}-3\times10^{5}$	$Sh = 2+0.109[(ND_I^{2}\rho/\mu)(N_p/N_{p\ stand})^{1/3}]^{0.38}Sc^{0.5}$
Ethyl alc.-ammonium nitrate	Yes	Spheres	267-35,000	$0.07-10^{3}$	$Sh = 2+0.47(d_p^{4/3}\epsilon^{1/3}\rho/\mu)^{0.62}Sc^{0.36}(D_I/T)^{0.17}$
Ethyl alc.-Stearic acid Ethyl alc.-naphthalene					$Sh = 2 + 0.44Re_p^{0.504}Sc^{0.385}$
Water-benzoic acid	Yes	Pellets		50,000	$Sh_a = 0.48Re_a^{0.397}Sc^{1/3}$ $Sh = 0.0267(2+1.10Re^{1/2}Sc^{1/3})N^{0.625}(D_v/d_p)$
Water-benzoic acid	Yes	Granulars	628-1,280	$1-10^{7}$	$Sh = [2+0.4(\epsilon d_p^{4}/\nu^{3})^{1/4}Sc^{1/3}]\phi_c$ (ϕ_c is a shape factor)

† Stirrers are four- or six-blade turbines.
Source: From Boon-Long et al.

D_I Stirrer diameter
D_v Diffusivity
d_p particle diameter
g gravitational constant
N stirrer speed RPM
N_p number of stirrer blades
Re_a Reynolds number referred to stirrer, $(ND_I^2\rho)/(\mu)$
Re_T Reynolds number referred to vessel, $(NT^2\rho)/(\mu)$
Sc Schmidt number, $\mu/\rho D_v$
Sh Sherwood number referred to particle, kd_p/D_v
Sh_a Sherwood number referred to stirrer, kD_I/D_v
Sh_T Sherwood number referred to vessel, kT/D_v
T vessel diameter
ρ fluid density
μ fluid viscosity
Re_p Reynolds number referred to particle