Chapter II

THEORY AND PREVIOUS WORKS

2.1 General

2.1.1 Mass Transfer Coefficient

Consider a solid being dissolved in a liquid, the mass transfer equation for the case of low mass transfer rates can be written as$^{(1)}$

$$dM = k\,ds\,\Delta C \qquad (2.1)$$

where k = Mass transfer coefficient, m/s

dM = Element of dissolved mass per unit time, kg/s

ds = Element of mass transfer area, m^2

ΔC = Concentration different of solid-liquid interface, kg/m^3

The integration of this equation for solid-liquid fluidized system is possible by using the following hypothesis:

a) The flow of liquid is a plug flow, and the concentration at every point in the liquid stream is uniform.

b) The temperature of system is uniform.

This hypothesis seemed to be quite satisfied in the case of solid-liquid fluidization, therefore, the Eq.(2.1) became$^{(2)}$

$$M = ks\,\Delta C_{LM} \qquad (2.2)$$

where k = Mean mass transfer coefficient, m/s

M = Dissolved mass per unit time, kg/s

s = Mass transfer area, m^2

ΔC_{LM} = Logarithemic mean concentration different of solid-liquid interface, kg/m^3

$$\Delta C_{LM} = \frac{C_2 - C_1}{\ln \frac{C_s - C_1}{C_s - C_2}} \qquad (2.3)$$

where C_s = Saturated concentration, kg/m^3

C_1 = Inlet concentration of liquid, kg/m^3

C_2 = Outlet concentration of liquid, kg/m^3

2.1.2 Rate of Chemical Reaction

Consider a chemical reaction with stoichiometric equation

$$A + B \longrightarrow X + Y$$

If the reaction is elementary and irreversible, a rate equation is given by(3)

$$-r_A = k'' C_{A1} C_{B1} \qquad (2.4)$$

where $-r_A$ = Rate of disappearance of A, $kg/m^3 s$

k'' = Reaction rate constant, $m^3/kg\ s$

C_{A1} = Initial concentration of A, kg/m^3

C_{B1} = Initial concentration of B, kg/m^3

In the case of one of the reactants has excess concentration (for $C_{B1} \gg C_{A1}$), the rate equation can be written as

$$-r_A = k' C_{A1} \qquad (2.5)$$

where k' = Reaction rate constant, s^{-1}

This reaction can be considered as a first order reaction as well.

In a solid-liquid reaction system, the mechanism of shrinking spherical particles can be explained according to the following steps.

Step 1. Diffusion of reactant B from the solid surface through the liquid film to the main body of liquid A

Step 2. Reaction at the interface between reactant B and liquid A.

If the chemical reaction rate is very fast as compared to the molecular diffusion rate, the system is said to be diffusion controlled. On the other hand if the chemical reaction rate is very slow as compared to the molecular diffusion rate, the system is said to be chemical controlled.

2.1.3 Dimensionless Groups Concerning Mass Transfer

There are four important dimensionless groups normally encountered in the mass transfer equation.

1) Reynolds Number(1), Re, represented the hydrodynamics between liquid and solid particle

$$Re = \frac{d_P U \rho_L}{\mu_L} \tag{2.6}$$

2) Schmidt Number(1), Sc, compared the physical properties of liquid between kinematic viscosity and mass diffusivity

$$Sc = \frac{\mu_L}{\rho_L D_{AB}} \tag{2.7}$$

3) Sherwood Number(1), Sh, measured the intensity of mass transfer

$$Sh = \frac{k d_P}{D_{AB}} \tag{2.8}$$

4) Initial Concentration Ratio, Cr, compared the initial concentration of A and the initial concentration of B

$$Cr = \frac{C_{A1}}{C_{B1}} \tag{2.9}$$

or

$$Cr = \frac{C_{A1}}{C_s} \tag{2.10}$$

2.2 Mass Transfer in Fluidized Bed

2.2.1 Mass Transfer without Chemical Reaction in Fluidized Bed

In the system of isothermal bed constituted of the spherical solid particles of uniform diameter, fluidizing by a liquid in the column which flows steadily after passing the microporous distributor, most of theories were developed from Fick's law(1). The mass transfer coefficients are represented by a relation between six independent variables in the form

$$k = f(d_p, U, \rho_L, \mu_L\ D_{AB}, \epsilon) \tag{2.11}$$

This results are always expressed in terms of four dimensionless groups

$$Sh = f(\epsilon, Re, Sc) \tag{2.12}$$

Then the general relation gives

$$Sh = k_1 \epsilon^a Re^b Sc^c \tag{2.13}$$

Recently DAMRONGLERD(4) has worked on the problem of dissolution of benzoic acid particles in water. The auther found that neither diameter of active particle nor diameter of column have effect on mass transfer coefficient, and also showed that the power of ϵ was

2.39 which agreed well with that of Richardson and Zaki(5) as shown in Fig.2.1. The expressions of mass transfer in fluidized bed in dense phase ($\epsilon < 0.815$) were:

$$Sh = 0.686 \epsilon^{-1.25} Re^{0.584} Sc^{1/3} \quad (2.14)$$

for a perforated plate distributor, as shown in Fig.2.2 and

$$Sh = 0.763 \epsilon^{-1.20} Re^{0.556} Sc^{1/3} \quad (2.15)$$

for a sintered plate distributor, as shown in Fig.2.3.

2.2.2 Mass Transfer with Chemical Reaction in Fluidized Bed

Mass transfer with chemical reaction in fluidized bed is of importance to engineers in many circumstances. It may control the mass transfer rate in which chemical process is brought to stable operating conditions, and it is also important in determining the processing time and equipment design. There are many applications of mass transfer with chemical reaction in fluidized beds, for example the hydrogenation of ethylene on alumina catalyst and the manufacture of sodium thiosulfate solution from sulfur and sodium sulfite solution.

In connection with fundamental studies on mass transfer with chemical reaction in fluidized bed, the important variables are the initial concentration of A, C_{A1} and the initial concentration of B, C_s. So, it has to add two independent variables in the Eq.(2.11), and the mass transfer coefficient will be

$$k = f(d_p, U, \rho_L, \mu_L, D_{AB}, \epsilon, C_{A1}, C_s) \quad (2.16)$$

The results can be expressed in term of five dimensionless groups

$$Sh = f(\epsilon, Re, Sc, Cr) \quad (2.17)$$

In case of mass transfer without chemical reaction in fluidized bed, Cr has no effect in Sh. The Eq.(2.17) becomes.

$$Sh = f_1(\epsilon, Re, Sc) + f_2(\epsilon, Cr, Sc) \qquad (2.18)$$

Then the general relation can be written as

$$Sh\,\epsilon^{a} Sc^{-c} = K_1 Re^{b} + K_2 Cr^{n} \qquad (2.19)$$

The correlation of mass transfer with chemical reaction in fluidized bed in dense phase for the perforated plate distributor is postulated as

$$Sh\,\epsilon^{1.25} Sc^{-1/3} = 0.686\ Re^{0.584} + K_2 Cr^{n} \qquad (2.20)$$

Where $Sh\,\epsilon^{1.25} Sc^{-1/3}$ represents a total mass transfer.

$0.686\ Re^{0.584}$ represents a mass transfer without chemical reaction, and equal to $Sh\epsilon^{1.25} Sc^{-1/3}$ for water system.

$K_2 Cr^{n}$ represents a mass transfer due to chemical reaction.

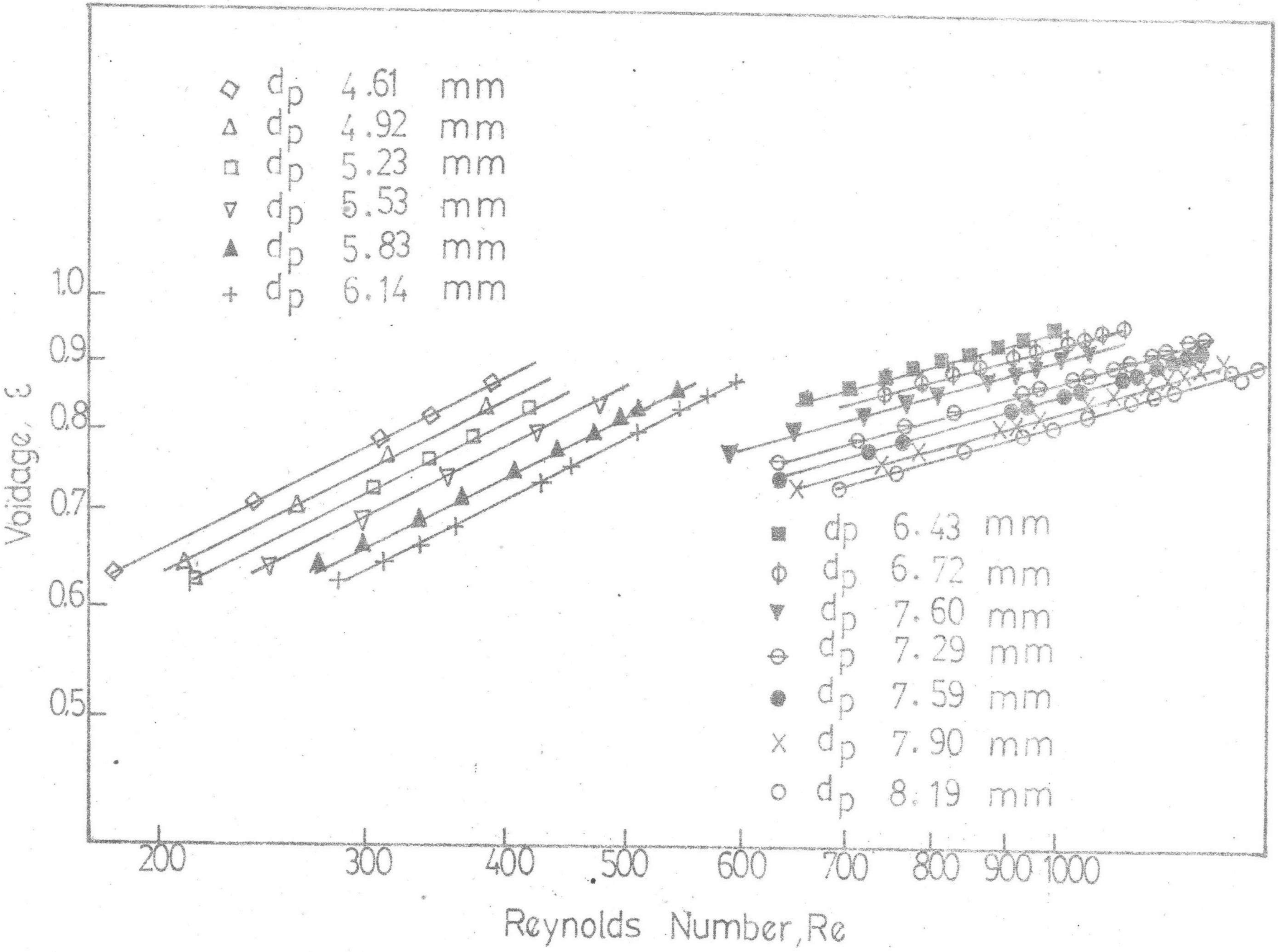

Fig.2.1 Variation of ∈ with Re at Different Particle Diameters

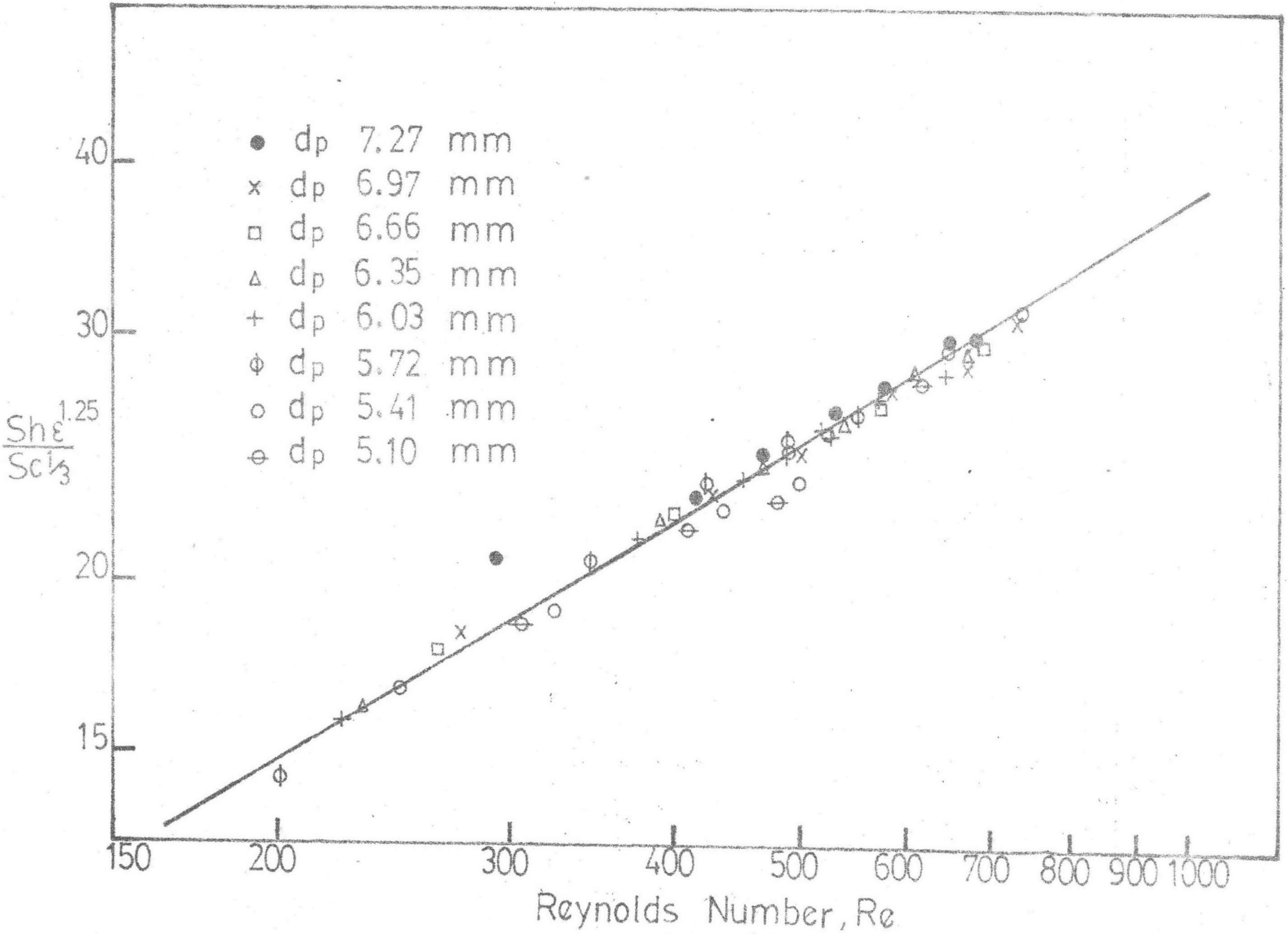

Fig.2.2 Variation of Sh $\epsilon^{1.25}$ $Sc^{-1/3}$ with Re Using Perforated Plate Distributor

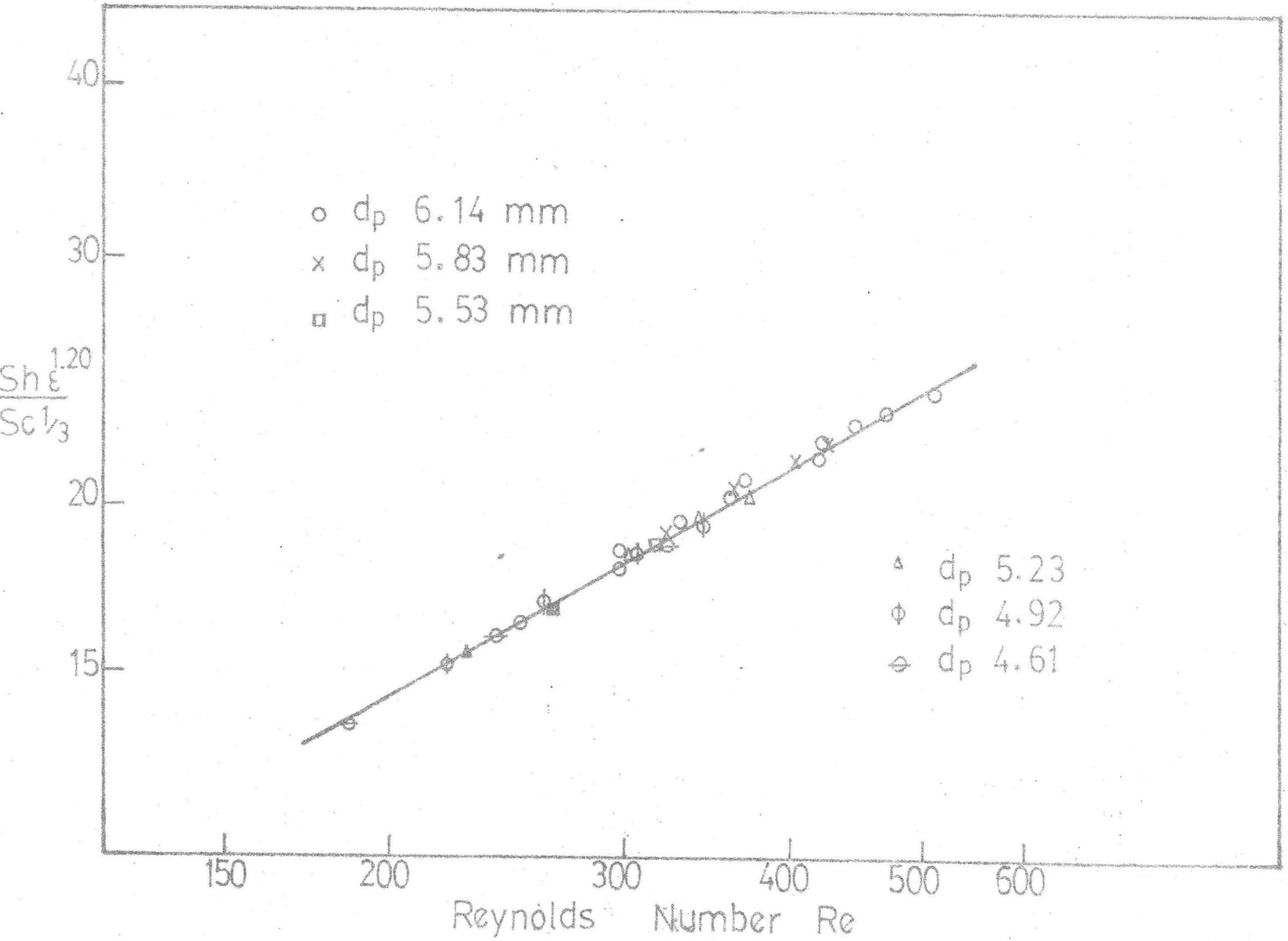

Fig.2.3 Variation of Sh $\epsilon^{1.25}Sc^{-1/3}$ with Re Using Sintered Plate Distributor