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Effect of axial dispersion on interphase mass transfer in packed absorption columns

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EFFECT OF AXIAL DISPERSION ON INTERPHASE MASS TRANSFER

IN PACKED ABSORPTION COLUMNS

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ABSTRACT

A steady state approach was followed in this investigation to determine the effects of liquid and gas flow rates, packing size and packing height on the interphase mass transfer coefficient and gas phase axial mixing Peclet numbers.

Experiments were performed on the absorption of carbon dioxide from a mixture of carbon dioxide and nitrogen in a packed column. Absorption was performed using 1/4, 3/8 and 1/2 inch Raschig rings, with a packing height of 3 feet and also using 3/8 inch Raschig rings with a packing height of 5 feet. The liquid and gas flow ranges used were 2865 to 5680 lb./hr.sq.ft. and 5.0 to 7.4 lb./hr.sq.ft., respectively.

Three mathematical models, viz. (i) plug flow in both the gas and liquid phases, (ii) axial mixing in gas phase and plug flow in liquid phase, and (iii) axial mixing in both gas and liquid phases, were used.

It is found that axial mixing in the gas phase increases with increases in liquid flow rate, packing size and packing height. The behavior of apparent and true mass transfer coefficients indicates a decrease in axial mixing with increases in gas flow rates. However, axial mixing is found to be small under the experimental conditions used in this investigation. The gas phase Peclet numbers obtained in this investigation are about fifty times greater than reported by workers using a transient technique under the same conditions. Correlations for the apparent and true over-all liquid phase mass transfer coefficients are also presented.

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I. INTRODUCTION

Many chemical engineering problems are solved by making simplifying assumptions concerning the characteristics of the system. For example, in calculating the heat transfer coefficient for the flow of a fluid through a pipe, the conduction term in the axial direction is often neglected as it is considered too small compared to both the convective transfer term in the axial direction and conduction term in the radial direction. Similarly, axial dispersion or mixing in the axial direction has been neglected in the calculation of mass transfer coefficients in packed columns. The height of an absorption column is computed by multiplying the number of transfer units (NTU) by the height of the transfer unit (HTU). The NTU and HTU concept was introduced by Colburn (1939, 1941) who assumed a piston or plug flow model for both the phases. In practice, however, there is always some axial mixing. Axial mixing tends to reduce the concentration driving force for interphase mass transfer from that which would exist for plug flow.

The phenomenon of axial mixing arises from the fact that "packets" of fluids do not all move through a packed bed at a constant and uniform velocity. This non-uniform velocity may result from (a) velocity gradients as the fluid flows through the packing and/or (b) eddy motion of the fluid itself. The former is more characteristic of a laminar flow regime; whereas, the latter is probably more characteristic of turbulent flow (Hartland and Mecklenburgh, 1968; Klinkenberg, 1968). Axial mixing is, also, the consequence of more complex events such as local trapping, by-passing acceleration and deacceleration, than the stream splitting or "random walk" mechanism that has served well in explaining radial mixing. Axial mixing reduces the concentration driving force for interphase mass transfer as illustrated in Figure 1, where the concentration profiles for piston flow are represented by the dotted lines and the solid lines represent a typical axial mixing case (Miyauchi and Vermeulen, 1963)

There are two methods that are used for evaluating axial diffusion coefficients or Peclet numbers. In the first one, a transient procedure is followed. A tracer is introduced into the inlet stream, and its rate is varied with time. At some other point in the stream, the concentration versus time response is measured and the value of axial diffusion coefficient obtained by comparing the data with the solution of a derived differential equation. In the second method, a steady state approach is followed. In this, a mathematical model is proposed and its solution obtained using pertinent boundary conditions. The axial diffusion coefficient is obtained by comparing the solution of the mathematical model with experimental value of the steady state axial concentration profile.

A review of the literature reveals that the axial mixing in the two-phase flow in a packed column has been studied only to a limited extent. It is also found that there is considerable disagreement amongst the authors on the effect of liquid and gas flow rates on Peclet number. In this investigation a detailed study of axial mixing in two-phase flow in a packed column is undertaken. A steady state approach is followed for the reasons discussed in the subsequent chapters of this thesis. Carbon dioxide is absorbed from an approximately 20% (by volume) mixture of carbon dioxide in nitrogen by continuous countercurrent contact with water in a packed column. Gas phase concentration

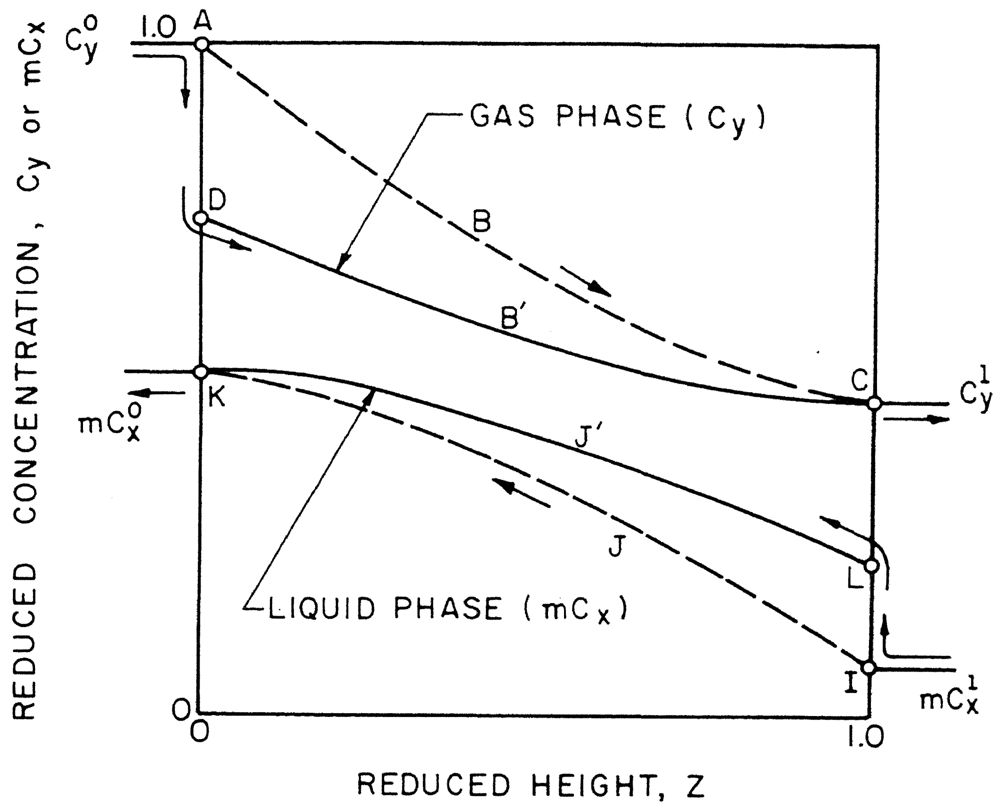

Figure 1. Concentration Profiles for Plug Flow and Axial Mixing Cases in a Typical Absorption Column (Miyauchi and Vermeulen, 1963).

Curve ADB'C = Actual distribution of C_y

Curve ILJ'K = Actual distribution of C_x

Curve ABC = Hypothetical distribution of C_y assuming piston flow

Curve IJK = Hypothetical distribution of C_x assuming piston flow profile data are obtained in axial direction in a 4 inch i.d. glass packed column. The absorption is performed using, individually, 1/4, 3/8 and 1/2 inch Raschig ring packings with 3 feet of packing height and also 3/8 inch Raschig rings with a packed height of 5 feet. The liquid and gas flow rate ranges used are 2856 to 5680 lb./hr.sq.ft. and 5.0 to 7.4 lb./hr.sq.ft., respectively.

The primary objectives of this investigation are as follows:

(a) To investigate the effect of liquid and gas flow rates on axial mixing in gas and liquid phases.

(b) To investigate the effect of packing diameter and column height on axial mixing in gas and liquid phases.

(c) To evaluate the true and apparent interphase mass transfer coefficients.

II. LITERATURE REVIEW

Geankoplis and Hixon (1950), Pratt (1951), and Gier and Hougan (1953), were amongst the earliest workers to recognize the effect of axial dispersion in liquid-liquid extraction columns. Danckwerts (1953), Kramer and Alberda (1953), Jacques and Vermeulen (1957), Carberry and Bretton (1958), and Ebach and White (1958) have determined values of the Peclet numbers for water flowing through beds of various types of packings over a wide range of Reynolds numbers. McHenry and Wilhem (1957) and Robinson (1960) were amongst those who determined Peclet numbers for gas streams flowing through packed beds. The above-mentioned workers have confined their studies to single phase systems only.

There are two useful models for describing the mixing in a packed bed. The first mixing model discussed by Aris and Amudson (1956), Klinkenberg and Sjenitzer (1956), Van Deemter, Zinderweg and Klinkenberg (1956), and Levenspiel (1962), assumes that packing can be characterized by a series of completely mixed cells. The mixing in a bed is, therefore, a function of only one parameter, the number of mixing cells in the bed. The other mixing model termed as the dispersion model discussed by Danckwerts (1953), Taylor (1954), Levenspiel and Smith (1957), Bischoff and Levenspiel (1962), and Levenspiel (1962) assumes that the various factors causing axial mixing can be described by a diffusional type process superimposed on plug flow. This is reasonable if the length over which a single mixing effect acts is small and if a large number of such events take place in the vessel. In laminar flow, the factors causing axial mixing are molecular diffusion and the overtaking of fluid elements due to the velocity profile. For turbulent flow, an additional factor, turbulent eddy diffusion, also plays a role in causing axial mixing.

With the dispersion model, deviation from plug flow is accounted for by a flux term, $D_e\frac{dc}{dx}$, where D_e is the axial dispersion coefficient which accounts for all the factors causing mixing in the axial direction. The coefficient, D_e, is a combination of the molecular diffusivity and eddy diffusivity and also is a function of the path of flow. Miyauchi (1957), Sleicher (1959), and Hartland and Mecklenburgh (1966), applied the dispersion model to a thin cross-section of a packed bed and derived a differential equation describing the dispersion flow model.

As has been mentioned before, there are essentially two methods used for evaluating axial diffusion coefficients or Peclet numbers. In the first one, a transient procedure is followed. A tracer is introduced into the inlet stream, and its rate is varied with time. At some other point in the stream the concentration versus time response is measured, and the value of axial diffusion coefficient is obtained by comparing the data with the solution of a derived differential equation. Sine waves have been used by Deisler and Wilhem (1953), Kramer and Alberda (1953), McHenry and Wilhem (1957), Ebach and White (1958), and Strang and Geankoplis (1958); pulses were used by Danckwerts, Jenkins and Place (1954), Carberry and Bretton (1958), and Ebach and White (1958); and a step function by Danckwerts (1953) and DeMaria and White (1960) has been used to obtain the necessary variation in inlet concentration with time. Sater and Levenspiel (1966) used an arbitrary "sloppy" pulse input. Tracer can be injected in one phase or both the phases.

In the second method a steady state approach is used. In this method a mathematical model is proposed, and its solution is obtained using pertinent boundary conditions. The axial diffusion coefficient is then obtained by comparing the solution of the mathematical model with the experimental results. Brittan and Woodburn (1966), and Brittan (1966, 1967) used this steady state method for the simultaneous determination of axial dispersion and interphase true mass transfer coefficient by measuring the gas phase concentration profile in the axial direction in a packed gas absorption column. It may be mentioned that steady state procedure has also been used by Penney and Bell (1969) to determine the axial mixing in an agitated heat exchanger by measuring the steady state axial temperature profile.

Typical theoretical effects of axial mixing upon mass transfer in countercurrent contactors are discussed by Miyauchi and Vermeulen (1963) where it has been shown that axial mixing tends to reduce the concentration driving force for mass transfer from that which could exist for piston flow in both phases. Sleicher (1959) analysed the effect of axial mixing in either phase in an extraction column by means of an idealized diffusion model that can be characterized by four dimensionless parameters: a Peclet number for each phase, a mass transfer number and an extraction factor. The principal results of the numerical solution are presented in the form of tables. Sleicher states that these results are useful in the design and scale-up of extraction columns and in the interpretation of experimental results from extractors and from some reactors in which a first order reaction occurs.

Experimental determinations of axial dispersion coefficients in liquid extraction columns based on time response technique have been reported by Levenspiel (1958), Jacques and Vermeulen (1959), Hazelbeck and Geankoplis (1963), Schmel and Babb (1964), Miyauchi and Oya (1965), Bibaud and Treybal (1966), and Vermeulen, Moon, Henrico and Miyauchi (1966). Afschar, Diboun and Schugerl (1968) evaluated the axial dispersion coefficient in co-current bubble flow of air and water in a column. Work for the determination of axial dispersion coefficient in packed gas absorption columns has been reported by DeMaria and White (1960), Hofmann (1966), Stemerding (1961), Dunn, Vermeulen, Wilke and Word (1962), Hoogendoorn and Lips (1965), Sater and Levenspiel (1966), and Hochman and Effron (1969). DeMaria and White (1960), and Sater and Levenspiel (1966), who studied axial mixing in an absorption column using, individually, 1/4, 3/8 and 1/2 inch Raschig rings, have presented their results in the form of equations correlating gas and liquid phase Peclet numbers with packing diameter, gas and liquid flow rates. It is found that correlation of Sater and Levenspiel (1966) gives Peclet numbers that are approximately one eighth the value given by the correlation presented by DeMaria and White (1960) for the same conditions. Dunn et al (1962) have presented equations correlating liquid and gas phase Peclet numbers with liquid and gas rates for 1 inch and 2 inch Raschig ring and 1 inch Berl saddle packings. Values of Peclet numbers obtained from the correlations of Sater and Levenspiel (1966), DeMaria and White (1960), and Dunn et al (1962) show a decrease with increases in gas and liquid rates.

Furzer and Ho (1967) have suggested the necessity of correlating $(H.T.U.)_{OL}^{a}$ and axial mixing effects with column height. They have presented a theoretical equation correlating $(H.T.U.)_{OL}^{a}$ with column height. Smoot and Babb (1962) have performed mass transfer studies in a pulsed liquid-liquid extraction column. Effect of height on $(H.T.U.)^{a}_{OL}$ and $(H.T.U.)^{t}_{OL}$ was studied, and it is reported that a variation of the column height from 2 to 4 feet had no significant effect on $(H.T.U.)^{a}_{OL}$ or $(H.T.U.)^{t}_{OL}$.

A review of the literature indicates that the study of the axial mixing in two phase flow in packed absorption column has been made only to a limited extent. Results of the gas phase Peclet numbers obtained by Sater and Levenspiel (1966) differ from that of DeMaria and White (1960) (using transient technique) by a factor of eight for the same conditions. Brittan (1966, 1967) studied axial mixing in a packed column with 3/8 inch Raschig ring packing using steady state procedure reported a small effect of axial mixing under his experimental conditions but indicated that it would increase to a significant magnitude at the industrial liquid rates. No experimental work is reported in the literature on the effect of height on the gas phase axial mixing for two phase counter-current flow in packed column.

The study described in this thesis is undertaken to clarify the disagreements in the Peclet number results obtained by various authors. Further, this investigation is also undertaken to study the effect of factors such as liquid and gas flow rates, packing size and packing height on axial mixing, so that a deeper understanding of axial diffusion in two phase flow in packed columns can be obtained.

III. MATHEMATICAL MODELS

The most common concept of the process of interphase absorption was given by the two-film theory due to Whitman (1923). Subsequently Chilton and Colburn (1935) put forth their concept of HTU and NTU which has been used for the design of continuous countercurrent absorption columns. Chilton and Colburn based their derivations on the assumption that there is plug flow in both liquid and gas phases. In recent years, workers (whose references have been made earlier) have been greatly concerned about the axial mixing in gas absorption. Published work on the axial mixing in two phase flow (gas and liquid) in packed column is rather limited (DeMaria and White, 1960; Dunn _et al_, 1962; Hofmann, 1961; Stemerding, 1961; Sater and Levenspiel, 1966). Brittan and Woodburn (1966) reported the effect of axial mixing on the performance of the absorption columns to be small under their experimental conditions but indicated that it may become significant if projected into the range of industrial liquid rates.

In this investigation the usual approach to the problem is followed of proposing a mathematical model and then solving the basic equation using pertinent boundary condition. The solution of this mathematical model is then tested for agreement with the experimental results.

In this chapter, an analysis of the mass transfer relations between gas and liquid phases, along the length of the column is presented. This analysis takes into consideration the following cases:

Case I: Plug flow in both liquid and gas phases.

Case II: Axial mixing in gas phase and plug flow in liquid phase.

Case III: Axial mixing in both gas and liquid phases.

Study of the case for plug flow in gas phase and axial mixing in liquid phase is not made as the axial mixing in liquid phase is considered to be insignificant. This is also reported by Iyer (1969).

Mathematical models with their respective boundary conditions for the above three cases are presented in this chapter.

For one-dimensional countercurrent two phase mass transfer processes Damkohler's (1937) equation of continuity for homogeneous continuous flow systems may be modified and rearranged into a dimensionless form as follows:

$$\frac{d^2C_y}{dZ^2} - P_G \frac{dC_y}{dZ} - N_{oy}P_G(C_y - mC_x) = 0 \qquad (3.1)$$

$$\frac{d^2C_x}{dZ^2} + P_L \frac{dC_x}{dZ} + N_{ox}P_L(C_y - mC_x) = 0 \qquad (3.2)$$

The dimensionless boundary conditions are

(a) $Z = 0$ (i) $$-\left(\frac{dC_y}{dZ}\right) = P_G(1.0 - C_y) \qquad (3.3)$$

(ii) $$-\left(\frac{dC_x}{dZ}\right) = 0 \qquad (3.4)$$

(b) $Z = 1$ (i) $$-\left(\frac{dC_y}{dZ}\right) = 0 \qquad (3.5)$$

(ii) $$-\left(\frac{dC_x}{dZ}\right) = P_L(C_x - C_x^1) \qquad (3.6)$$

In the mathematical models shown above, P_G and P_L are dimensionless parameters for axial mixing in the gas and liquid phases, respectively. These parameters are inversely proportional to the eddy diffusivities in the gas and liquid phases, respectively.

$$P_G = \frac{U_y L_e}{D_{ey}}$$

and

$$P_L = \frac{U_x L_e}{D_{ex}}$$

where L_e is the effective length of the packing. D_{ey} and D_{ex} are the eddy diffusivities in gas and liquid phases, respectively.

Further,

$$U_y = \frac{F_y}{\varepsilon_y}$$

and

$$U_x = \frac{F_x}{\varepsilon_x}$$

where F_y and F_x are the superficial mass flow rates of the gas and liquid phases, respectively. ε_y and ε_x are void fractions for gas and liquid phases, respectively.

$$N_{oy} = \frac{K_y a L_e}{F_y}$$

and

$$N_{ox} = \frac{K_y a L_e}{F_x}$$

where K_y is the over-all mass transfer coefficient related to gas phase, and a is the interfacial area per unit volume.

Mathematical models for the three cases mentioned earlier have been derived from Equations 3.1 and 3.2. Models in the form of differential equations along with their respective boundary conditions are given as follows:

A. Case I (One Parameter System)

Conditions of plug flow in the gas and the liquid phases are assumed in this model, i.e., $P_G \to \infty$, and $P_L \to \infty$. Therefore, Equations 3.1 and 3.2 are reduced to

$$\frac{dC_y}{dZ} + N_{oy}(C_y - mC_x) = 0 \qquad (3.7)$$

and

$$\frac{dC_x}{dZ} + N_{ox}(C_y - mC_x) = 0 \qquad (3.8)$$

The necessary boundary conditions are

(a) $Z = 0$, (i) $C_y = 1.0$ (3.3a)

(ii) $-(\frac{dC_x}{dZ}) = 0$

(b) $Z = 1$, (i) $-(\frac{dC_y}{dZ}) = 0$ (3.4)

(ii) $C_x = C_x^1$ (3.6a)

B. Case II (Two Parameter System)

Conditions of axial mixing in the gas phase and plug flow in the liquid phase are assumed in this model, i.e., P_G is finite and $P_L \to \infty$. Therefore, Equations 3.1 and 3.2 are reduced to

$$\frac{d^2C_y}{dZ^2} - P_G \frac{dC_y}{dZ} - N_{oy}P_G(C_y - mC_x) = 0 \qquad (3.1)$$

and

$$\frac{dC_x}{dZ} + N_{ox}(C_y - mC_x) = 0 \qquad (3.8)$$

and the necessary boundary conditions are

$$\text{(a)}\quad Z = 0, \qquad \text{(i)} \quad -\left(\frac{dC_y}{dZ}\right) = P_G(1.0 - C_y) \tag{3.3}$$

$$\text{(ii)} \quad -\left(\frac{dC_x}{dZ}\right) = 0 \tag{3.4}$$

$$\text{(b)}\quad Z = 1, \qquad \text{(i)} \quad -\left(\frac{dC_y}{dZ}\right) = 0 \tag{3.5}$$

$$\text{(ii)} \quad C_x = C_x^1 \tag{3.6}$$

C. Case III (Three Parameter System)

This case represents the extreme case where axial mixing is assumed to be of importance in both the gas and liquid phases, i.e., the axial parameters P_G and P_L in the respective phases are finite. This case is represented by Equations 3.1 and 3.2, and the boundary conditions are given by Equations 3.3, 3.4, 3.5 and 3.6.

In this study, a non-linear regression analysis of the above-mentioned mathematical models is performed, and by curve fitting the experimental data, the values of the unknown parameters N_{Oy}, P_G and P_L, and other quantities are estimated as described later. A comparative study of the three models is also made to determine the most suitable model for the process of gas absorption for the experimental system used in this work.

IV. SOLUTIONS OF THE MATHEMATICAL MODELS

The solutions of mathematical models for three cases as given in the preceding section are derived by Miyauchi (1957) and are presented here.

A. Case I

For plug flow in both liquid and gas phases (i.e., $P_G \to \infty$; $P_L \to \infty$) and $\Lambda \neq 1$. The solution is as follows:

$$\frac{C_y - mC_x^1}{1.0 - mC_x^1} = \frac{e^{\lambda Z} - \Lambda e^{\lambda}}{1 - \Lambda e^{\lambda}} \qquad (4.1)$$

and

$$\frac{m(C_x - mC_x^1)}{1.0 - mC_x^1} = \frac{(e^{\lambda Z} - e^{\lambda})\Lambda}{1 - \Lambda e^{\lambda}} \qquad (4.2)$$

where

$$\Lambda = m\frac{F_y}{F_x} \qquad (4.3)$$

$$\lambda = - N_{oy}(1 - \Lambda) \qquad (4.4)$$

B. Case II

For plug flow in liquid phase and axial mixing in gas phase (i.e., P_G finite; $P_L \to \infty$) and $\Lambda \neq$ 1, the solution is given as follows:

$$\frac{C_y - mC_y^1}{1.0 - mC_x^1} = F_1 e^{\lambda_1 Z} + F_2 e^{\lambda_2 Z} + F_3 e^{\lambda_3 Z} \qquad (4.5)$$

$$\frac{m(C_x - C_x^1)}{1.0 - mC_x^1} = f_1 F_1 e^{\lambda_1 Z} + f_2 F_2 e^{\lambda_2 Z} + f_3 F_3 e^{\lambda_3 Z} \qquad (4.6)$$

where

$$F_1 = \frac{D_{F1}}{D_F} \qquad (4.7)$$

$$F_2 = \frac{D_{F2}}{D_F} \qquad (4.8)$$

$$F_3 = \frac{D_{F3}}{D_F} \qquad (4.9)$$

$$D_F = D_{F1} + \begin{vmatrix} 1-\lambda_2/P_G & 1-\lambda_3/P_L \\ \lambda_2 e^{\lambda_2} & \lambda_3 e^{\lambda_3} \end{vmatrix} \qquad (4.10)$$

$$D_{F1} = \begin{vmatrix} \lambda_2 e^{\lambda_2} & \lambda_3 e^{\lambda_3} \\ f_2 e^{\lambda_2} & f_3 e^{\lambda_3} \end{vmatrix} \qquad (4.11)$$

$$D_{F2} = \lambda_3 e^{\lambda_3} \qquad (4.12)$$

$$D_{F3} = -\lambda_2 e^{\lambda_2} \qquad (4.13)$$

and

$$f_i = 1 + \lambda_i/N_{oy} - \lambda_i^2/N_{oy}P_G \qquad (4.14)$$

$(i = 1,\ 2 \text{ and } 3)$

$$\lambda_1 = 0 \qquad (4.15)$$

$$\lambda_2 = (a/2) + \sqrt{(a/2)^2 + b} \qquad (4.16)$$

$$\lambda_3 = (a/2) - \sqrt{(a/2)^2 + b} \qquad (4.17)$$

$$a = P_G + (\Lambda)N_{oy} \qquad (4.18)$$

$$b = (1 - \Lambda)N_{oy}P_L \qquad (4.19)$$

C. Case III

For axial mixing in both gas and liquid phases (i.e., P_G finite; P_L finite) and $\Lambda \neq 1$, the analytical solution is given as follows:

$$\frac{C_y - mC_x^1}{1.0 - mC_x^1} = A_1 e^{\lambda_1 Z} + A_2 e^{\lambda_2 Z} + A_3 e^{\lambda_3 Z} + A_4 e^{\lambda_4 Z} \quad (4.20)$$

$$\frac{m(C_y - C_x^1)}{1.0 - mC_x^1} = a_1 A_1 e^{\lambda_1 Z} + a_2 A_2 e^{\lambda_2 Z} + a_3 A_3 e^{\lambda_3 Z} + a_4 A_4 e^{\lambda_4 Z} \quad (4.21)$$

where

$$A_1 = \frac{D_{A1}}{D_A} \quad (4.22)$$

$$A_2 = \frac{D_{A2}}{D_A} \quad (4.23)$$

$$A_3 = \frac{D_{A3}}{D_A} \quad (4.24)$$

$$A_4 = \frac{D_{A4}}{D_A} \quad (4.25)$$

$$D_A = D_{A1} - \begin{vmatrix} 1-\lambda_2/P_G & 1-\lambda_3/P_G & 1-\lambda_4/P_G \\ \lambda_2 a_2 & \lambda_3 a_3 & \lambda_4 a_4 \\ \lambda_2 e^{\lambda_2} & \lambda_3 e^{\lambda_3} & \lambda_4 e^{\lambda_4} \end{vmatrix} \quad (4.26)$$

$$D_{A1} = \begin{vmatrix} \lambda_2 a_2 & \lambda_3 a_3 & \lambda_4 a_4 \\ \lambda_2 e^{\lambda_2} & \lambda_3 e^{\lambda_3} & \lambda_4 e^{\lambda_4} \\ (1+\lambda_2/P_L) a_2 e^{\lambda_2} & (1+\lambda_3/P_L) a_3 e^{\lambda_3} & (1+\lambda_4/P_L) a_4 e^{\lambda_4} \end{vmatrix} \quad (4.27)$$

$$D_{A2} = - \begin{vmatrix} \lambda_3 a_3 & \lambda_4 a_4 \\ \lambda_3 e^{\lambda_3} & \lambda_4 e^{\lambda_4} \end{vmatrix} \quad (4.28)$$

$$D_{A3} = \begin{vmatrix} \lambda_2 a_2 & \lambda_4 a_4 \\ \lambda_2 e^{\lambda_2} & \lambda_4 e^{\lambda_4} \end{vmatrix} \quad (4.29)$$

$$D_{A4} = - \begin{vmatrix} \lambda_2 a_2 & \lambda_3 a_3 \\ \lambda_2 e^{\lambda_2} & \lambda_3 e^{\lambda_3} \end{vmatrix} \quad (4.30)$$

$$a_j = 1 + \lambda_J/N_{oy} - \lambda_J{}^2/N_{oy}P_G \quad (4.31)$$

$$(J = 1,\ 2,\ 3 \text{ and } 4)$$

$$\lambda_1 = 0 \quad (4.32)$$

$$\lambda_2 = \alpha/3 + 2\sqrt{P}\cos(\upsilon/3) \quad (4.33)$$

$$\lambda_3 = \alpha/3 + 2\sqrt{P}\cos(\upsilon/3 + 2\pi/3) \quad (4.34)$$

$$\lambda_4 = \alpha/3 + 2\sqrt{P}\cos(\upsilon/3 + 4\pi/3) \quad (4.35)$$

where υ is determined as an angle between 0 and π, such that

$$\cos\upsilon = q/p^{3/2}, \quad (4.36)$$

and

$$p = (\alpha/3)^2 + \beta/3 \quad (4.37)$$

$$q = (\alpha/3)^3 + \alpha\beta/6 + \gamma/2\ , \quad (4.38)$$

where

$$\alpha = P_G - P_L \quad (4.39)$$

$$\beta = N_{oy}P_G + P_GP_L + N_{oy}P_L(\Lambda) \quad (4.40)$$

$$\gamma = N_{oy}P_GP_L(1-\Lambda) \quad (4.41)$$

The above solution holds only when

$$q^2 - p^3 = \frac{1}{27}(\alpha^3\gamma - \alpha^2\beta^2/4 + 9\alpha\beta\gamma/2 - \beta^2 + 27\gamma^2/4) < 0 \quad (4.42)$$

Mathematical models for the three cases represented by Equations 4.1, 4.5 and 4.20 are curve fitted with the experimental data (composition vs. height) by non-linear regression analysis to obtain the parameter N_{OX} for Case I, N_{OX} and P_G for Case II and P_G and P_L for Case III. A standard procedure (Draper and Smith, 1966) of (i) linearization of non-linear functions by Taylor series expansion, (ii) obtaining of normal equations, and (iii) calculation of the desired parameters by an iterative technique is used. Detailed equations describing the calculations for the Case I are given in Appendix A.

A detailed description of the calculations for Case II and Case III are excluded in this discussion in favor of the detailed computer programs given in Appendix I. Because of the complex nature of the models, their regression analysis involves a great deal of algebraic manipulation which besides being a duplication of work (since computer programs show all the steps) would have unnecessarily increased the bulk of the thesis. Writing computer programs of the nature given in Appendix I is laborious, painstaking and time consuming and as such would be of much help to a person interested in this field of research.

Besides the calculation of error term in the least square sense of the deviation of the computed gas phase concentration profile from the experimental profile (as described in Appendix A), the following other quantities are calculated:

1. Calculation of Average Absolute Percentage Deviation: The Average Absolute Percentage Deviation (AAPD) is a form of representing

the deviation between the predicted value of the gas phase concentration and experimental data. Mathematically it is written as

$$\text{AAPD} = \frac{100}{n} \sum_{i=1}^{n} \left[\frac{|Y_i - Y_i^*|}{Y_i} \right] \qquad (4.43)$$

2. <u>The "Variance" on Gas Phase Concentration - σ_y^2</u>: An estimate of the probability that the predicted value of the gas phase concentration differs from the experimentally measured value is determined in terms of "variance" or as standard deviation:

$$\sigma_y^2 = \frac{1}{DF} \sum_{i=1}^{n} (Y_i - Y_i^*) \qquad (4.44)$$

where DF (Degrees of Freedom) = n - m,

n = total number of data points, and

m = total number of parameters to be determined.

3. <u>The "Variance" of N_{oy}, P_G and P_L</u>: These values are calculated as follows.

$$\sigma_{N_{oy}}^2 = \frac{\sum_{i=1}^{n} [Y_i - Y_i^*]^2}{(n-1) \left[\frac{\partial Y_i^*}{\partial (N_{oy})} \right]^2} \qquad (4.44)$$

$$\sigma_{P_G}^2 = \frac{\sum_{i=1}^{n} [Y_i - Y_i^*]^2}{(n-1) \left[\frac{\partial Y_i^*}{\partial (P_G)} \right]^2} \qquad (4.45)$$

$$\sigma^2_{P_L} = \frac{\sum_{i=1}^{n} [Y_i - Y_i^*]^2}{(n-1)\left[\frac{\partial Y_i^*}{\partial (P_L)}\right]^2} \qquad (4.46)$$

4. <u>Confidence Limits</u>: The 95% confidence limits on N_{oy}, P_G and P_L are also calculated.

AAPD, "variance" on gas phase concentration and "variance" of N_{oy}, P_G and P_L are also calculated for Case I and Case II. Confidence limits are also calculated for the aforesaid cases.

V. EXPERIMENTAL SYSTEM, APPARATUS AND PROCEDURE

The system chosen for this investigation was carbon dioxide-nitrogen-water. This system was chosen because the dissolution of carbon dioxide in water obeys the general principles governing the absorption of a sparingly soluble gas, i.e., it obeys Henry's law which was necessary so that the mathematical models discussed earlier could be used. In addition, the gas mixture could be easily analysed, was cheaply available and involved no safety problems.

At partial pressures below one atmosphere, H, the Henry's law constant for the system CO_2-H_2O, is a constant and dependent only on the temperature for the above mentioned system. The value of the Henry's law constant used in the present investigation at the operational temperature of 28^oC is 1760 atm./mol. fraction (Perry, 1957).

It is considered that a small amount of free CO_2 content of the process water would not have significant effect on the column performance.

A. Experimental Apparatus and Procedure.

Carbon dioxide was absorbed from a mixture of about 20% CO_2 with nitrogen by continuous counter-current contact with water in a packed column. Experiments were conducted at a constant temperature of 28^oC ±0.2^oC. The progress of the absorption was followed by sampling the gas phase at six or nine axial locations in the packed bed depending upon the total height of the columns used, in addition to the determination of the exit compositions. The gas analysis of the inlet gas mixture was provided by the supplier, the Matheson Co., Joilet, Ill. Gas composition was analysed by a gas chromatograph (see Figure 12), specifications of which are given in Appendix K.

Details of the operating variables for the gas chromatograph are as follows:

Packing	Porapack Type Q 100/120 uncoated
Packed Column	Stainless steel, O.D.1/8 inch, Length - 6 feet
Bridge Current	135 ma.
Detector Temperature	135°C
Oven Temperature	60°C
Carrier Gas	Helium

A Beckman Micro thermal conductivity cell was used. It takes less gas volume and gives less peak spreading. A Carle micro valve was used to withdraw samples and feed them to the gas chromatograph. The gas chromatograph was coupled to a Beckman 10 inch recorder equipped with a Disc integrater.

1. The Absorption Tower: The tower consisted of a 4 inch i.d. glass column. Details of the apparatus are shown in Figures 2 through 12. Experiments were conducted at two packed heights of 3 feet and 5 feet measured from the packing support grid.

Six sampling points were provided for 3 feet packed column, at regular intervals of 6 inches, the first being at a height of 6 inches from the bottom support grid. In the case of 5 feet packing height nine sampling points were provided, the distance between sixth and seventh position being 1 foot. The rest of the details were the same as for the 3 feet packed column (details given in Appendix H).

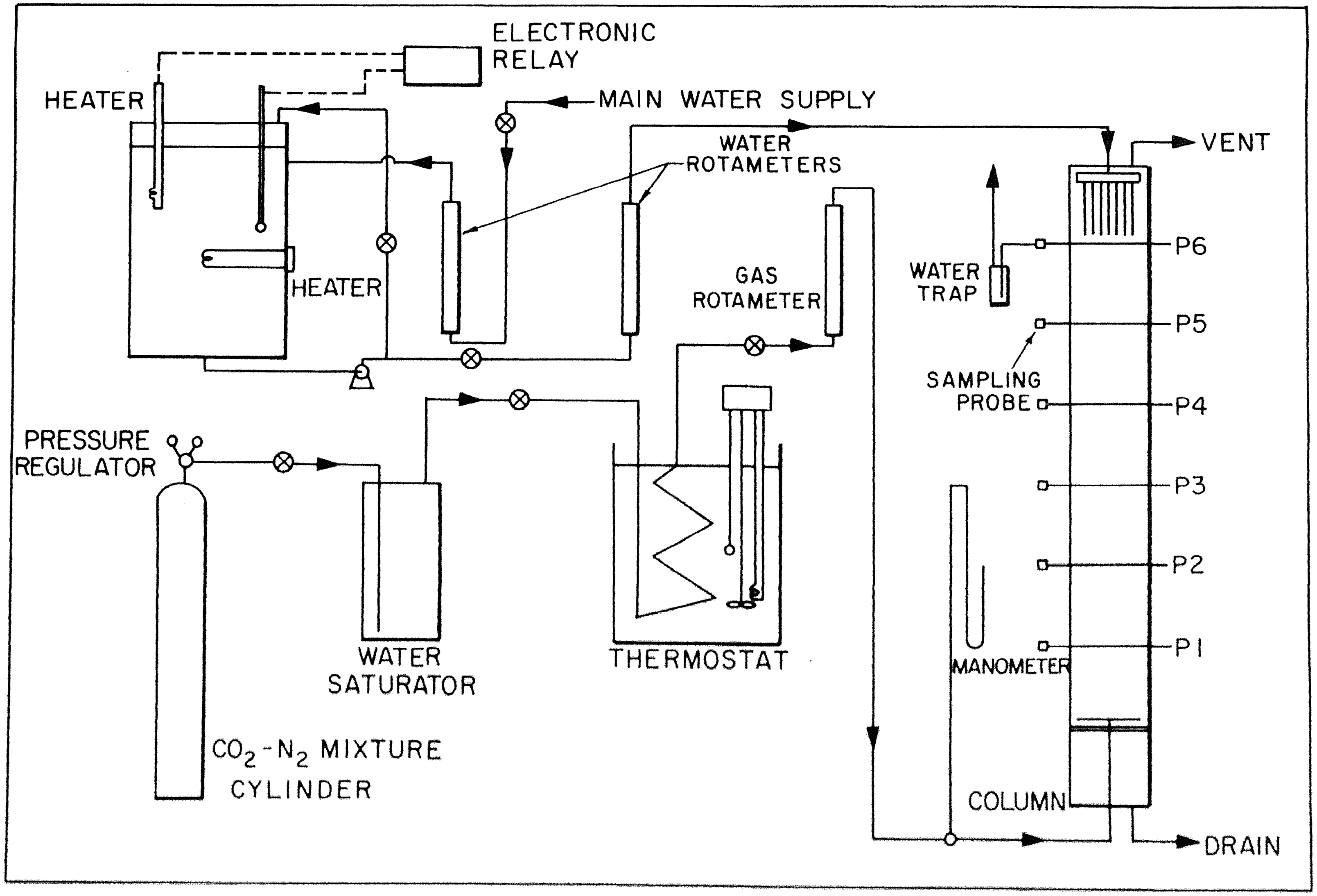

Figure 2. Flow Chart for Experimental Apparatus

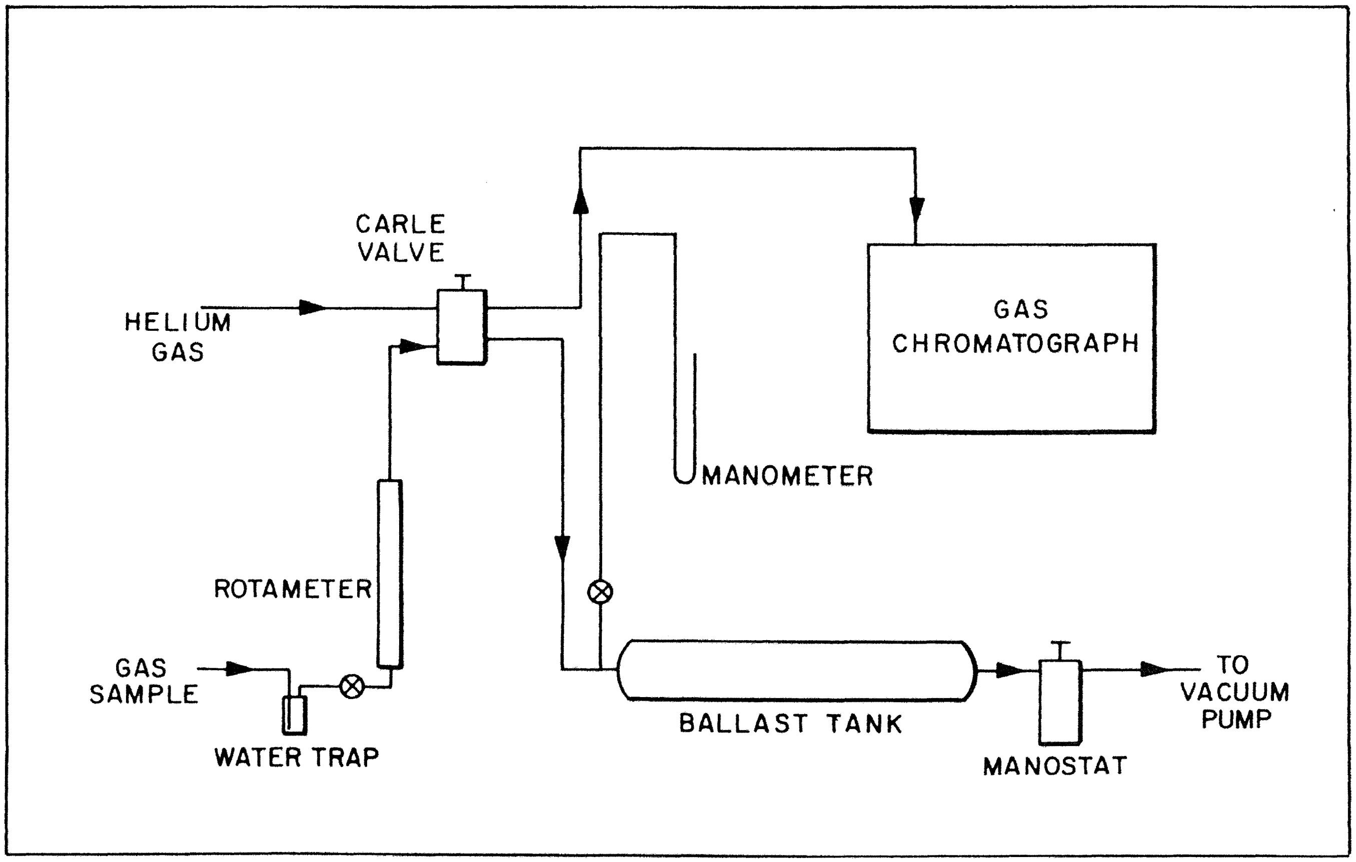

Figure 3. Gas Analysis System

Figure 4. General View of the Experimental Apparatus

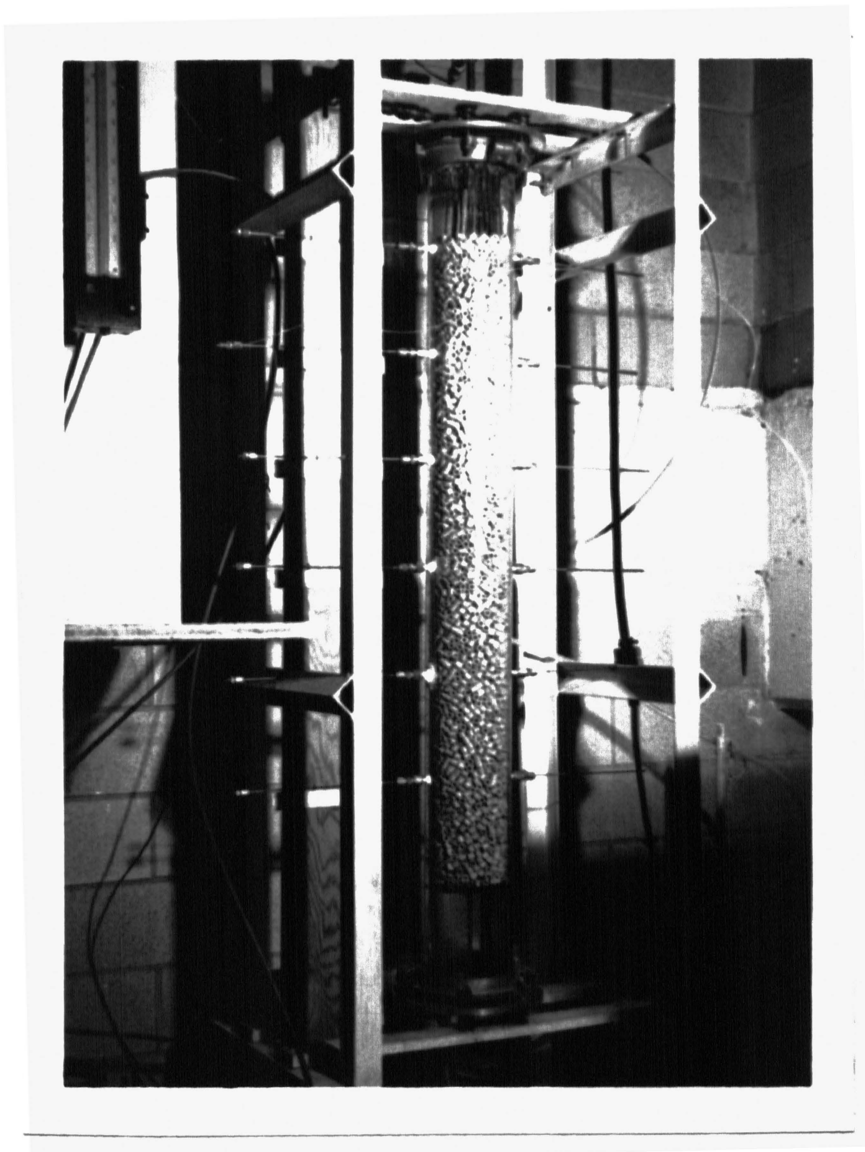

Figure 5. Packed Column with Sampling Probes

Figure 6. Empty Column, Downcomers, Sampling Probes and Grid Support

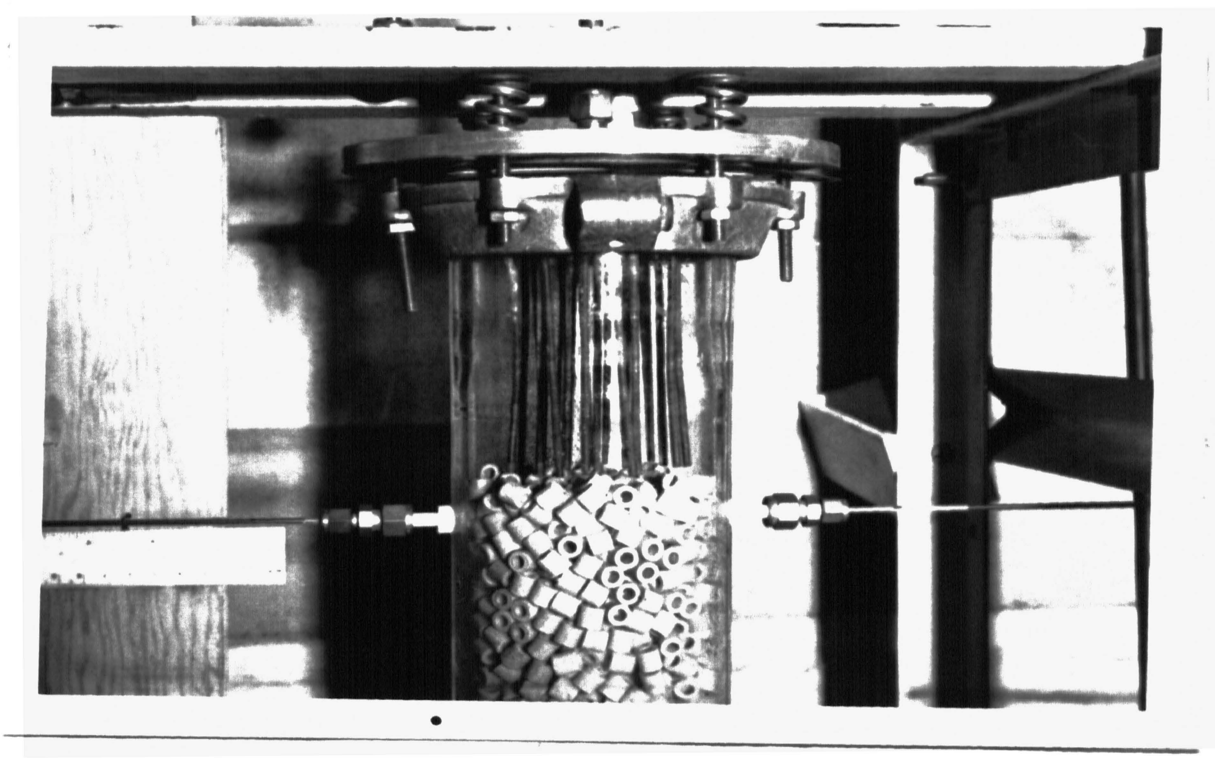

Figure 7. Downcomers (Water Distributor)

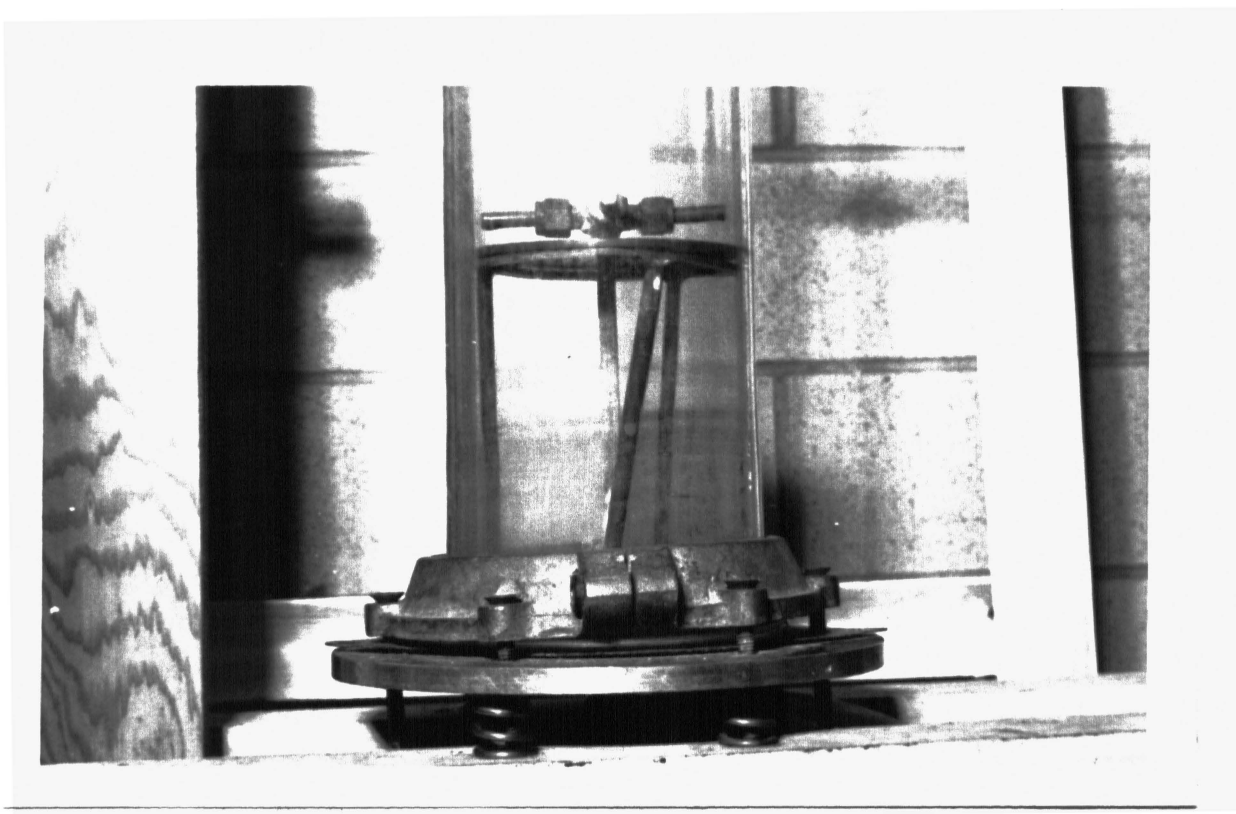

Figure 8. Gas Mixture Distributor and Support Grid (View 1)

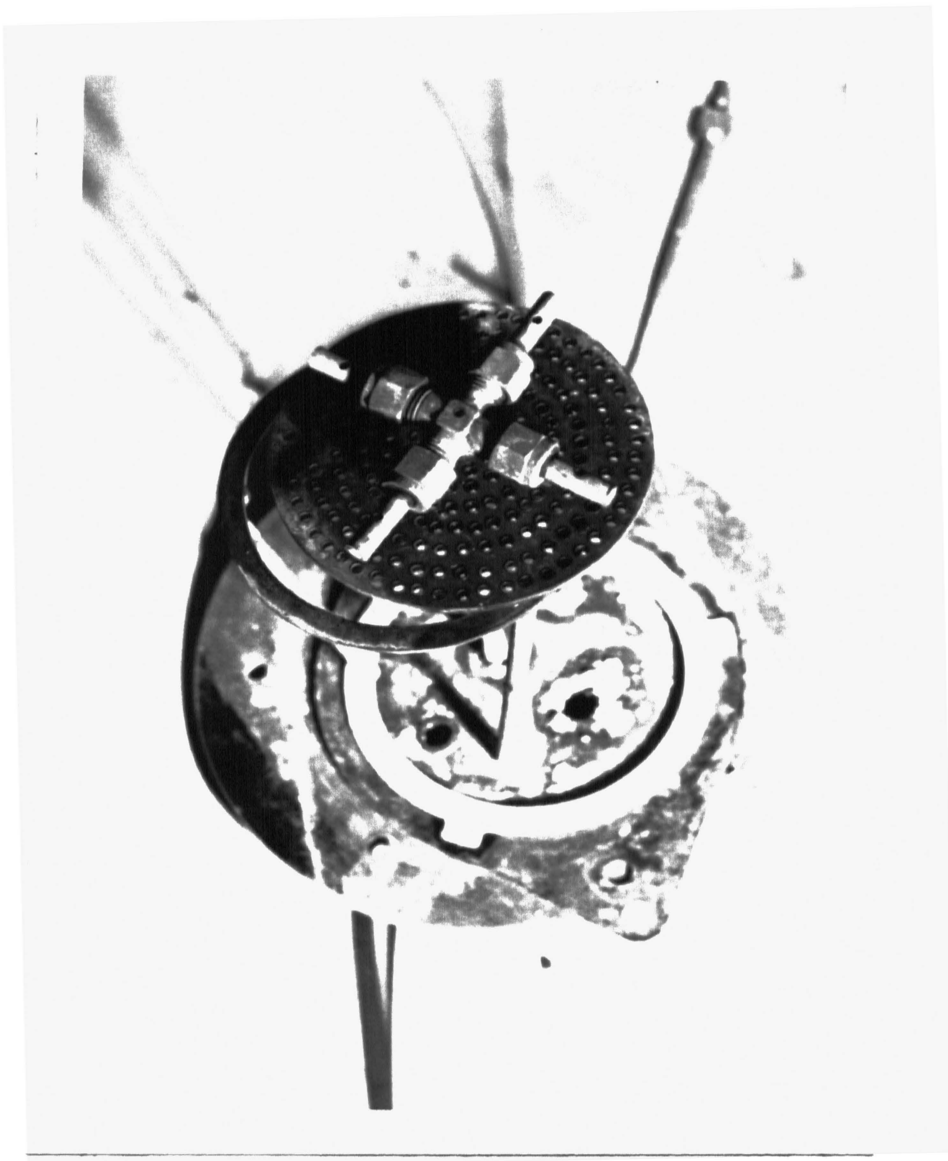

Figure 9. Gas Distributor and Support Grid (View 2)

Three sizes of unglazed porcelain Raschig ring packings were used - 1/4 by 1/4 inch, 3/8 by 3/8 inch and 1/2 by 1/2 inch. Experiments at two packing heights were conducted only for the 3/8 by 3/8 inch packing. The normal wet packing method was employed to pack the column. The minimum tower to packing diameter ratio was 8:1 which is the generally accepted minimum as proposed by Baker and co-workers (1935).

The gas inlet consisted of a 1/4 inch o.d. copper tube inserted into the packing above the grid support. A distributer with four arms with 5, 1/16 inch holes (one on each arm and one at the center) was provided at the end of the tube to uniformly distribute the gas in the column. The liquid level at the base of the packing was kept in contact with the packing support grid by means of a liquid seal arrangement to avoid the end effects due to the absorption of gas below the packing grid. An outlet was provided at the top of the column for the gas to leave the tower. Provisions were made to draw samples of the exit gas from the column.

Liquid entered the packing from a small container atop the packing which fed the downcomers. The container was supported by the flange covering the top of the column. The downcomers consisted of 20, 1/8 inch o.d. copper tubes fixed to the bottom of the container. These were evenly spread over the tower cross-section to provide a uniform distribution of water. The lower ends of the downcomers were placed in contact with the packing to avoid any further absorption of carbon dioxide after the gas phase leaves the packing. A thermocouple was provided just above the top of the column in the line carrying the water to observe the liquid temperature immediately prior to its entry into the column.

A manometer connected to the gas feed line allowed the pressure drop across the tower to be determined. It also acted as a warning indicator of any pressure build up in the system.

2. Gas Supply: Analysed mixtures of carbon dioxide and nitrogen were obtained from Matheson Co., Joilet, Ill., which were supplied in cylinders under 2000 lb./sq. in. pressure. The gas mixture was bubbled through water for saturation and then passed through a copper coil immersed in a constant temperature bath to heat and maintain the gas at a temperature of $28^{o}C \pm 0.2^{o}C$. The gas mixture was next passed through a previously calibrated rotameter (calibration described later). In order to be sure that gas mixture entered the column at the desired temperature a thermocouple was provided just before the gas inlet to the absorber.

3. Water Supply: Water from the main supply line was fed through a rotameter at the desired flow rate to a 50 gallon stainless steel tank. A 4500 watt electric heater was provided in the tank to heat the water to approximately desired temperature. The heating was controlled by varying the power to heater by means of an auto-transformer. Another 1000 watt heater was provided in the tank whose heating was regulated by means of an electronic relay. A centrifugal pump was employed to convey water to the top of the column. Since the rate of pumping was higher than required to be put in the absorber, the excess water was fed back to the tank. In this way a constant head was continuously maintained during the experimental run while at the same time providing stirring of the water in the tank. The water temperature, by providing two heaters and water circulation systems, could be maintained to $\pm 0.2^{o}C$ of the

desired value. The flow rate to the column was metered by a previously calibrated rotameter (calibration described later). The effluent liquid from the column was fed to the drain.

4. Gas Sampling: The main problem associated with gas sampling from within the packing was the difficulty of obtaining a sample representative of the true mean gas composition at the cross-section in question. Considerable deviation in the $K_L^a a$ values reported by Rixon (1948) was attributed to the fact that sampling was effected at a single point within the packing rather than over an entire cross-section. Use of a movable probe to draw samples at various points in the radial direction was considered out of the question since it would disturb the packing and consequently change the liquid and gas profiles every time the probe position is changed.

This problem was overcome to a certain extent by employing two coaxial tubes, the outer of which remained fixed in the packing whilst the inner was free to move (see Figures 6 and 10). The outer tube was 0.095 inch i.d. teflon tube while the inner tube was of 0.095 inch o.d. stainless steel, of wall thickness, 0.012 inch. The inside diameter of teflon tube and outside diameter of stainless steel tubes were so chosen that the inner tube fit snugly into the outer. Seven holes each approximately 1/16 x 1/16 inch in size were provided in the outer teflon tube at an interval of 1/2 inch over a total length of 4 inches. One hole, 1/32 inch in diameter was drilled in the inner stainless tube. By moving the inside tube, this hole could be made to coincide with any of the seven holes in the outer tube. A pointer attached to the stainless steel tube traveling on a graduated scale indicated with which of the holes on the outer teflon tube the hole on the inner tube was coinciding

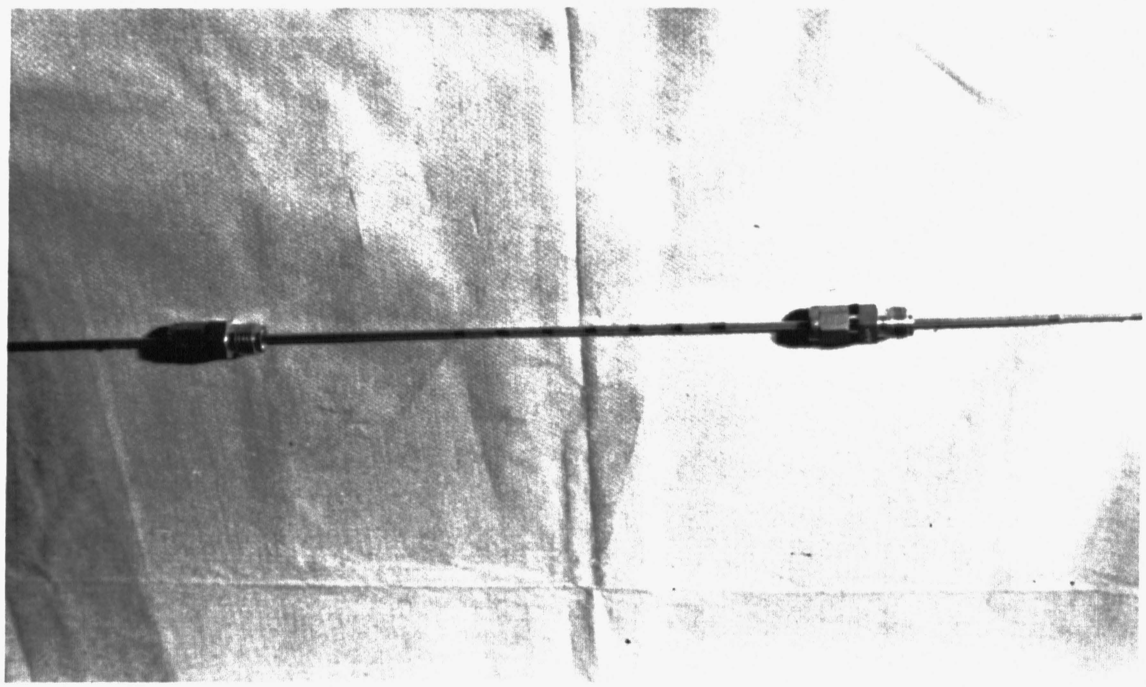

Figure 10. Sampling Probe

at any time. The holes were kept of small sizes as gas drawn through large size holes as used by Brittan (1966) could disturb the gas velocity profile and thus disturb the concentration profile in the whole column. A teflon tube was used so that the inner stainless steel tube could move smoothly without any gas leakage and secondly so that water would not adhere to teflon material. The diameters of tubes were kept small so that these tubes might not bring in any additional 'packing effect.' Large diameter sample tubes would also create large dead gas volume. For the same reason, a narrow 20-guage teflon tube was used to carry the sample to the gas chromatograph. Efforts were also made to keep the total length of the sample-carrying tube to a minimum by keeping the chromatograph close to the absorption column and carrying the sample direct to it without the use of any manifold arrangement.

However, because of the very small diameter tubes and holes, very often water was sucked in the gas sample line. In order to prevent water entering into the gas chromatograph, a small water trap fitted with a rubber membrane at one end was used (see Figure 11). The water collected could be removed by a hypodermic syringe.

5. Gas Analysis: Samples were withdrawn by vacuum at the rate of about 100 ml./min. This was about three percent (maximum) of the overall gas flow rates employed. The gas phase rather than liquid phase analysis was employed, the method being simpler and considerably more accurate than low concentration liquid phase determinations.

As mentioned earlier, the gas phase concentration analysis was done with the help of a gas chromatograph using thermal conductivity measurements (see Figure 12). The peaks of nitrogen and carbon dioxide

Figure 11. Water Trap for Gas Samples

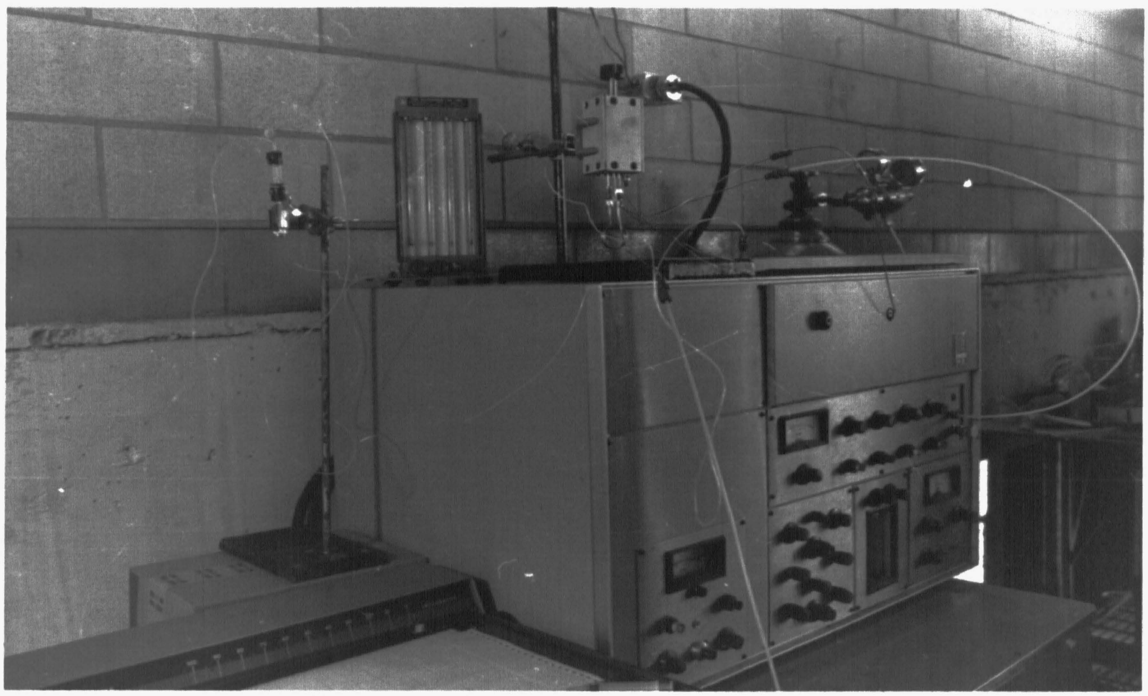

Figure 12. Gas Chromatograph

obtained were well separated. Disc integrater gave the areas under the peak curves automatically. Sample calculations are given in Appendix B to calculate carbon dioxide concentration at any point.

It was observed that water flowing out of the downcomers was impinging against the top of the packing and creating turbulence. In order to avoid this end effect, exit gas compositions were not used in the calculations though they are listed in the Tables XLVIII through XLI.

B. Calibration of Rotameters

Rotameters were used to measure the gas mixture flow rate to the column and gas sample flow rate to the chromatograph. Rotameters were also used to measure liquid flow rates.

A wet test meter was used for the calibration of rotameter for measuring gas mixture flow rates. Since the wet test meter used water, gas mixture was passed through the meter for a sufficiently long time to insure complete saturation of water with carbon dioxide. A number of sets of data were taken to ascertain the complete saturation. Calibration data are given in Appendix J.

The calibration curve as provided by the manufacturers was used for gas sample rotameter because the sampling rate was not required to be exactly 100 ml./min., but should be the same for all the samples withdrawn (see Figure 41).

Rotameters for measuring water rates were calibrated by collecting water for a definite period of time. The calibration data are given in Appendix J.

Specifications for equipment used in this investigation are given in Appendix K.

C. Selection of Operating Variables

The primary variables under investigation were liquid rate, gas rate, packing size and packing height and their effect on the absorber performance parameter, e.g., Peclet number, K_La and $(H.T.U.)_{OL}$, were to be determined. Operation at very low liquid rates was avoided due to the liquid distribution problems which are discussed in Chapter VI. The flooding characteristics and sucking of water in gas sample line imposed an upper limit to the magnitude of the liquid rate which could be employed. In all, six liquid rates were used, viz., 2865, 3580, 4300, 5020, and 5680 lb./hr.sq.ft.

Gas flow rates were selected in order to provide a satisfactory degree of absorption from the viewpoint of accuracy of measuring gas phase compositions. Three gas feed rates were employed--5.0, 6.2 and 7.38 lb./hr.sq.ft. Gas mixture composition was about 20% CO_2 (by volume) for all experiments (the exact compositions used are given in Appendix H).

Three sizes of unglazed porcelain Raschig ring packings were used - 1/4 by 1/4 inch, 3/8 by 3/8 inch, and 1/2 by 1/2 inch. These sizes were selected to keep a minimum of column to packing diameter ratio of 8:1.

Packing heights of 3 feet and 5 feet were selected. Any further increase in height would have resulted in excessive channelling.

All experiments were conducted at a temperature of $28^{o}C \pm 0.2^{o}C$.

D. Experimental Procedure

Refer to Figures 2 and 3.

Preliminary preparation prior to the initial run on any day involved the raising of all tank and bath temperatures to the requisite values. When the correct temperatures were attained, water was pumped to the column at the required rate. The flow from the mains into the hot water tank was maintained at a similar rate, and the temperature of the heating tank which warmed this stream was adjusted accordingly. Liquid was allowed to pass through the absorber at the required rate. The gas mixture of known composition (as supplied by Matheson Co., Joilet, Ill.) was passed directly to the gas chromatograph and the calibration peaks for carbon dioxide and nitrogen were obtained for the calibration of gas chromatograph as discussed in Appendix B. After the calibration of the gas chromatograph, the gas mixture line was connected to the absorption column and gas passed through the column at a requisite rate. The absorber was allowed to run for about half an hour before any measurement of the gas compositions at various packing heights were measured. This ensured that all parts of the column would be at the correct temperature, and that liquid distribution, hold up on the packing and concentration in the column were allowed sufficient time to assume steady values. It is probable that points at greater packing depth required longer time to attain steady state after start-up due to dispersion and bed capacitance effects. Therefore, repeated observations at the sampling point near the gas inlet were taken to ensure steady state before the complete set of axial gas composition data were obtained. It was found that it took about half an hour to reach steady state conditions. For this reason, an ascending order of sampling from position P1 to position P6 or P9 was adopted. Seven samples in the radial direction at each axial position were analysed. There were six and nine axial positions for 3 and 5 feet packing, respectively, 6 inches apart, the first one fixed at a distance of 6 inches from the bottom support grid. The normal duration for one run was about 2 to 2½ hours.

Fifteen sets of data at five liquid and three gas rates were taken for each of the three packing sizes using 3 feet packing height and an additional fifteen sets of data were taken for 3/8 inch packing size for 5 feet packing height.

VI. CORRELATION AND DISCUSSION OF EXPERIMENTAL RESULTS

Published gas and liquid side axial dispersion coefficients for two phase operations are scarce, but those available indicate an effect of dispersion on absorption. DeMaria and White (1960), Dunn et al (1962), Sater and Levenspeil (1966), Hoogendoorn and Lips (1965) and Hochman and Effron (1969) have determined axial dispersion coefficients by transient response techniques. Brittan and Woodburn (1966) have suggested that there are shortcomings in the transient techniques due to a disregard of effects such as fluid capacitance and non-flat velocity profiles. The phenomenon of fluid capacitance can be described as the development of dead spaces or pockets in a packed column where the liquid and gas have infinite residence time but play a part in a chemical or physical process by the diffusion of material into or out of them. The presence of fluid capacitance has been reported by Shulman et al (1955), Carberry and Bretton (1956), Dean and Lapidus (1960), Gottschilch (1963), and Hoogendoorn and Lips (1965). Schwarts and Smith (1953), and Cairns and Prausnitz (1959) have pointed out the existence of velocity variations across a packed bed particularly near the pipe wall due to the increase in void fraction caused by the packing element trying to conform to the circular shape of the wall.

In this investigation, steady state average (radial) gas phase composition data in the axial direction are experimentally obtained and compared with the axial concentration profiles as estimated by the mathematical models presented by Miyauchi (1957) as discussed earlier. The steady state procedure avoids difficulties of fluid capacitance and non-flat velocity profiles associated with transient analysis. In addition, the steady state techniques enable one to simultaenously obtain axial dispersion coefficients and interphase mass transfer coefficients. This is in contrast to the transient response technique where only axial dispersion coefficients are evaluated.

This chapter has been divided into two parts for clarity of the subject matter. The first part is devoted to the discussion pertaining to the solutions of the mathematical models and their validity with respect to the experimental data. The second part deals with the evaluation of absorption column variables such as over-all mass transfer coefficients and axial dispersion Peclet numbers in the presence of axial mixing in the gas phase.

A. Part I

This part of the thesis is concerned mainly with evaluating the applicability of Model I, Model II and Model III as a primary representation of the packed bed environ. Each model is separately tested by treating it as if it were an actual physical system. A comparative study of the three models is also made by testing for agreement with the experimental results.

The mathematical models used in this study are developed by other workers as mentioned earlier. Numerical solutions of these models are discarded in favor of analytical solutions to minimize computation errors. The analytical solutions of these models as developed by Miyauchi (1957) are used. The solutions of Model II and Model III are complex and lengthy. Each of the three models is subjected to non-linear regression analysis. In order to obtain the least squares normal equations, an analytical procedure of differentiation is adopted to avoid errors inherent in numerical procedures. An iterative technique is used for minimizing the sum of the squares of the deviations of the calculated from the observed gas phase compositions in order to evaluate the best estimates of the mass transfer coefficient and the axial mixing parameters. Details of the regression analysis equations for Models I, II, and III are given in Appendix A.

Experiments are conducted on the absorption of carbon dioxide in a packed column using 1/4, 3/8 and 1/2 inch Raschig ring packings, individually, with 3 feet packing height and also using a 3/8 inch Raschig ring packing with 5 feet of packing height. The results presented in Tables XXXVI through XLVII show axial concentration profiles from the curve fits of the three absorption models versus the experimental data. The 'goodness of fit' for Case I, II and III for three packing sizes and two packing heights is calculated and presented in Tables II through IX. Model I and II show excellent agreement between the experimental and calculated profiles. The 'error' in the least squares sense is of the order of 10^{-3} to 10^{-4}. Although Model I is somewhat simple in form, the excellent fit in every case of the calculated gas profile using Model II to the experimental profiles is a strong indication that Model II embodying the gas phase axial mixing term has as strong a claim as Model I to being the correct absorber mechanism. The computed gas phase axial concentration profiles for 1/4, 3/8 and 1/2 inch packings with 3 feet of packing height and also for 3/8 inch packing with 3 feet of packing height using Model II are shown in Figures 13 through 16 along with experimental data.

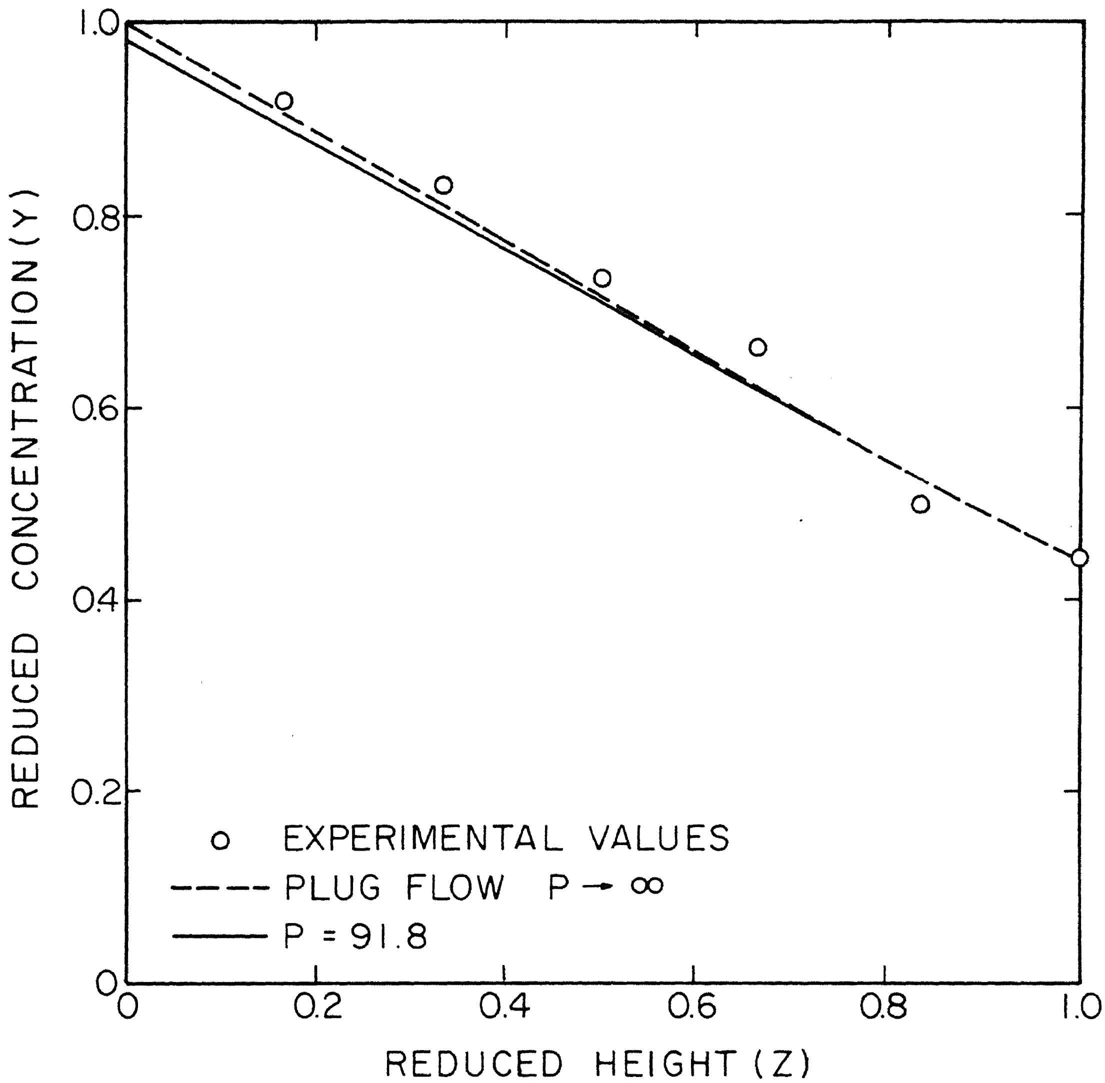

Figure 13. Effect of Axial Mixing on Axial Concentration Profile, 1/4 in. Raschig Rings, Packing Height - 3 ft., L = 5680.0 lb./hr.sq.ft. and G = 5.005 lb./hr.sq.ft.

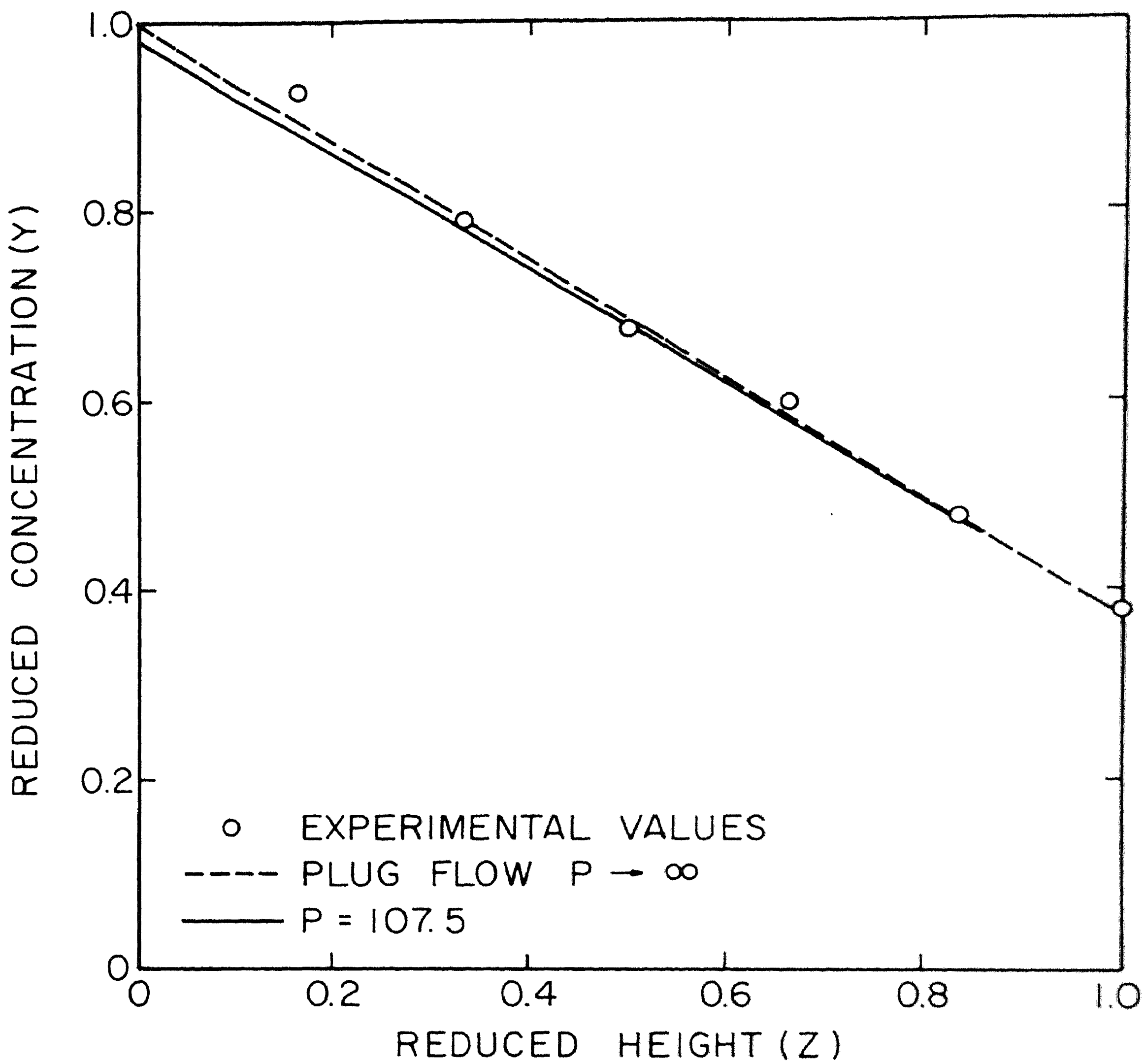

Figure 14. Effect of Axial Mixing on Axial Concentration Profile, 3/8 in. Raschig Rings, Packing Height - 3 ft., L = 5680.0 lb./hr.sq.ft. and G = 5.005 lb./hr.sq.ft.

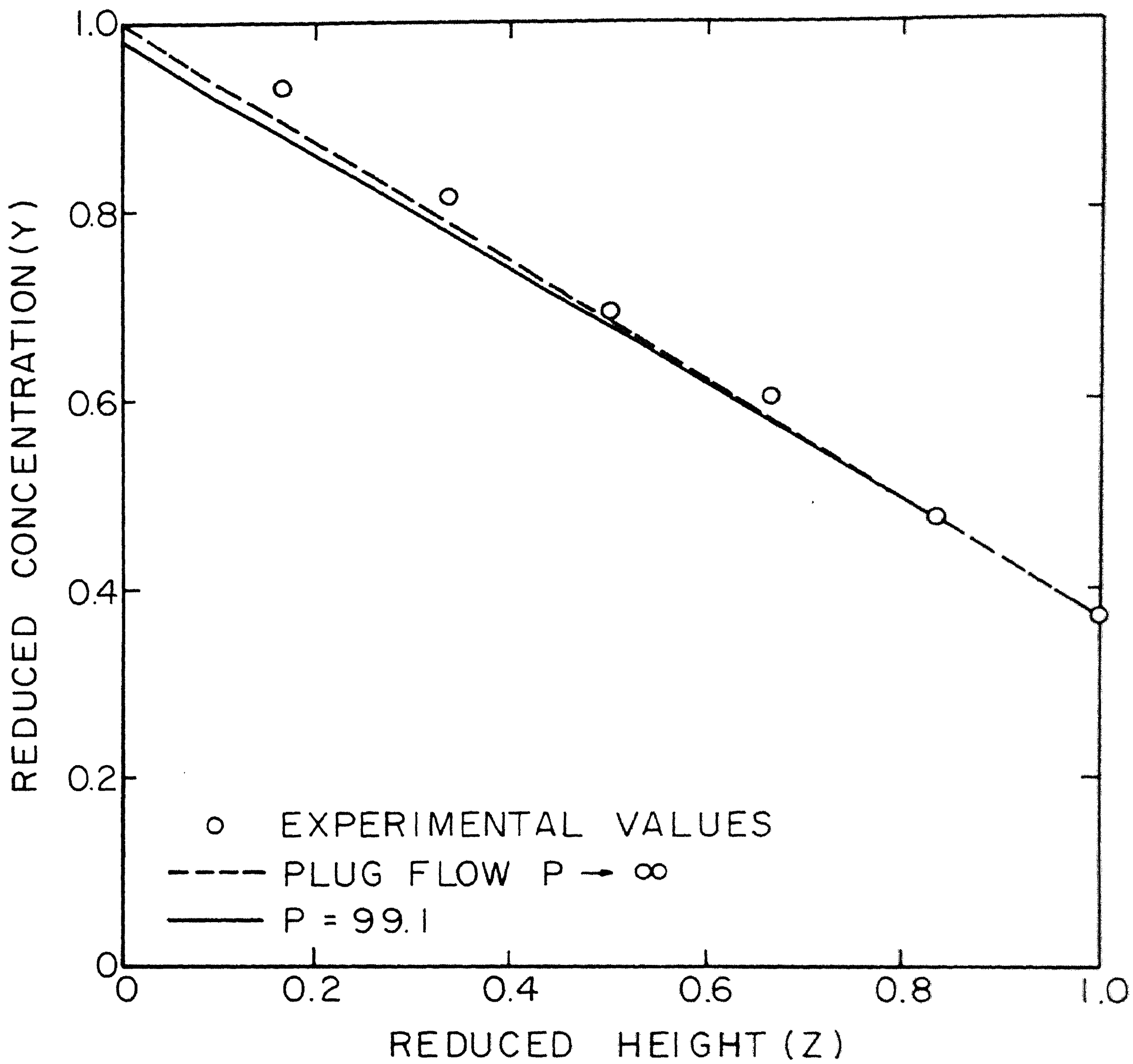

Figure 15. Effect of Axial Mixing on Axial Concentration Profile, 1/2 in. Raschig Rings, Packing Height - 3 ft., L = 5680.0 lb./hr.sq.ft. and G = 5.074 lb./hr.sq.ft.

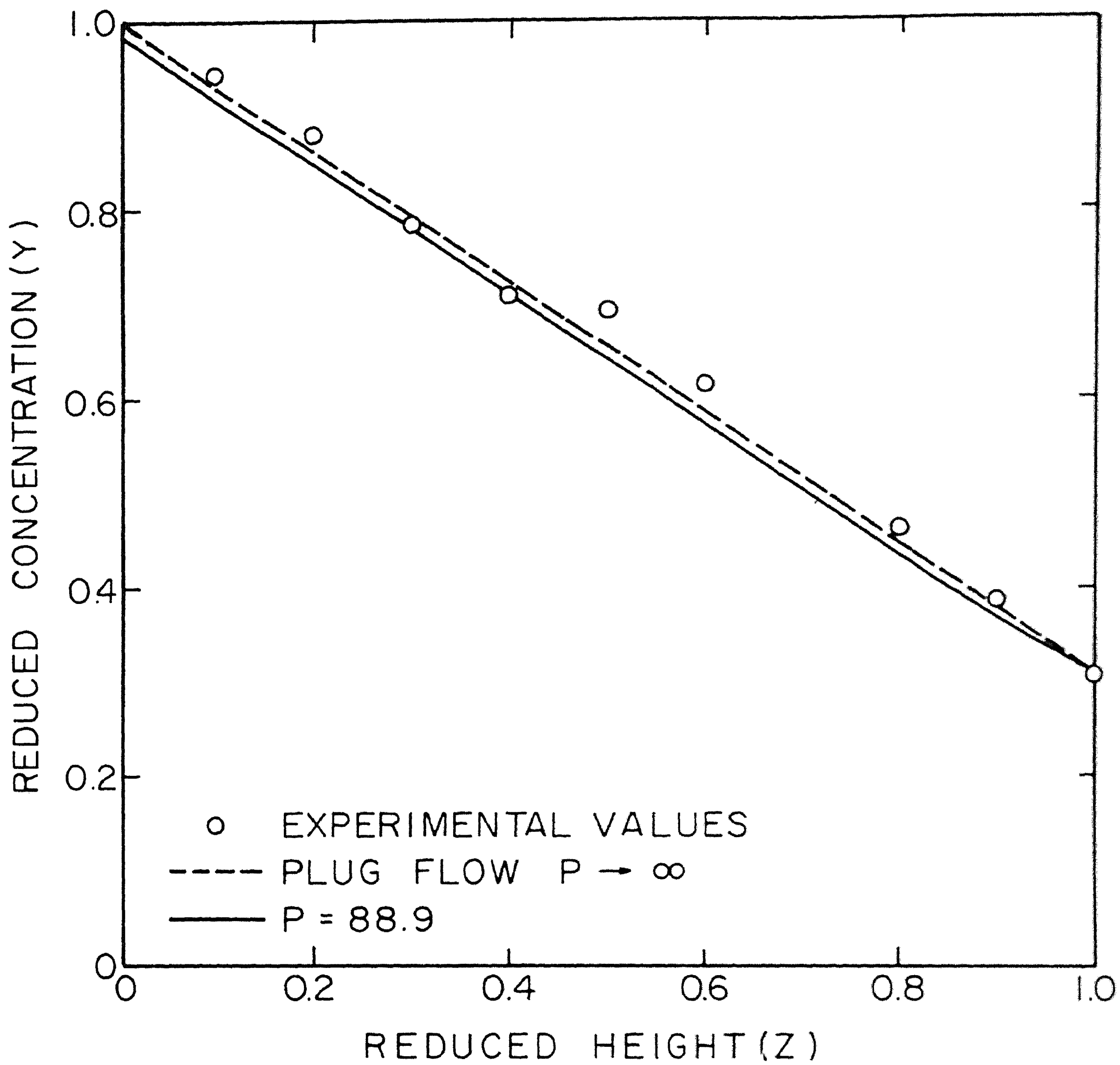

Figure 16. Effect of Axial Mixing on Axial Concentration Profile, 3/8 in. Raschig Rings, Packing Height - 5 ft., L = 5680.0 lb./hr.sq.ft. and G = 5.021 lb./hr.sq.ft.

Of the three models discussed earlier, the first one, plug flow in both gas and liquid phases has, hitherto, been used in the vast majority of absorption studies. Strong evidence (see Introduction and Literature Review) indicates that though the computed concentration profiles using Model I may agree with experimental data very closely, it cannot explain the intricate mechanism of interphase mass transfer involving axial as well as radial diffusion. The classic example of this situation is the two film theory of interphase mass transfer. While it undoubtedly is a good working model in that field, radically different models are probably equally justified by mass transfer data at this time.

Correspondence between the data and a theoretical model does not necessarily prove that the model truely represents the physical system. Rather, it may only demonstrate that a theoretical relation reproduces a result which is due to a reality more complicated than or even quite different from the assumed model.

Further, there is experimental evidence as discussed in Part II of this chapter that plug flow model will not be suitable for mass transfer work at industrial liquid rates and heights.

Model III shows the worst fit of all the three models. The average error (in the least square sense) for fifteen sets of data at various liquid and gas flow rates for Case I, Case II and Case III are presented in Tables II through IX. The percent difference in average errors for the three models are presented in Table I. Notice that the percent error for Case III is always higher than Case II (+4.64 to +20.17). In addition, the response of Model III to the experimental data is not satisfactory. No significant changes from the starting values of 50.0 and 60.0 for P_G and P_L, respectively, were obtained for the curve fit

TABLE I

PERCENT DIFFERENCE IN ERROR FOR VARIOUS CASES

Packing Size (in.)	Packing Height (ft.)	Percent Difference in Error for Various Cases		
		II - I*	III - I*	III - II*
1/4	3	+12.04	+23.08	+10.99
3/8	3	+14.61	+34.78	+20.17
1/2	3	+22.51	+28.19	+ 4.64
3/8	5	+25.41	+30.12	+ 3.75

*Based on the Model indicated by *, e.g., (III-I)(100)/I.

by the iterative procedure (See Tables VI through IX). Therefore, the Model III is considered unsuitable to adequately represent the Case III (axial mixing in both gas and liquid phases) and, thus, is rejected.

However, it is considered that Case III needs to be further investigated probably using some other mathematical model. It is recommended that in the future experimental study to discriminate between Model II and III sequential design procedures as reported by Box and Hill (1967) and Hunter and Reiner (1965) should be adopted. Sequential design procedures discriminate amongst the various models by making calculations after each experiment to determine the most discriminating process conditions for use in the next experiment.

B. Part II

The second part of this chapter consists of the study of the effect of axial mixing as embodied in Model II on the parameters characterizing absorption column performance. In this context the term performance means the study of the effect of gas and liquid rates, packing size and height on apparent and true over-all liquid phase mass transfer coefficients, height of over-all transfer units (liquid phase) and gas phase Peclet number. Liquid phase over-all mass transfer coefficients are calculated from gas phase over-all mass transfer coefficients assuming that Henry's law holds for the system. As stated earlier, the true mass transfer coefficient ($K_L^t a$) is defined as the over-all mass transfer coefficient from which the effects of axial dispersion have been segregated.

1. Effect of Gas Rate on $K_L^t a$ and $K_L^a a$: As shown in Figures 17 and

18 the gas rate has no significant effect on $K_L^t a$ for the packing size of 1/2 inch, with a packing height of 3 feet or for the packing size of 3/8 inch with the packing heights of 3 feet and 5 feet. In the case of 1/4 inch Raschig ring packing, $K_L^t a$ increases with increases in gas flow rate. This is attributed to the greater interstitial turbulence that is created by gas flow through and around small size packing. The apparent mass transfer coefficient ($K_L^a a$) shows a similar behavior as $K_L^t a$ for all packing sizes and heights (see Figures 17 and 18).

2. Effect of Liquid Rate on $K_L^t a$ and $K_L^a a$: As shown in Figures 19 through 22 for all packing sizes and packing heights, $K_L^t a$ and $K_L^a a$ increase with increases in liquid flow rate.

Correlations representing the apparent and true over-all liquid phase mass transfer coefficient data of Tables X through XIII have been determined by the least squares procedure. For 1/4 inch packing a multiple regression technique is used to correlate $K_L^a a$ and $K_L^t a$, individually, with both liquid and gas flow rates. For each correlation the Average Absolute Percent Deviation (AAPD) of computed gas composition from the experimental composition, is also calculated. These correlations hold for the ranges $2865 \leq L \leq 5680$ lb./hr.sq.ft. and $5.0 \leq G \leq 7.4$ lb./hr.sq.ft.

For plug flow in both gas and liquid phases, the correlations of $K_L^a a$ are as follows:

1/4 inch Raschig ring with packing height of 3 feet

$$K_L^a a = 0.00033\, L^{1.18} G^{0.93} \tag{6.1}$$

AAPD = 9.4

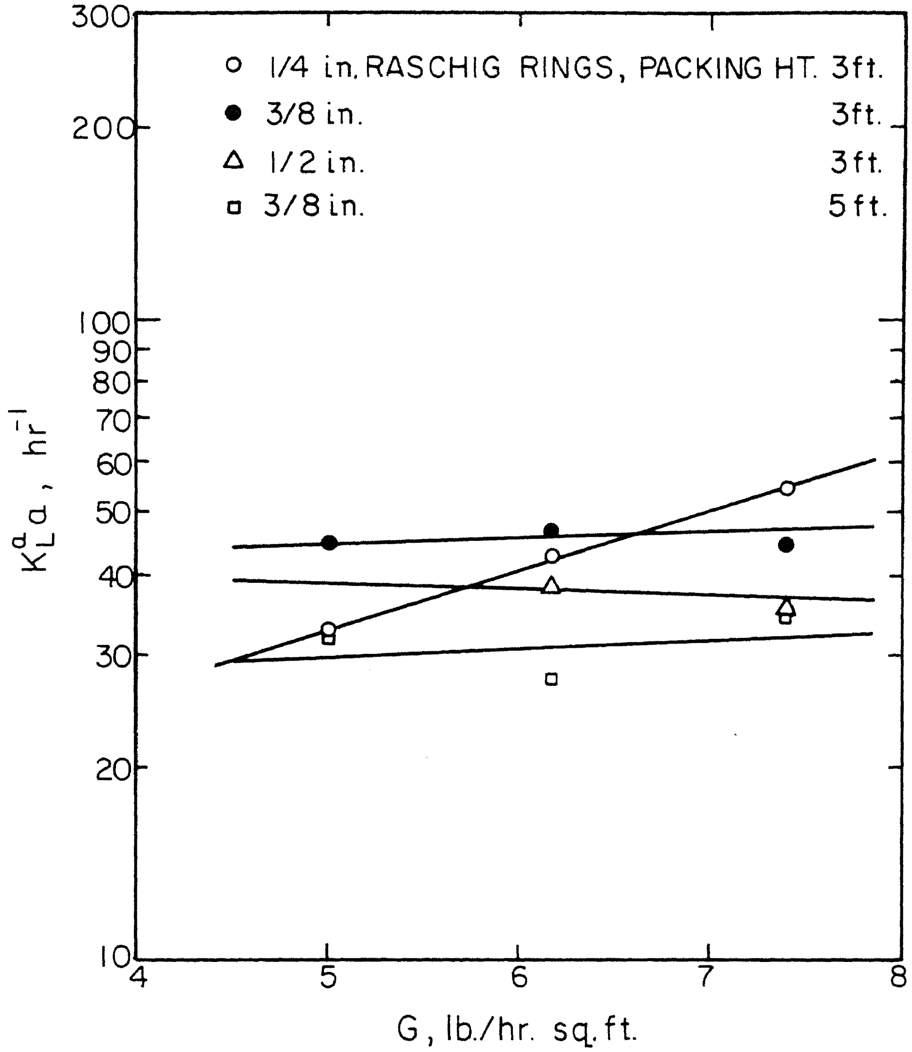

Figure 17. $K_L^a a$ vs. Gas Rate, L = 5680.0 lb./hr.sq.ft.

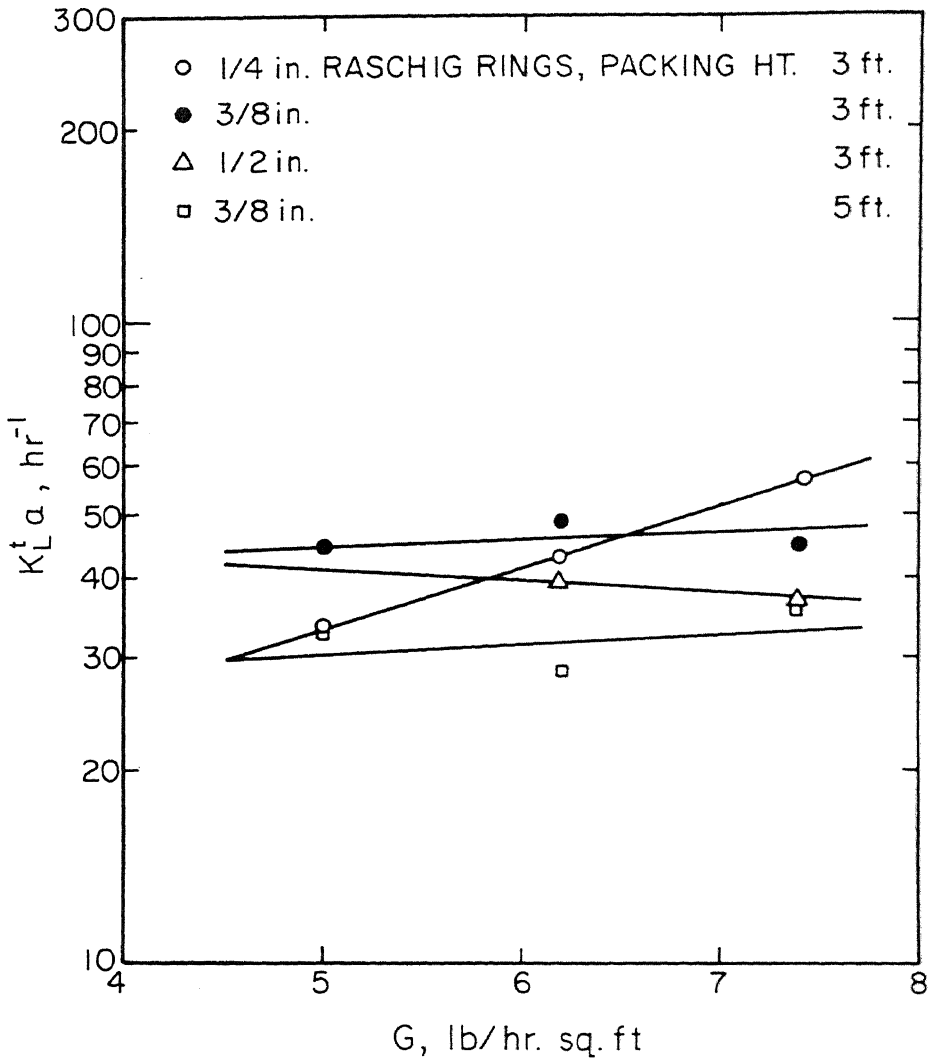

Figure 18. $K_L^t a$ vs. Gas Rate, L = 5680.0 lb./hr.sq.ft.

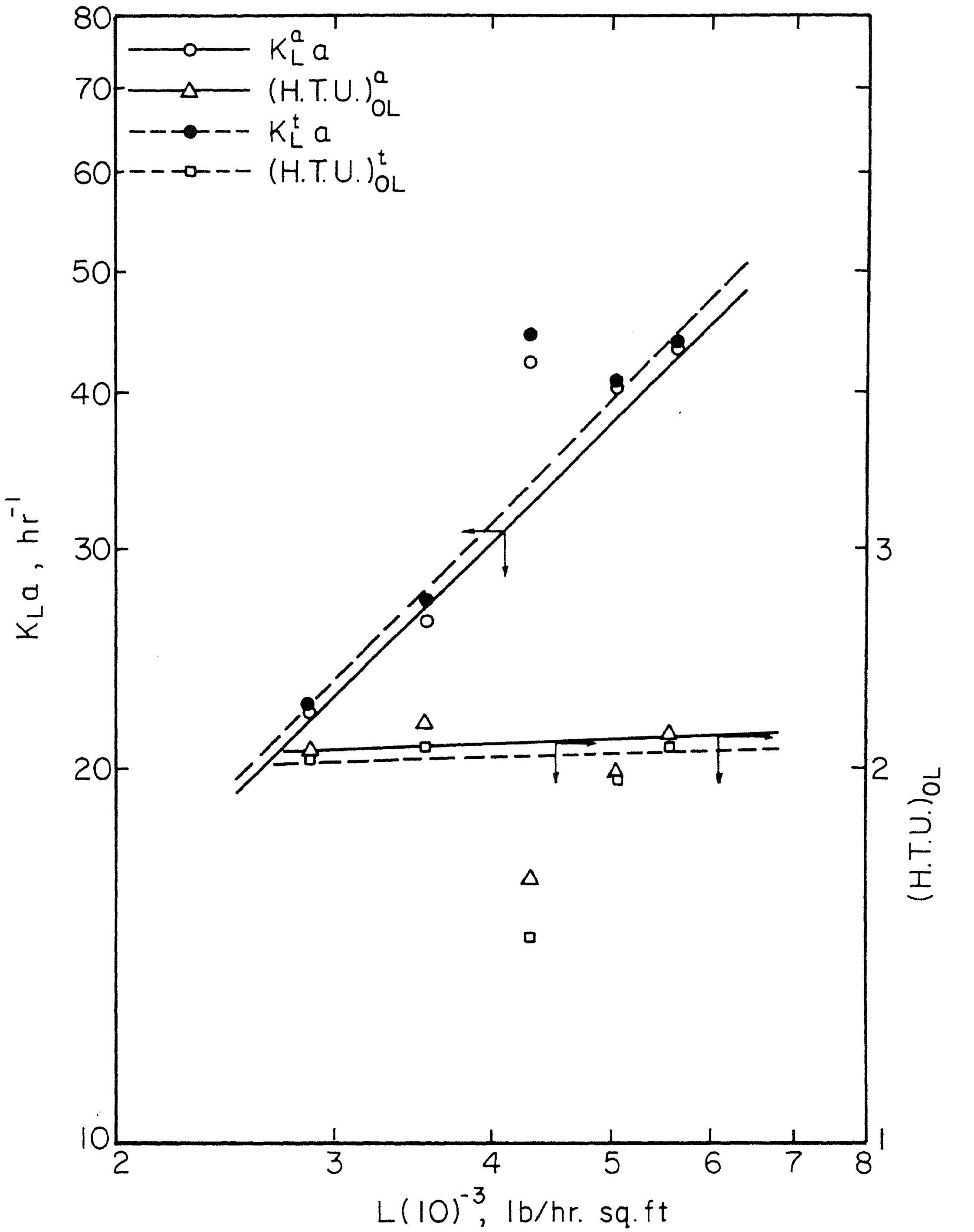

Figure 19. Effect of Water Rate on $K_L a$ and $(H.T.U.)_{OL}$, G = 6.198 lb./hr.sq.ft., 1/4 in. Raschig Rings, Packing Height - 3 ft.

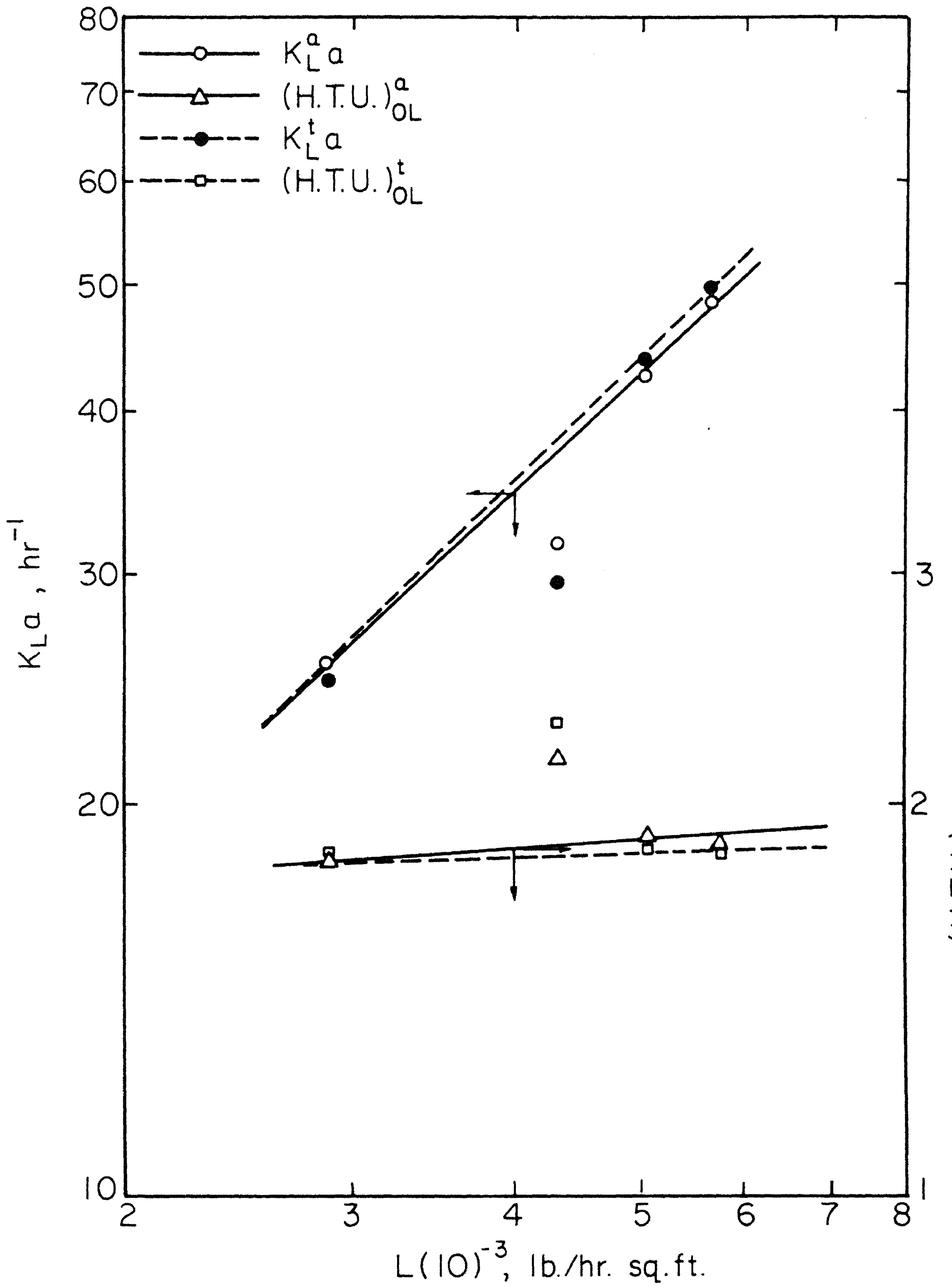

Figure 20. Effect of Liquid Flow Rate on K_La and $(H.T.U.)_{OL}$, G = 6.228 lb./hr.sq.ft., 3/8 in. Raschig Rings, Packing Height - 3 ft.

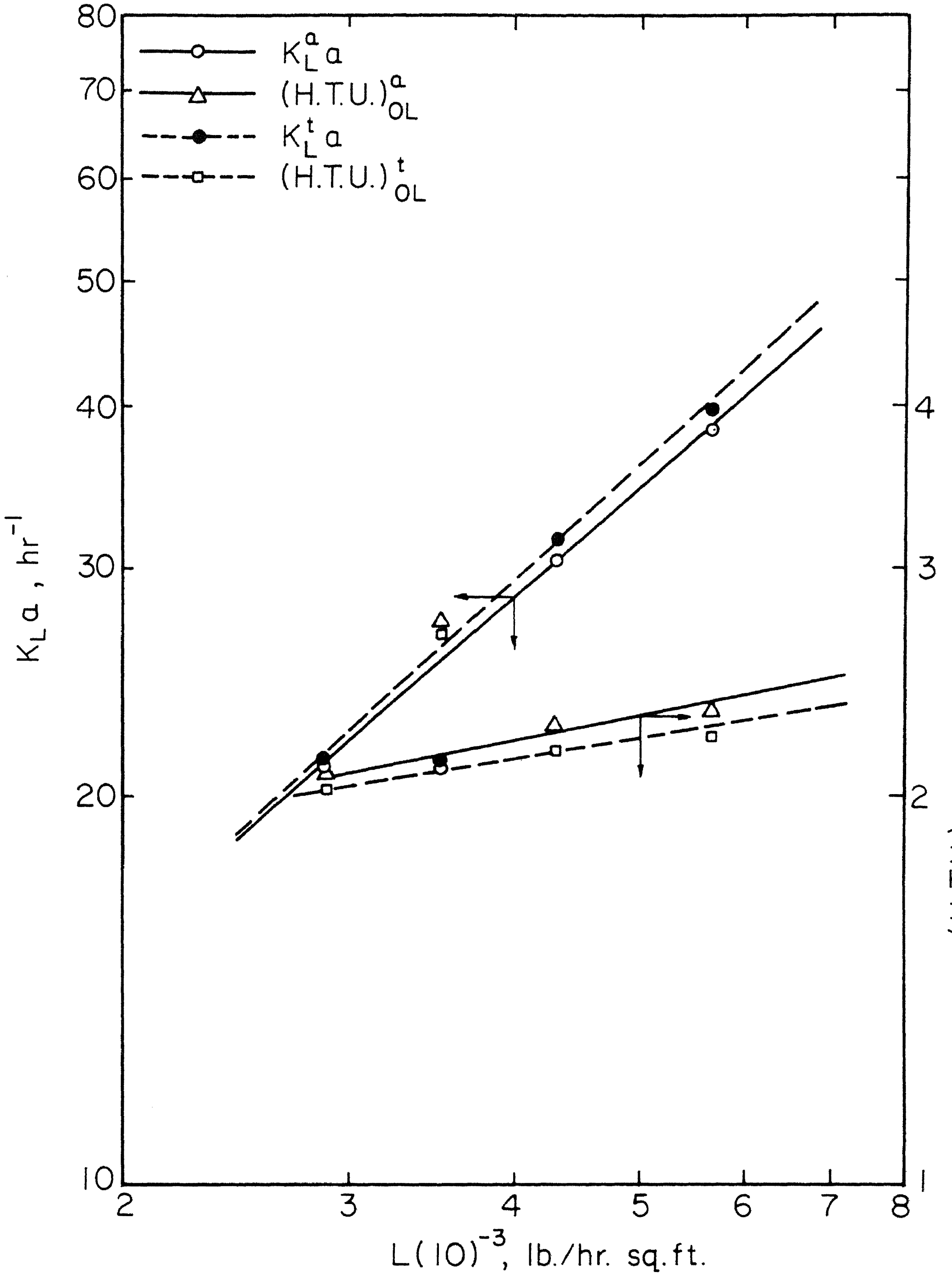

Figure 21. Effect of Liquid Flow Rate on K_La and $(H.T.U.)_{OL}$, G = 6.25 lb./hr.sq.ft., 1/2 in. Raschig Rings, Packing Height - 3 ft.

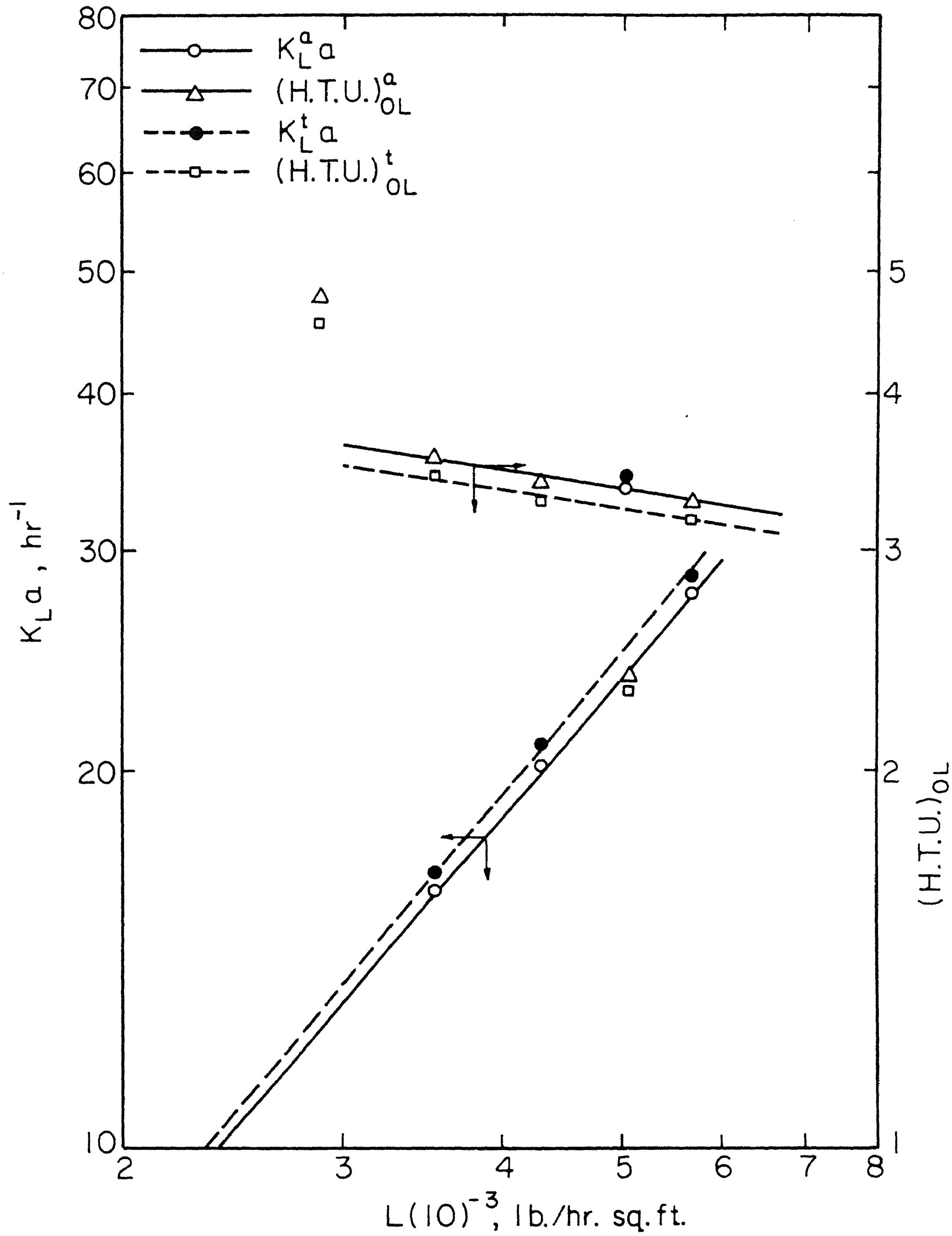

Figure 22. Effect of Liquid Flow Rate on $K_L a$ and $(H.T.U.)_{OL}$, G = 6.218 lb./hr.sq.ft., 3/8 in. Raschig Rings, Packing Height - 5 ft.

3/8 inch Raschig ring with packing height of 3 feet

$$K_L^a a = 0.0165\ L^{0.91} \qquad (6.2)$$

AAPD = 8.25

1/2 inch Raschig ring with packing height of 3 feet

$$K_L^a a = 0.0084\ L^{0.91} \qquad (6.3)$$

AAPD = 11.56

3/8 inch Raschig ring with packing height of 5 feet

$$K_L^a a = 0.00033\ L^{1.6} \qquad (6.4)$$

AAPD = 9.48

For axial mixing in gas phase and plug flow in liquid phase, the following correlations are presented.

1/4 inch Raschig ring with packing height of 3 feet

$$K_L^t a = 0.00025\ L^{1.24} G^{0.8} \qquad (6.5)$$

AAPD = 10.64

3/8 inch Raschig ring with packing height of 3 feet

$$K_L^t a = 0.011\ L^{0.96} \qquad (6.6)$$

AAPD = 9.92

1/2 inch Raschig ring with packing height of 3 feet

$$K_L^t a = 0.0115\ L^{0.94} \qquad (6.7)$$

AAPD = 11.44

3/8 inch Raschig ring with packing height of 5 feet

$$K_L^t a = 0.000036\ L^{1.6} \qquad (6.8)$$

AAPD = 9.51

It is observed that Average Absolute Percentage Deviation is about 10% in each case. Other empirical mathematical models were also tried but they gave higher values for AAPD. The major deviation between calculated and experimental values of $K_L a$ is mainly at the lower liquid rates where the data scatter badly because of the poor gas and liquid contact (see Figures 23 through 26). Unfortunately experiments at higher liquid rates than used in this study could not be performed because of the limitations of the experiment. The solid lines in the above-mentioned figures are the least squares lines.

For comparison, correlations as reported by other investigators are also given below.

Brittan (1966) reported the following correlations for carbon dioxide absorption in water using 3/8 inch Raschig ring packing with packed height of 2.9 feet. The range of flow rates used were 3678 $\leq L \leq$ 9195 lb./hr.sq.ft. and 3.82 $\leq G \leq$ 9.6 lb./hr.sq.ft.

$$K_L^a a = 3.12\ L^{0.32} \tag{6.9}$$

$$K_L^t a = 1.216\ L^{0.43} \tag{6.10}$$

Allen (1940) carried out absorption and desorption tests with carbon dioxide water system using a 2 inch i.d. tower packed to a height of 1 foot with 3/8 inch ceramic Raschig rings. A correlation for plug flow conditions for liquid rates below 10,000 lb./hr.sq.ft. and a gas rate of 58.5 lb./hr.sq.ft. was reported which is given below.

$$K_L^a a = 0.65\ L^{0.54} \tag{6.11}$$

Table XIV shows values of mass transfer coefficients for 3/8 inch Raschig rings packing as obtained from the correlations of Brittan, Allen and experimental data of this investigation. Mass transfer coefficients obtained from the data are lower by about 25% at lower liquid rates in comparison with the results from Brittan correlations but show remarkable agreement (±1%) at higher rates.

Calculated values of $K_L^a a$ obtained from the Allen correlation for assumed plug flow conditions show uniformly higher values of about 60%

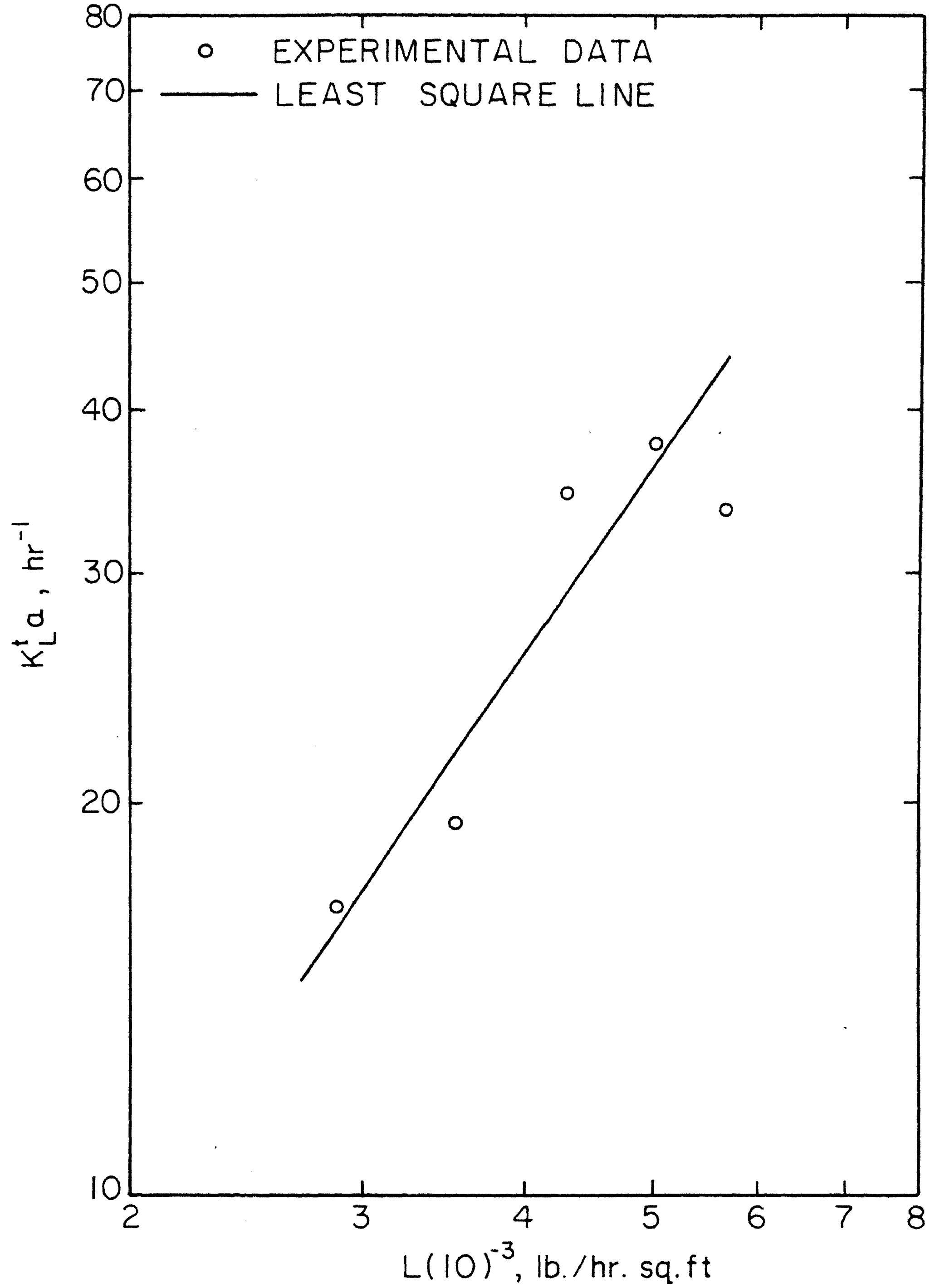

Figure 23. $K_L^t a$ vs. Liquid Flow Rate, G = 5.005 lb./hr.sq.ft., 1/4 in. Raschig Rings, Packing Height - 3 ft.

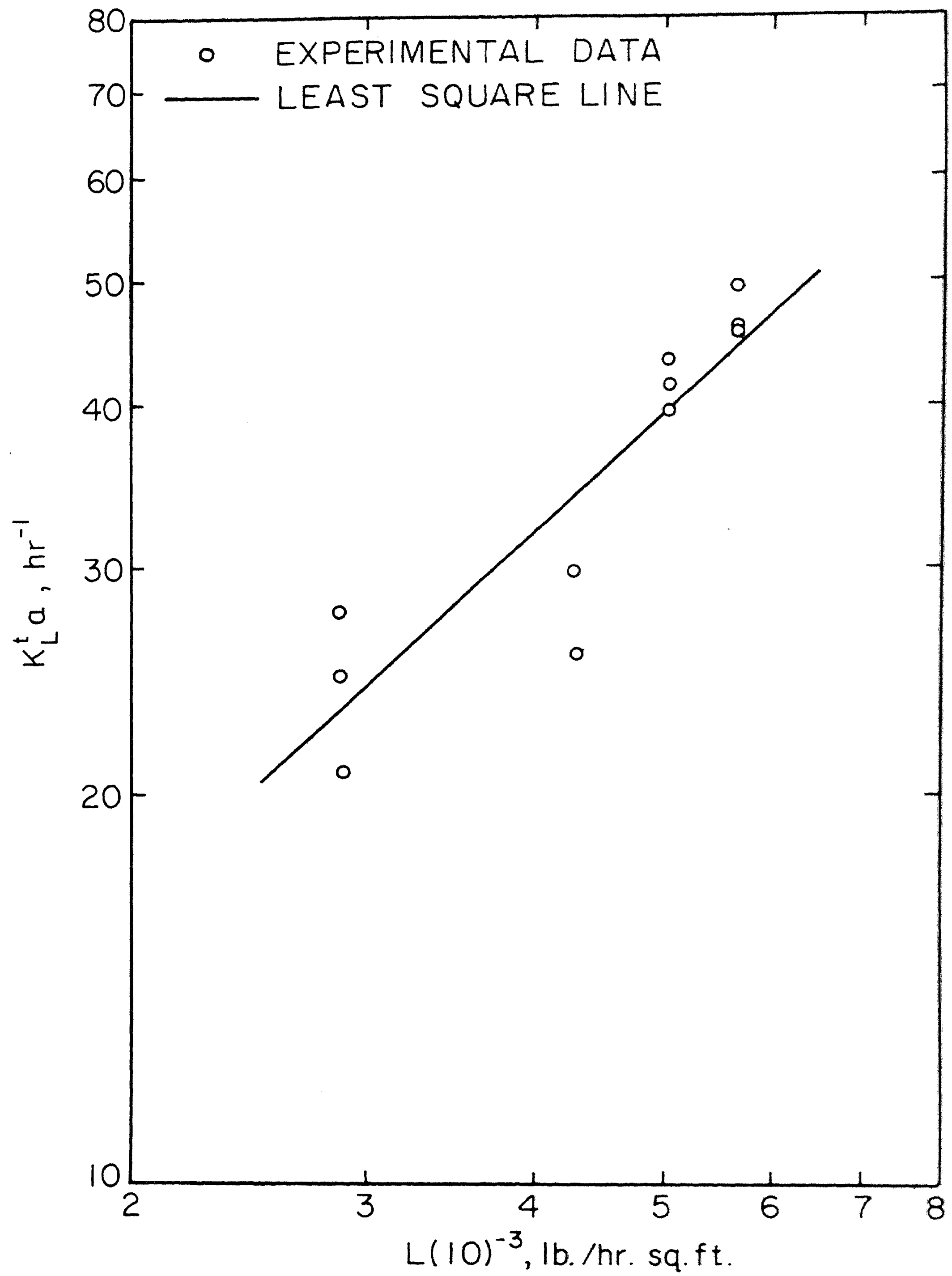

Figure 24. $K_L^t a$ vs. Liquid Flow Rate, 3/8 in. Raschig Rings, Packing Height - 3 ft.

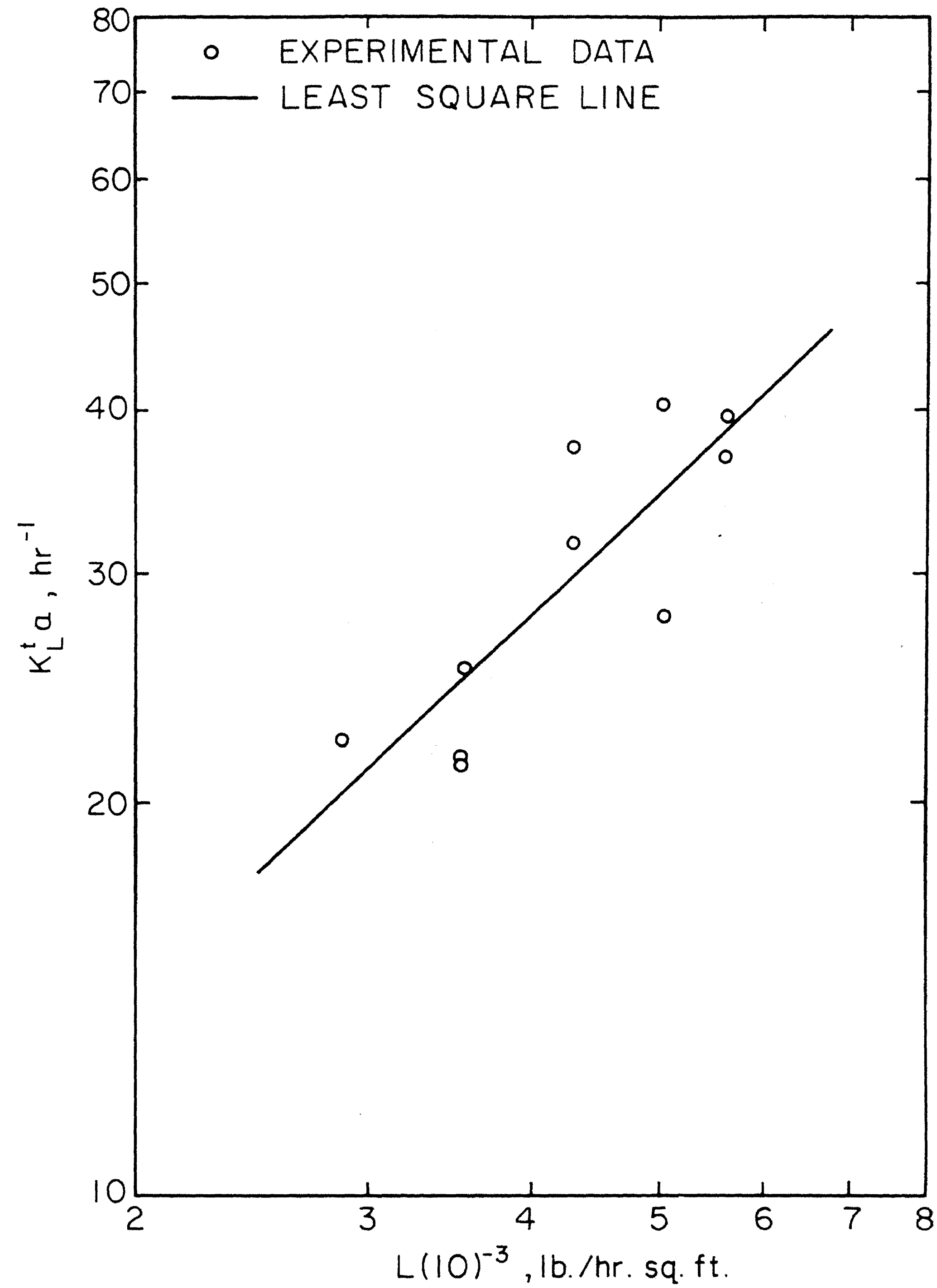

Figure 25. $K_L^t a$ vs. Liquid Flow Rate, 1/2 in. Raschig Rings, Packing Height - 3 ft.

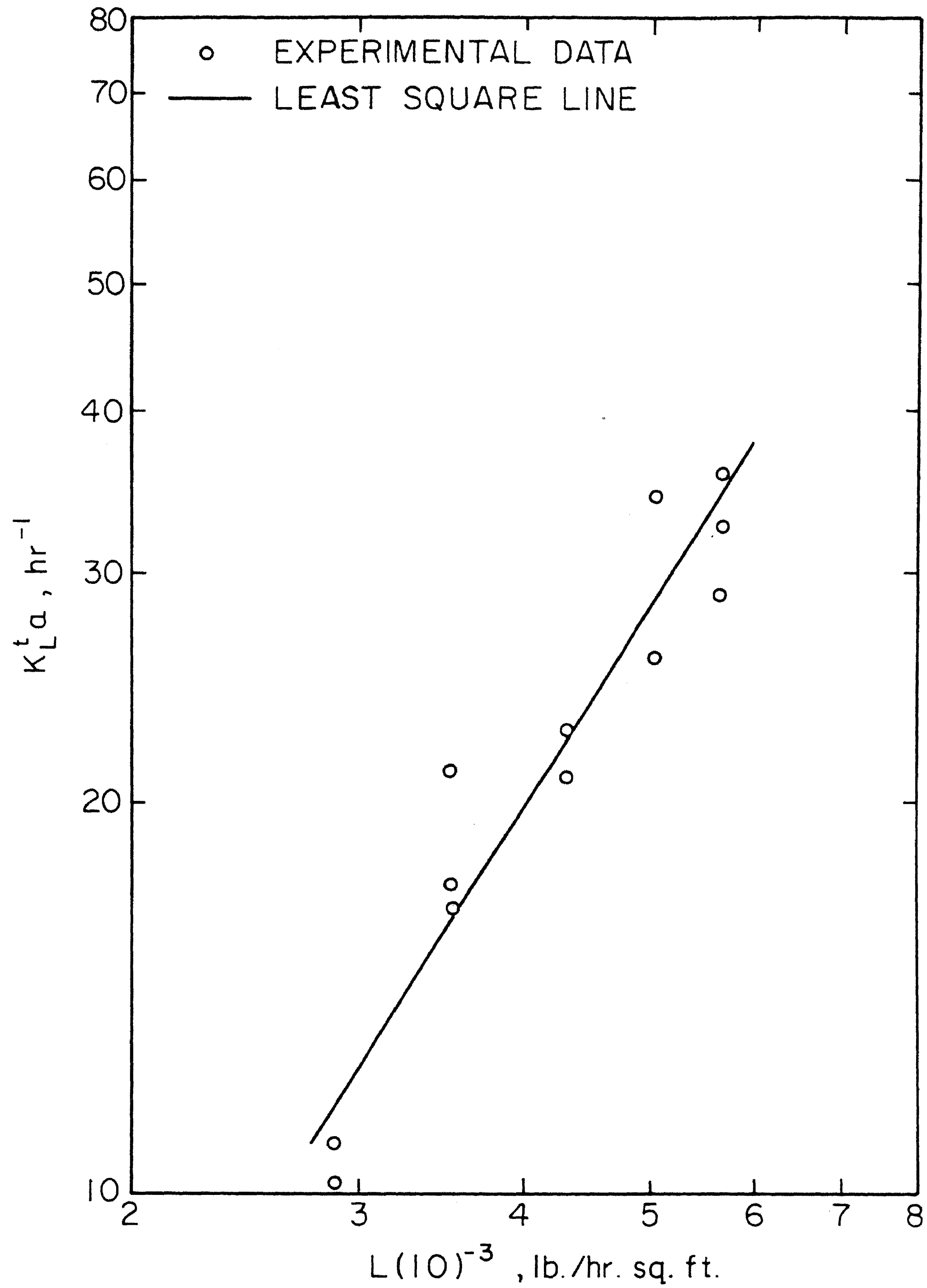

Figure 26. $K_L^t a$ vs. Liquid Flow Rate, 3/8 in. Raschig Rings, Packing Height - 5 ft.

compared to $K_L^a a$ values obtained from the data of this work. This can be explained by the use of the small height and high water and gas flow rates by Allen (1964). The small height reduces the channelling effects whereas higher water and gas flow rates provide greater turbulence.

The difference between the correlations (obtained from the data of the present work) for apparent and true mass transfer coefficients for the respective packing sizes and packing heights depends in part on the magnitude of the axial diffusion. For 3/8 inch packing with 3 feet packing height the exponents of the equations 6.2 and 6.6 differ significantly from those of equations 6.9 and 6.10, respectively. The reason is that $K_L^a a$ and $K_L^t a$ values obtained from the data of this investigation show a faster increase with liquid rates than those obtained by Brittan (1966). The use of large size sampling tubes (3/8 inch o.d.) used by Brittan compared to 0.095 inch o.d. tubes used in this study could create a difference in liquid and gas flow pattern resulting in this disagreement.

3. <u>Effect of Packing Size on $K_L^t a$ and $K_L^a a$:</u> As shown in Figures 27 and 28, $K_L^a a$ and $K_L^t a$ decrease with increases in packing size. Holloway (1940) who studied the absorption of carbon dioxide and oxygen in water using 1/2, 1-1/2 and 2 inch Raschig ring packings also reported $K_L^a a$ to decrease with increases in packing size. This can be attributed to the greater channelling effects in absorption columns packed with large size packings adversely affecting the over-all mass transfer coefficients.

4. <u>Effect of Packing Height on $K_L^t a$ and $K_L^a a$:</u> True and apparent over-all mass coefficients for the column packed with 5 feet of 3/8

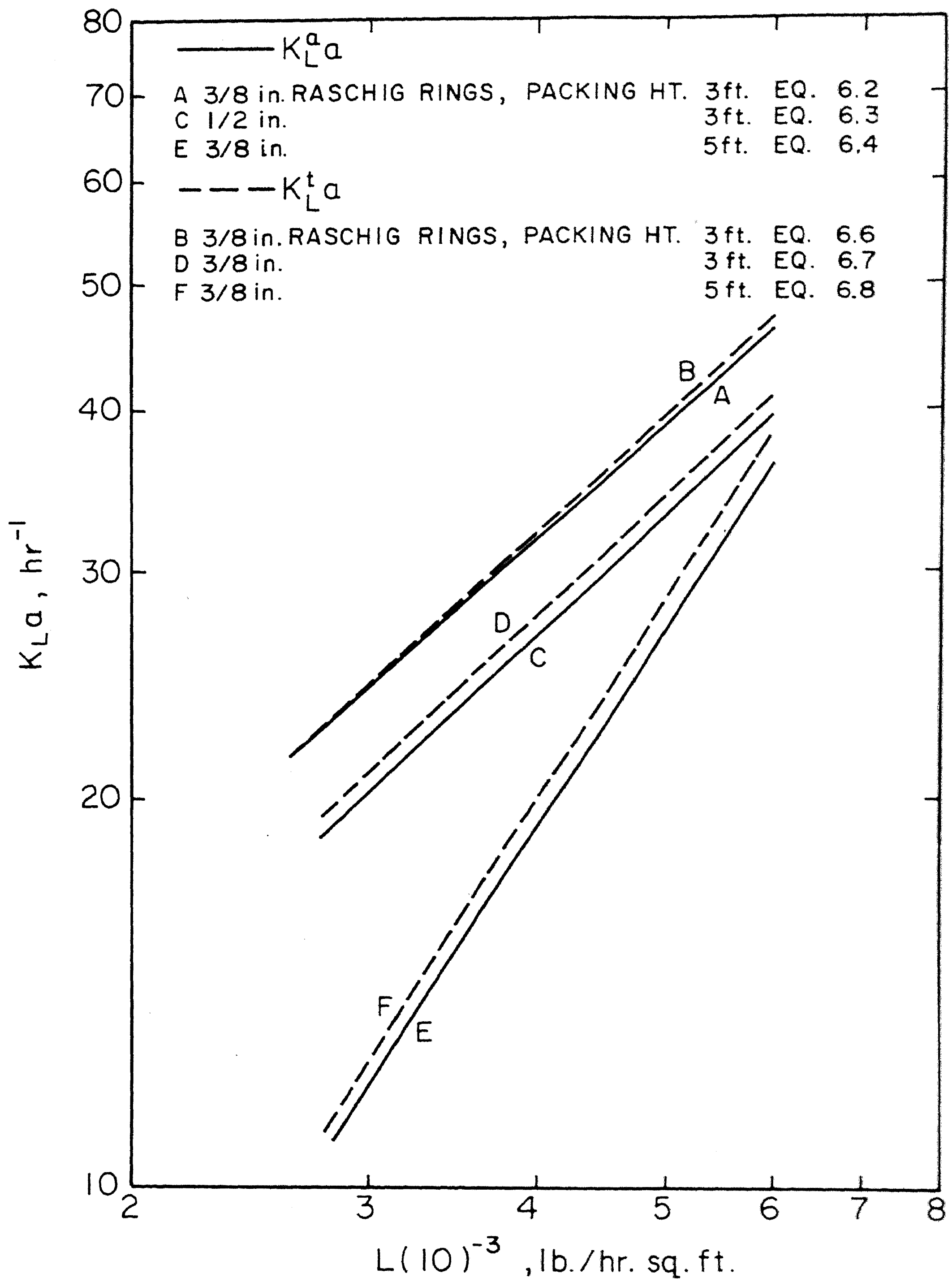

Figure 27. Equations 6.2, 6.3, 6.4, 6.6, 6.7 and 6.8

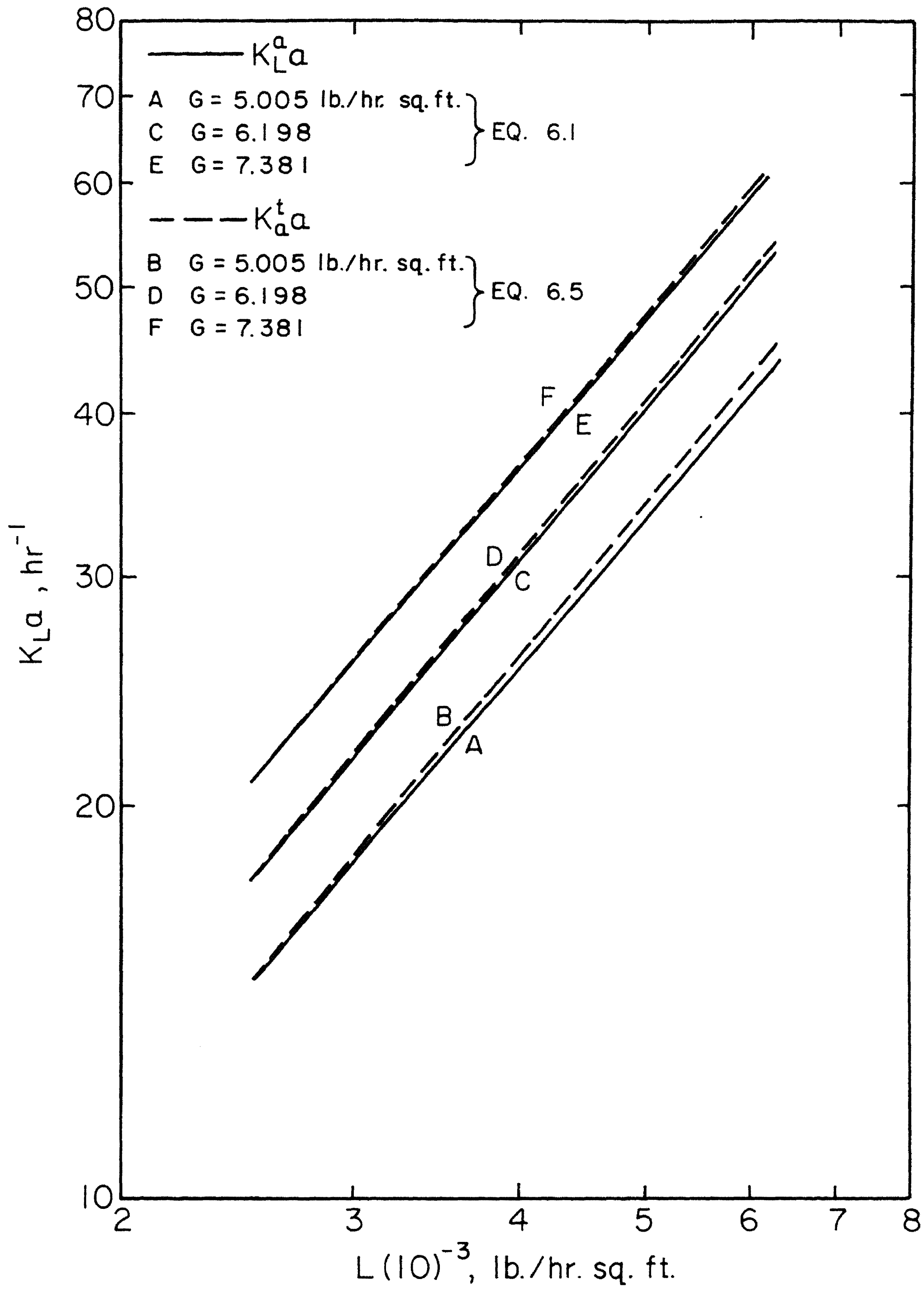

Figure 28. Equations 6.1 and 6.5, 1/4 in. Raschig Rings, Packing Height - 3 ft.

inch size packing are found to be lower than those for the column packed with 3 feet of the same size packing (see Figures 27 and 28). It is further observed that for 5 feet packing height $K_L^a a$ and $K_L^t a$ are low at lower liquid flow rates compared to 3 feet of packing height but increase rapidly as the liquid rate is increased. It is believed that poor contact between liquid and gas at low liquid rates and greater channelling at greater packing height is responsible for this behavior. At higher liquid rates, the better interfacial contact due to greater turbulence offsets the adverse effects of the poor gas-liquid contact and hence a fast improvement in true and apparent over-all mass transfer coefficients is achieved.

5. Apparent and True Mass Transfer Coefficients: Figures 27 and 28 show plots of the correlations obtained in this work for $K_L^a a$ and $K_L^t a$ for 1/4, 3/8 and 1/2 inch packings with 3 feet packing height and also for 3/8 inch packing with a packing height of 5 feet. These plots are not included in Figures 19 to 22 to avoid over-crowding the figures.

As seen from the above-mentioned figures, the difference in magnitude between $K_L^a a$ and $K_L^t a$ increases with increases in liquid rate, packing size and packing height.

The difference between the two mass transfer coefficients for 1/4 inch packing is found to decrease with increases in gas rate (see Figure 28). The data in Tables XI through XIII indicate a similar effect of gas rate for other packing sizes and packing heights.

The difference between the apparent and true mass transfer coefficients for the liquid and gas rates, packing sizes and heights studied in this investigation is not very large. A maximum value of 4.5% on the basis of $K_L^a a$ would be a good estimate. However, the rate of increase in the deviation with liquid rate is appreciable. If the increase in the difference between $K_L^a a$ and $K_L^t a$ as indicated in Figures 27 and 28 is maintained, substantial deviation would result at industrial liquid rates and heights.

Cooper et al (1941) found for the absorption of CO_2 in water that HTU_{OL} increased with decreasing gas rate at a constant liquid rate. The authors explained it as follows:

> "It is shown that calculated average linear water velocities down the column exceed in this range by several fold the average linear gas velocity. This is believed to result in circulation of gas within the column from top towards bottom, thereby altering the carbon dioxide content of the gas from that corresponding to true counter-current flow in such a way as to reduce the driving forces and give a high value of the $(H.T.U.)_{OL}$ calculated from terminal conditions."

Brittan (1966) also observed that the degree of backmixing increased with decreasing gas rate, that is, increasing degree of absorption.

Considering the above, one could speculate that using systems with low Henry's law constant would help in the study of axial mixing. Based on this speculation experiments on the absorption of ammonia from a mixture of ammonia-nitrogen by water were conducted. The work had to be discontinued because the author could not develop a procedure which could quickly and accurately analyze the gas samples. However, the author is in no way trying to suggest or imply that absorption in any way influences axial diffusion. In a packed bed, axial diffusion is believed to be caused by splitting of the fluid streams as they flow around the particles and by the variations in velocity across the bed and not primarily affected by the quantity of solute transferring through the interface.

6. $(H.T.U.)^{a}_{OL}$ and $(H.T.U.)^{t}_{OL}$: Over-all liquid phase Height of Transfer Units are calculated from the experimental data of this investigation and are plotted versus liquid flow rates as shown in Figures 19 through 22. These are basically the same as the plots of the mass transfer coefficients versus liquid flow rates. They are presented here to compare the findings of other workers who have presented their results in terms of the Height of Transfer Units. For the column packed with a 5 feet height of packing both $(H.T.U.)^{a}_{OL}$ and $(H.T.U.)^{t}_{OL}$ are about one and a half times more than the $(H.T.U.)^{a}_{OL}$ and $(H.T.U.)^{t}_{OL}$ for 3 feet of packing height for the same packing size, liquid and gas flow rates. As has been discussed earlier, this is because of the lower value of mass transfer coefficients due to higher axial dispersion and channelling effects.

Furzer and Ho (1967) have shown by mathematical analysis that $(H.T.U.)^{a}_{OL}$ would increase with packed height, all other factors held constant, due to axial dispersion effects. Smoot and Babb (1962) studied the effect of height on $(H.T.U.)^{a}_{OL}$ in a liquid-liquid extraction column 2 inches in diameter with perforated plates. No significant effect of height was reported.

7. Effect of Liquid Flow Rate on Gas Phase Peclet Number: As shown in Figures 29 through 31, the gas phase Peclet number decreases with increases in the liquid rate, and after passing through a minimum, shows a tendency to increase in magnitude for 1/4, 3/8 and 1/2 inch packing with 3 feet packing height. However, in the case of 3/8 inch packing with 5 feet of packing (see Figure 32), there is no significant effect of liquid rate. There is a decrease of about 4.8% in the Peclet

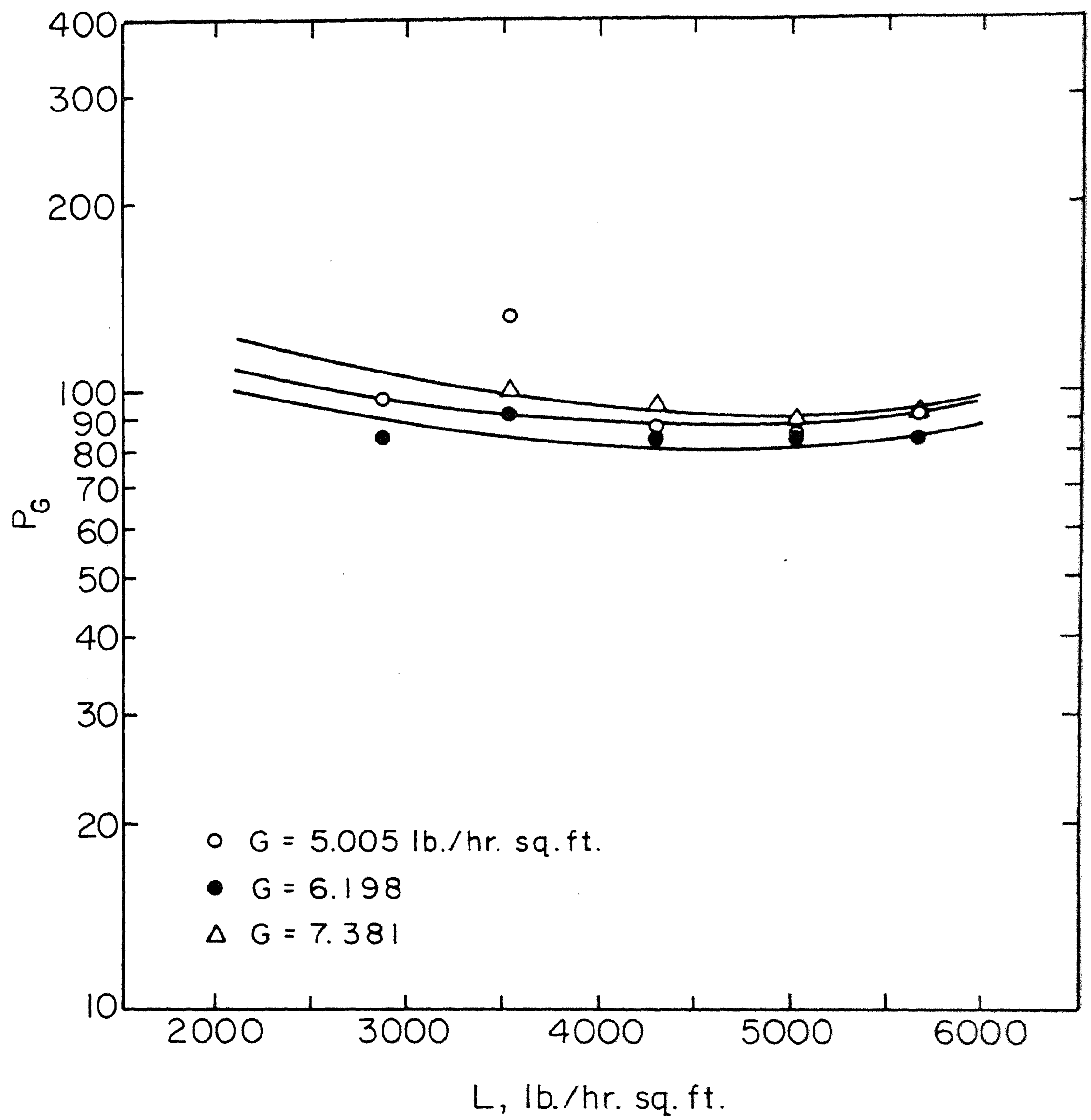

Figure 29. Gas Phase Peclet Number vs. Liquid Flow Rate, 1/4 in. Raschig Rings, Packing Height - 3 ft.

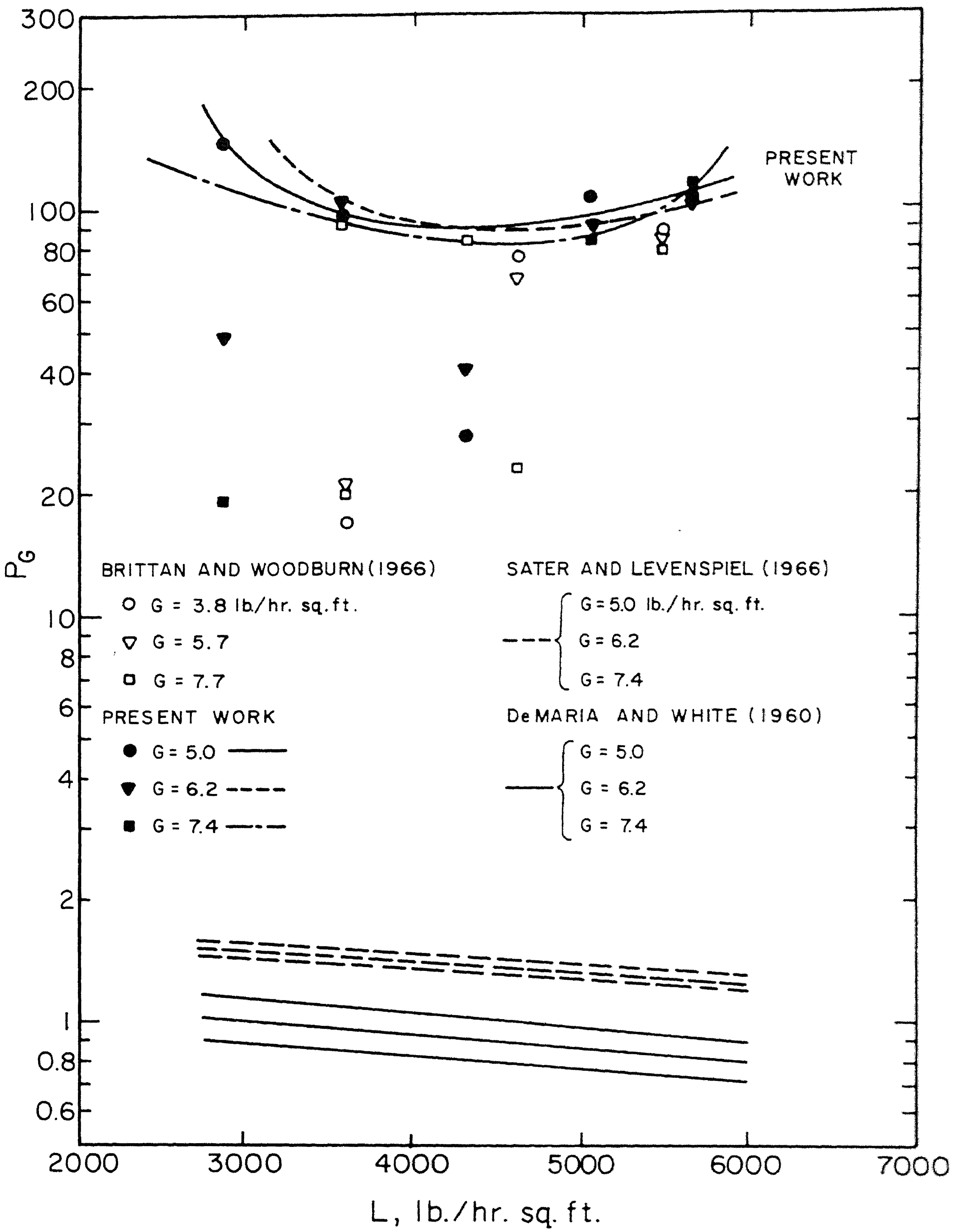

Figure 30. Gas Phase Peclet Number vs. Liquid Flow Rate, 3/8 in. Raschig Rings, Packing Height - 3 ft.

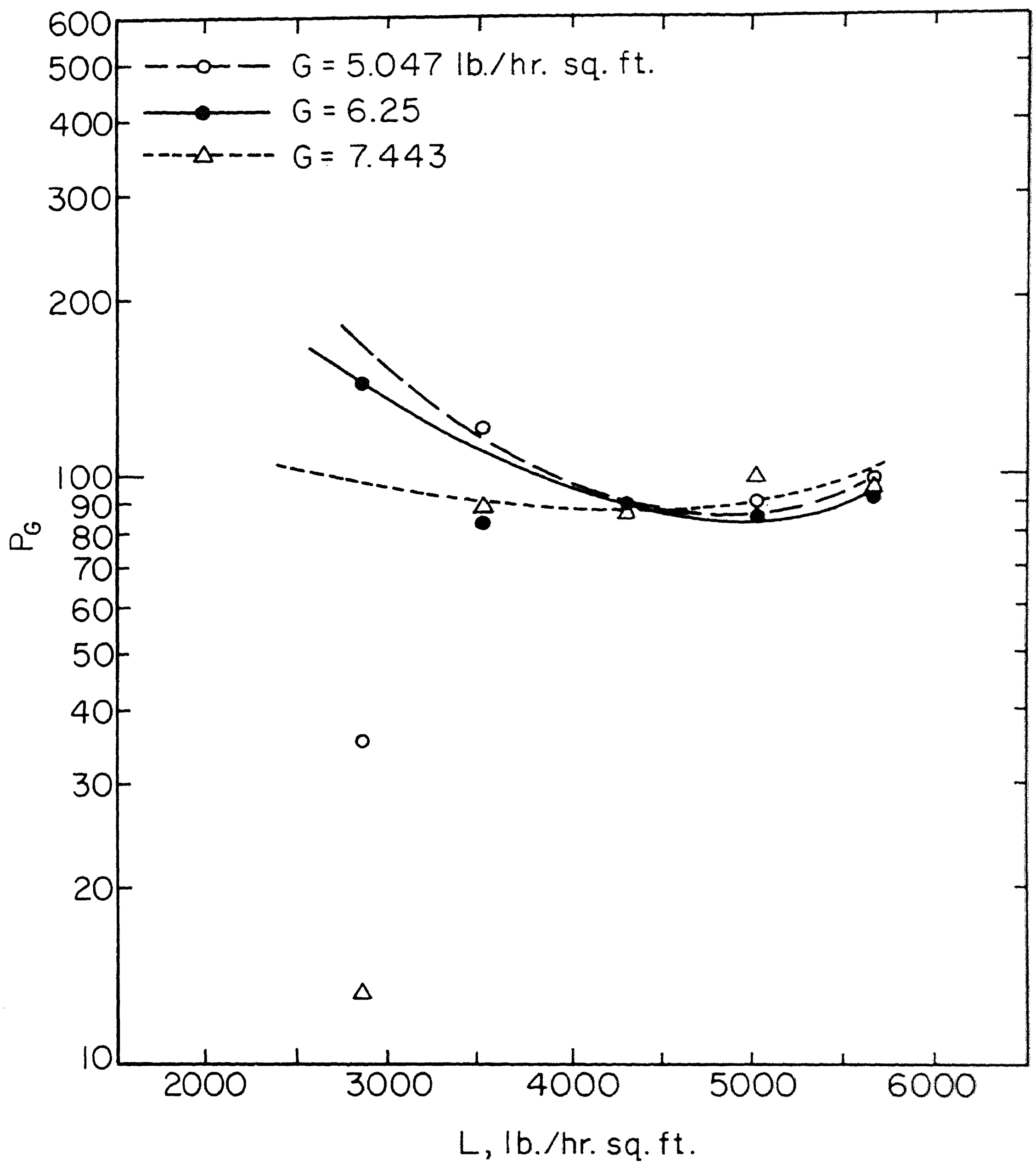

Figure 31. Gas Phase Peclet Number vs. Liquid Flow Rate, 1/2 in. Raschig Rings, Packing Height - 3 ft.

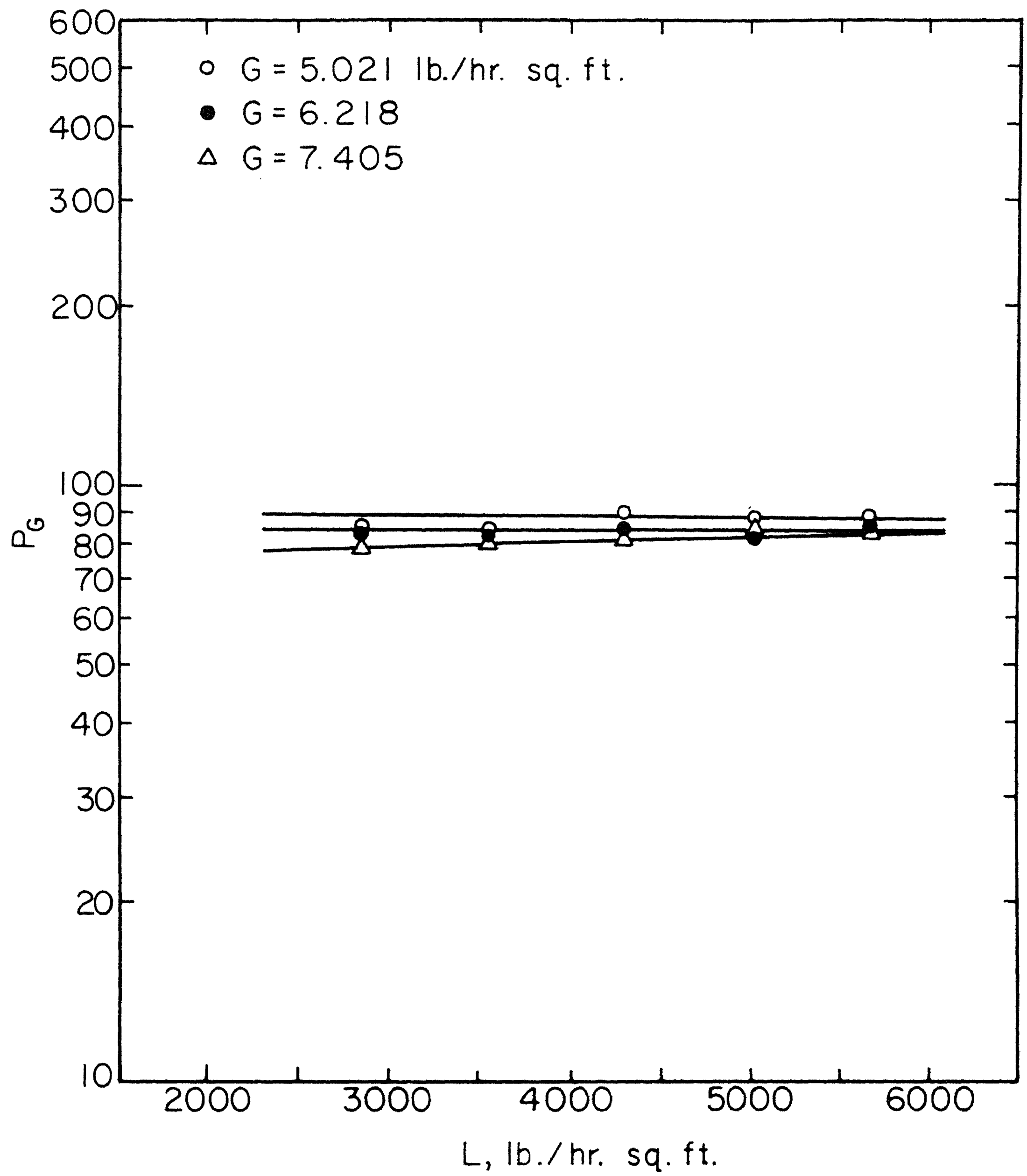

Figure 32. Gas Phase Peclet Number vs. Liquid Flow Rate, 3/8 in. Raschig Rings, Packing Height - 5 ft.

number for an increase of liquid rate from 2865 to 5680 lb./hr.sq.ft.

Brittan (1966) reported that axial mixing in gas phase increases with increases in liquid rate. That is, the Peclet number decreases with increases in liquid rates. Since Brittan did not present Peclet number data, gas phase Peclet numbers were calculated using Brittan's data by the author of this work using the two parameter model as presented by Miyauchi (1957). The results (average values of runs) are presented in Figure 30.

There is scatter in the data when Peclet number (as calculated from the data of the present investigation) are plotted versus liquid flow rates, particularly for 3/8 and 1/2 inch packing sizes with 3 feet packing height (see Figures 30 and 31). Brittan (1967) has also reported that computed values of gas phase Peclet number from the experimental data showed scatter in the data. However, as mentioned above, Peclet numbers computed by Brittan are not available nor is there any discussion (Brittan, 1967) about the behavior of gas phase Peclet number with respect to liquid and gas flow rates. Peclet numbers calculated from Brittan's data as stated earlier show a far greater scatter as shown in Figure 30, compared to the findings of this study. The scatter as observed by the author of this work as well as by Brittan (1967) is probably due to the proximity to piston flow where small deviations in the experimental concentration measurements can cause large differences in the Peclet number. However, as discussed in the Error Analysis (Appendix L), a deviation of ±1.0 to ±5.0% in the experimental data only caused a deviation of about 6% in the number of transfer units. Therefore, this small deviation in the experimental concentration measurements would not result in large deviations in the mass transfer coefficients.

Correlations of Sater and Levenspiel (1960) and DeMaria and White (1966) using a transient technique indicated a decrease in gas phase Peclet number with increases in liquid rate (see Figure 30). The values of gas phase Peclet numbers for 3/8 inch packing with packing height of 3 feet are plotted on the figure. The results obtained from the transient-response studies of DeMaria and White (1960) and Sater and Levenspiel (1966) give Peclet numbers which are about one-fiftieth in magnitude compared to ones obtained in this work or from the data of Brittan when considering about the same liquid and gas rates. Evidently, there is a great disparity in the results due to the basic difference in the two experimental techniques used by the respective authors.

Because of the nature of Peclet number versus liquid flow rate curves and the scatter therein, no efforts were made to correlate Peclet number with liquid or gas flow rates for the data obtained in this work or by Brittan (1967).

8. Effect of Gas Flow Rate on Gas Phase Peclet Number: As shown in Figure 33 and 34, the gas phase Peclet number obtained in this work initially shows a decrease with increases in gas rate and after passing through a minimum show an increase with increases in gas rate (at a constant liquid rate) for all packing sizes with 3 feet of packing height. However, in the case of 3/8 inch packing with 5 feet of packing height for all gas and liquid rates (see Figure 34) there is a progressive decrease of about 5 to 8% in Peclet number for an increase in gas flow rate from 5.0 to 7.4 lb./hr.sq.ft. Behavior of Peclet number with respect to gas flow rate shows scatter in the data. It is believed to be

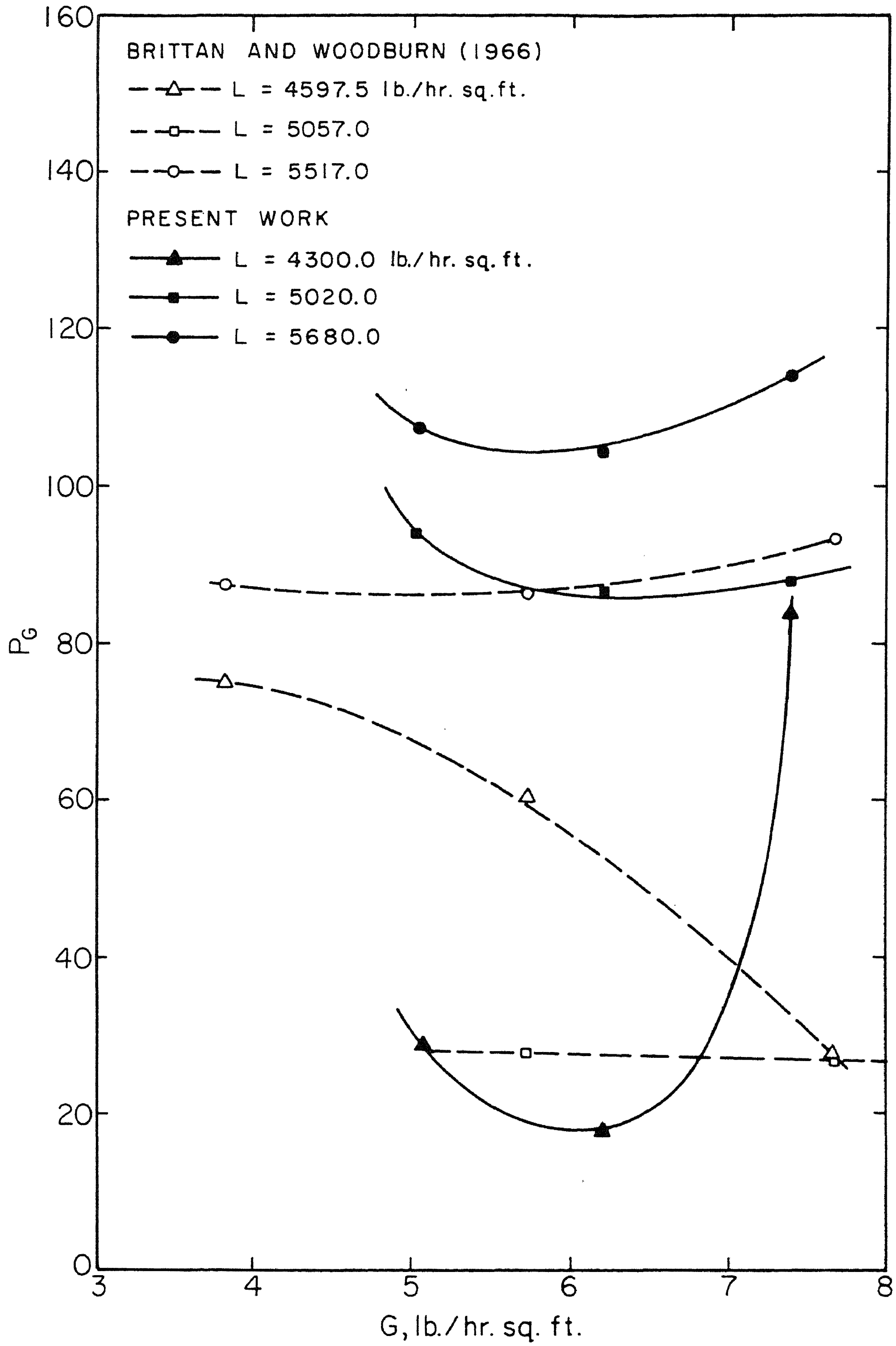

Figure 33. Gas Phase Peclet Number vs. Gas Flow Rate, 3/8 in. Raschig Rings, Packing Height - 3 ft.

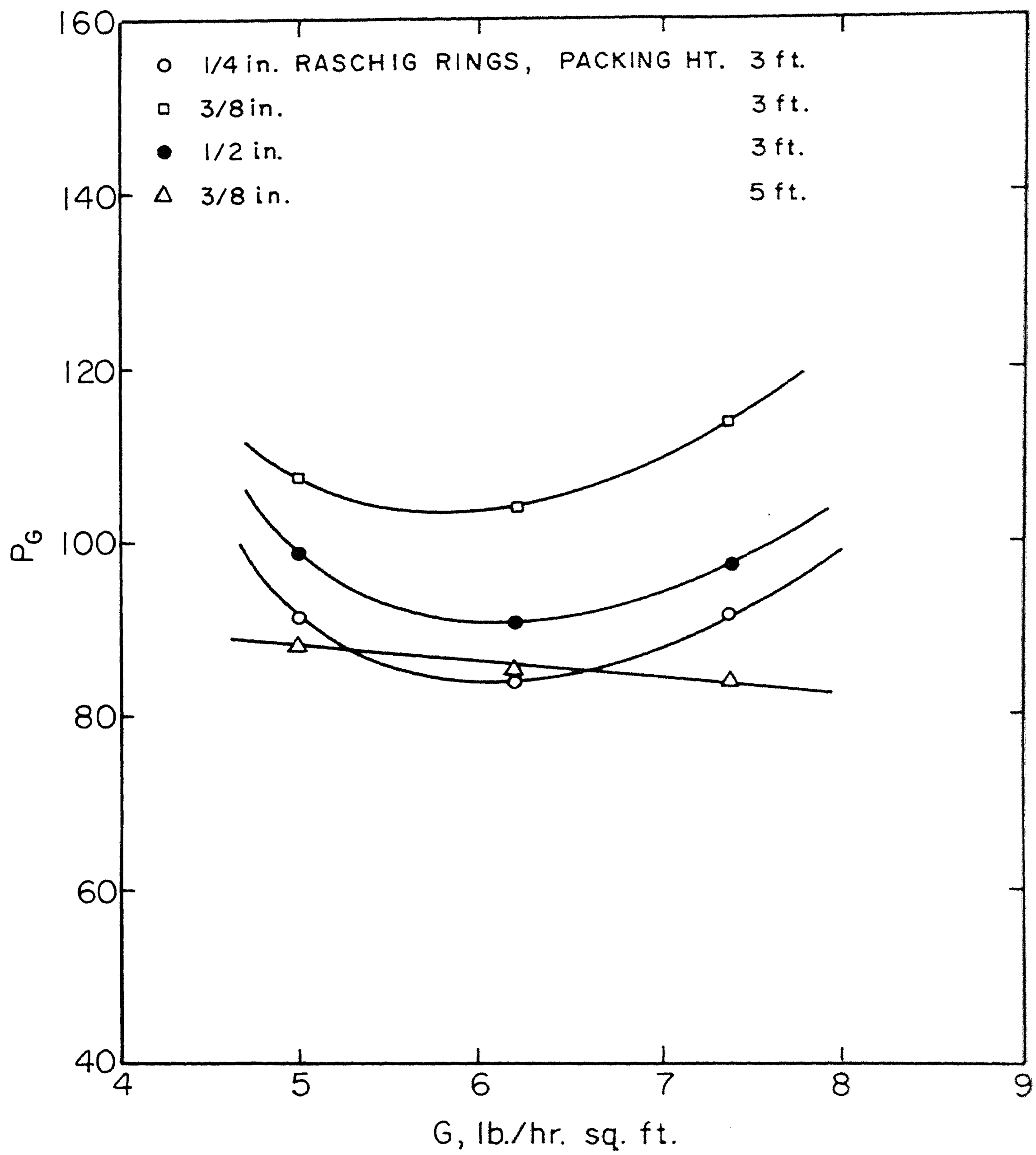

Figure 34. Gas Phase Peclet Number vs. Gas Flow Rate, L = 5680.0 lb./hr.sq.ft.

so for the reason that the velocity of rise of gas bubbles in the absorption column is much larger than the liquid velocity and, therefore, any deviation in gas flow rate or change in gas flow pattern would seriously affect the Peclet number.

Brittan (1967) reported that axial mixing in the gas phase decreased with increases in gas rate, that is, gas phase Peclet number increased with increases in gas flow rate. Brittan (1967) did not support this finding either by presenting Peclet number calculated from his data or by a detailed discussion. As stated earlier, Peclet numbers were calculated from his data by the author of this work and the plots of Peclet number versus gas flow rate for various liquid rates are presented in Figure 33. It may be mentioned here that in Figure 33 only those Peclet numbers from Brittan's work are presented where the gas and liquid flow rates are close to those that have been used in this investigation. As may be seen from the figure, the behavior of Peclet number does not show any decreasing or increasing trend with gas flow rate. However, Brittan reported the gas phase axial mixing to decrease with increases in gas flow rates.

The correlations of DeMaria and White (1960), and Sater and Levenspiel (1966) based upon transient techniques indicate a decrease in the gas phase Peclet number, i.e., an increase in axial mixing with increases in gas rate for all packing sizes. In this study as well as in that by Brittan (1966) it is observed that gas phase axial mixing decreases with increases in gas flow rate. The magnitude of the Peclet number obtained from the above mentioned correlations is about one-fiftieth compared to the magnitude of Peclet number obtained from the data of this work or that of Brittan at about the same gas and liquid flow rates.

Stemerding (1961) carried out experiments in a packed column filled with 13 mm Raschig rings. Water was flowing down and air flowing up in the form of bubbles through the water phase. It was reported that the liquid phase axial diffusion coefficient was essentially independent of water rate and only dependent on the air flow rate. At fairly low air flow rates, a maximum value of liquid phase axial diffusion coefficient was found as the gas flow rate was varied. Since Stemerding did not report the behavior of gas phase axial coefficient, the results could not be directly compared with the findings of this investigation. However, there is considerable possibility that Stemerding might have observed a similar behavior (i.e., a minimum gas phase Peclet number) for gas phase axial diffusion coefficient also.

After a critical review of the results of the workers in the field as well as findings of this investigation, it can be concluded that there is considerable disagreement amongst the authors on the effects of liquid and gas flow rates on Peclet number. The only way to explain the above is that Peclet number is sensitive to liquid and gas flow rates as well as to flow pattern of gas and liquid phases, particularly in the proximity of piston flow. There is a wide difference in magnitude of the values of gas phase Peclet number as evaluated by steady state procedure followed by the author of this work and Brittan (1966) compared to transient response techniques followed by DeMaria and White (1960) and Sater and Levenspiel (1966) for the study of axial dispersion in two phase flow (gas and liquid) in packed columns. The assumption of a flat velocity profile and no liquid capacitance in a packed column made in the study of axial mixing by transient response techniques could be responsible for such a disparity. A more comprehensive model as reported by Turner (1958, 1959) or Levenspiel and Bischoff (1963) with a greater number of parameters should be used to incorporate the effects of flow structure in a packed bed.

9. Effect of Packing Size on Gas Phase Peclet Number: The Peclet numbers show a decreasing trend with packing size (see Figure 35). DeMaria and White (1960) and Sater and Levenspiel (1966) also reported Peclet number to decrease with packing size.

10. Effect of Packing Height on Gas Phase Peclet Number: The Peclet numbers show a small decrease with increases in height as seen from Figures 30 and 32.

For 3/8 inch Raschig ring and 3 feet packing height, 60% of Peclet number data points have magnitude greater than 90, whereas for 3/8 inch Raschig ring with 5 feet packing height 99% of the Peclet number data points have magnitude less than 90.

11. Transverse Concentration Profiles: Transverse gas phase concentration profiles for three packing sizes and two packing heights are shown in Figures 36 through 40.

It is seen from the above-mentioned figures that there are more deviations in concentration in the radial direction at the bottom than at the top of the column; that is, channelling is less at the bottom and increases as the gas travels up the column. As seen from Figures 36 through 40, channelling also increases with the increases in gas and liquid flow rates and packing diameter and height. All the above observations are understandable and as expected.

12. Reproducibility of Data: A number of experiments for 3/8 inch

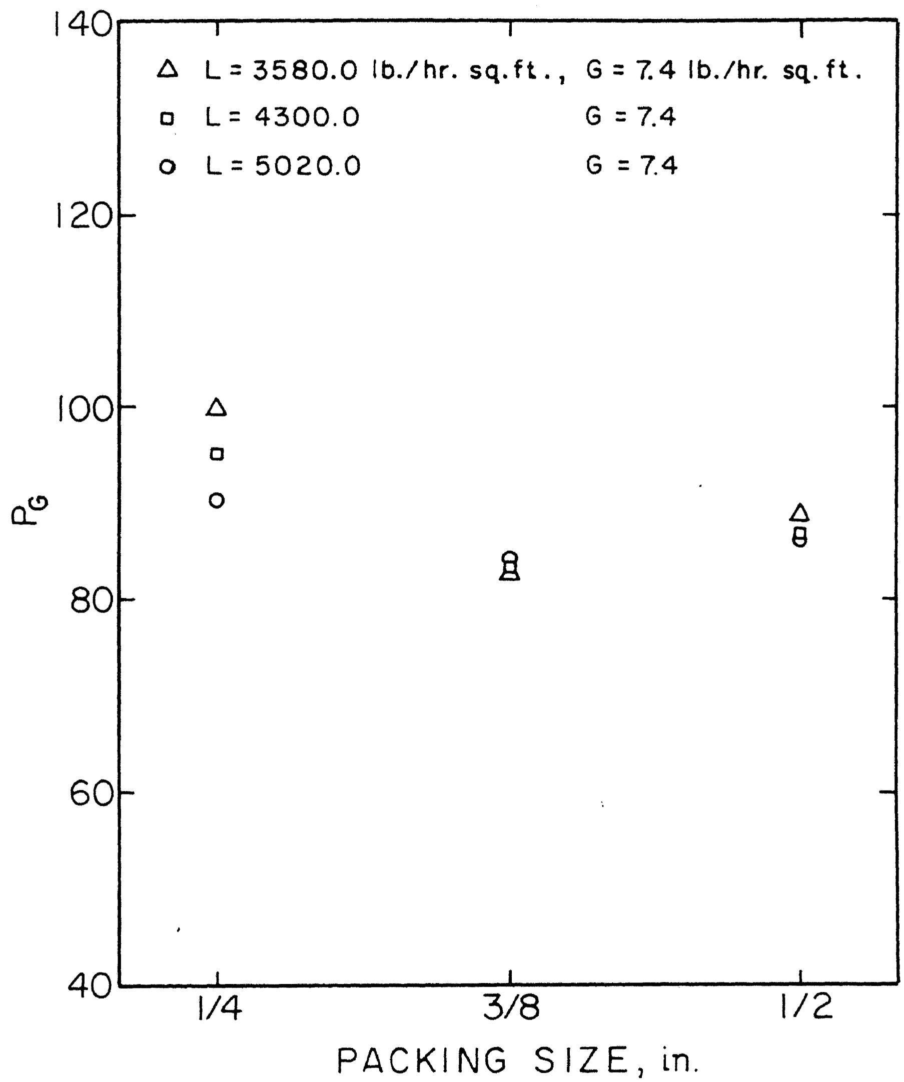

Figure 35. Gas Phase Peclet Number vs. Packing Size (Raschig Rings)

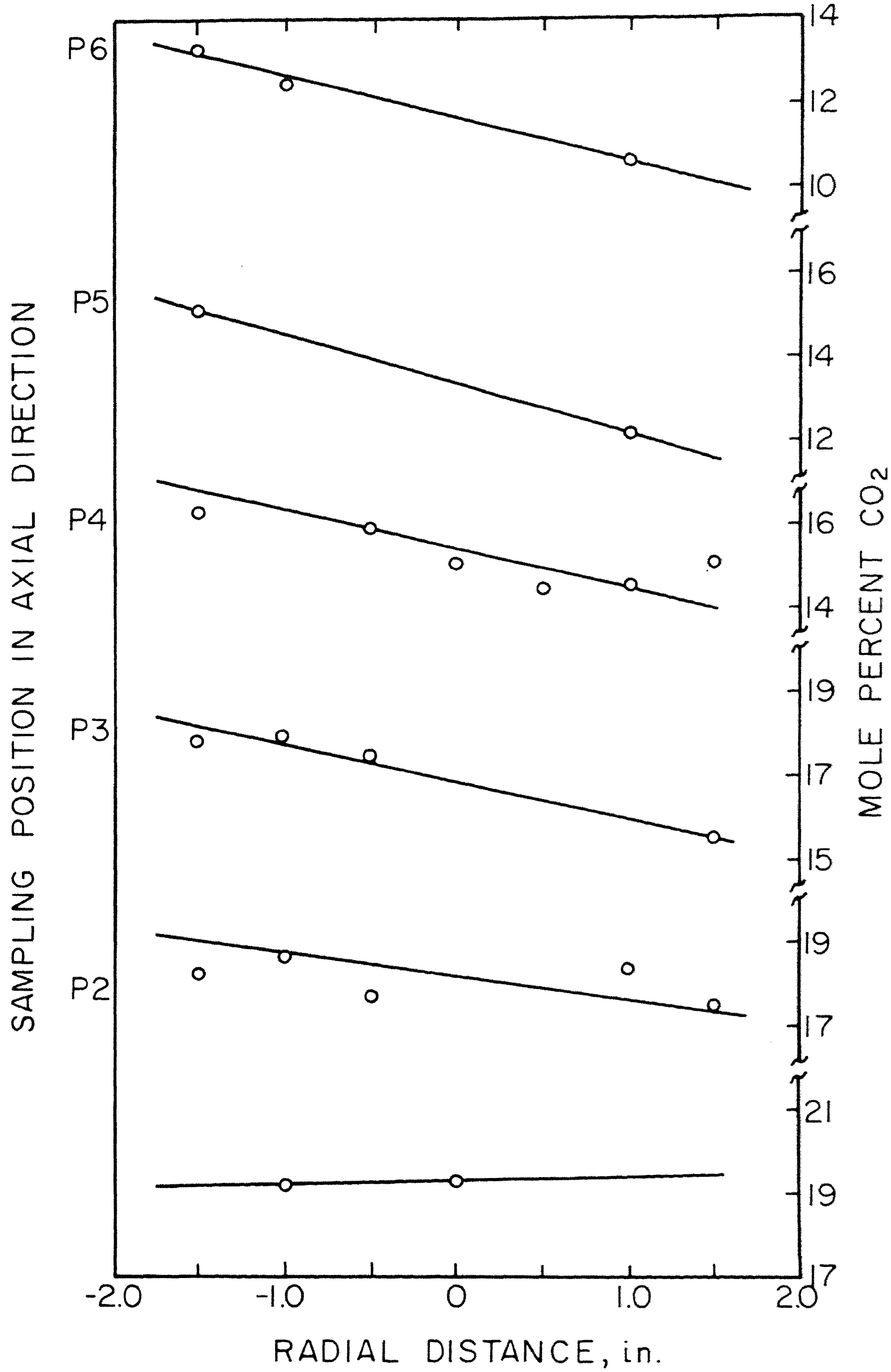

Figure 36. Axial Concentration Profile, 1/4 in. Raschig Rings, Packing Height - 3 ft., L = 3580.0 lb./hr.sq.ft. and G = 5.005 lb./hr.sq.ft.

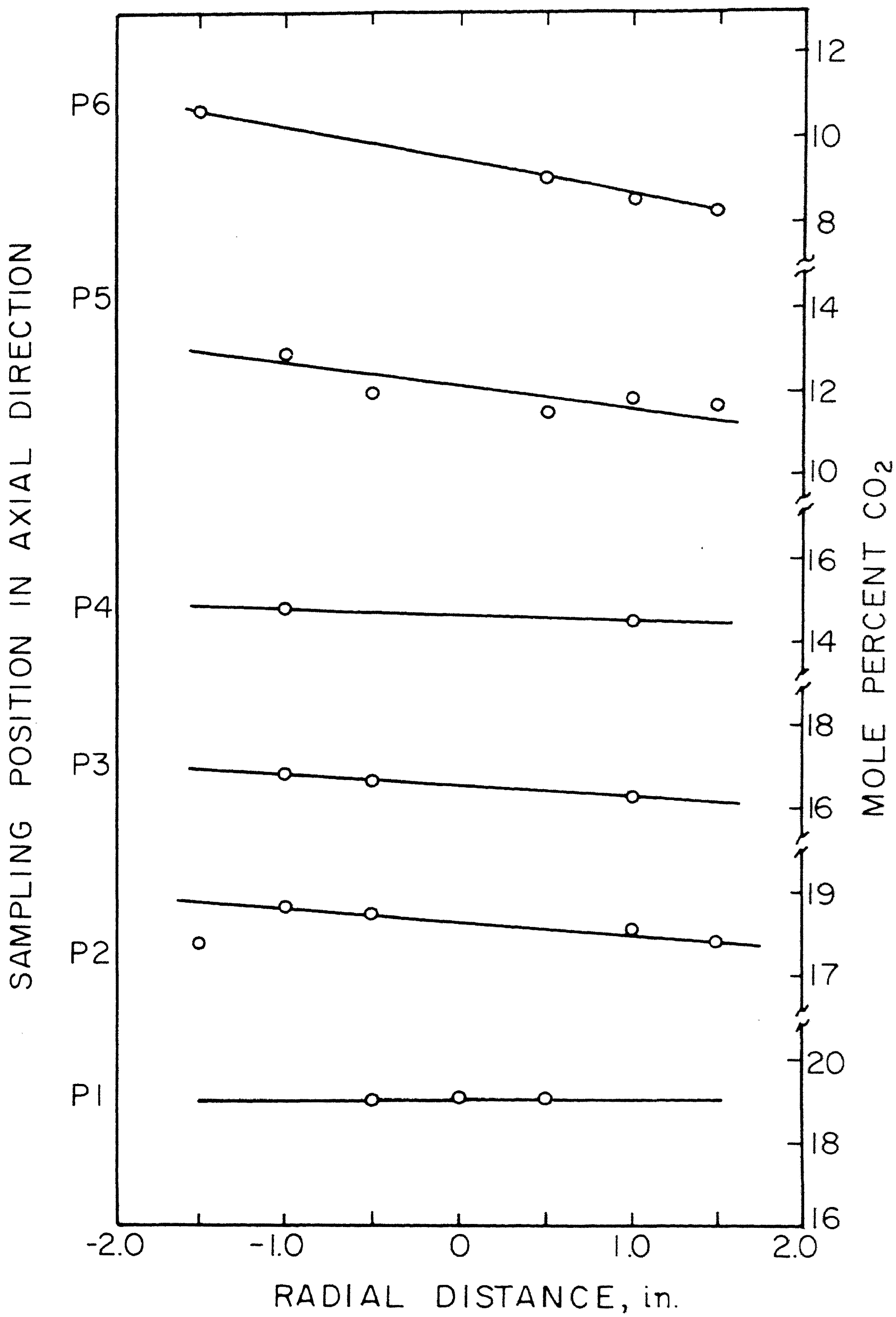

Figure 37. Axial Concentration Profile, 3/8 in. Raschig Rings, Packing Height - 3 ft., L = 3580.0 lb./hr.sq.ft. and G = 5.021 lb./hr.sq.ft.

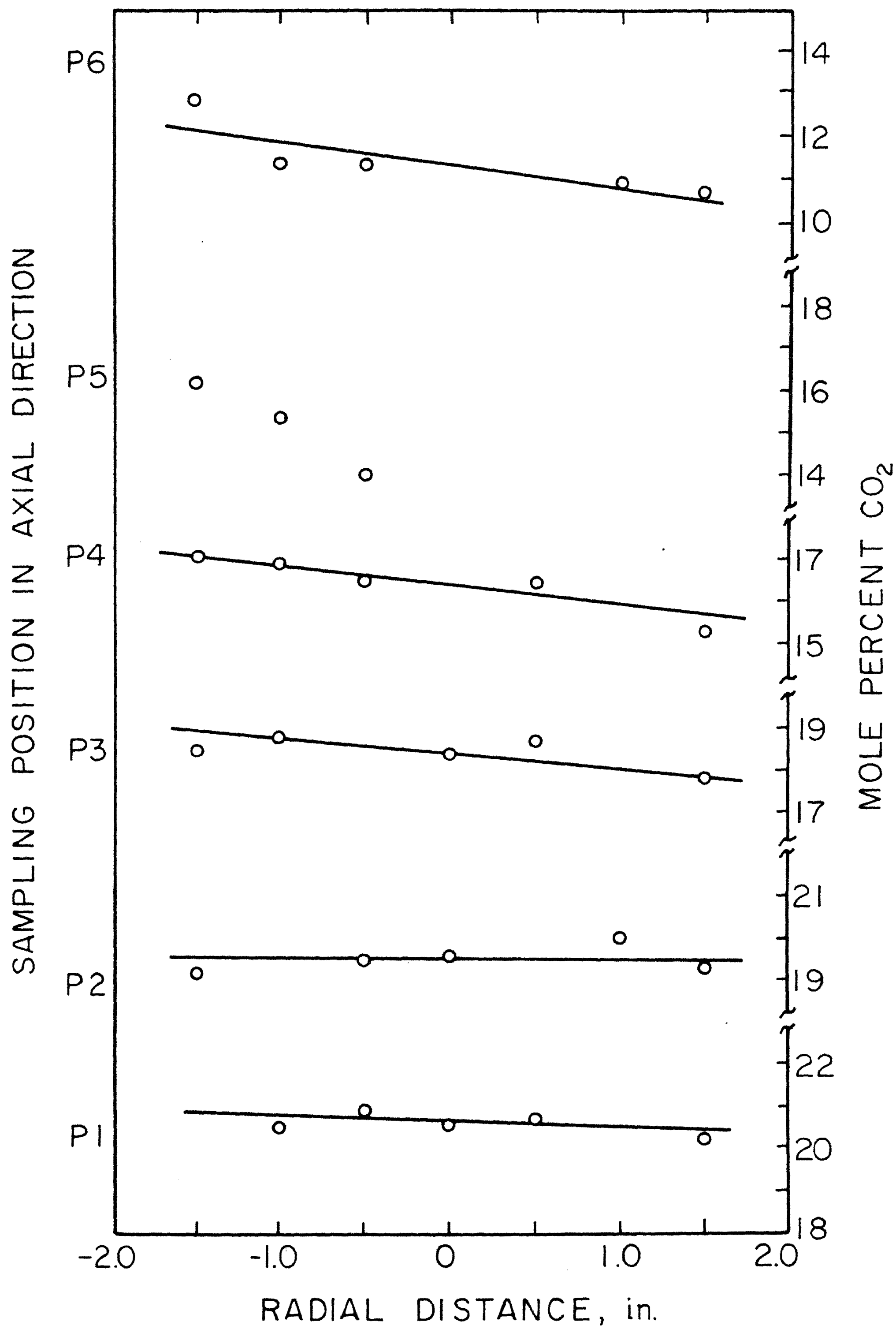

Figure 38. Axial Concentration Profile, 1/2 in. Raschig Rings, Packing Height - 3 ft., L = 3580.0 lb./hr.sq.ft. and G = 5.047 lb./hr.sq.ft.

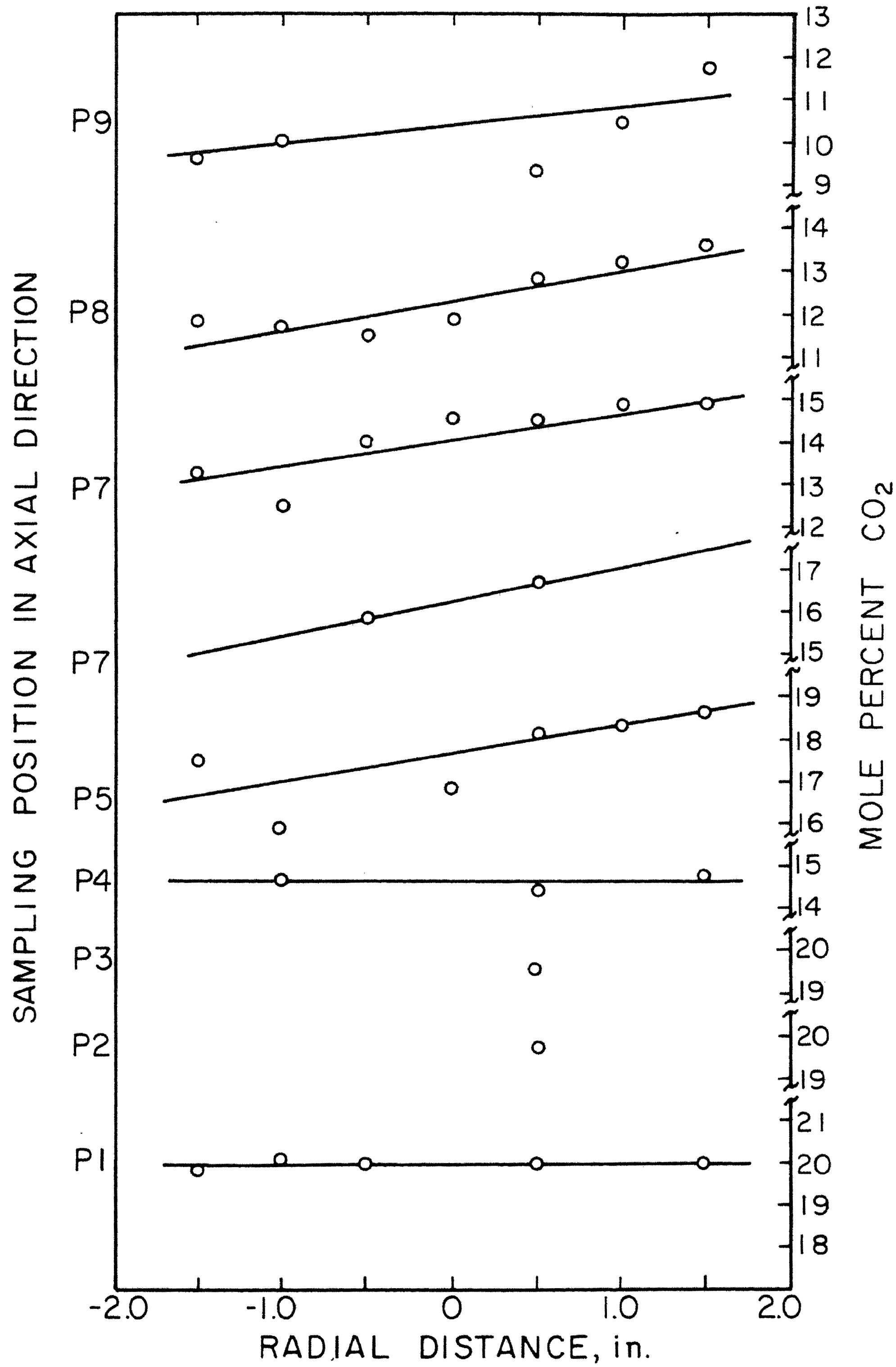

Figure 39. Axial Concentration Profile, 3/8 in. Raschig Rings, Packing Height - 5 ft., L = 3580.0 lb./hr.sq.ft. and G = 5.021 lb./hr.sq.ft.

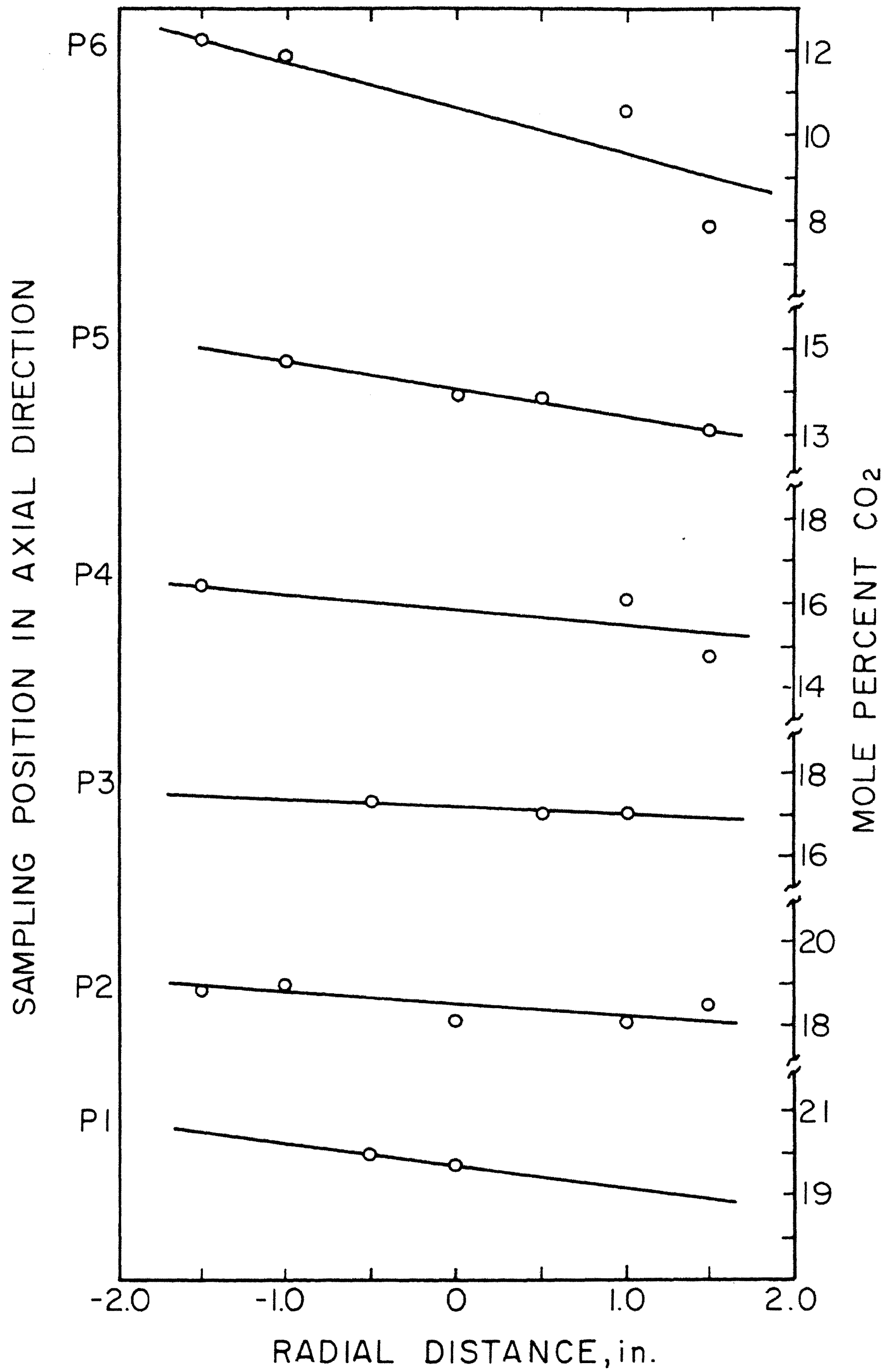

Figure 40. Axial Concentration Profile, 3/8 in. Raschig Rings, Packing Height - 3 ft., L = 5680.0 lb./hr.sq.ft. and G = 7.443 lb./hr.sq.ft.

packing with 3 feet height were duplicated to check the reproducibility of data. For a liquid rate of 5020 lb./hr.sq.ft. and gas rates of 6.2 and 7.4 lb./hr.sq.ft. the average percentage deviation in Peclet number was about 5%.

Experiments for 3/8 inch packing with 3 feet height were also performed at a liquid flow rate of 1490 lb./hr.sq.ft. and gas rates of 3.9, 5.0 and 6.2 lb./hr.sq.ft. as shown in Table III. It was found difficult to draw gas samples at such low liquid and gas rates. In addition, the results were considered unreliable due to poor gas-liquid contact at those flow rates. Gas concentration at a specific sampling point showed about 4.5% (average) fluctuations over a period of fifteen minutes compared to less than 1% at higher water and gas flow rates ($L \leq 2865$ lb./hr.sq.ft. and $G \leq 5$ lb./hr.sq.ft.). Therefore, experiments at the above-mentioned flow rates were discontinued for 1/4 and 1/2 inch Raschig ring packing sizes with 3 feet packing height and also for 3/8 inch packing size with 5 feet of packing height.

13. Confidence Limits: The 95% confidence intervals are calculated for parameters: Number of Transfer Units, gas and liquid phase Peclet numbers. Since experimental data very seldom fit a mathematical model exactly, the calculated parameters are only estimates of true parameters. The confidence limit gives the range in which the true parameter can be expected to be found with a given probability. Standard deviation and confidence intervals for computed parameters are presented in Tables XX through XXV.

All calculations in this investigation are made with double precision using an IBM 360 computer.

VII. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The purpose of this investigation was to study the effect of axial dispersion on interphase mass transfer in a packed absorption column. Steady state gas phase concentration profile data were obtained in the axial direction for the absorption of carbon dioxide from a mixture of carbon dioxide and nitrogen which is in continuous counter-current contact with water in a packed column. The axial profiles thus obtained were matched with axial concentration profiles obtained from three mathematical models - (i) plug flow in both phases, (ii) axial mixing in gas phase and plug flow in liquid phase, and (iii) axial mixing in both gas and liquid phases - to evaluate which of the models best explains the actual physical phenomena for this system.

The absorption was performed in a column packed individually with 1/4, 3/8 and 1/2 inch Raschig ring packings with 3 feet of packing height and also with 3/8 inch Raschig rings with a packing height of 5 feet. The liquid and gas flow rate ranges used were 2865 to 5680 lb./hr.sq.ft. and 5.0 to 7.4 lb./hr.sq.ft., respectively, with the inlet carbon dioxide content of about 20% (by volume) in the mixture.

A. Conclusions

The experimental technique used was found to be satisfactory. The data of this work have been presented in the form of correlations for the evaluation of apparent and true liquid phase mass transfer coefficients based on the mathematical model for axial mixing in the gas phase and plug flow in the liquid phase for various packing sizes and packing heights. It was observed that both apparent and true mass transfer coefficients increased with increases in liquid flow rate. Except for 1/4 inch packing size, both apparent and true liquid phase mass transfer coefficients were found to be independent of gas rate. For 1/4 inch packing, mass transfer coefficients were found to increase with increases in gas flow rate.

It was further observed that both the apparent and true mass transfer coefficients decreased with increases in packing size and packing height.

The difference in magnitude between $K_L^a a$ and $K_L^t a$ increased with increases in liquid rate, packing size and packing height but decreased with gas flow rate.

The effect of liquid and gas flow rates on $K_L^a a$ and $K_L^t a$ as found in this investigation for 3/8 inch Raschig ring packing and 3 feet packing height was in agreement with Brittan and Woodburn (1966) who used the same experimental technique. Brittan and Woodburn (1966) confined their studies to 3/8 inch Raschig ring packing and about 3 feet of packing height and therefore this was the only data for which a direct comparison with the present work was possible.

Gas phase Peclet numbers obtained in this work were observed to pass through a minimum with the increases in both the gas and liquid rates. No such behavior is reported by any other worker. Gas phase Peclet numbers of the present work compare well in magnitude with the Peclet numbers calculated from Brittan's data who used the same experimental technique. But the Peclet numbers determined in this work were found to be about fifty times higher compared to the results obtained by the workers using the transient-response techniques. It is believed that a disregard of non-flat velocity profile and liquid and gas capacitance in packed columns has resulted in giving higher axial diffusion coefficients by previous workers using the transient-response procedure.

Gas phase Peclet numbers show decreasing trend with increases in packing size and packing height.

Axial diffusion for the carbon dioxide-nitrogen-water system for the ranges of gas and liquid flow rates and the packing heights used in this study was found to be small. But considering the increasing trend in the difference between $K_L^a a$ and $K_L^t a$ with liquid rate and packed height, substantial axial diffusion would result at industrial liquid rates and heights.

B. Recommendations

In most of the studies it is assumed that the correct form of the mathematical model is known, and the problem is to estimate some parameters under certain experimental conditions. In this case there are a number of rival condidate models. Experiments should be so planned that the inadequate models can be detected and eliminated most efficiently. In order to achieve this a sequential procedure is recommended in which calculations made after each experiment determine the most discriminatory process conditions for use in the next experiment. In other words, the basic idea is to select for the next experiment conditions at which the models differ the most.

NOMENCLATURE

a = Interfacial area between two phases, per unit volume, sq.ft./cu.ft.

c_i = Concentration of a transferring component in i phase, mole/cu.ft.

c_y^o = Initial concentration of the incoming gas phase, mole/cu.ft.

c_x^{Le} = Initial concentration of incoming liquid phase, mole/cu.ft.

D_{ei} = Axial dispersion coefficient of i phase, in the direction of flow, sq.ft./hr.

F_i = Superficial mass flow rate of i phase, lb./hr.sq.ft.

G = Gas flow rate lb./hr.sq.ft.

H = Henry's law constant, atm./mole fraction

H.T.U. = Height of Transfer unit in ft.

K_La = Liquid phase mass transfer coefficient, mole/(hr.)(cu.ft.)(mole/cu.ft.)

Le = Total effective height of packing, ft.

L = Liquid flow rate, lb./hr.sq.ft.

m = Equilibrium coefficient, dimensionless

n = Number of data points along the length of the column

N_{oi} = Number of over-all transfer units of i phase

P_G = Gas Phase Peclet number, $\frac{(U_x\ L_e)}{D_{ey}}$, dimensionless

P_L = Liquid phase Peclet number, $\frac{(U_x\ Le)}{D_{ey}}$, dimensionless

P_T = Total pressure, mm.Hg.

U_i = Superficial velocity of the i phase, ft./hr.

x = Mole fraction CO_2 in liquid

x_{in} = Initial concentration of liquid phase, mol. fraction

y = Mole fraction CO_2 in gas phase

y_{in} = Initial concentration of gas phase, mol. fraction

z = Axial co-ordinate, ft.

Reduced Co-ordinates:

C_i = c_i/c_y^o

C_y^o = c_y^o/c_y^o = 1.0

C_y = c_y/c_y^o

C_x^1 = c_x^1/c_y^o

C_x = c_x/c_y^o

C_y^* = Concentration of the solute in the y phase, predicted from the mathematical models, dimensionless

X = x/x_{in}

Y = y/y_{in}

Z = z/Le

Greek Letters:

ε_i = Void fraction of i phase, cu.ft./cu.ft.

$\bar{\varepsilon}$ = $(C_{y_i} - C^*_{y_i})$, deviation between experimental and predicted gas phase phase concentration

Λ = Extraction factor, $(mF_y)/F_x$, dimensionless

σ_y^2 = Variance on gas phase concentration

σ_y = Standard deviation on gas phase concentration

Subscripts:

i	=	designates phase concerned, X, Y or x, y
i	=	1, 2, 3 . . . n
x,y	=	Liquid or gas phase
OL	=	Over-all based on liquid phase
OG	=	Over-all based on gas phase

Superscripts

a	=	Apparent
t	=	True
0	=	Feed inlet end, outside column
1	=	Feed outlet end, outside column

BIBLIOGRAPHY

1. Allen, H. V., S. M. Thesis, Mass. Inst. Technol., Cambridge, Massachusetts (1936). See Sherwood, T. K., and F. A. L. Holloway, Trans. Am. Inst. Chem. Engrs., 36, 39 (1940).

2. Afschar, A. S., M. Diboun and K. Schugler, Chem. Eng. Science, 23, 253 (1968).

3. Aris, R. and N. R. Anudson, A.I.Ch.E. Journal, 3, 280 (1957).

4. Baker, T., T. H. Chilton and H. C. Vernon, Tran. Am. Inst. Chem. Engrs., 31, 296 (1935).

5. Bibaud, R. E. and R. E. Treybal, A.I.Ch.E. Journal, 12, 472 (1966).

6. Bischoff, K. B. and O. Levenspiel, Chem. Eng. Sci., 17, 245 (1962).

7. Box, G. E. P. and W. J. Hill, Technometrics, 9, 1, 57 (1967).

8. Brittan, M. I., M. Sc. Thesis, University of Witwaterstand, Johannesburg, South Africa (1964).

9. Brittan, M. I. and E. T. Woodburn, A.I.Ch.E. Journal, 12, 541 (1966).

10. Brittan, M. I., Chem. Eng. Sci., 22, 1019 (1967).

11. Cairns, E. J. and J. M. Prausnitz, Ind. Eng. Chem., 51, 12, 1441 (1959).

12. Carberry, J. J., and R. H. Bretton, A.I.Ch.E. Journal, 4, 367 (1958).

13. Chilton, T. H. and A. P. Colburn, Ind. Engr. Chem., 27, 255, (1935).

14. Colburn, A. P., Trans. Am. Inst. Chem. Engrs., 29, 174 (1939).

15. Colburn, A. P., Ind. Eng. Chem., 33, 459 (1941).

16. Cooper, C. M., R. J. Christl and L. C. Peery, Trans. Am. Inst. Chem. Engrs., 37, 979 (1941).

17. Damkohler, G., "Der Chemie-Ingenieur," A. Eucken and M. Jacob, Akademische Verlagsgesellschaft M. B. H., (Leipzig), 3, pt. 1, 366 (1937).

18. Danckwerts, P. V., Chem. Engg. Sci., 2, 1, (1953).

19. Danckwerts, P. V., J. W. Jenkins, and G. Place, Chem. Eng. Sci., 3, 26 (1954).

20. Dean, H. A. and L. Lapidus, A.I.Ch.E. Journal, 6, 4, 656 (1960).

21. Deisler, P. F. and R. H. Wilhem, Ind. Eng. Chem., 45, 1219 (1953).

22. DeMaria, F. and R. R. White, A.I.Ch.E. Journal, 6, 473 (1960).

23. Draper, N. R. and H. Smith, "Applied Regression Analysis," p. 236, John Wiley, New York, (1966).

24. Dunn, W. E., T. Verneulen, C. R. Wilke and T. T. Word, "Longitudinal Mixing in Packed Gas Absorption Columns," Univ. of Calif. Rad. Lab. Report--10394, July (1962).

25. Ebach, E. A. and R. R. White, A.I.Ch.E. Journal, 4, 161 (1958).

26. Furzer, A. and G. E. Ho, A.I.Ch.E. Journal, 13, 614 (1967).

27. Geankoplis, C. J. and A. N. Hixon, Ind. Eng. Chem., 4, 1141 (1950).

28. Gier, T. E. and J. O. Hougan, Ind. Eng. Chem., 45, 1362 (1953).

29. Gottschlich. C. F., A.I.Ch.E. Journal, 9, 1, 88 (1963).

30. Hartland, S., and J. C. Mecklenburgh, Chem. Eng. Sci., 21, 1209 (1966).

31. Hartland, S. and J. C. Mecklenburgh, Chem. Eng. Sci., 23, 186 (1968).

32. Hezelbeck, D. E. and C. J. Geankoplis, Ind. Eng. Chem. Fundamentals, 2, 310 (1963).

33. Hochman, J. M. and E. Effron, Ind. Eng. Chem. Fund., 8, 1, 63 (1969).

34. Hofmann, H., Chem. Eng. Sci., 14, 193 (1961).

35. Hoogendoorn, C. J. and J. Lips, Can. J. Chem. Eng., 125 (1965).

36. Hunter, W. G. and A. M. Reiner, Technometrics, 7, 3, 307 (1965).

37. Jacques, G. L. and T. Vermeulen, "Longitudinal Dispersion in Solvent-Extraction Columns," Univ. of Calif. Rod. Lab. Report--3029, Nov. (1957).

38. Jacques, G. L. and T. Vermeulen, Univ. of Calif. Rad. Lab. Report--8658 (1959).

39. Klinkenberg, A. and F. Sjenitzer, Chem. Eng. Sci., 5, 258 (1956).

40. Klinkenberg, A., Chem. Eng. Sci., 23, 92 (1968).

41. Kramer, H. and G. Alberda, Chem. Eng. Sci., 2, 173 (1953).

42. Levenspiel, O. and W. K. Smith, Chem. Eng. Sci., 6, 227 (1957).

43. Levenspiel, O., Ind. Eng. Chem., 50, 343 (1958).

44. Levenspiel, O. and K. B. Bischoff, "Advances in Chemical Engineering," Vol. 4, p. 95, Academic Press, New York (1963).

45. Levenspiel, O. L., Chemical Reaction Engineering, John Wiley and Sons, New York (1962).

46. McHenry, K. W. and R. H. Wilhem, A.I.Ch.E. Journal, 3, 83 (1957).

47. Miyauchi, T., "Longitudinal Dispersion in Solvent Extraction Columns," Mathematical Theory, University of Calif. Rad. Lab. Rept., UCRL-3911, Aug. (1957).

48. Miyauchi, T. and T. Vermeulen, Ind. Eng. Chem. Fundamentals, 2, 113 (1963).

49. Miyauchi, T. and H. Oya, A.I.Ch.E. Journal, 11, 395 (1965).

50. Oliver, J., Personal Communication (1969).

51. Penney, W. R. and K. J. Bell, Chem. Eng. Sym. Series, 65, 92, 21 (1969).

52. Perry, J. H., "Chemical Engineering Handbook," p. 674, McGraw-Hill, New York (1950).

53. Pratt, H. R. C., Trans. Inst. of Chem. Engrs. (London), 29, 195 (1951).

54. Rixon, F. F., Trans. Inst. Chem. Engrs., 26, 119 (1948).

55. Robinson, J. M., Lawrence Radiation Laboratory Report, Univ. of Calif., Univ. of Calif. Rad. Lab. Report--9193, June (1960).

56. Sater, V. E. and O. Levelspiel, Ind. Eng. Chem. Fundamentals, 5, 86, (1966).

57. Schmel, G. A. and A. L. Babb, Ind. Eng. Chem., Chem. Proc. Design Devel., 3, 210 (1964).

58. Schulman, H. L., C. F. Ullrich, A. Z. Proulx and J. O. Zimmerman, A.I.Ch.E. Journal, 1, 253 (1955).

59. Schwartz, C. E. and J. M. Smith, Ind. Eng. Chem., 45, 6, 1209 (1953).

60. Sleicher, C. A., A.I.Ch.E. Journal, 5, 145 (1959).

61. Smoot, L. D. and A. L. Babb, Ind. Eng. Chem. Fundamentals, 1, 2, 95 (1962).

62. Stemerding, A. Proc. of the Second European Symposium on Chemical Reaction Engineering, Chem. Eng. Sci., 14, 209 (1961).

63. Strang, D. A. and C. J. Geankoplis, Ind. Eng. Chem., 50, 1305 (1958).

64. Taylor, G. I., Proc. Roy. Soc. (London), A223, 446 (1954).

65. Turner, G. A., Chem. Eng. Sci., 7, 156 (1958).

66. Turner, G. A., Chem. Eng. Sci., 10, 14 (1959).

67. Van Deemter, J. J., F. J. Zinderweg and A. Klinkenberg, Chem. Eng. Sci., 5, 271 (1956).

68. Vermeulen, T., J. S. Moon, A. Henrico and T. Miyauchi, Chem. Eng. Progress, 62, 9, 95 (1966).

69. Whitman, W. G., Chem. and Met. Eng., 29, 147 (1923).

VITA

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APPENDIX A

NON-LINEAR REGRESSION ANALYSIS FOR CASE I, II AND III

Non-linear regression analysis for the three mathematical models is presented in this section.

A. Non-Linear Regression Analysis for Case I

Equations as given in Chapter IV for Case I can be written as

$$\frac{C_{y_i} - mC_x^1}{1.0 - mC_y^1} = \frac{e^{\lambda Z_i} - \Lambda e^{\lambda}}{1.0 - \Lambda e^{\lambda}} \qquad (4.1)$$

$$\lambda = -N_{oy}(1 - \Lambda) \qquad (4.4)$$

where C_{y_i} = experimental gas phase composition at any point Z_i in the column,

Z_i = height of the point i from the base of the column.

Let

$$\frac{C_{y_i} - mC_y^1}{1.0 - mC_y^1} = C^*_{y_i} \qquad (A.1)$$

Let

$$N_{oy} = T$$

∴ Equation A.1 reduces to

$$C^*_{y_i} = \frac{e^{\lambda Z_i} - \Lambda e^{\lambda}}{1.0 - \Lambda e^{\lambda}} \qquad (A.2)$$

$$\lambda = -T(1 - \Lambda) \qquad (A.3)$$

Let the deviation between the experimental and predicted values be ε,

i.e., $\bar{\varepsilon}_i = (C_{y_i} - C^*_{y_i})$ (A.4)

where C_{y_i} = concentration of carbon dioxide in the gas phase at the point Z_i.

The best fitting curve through the data is the curve which makes the sum of the squares of deviations minimum, i.e.,

$$S = \sum_{i=1}^{n} (\bar{\varepsilon}_i)^2 \qquad \text{(A.5)}$$

is a minimum where

$$i = 1, 2, \ldots, (n-1), n$$

$$n = \text{total number of data points.}$$

This deviation will be minimum when

$$\frac{dS}{dT} = 0, \text{ i.e.,} \qquad \text{(A.6)}$$

$$\frac{dS}{dT} = -2.0 \sum_{i=1}^{n} (C_{y_i} - C^*_{y_i}) \frac{\partial C^*_{y_i}}{\partial T} = 0 \qquad \text{(A.7)}$$

Since parameter T appears in a non-linear manner in Equation A.2, it is necessary to use a non-linear least square approach. Expanding Equation A.2 in Taylor series in terms of T about an initial value of T_o,

$$C^*_y = C^*_{y(T_o)} + \left(\frac{\partial C^*_y}{\partial T}\right)_{T_o} (T - T_o) \qquad \text{(A.8)}$$

(neglecting higher order terms)

Now, the partial derivative of C^*_y with respect to T at $T = T_o$ is obtained. Equaton A.2 can be written as

$$C^*_y = A_o e^{\lambda Z} + B_o \qquad \text{(A.9)}$$

where

$$A_o = \frac{1}{(1 - \Lambda e^{\lambda})}$$

$$B_o = \frac{1}{(1 - \Lambda e^{\lambda})}$$

$$C_y^* = \left[\left(\frac{\partial A_o}{\partial T}\right) e^{\lambda Z} + A_o Z \left(\frac{\partial \lambda}{\partial T}\right) e^{\lambda Z} + \left(\frac{\partial B_o}{\partial T}\right) \right] \tag{A.10}$$

$$\frac{\partial A_o}{\partial T} = - \frac{\Lambda e^{\lambda}(1 - \Lambda)}{(1.0 - \Lambda e^{\lambda})^2} \tag{A.11}$$

$$\frac{\partial B_o}{\partial T} = \frac{\left[-\left(\frac{\Lambda e^{\lambda}}{1.0 - \Lambda e^{\lambda}}\right)\left(\frac{\partial \lambda}{\partial T}\right) - (e^{\lambda})^2 F^2 \left(\frac{\partial \lambda}{\partial T}\right) \right]}{(1.0 - \Lambda e^{\lambda})^2} \tag{A.12}$$

$$\frac{\partial \lambda}{\partial T} = - (1.0 - \Lambda) \tag{A.13}$$

From Equation A.7,

$$\sum_{i=1}^{n} (C_{y_i} - C_{y_i}^*) \left(\frac{\partial C_{y_i}^*}{\partial T}\right) = 0 \tag{A.14}$$

$$\sum_{i=1}^{n} C_{y_i} \left[e^{\lambda Z_i} \left(\frac{\partial A_o}{\partial T}\right) + A_o Z_i e^{\lambda Z_i} \left(\frac{\partial \lambda}{\partial T}\right) + \left(\frac{\partial B_o}{\partial T}\right) \right]_{T = T_o}$$

$$- \sum_{i=1}^{n} C_{y_i (T_o)}^* \left[e^{\lambda Z_i} \left(\frac{\partial A_o}{\partial T}\right) + A_o Z_i e^{\lambda Z_i} \left(\frac{\partial \lambda}{\partial T}\right) + \left(\frac{\partial A_o}{\partial T}\right) \right]_{T = T_o}$$

$$- \sum_{i=1}^{n} \left[\left(\frac{\partial C_{y_i}^*}{\partial T}\right)_{T_o} \left(\frac{\partial C_{y_i}^*}{\partial T}\right)_{T_o} (\Delta T) \right] = 0 \tag{A.15}$$

Equation A.15 represents the 'normal equation' with T as the parameter.

$$\therefore \quad \Delta T = \frac{\sum_{i=1}^{n} \left[(C_{y_i}) \left(\frac{\partial C_{y_i}^*}{\partial T}\right)_{T_o} \right] - \sum_{i=1}^{n} \left[(C_{y_i})_{T_o} \left(\frac{\partial C_{y_i}^*}{\partial T}\right)_{T_o} \right]}{\sum_{i=1}^{n} \left(\frac{\partial C_{y_i}^*}{\partial T}\right)_{T_o}^2} \tag{A.16}$$

$$\therefore \qquad T = T_o + \Delta T \qquad (A.17)$$

T is taken as the new starting value and is further up-dated in an iterative manner until convergence is satisfactory.

B. Non-Linear Regression Analysis for Case II

$$\frac{C_y - mC_x^l}{1.0 - mC_x^l} = F_1 e^{\lambda_1 Z} + F_2 e^{\lambda_2 Z} + F_3 e^{\lambda_3 Z} \qquad (4.5)$$

See Chapter IV for other terms of the Equation 4.5. The parameters to be evaluated are N_{oy} and P_G.

Let

$$\frac{C_y - mC_x^l}{1.0 - mC_x^l} = C^*_{y_i} \qquad (A.1)$$

$$C^*_{y_i} = F_1 e^{\lambda_1 Z} + F_2 e^{\lambda_2 Z} + F_3 e^{\lambda_3 Z} \qquad (A.18)$$

Let the deviation between the experimental and calculated values of concentration be

$$\bar{\varepsilon}_i = (C_{y_i} - C^*_{y_i}) \qquad (A.4)$$

where C_{y_i} = experimental concentration of carbon dioxide in the gas phase at point Z_i

The best fitting curve through the data is the curve which makes the sum of the squares of deviation minimum.

$$S = \sum_{i=1}^{n} (C_{y_i} - C^*_{y_i})$$

Let

$$N_{oy} = T$$

$$P_G = P$$

S will be minimum when

$$\frac{\partial S}{\partial T} = -2.0 \sum_{i=1}^{n} (C_{y_i} - C^*_{y_i}) \frac{\partial C^*_{y_i}}{\partial T} = 0 \qquad (A.19)$$

$$\frac{\partial S}{\partial P} = -2.0 \sum_{i=1}^{n} (C_{y_i} - C^*_{y_i}) \frac{\partial C^*_{y_i}}{\partial P} = 0 \qquad (A.20)$$

Since parameters T and P appear in non-linear manner in the mathematical model for Case II, it is necessary to use a non-linear least square approach.

Expanding C^*_y in Taylor series in terms of T and P about some initial values T_o and P_o, respectively,

$$C^*_{y_i} = (C^*_{y_i})_{T_o,P_o} + (\frac{\partial C^*_{y_i}}{\partial P})_{T_o,P_o}(T-T_o) + (\frac{\partial C^*_{y_i}}{\partial P})_{T_o,P_o}(P-P_o) \qquad (A.21)$$

(neglecting higher order terms)

Substituting in Equations A.19 and A.20,

$$\sum_{i=1}^{n} [\{C_{y_i} - (C^*_{y_i})_{T_o,P_o} - (\frac{\partial C^*_{y_i}}{\partial T})_{T_o,P_o}(T-T_o) - (\frac{\partial C^*_{y}}{\partial P})_{T_o,P_o}(P-P_o)\}(\frac{\partial C^*_{y_i}}{\partial T})_{T_o,P_o}]$$

$$= 0 \qquad (A.22)$$

$$\sum_{i=1}^{n} [\{C_{y_i} - (C^*_{y_i})_{T_o,P_o} - (\frac{\partial C^*_{y_i}}{\partial T})_{T_o,P_o}(T-T_o) - (\frac{\partial C^*_{y}}{\partial P})_{T_o,P_o}(P-P_o)\}(\frac{\partial C^*_{y_i}}{\partial P})_{T_o,P_o}]$$

$$= 0 \qquad (A.23)$$

Equations A.22 and A.23 are the normal equations.

Terms of the above equations are evaluated by obtaining partial derivatives with respect to T and P of the equations of the mathematical model. By solving the Equations A.22 and A.23, T and P can be calculated about the starting values of T_o and P_o. Next, T and P are taken as new starting values and are further up-dated in an iterative manner until convergence is satisfactory.

C. Non-Linear Regression Analysis for Case III

$$\frac{C_y - mC_x^1}{1.0 - mC_x^1} = A_1e^{\lambda_1 Z} + A_2e^{\lambda_2 Z} + A_3e^{\lambda_3 Z} + A_4e^{\lambda_4 Z} \qquad (4.20)$$

See Chapter IV for other terms of the Equation 4.20.

The parameters to be evaluated are N_{oy}, P_G and P_L.

Let

$$\frac{C_y - mC_x^1}{1.0 - mC_x^1} = C^*_{y_i} \qquad (A.1)$$

$$C^*_{y_i} = A_1e^{\lambda_1 Z} + A_2e^{\lambda_2 Z} + A_3e^{\lambda_3 Z} + A_4e^{\lambda_4 Z} \qquad (A.24)$$

Let the deviation between the experimental and calculated values of concentration be

$$\bar{\varepsilon}_i = (C_{y_i} - C^*_{y_i}) \qquad (A.4)$$

where $C^*_{y_i}$ = experimental concentration of carbon dioxide in the gas phase at point Z_i.

The best fitting curve through the data is the curve which makes the sum of the squares of deviation minimum.

$$S = \sum_{i=1}^{n} (C_{y_i} - C^*_{y_i})$$

Let

$$N_{oy} = T$$

$$P_G = P$$

$$P_L = R$$

S will be minimum when

$$\frac{\partial S}{\partial T} = -2.0 \sum_{i=1}^{n} (C_{y_i} - C^*_{y_i}) \frac{\partial C_{y_i}}{\partial T} = 0 \qquad (A.25)$$

$$\frac{\partial S}{\partial P} = -2.0 \sum_{i=1}^{n} (C_{y_i} - C^*_{y_i}) \frac{\partial C^*_{y_i}}{\partial P} = 0 \qquad (A.26)$$

$$\frac{\partial S}{\partial R} = -2.0 \sum_{i=1}^{n} (C_{y_i} - C^*_{y_i}) \frac{\partial C^*_{y_i}}{\partial R} = 0 \qquad (A.27)$$

Since parameters T, P and R appear in non-linear manner in the mathematical model for Case III, it is necessary to use a non-linear least square approach.

Expanding C^*_y in Taylor series in terms of T, P and R about some initial values of T_o, P_o and R_o, respectively,

$$C^*_{y_i} = (C^*_{y_i})_{T_o,P_o,R_o} + \left(\frac{\partial C^*_{y_i}}{\partial T}\right)_{T_o,P_o,R_o} (T-T_o) + \left(\frac{\partial C^*_{y_i}}{\partial P}\right)_{T_o,P_o,R_o} (P-P_o)$$

$$+ \left(\frac{\partial C^*_{y_i}}{\partial R}\right)_{T_o,P_o,R_o} (R-R_o)$$

(neglecting higher order terms) (A.28)

Substituting in Equations A.25, A.26 and A.27,

$$\sum_{i=1}^{n} [\{C_{y_i} - (C^*_{y_i})_{T_o,P_o,R_o} - (\frac{\partial C^*_{y_i}}{\partial T})_{T_o,P_o,R_o}(T-T_o) - (\frac{\partial C^*_{y_i}}{\partial P})_{T_o,P_o,R_o}(P-P_o)$$

$$- (\frac{\partial C^*_{y_i}}{\partial R})_{T_o,P_o,R_o}(R-R_o)\}(\frac{\partial C^*_{y_i}}{\partial T})_{T_o,P_o,R_o}] = 0 \qquad (A.29)$$

$$\sum_{i=1}^{n} [\{C_{y_i} - (C^*_{y_i})_{T_o,P_o,R_o} - (\frac{\partial C^*_{y_i}}{\partial T})_{T_o,P_o,R_o}(T-T_o) - (\frac{\partial C^*_{y_i}}{\partial P})_{T_o,P_o,R_o}(P-P_o)$$

$$- (\frac{\partial C^*_{y_i}}{\partial R})_{T_o,P_o,R_o}(R-R_o)\}(\frac{\partial C^*_{y_i}}{\partial P})_{T_o,P_o,R_o}] = 0 \qquad (A.30)$$

$$\sum_{i=1}^{n} [\{C_{y_i} - (C^*_{y_i})_{T_o,P_o,R_o} - (\frac{\partial C^*_{y_i}}{\partial T})_{T_o,P_o,R_o}(T-T_o) - (\frac{\partial C^*_{y_i}}{\partial R})_{T_o,P_o,R_o}(P-P_o)$$

$$- (\frac{\partial C^*_{y_i}}{\partial R})_{T_o,P_o,R_o}(R-R_o)\}(\frac{\partial C^*_{y_i}}{\partial R})_{T_o,P_o,R_o}] = 0 \qquad (A.31)$$

Equations A.29, A.30 and A.31 are normal equations.

The procedure adopted for evaluating the values for T, P and R is the same as for Case II.

APPENDIX B

EXPERIMENTAL DATA PROCESSING

The composition of nitrogen and carbon dioxide at various points in the absorption column was obtained in the form of peaks on the chromatogram. At the beginning of every run the gas mixture was directly passed through the gas chromatograph for standardization purposes instead of being passed through the absorber. After obtaining satisfactory peaks the gas mixture line was connected to the absorber. With the help of a calibration factor, correct compositions at various points were obtained as shown by sample calculations given below.

Run No. 22

Packing Size	1/4 in. Raschig rings
Height of Column	4 feet
Water Rate	2865 lb./hr.sq.ft.
Gas Rate	5.0047 lb./hr.sq.ft.
Gas Composition	19.75% CO_2

Calibration Peaks

Nitrogen	143
Carbon Dioxide	204.5

Peaks obtained at position P2 during the run

Nitrogen	143
Carbon Dioxide	278.0

$$\text{Mol. fraction } CO_2 = \frac{(CO_2 \text{ Peak})(F)}{(N_2 \text{ Peak})(A.F.)+(CO_2 \text{ Peak})F}$$

where A. F. is the attenuation factor and F is the calibration factor.

$$0.1975 = \frac{(284.5)(F)}{(143)8 + 284.5}$$

$$F = .9896$$

Composition at point 2

$$\text{Mol. fraction } CO_2 = \frac{(278)(.9892)}{(145.5)(8)+(278)(.9892)}$$

$$= 0.19110$$

All the compositions at various points for all the runs were calculated in the above manner and are listed in Appendix H. All calculations have been rounded off to five significant places. The arithmetic average of all radial compositions at one column cross-section was calculated to estimate the average gas composition at one column height. Axial profiles for all experiments with different gas and liquid flow rates, packing sizes and packing heights, are tabulated in Appendix G.

Values of parameters N_{oy} for Case I, N_{oy} and P_G for Case II, and N_{oy}, P_G and P_L for Case III were obtained by curve fitting the experimental axial profiles in mathematical models for Case I, Case II and Case III respectively. Computer programs as given in Appendix I were used for carrying out calculation for curve fitting.

A. Starting Values for the Models

Model I: Starting value for N_{oy} was arbitrarily chosen as 1.0 and an up-dated value of N_{oy} was obtained.

Model II: Improved value of N_{oy} from Model I was taken as the starting value, and a value for P_G was arbitrarily chosen (20.0). Improved values of N_{oy} and P_G were obtained.

Model III:

(a) Improved values of N_{oy} and P_G from Model II were used as starting values for Model III, with the value of P_L chosen arbitrarily (60.0). Some of the values during computer processing became so large that the data could not be processed.

(b) Next, improved value N_{oy} was taken from Model I and values of P_G and P_L were chosen arbitrarily (P_G = 50.0, P_L = 60.0).

All the data was processed in this manner.

B. Criteria of Convergence

The ratios of changes in the parameters N_{oy}, P_G and P_L to the respective parameters should be less or equal to 0.0001.

APPENDIX C

N_{oy} FOR CASE I, N_{oy} AND P_G FOR CASE II, N_{oy}, P_G AND P_L FOR CASE III AND LEAST SQUARE ERROR OF CONCENTRATION PROFILES FOR THREE CASES

TABLE II

N_{oy} AND ERROR FOR CASE I AND N_{oy}, P_G AND ERROR FOR CASE II

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	L lb./hr.sq.ft.	G lb./hr.sq.ft.	Case I - Plug Flow			Case II - Axial Mixing in Gas Phase			
			N	Error x 10^4	AAPD	N	P	Error x 10^4	AAPD
22	2865.0	5.0047	0.56461	0.87136	1.8371	0.58675	99.47832	1.22927	2.3636
23	2865.0	6.1977	0.63404	1.63283	2.5013	0.63466	84.86902	1.69937	2.4868
24	2865.0	7.3805	0.54133	2.31117	3.1347	0.45972	7.88721	1.72887	2.5821
32.	3580.0	5.0047	0.65749	1.38253	2.8298	0.67744	84.13800	1.78465	2.9652
33	3580.0	6.1977	0.75088	1.10681	2.4628	0.77939	91.54670	1.61146	3.0727
34	3580.0	7.3805	0.79933	0.54030	1.6254	0.81410	100.11421	0.74418	1.8215
42	4300.0	5.0047	1.19339	0.39640	1.5869	1.20178	88.50962	0.54210	1.7166
43	4300.0	6.1977	1.19242	2.02879	3.3918	1.24532	84.19711	1.19468	3.6329
44	4300.0	7.3805	0.92231	1.63721	2.6262	0.93144	95.46814	1.74523	2.6779
52	5020.0	5.0047	1.2907	6.50582	7.4659	1.33119	84.96104	7.79903	7.9544
53	5020.0	6.1977	1.15683	2.43259	4.1810	1.16062	84.97129	2.56234	4.4471
54	5020.0	7.3805	1.06091	1.49302	3.1370	1.08365	90.75262	1.88239	3.3620

TABLE II (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case I - Plug Flow			Case II - Axial Mixing in Gas Phase			
			N_{oy}	Error x 10^4	AAPD	N_{oy}	P_G	Error x 10^4	AAPD
62	5680.0	5.0047	1.17271	1.86797	3.8496	1.19038	91.75947	2.24900	4.2965
63	5680.0	6.1977	1.22285	0.75076	2.4315	1.24532	84.19711	1.19468	3.3454
64	5680.0	7.3805	1.33705	1.89707	3.4879	1.35402	90.98505	2.18117	3.7124
			Average Error	1.79640				2.01265	

TABLE III

N_{oy} AND ERROR FOR CASE I AND N_{oy}, P_G AND ERROR FOR CASE II

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	L lb./hr.sq.ft.	G lb./hr.sq.ft.	Case I - Plug Flow			Case II - Axial Mixing in Gas Phase			
			N_{oy}	Error x 10^4	AAPD	N_{oy}	P_G	Error x 10^4	AAPD
22	2865.0	5.0214	0.91461	5.18383	5.7951	0.97183	157.09258	6.24499	6.2829
23	2865.0	6.2280	0.71984	2.91064	3.9709	0.70109	83.48677	2.96460	3.8957
24	2865.0	7.3805	0.53680	0.54551	1.5652	0.10207	19.02805	0.24729	1.0572
32	3580.0	5.0214	1.82344	0.81705	1.9686	1.82146	88.12171	1.49650	2.9589
33	3580.0	6.2184	1.62503	1.13331	2.5820	1.76250	28.40931	0.56672	1.8016
34	3580.0	7.3805	1.90152	1.10059	2.3366	1.55415	83.34756	1.84005	2.8421
42	4300.0	5.1900	1.51816	2.73551	4.2727	1.46155	28.30795	2.19518	4.1343
43	4300.0	6.2280	0.89885	2.13655	3.6022	0.84241	17.57451	1.35765	2.6669
44	4300.0	7.5400	0.58501	1.25905	1.7359	0.60184	83.96037	1.55554	1.9960
52	5020.0	5.0471	1.39360	5.99839	7.0311	1.44534	104.49573	7.66744	8.1428
53	5020.0	6.2184	1.20419	0.77926	2.3308	1.22335	86.84836	1.12285	2.7717
54	5020.0	7.4468	0.95290	0.09205	0.6179	0.95463	88.23839	0.15941	0.5943

TABLE III (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case I - Plug Flow			Case II - Axial Mixing in Gas Phase			
			N_{oy}	Error x 10^4	AAPD	N_{oy}	P_G	Error x 10^4	AAPD
62	5680.0	5.0496	1.55607	0.70196	1.9860	1.57867	107.54863	1.12054	2.3513
63	5680.0	6.2499	1.37588	1.53959	3.4129	1.40510	104.24669	2.06662	3.5250
64	5680.0	7.4426	1.05760	1.20025	2.7261	1.08508	114.26855	1.63980	3.1853
11	1490.0	3.9392	0.25097	0.88021	1.6759	0.26689	147.03145	1.07918	1.9676
12	1490.0	5.0214	1.22498	4.75066	3.3714	0.88033	154.39563	5.12185	3.9806
13	1490.0	6.2184	0.45826	7.40079	5.8208	4.21249	1.50579	0.35940	1.3335
21	2865.0	3.9392	1.16279	0.65851	1.9734	1.18128	83.69253	0.98376	2.0975
31	3580.0	3.9412	1.92000	1.09749	3.4056	1.94827	99.25568	1.59203	3.8109
533*	5020.0	6.2534	0.97021	0.63451	1.5974	0.98353	89.85968	0.86354	1.5939
544*	5020.0	7.4468	1.00508	0.52839	1.7140	1.00027	85.03970	0.53685	1.4774
		Average Error (Runs 22-64)		1.87557				2.14968	

*Duplicate runs.

TABLE IV

N_{oy} AND ERROR FOR CASE I AND N_{oy}, P_G AND ERROR FOR CASE II

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	L lb./hr.sq.ft.	G lb./hr.sq.ft.	Case I - Plug Flow			Case II - Axial Mixing in Gas Phase			
			N_{oy}	Error x 10^4	AAPD	N_{oy}	P_G	Error x 10^4	AAPD
22	2865.0	5.0471	1.81931	0.67772	2.0857	2.07922	35.65594	0.30213	1.3647
23	2865.0	6.2499	6.59430	3.48563	3.9606	0.63468	146.47624	4.17128	4.3562
24	2865.0	7.4426	1.03899	4.68436	4.5623	1.27374	13.34211	3.80668	4.1705
32	3580.0	5.0471	0.83789	3.98495	4.9565	0.90151	83.53611	5.04772	5.6034
33	3580.0	6.2499	0.59167	3.35566	3.9333	0.61248	83.20775	3.96598	4.4423
34	3580.0	7.4426	0.49350	3.40608	3.6793	0.51281	89.43554	3.89158	4.0744
42	4300.0	5.0471	1.28750	1.51589	3.4217	1.31726	86.14331	2.23315	4.1950
43	4300.0	6.2499	0.85677	2.86415	3.9743	0.89364	88.17815	3.93738	4.7727
44	4300.0	7.4430	1.04715	1.47886	2.8576	1.04509	86.64175	1.56493	2.8771
52	5020.0	5.0471	1.57239	2.27005	4.4141	1.61353	90.12315	3.40328	5.3356
53	5020.0	6.2499	0.75871	4.01552	4.3662	0.78109	86.54074	4.79706	5.0104
54	5020.0	7.4430	0.91119	1.86630	3.2736	0.94593	99.86582	2.61356	3.9613

TABLE IV (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case I - Plug Flow			Case II - Axial Mixing in Gas Phase			
			N_{oy}	Error x 10^4	AAPD	N_{oy}	P_G	Error x 10^4	AAPD
62	5680.0	5.0740	1.51416	1.28128	3.1202	1.54506	99.09005	2.02563	3.6504
63	5680.0	6.2499	1.08237	3.47071	4.8358	1.12234	91.07285	4.80009	5.2241
64	5680.0	7.4430	0.84441	1.22841	2.6012	0.87413	97.93285	1.91444	5.3410
			Average Error	2.6380				3.2330	

TABLE V

N_{oy} AND ERROR FOR CASE I AND N_{oy}, P_G AND ERROR FOR CASE II

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case I - Plug Flow			Case II - Axial Mixing in Gas Phase			
			N_{oy}	Error x 10^4	AAPD	N_{oy}	P_G	Error x 10^4	AAPD
22	2865.0	5.0214	0.62153	6.99815	4.7633	0.64905	86.07501	8.03161	5.1689
23	2865.0	6.2184	0.46075	7.18647	4.3142	0.48560	84.10892	8.05207	4.9952
24	2865.0	7.4051	2.88999	4.00608	2.8590	2.25694	79.50160	5.93243	3.8210
32	3580.0	7.0214	0.07903	6.74930	4.8604	1.01630	84.39420	8.09918	5.3543
33	3580.0	6.2184	0.76417	2.75741	2.8349	0.79185	83.44920	3.37371	3.2981
34	3580.0	7.4051	0.81539	4.41914	3.3775	0.84751	81.28302	5.25109	3.5007
42	4300.0	5.0214	1.29954	6.23916	5.8199	1.35377	90.15008	8.28386	6.4728
43	4300.0	6.2184	0.97265	3.94508	3.5540	1.00330	84.14994	4.73985	3.8245
44	4300.0	7.4051	3.38741	3.23215	3.8428	2.58333	81.97402	6.22575	4.5199
52	5020.0	5.0214	2.01886	6.27390	6.7631	2.08599	88.53156	8.00719	7.5694
53	5020.0	6.2184	1.60956	4.00873	4.2649	1.64618	81.88517	4.94654	4.7874
54	5020.0	7.4051	0.99380	2.41794	2.9285	1.02165	84.38106	3.09575	3.1651

TABLE V (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case I - Plug Flow			Case II - Axial Mixing in Gas Phase			
			N_{oy}	Error x 10^4	AAPD	N_{oy}	P_G	Error x 10^4	AAPD
62	5680.0	5.0214	1.89135	1.29035	2.8340	1.91827	88.93275	1.94849	3.2322
63	5680.0	6.2184	1.32303	9.61200	6.9217	1.36947	85.19678	11.39781	7.4493
64	5680.0	7.4051	1.40337	6.71820	5.5470	1.42398	84.10498	7.74132	6.2756
		Average Error		5.0569				6.34170	

TABLE VI

N_{oy}, P_G, P_L AND ERROR FOR CASE III

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	L $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	G $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	Case III - Axial Mixing in Gas and Liquid Phases				
			N_{oy}	P_G	P_L	Error x 10^4	AAPD
22	2865.0	5.0047	0.55507	49.98093	60.00010	1.25006	2.3333
23	2865.0	6.1977	0.62553	49.99121	60.00052	1.73183	2.5793
24	2865.0	7.3805	0.54130	50.00000	60.00000	2.10125	2.9879
32	3580.0	5.0047	0.64813	49.98509	60.00099	1.93076	3.3338
33	3580.0	6.1977	0.73766	49.97938	60.00146	1.64295	3.1057
34	3580.0	7.3805	0.78801	49.98358	60.00122	0.84628	2.0164
42	4300.0	5.0047	1.19113	49.99850	60.00016	0.62176	2.0498
43	4300.0	6.1977	1.17872	49.98905	60.00117	2.75025	4.1705
44	4300.0	7.3805	0.91574	49.99169	60.00072	1.82329	2.8806
52	5020.0	5.0047	1.28591	49.99905	60.00009	7.75841	8.4269
53	5020.0	6.1977	1.15304	49.99759	60.00028	2.62653	4.5694
54	5020.0	7.3805	1.05145	49.99102	60.00089	1.98178	3.5281

TABLE VI (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case III - Axial Mixing in Gas and Liquid Phases				
			N_{oy}	P_G	P_L	Error x 10^4	AAPD
62	5680.0	5.0047	1.16959	50.00055	59.99994	2.35263	4.7145
63	5680.0	6.1977	1.21867	49.99915	60.00009	1.42636	3.4171
64	5680.0	7.3805	1.33505	49.99839	60.00018	2.30694	4.0619
					Average Error	2.2101	

TABLE VII

N_{oy}, P_G, P_L AND ERROR FOR CASE III

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case III - Axial Mixing in Gas and Liquid Phases				
			N_{oy}	P_G	P_L	Error x 10^4	AAPD
22	2865.0	5.0214	0.87050	49.94310	60.00476	6.61706	6.5772
23	2865.0	6.2280	0.64440	49.94456	60.00315	3.14221	3.8022
24	2865.0	7.3805	0.53755	50.00176	59.99992	3.60458	1.2804
32	3580.0	5.0214	1.81482	49.99440	60.00075	1.76963	3.4014
33	3580.0	6.2184	1.65374	50.02242	59.99712	0.71657	2.1375
34	3580.0	7.3805	1.92157	50.40738	59.93360	1.77782	2.8336
42	4300.0	5.1900	1.52579	50.00074	59.99985	2.29851	3.9970
43	4300.0	6.2280	0.89900	50.00027	59.99998	1.67819	3.0412
44	4300.0	7.5400	0.57755	49.98574	60.00078	1.56494	1.9509
52	5020.0	5.0471	1.38747	49.99825	60.00018	7.82701	8.5101
53	5020.0	6.2184	1.20050	49.99697	60.00032	1.22182	3.0739
54	5020.0	7.4468	0.94838	49.99480	60.00047	0.22168	0.9031

TABLE VII (CONTINUED)

Run	L lb./hr.sq.ft.	G lb./hr.sq.ft.	Case III - Axial Mixing in Gas and Liquid Phases				
			N_{oy}	P_G	P_L	Error x 10^4	AAPD
62	5680.0	5.0496	1.55600	50.00000	60.00000	1.36144	2.8594
63	5680.0	6.2499	1.37429	49.99957	60.00005	2.28374	4.0692
64	5680.0	7.4426	1.04923	49.99225	60.00077	1.83381	3.3967
11	1490.0	3.9392	0.24529	49.96984	60.00053	1.09097	1.9051
12	1490.0	5.0214	1.23200	50.00000	60.00000	5.07807	3.7047
13	1490.0	6.2184	0.48308	50.07083	59.99749	6.53768	5.3491
21	2865.0	3.9392	1.15705	49.99515	60.00051	1.07671	2.5047
31	3580.0	3.9412	1.91900	50.00000	60.00000	1.85602	4.3727
533*	5020.0	6.2534	0.96472	49.99444	60.00051	0.94534	2.0431
544*	5020.0	7.4468	1.00356	49.99831	60.00015	0.58376	1.3940
					Average Error (Runs 22-64)	2.52790	

*Duplicate Runs

TABLE VIII

N_{oy}, P_G, P_L AND ERROR FOR CASE III

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case III - Axial Mixing in Gas and Liquid Phases				
			N_{oy}	P_G	P_L	Error x 10^4	AAPD
22	2865.0	5.0471	1.87760	49.87586	60.01850	0.44243	1.4777
23	2865.0	6.2499	0.57212	49.95451	60.00235	4.33261	4.4743
24	2865.0	7.4426	1.03890	50.00000	60.00000	4.29508	4.5141
32	3580.0	5.0471	0.82304	49.98028	60.00161	5.18870	5.6614
33	3580.0	6.2499	0.57826	49.97560	60.00136	4.16481	4.4441
34	3580.0	7.4426	0.48004	49.96872	60.00134	4.08169	4.1092
42	4300.0	5.0471	1.28224	49.99646	60.00040	2.33389	4.2860
43	4300.0	6.2499	0.84307	49.98209	60.00148	3.88541	4.6935
44	4300.0	7.4430	1.04587	49.99875	60.00012	1.64328	2.9671
52	5020.0	5.0471	1.57200	50.00000	60.00000	2.24350	4.2118
53	5020.0	6.2499	0.74769	49.98913	60.00085	5.10670	4.9658
54	5020.0	7.4430	0.89788	49.98361	60.00142	2.71388	4.0396

TABLE VIII (CONTINUED)

Run	$L \frac{lb.}{hr.sq.ft.}$	$G \frac{lb.}{hr.sq.ft.}$	Case III - Axial Mixing in Gas and Liquid Phases				
			N_{oy}	P_G	P_L	Error x 10^4	AAPD
62	5680.0	5.0740	1.51400	50.00000	60.00000	2.24350	4.2118
63	5680.0	6.2499	1.07317	49.99369	60.00063	4.78558	5.6427
64	5680.0	7.4430	0.83258	49.98515	60.00123	1.97645	3.3117
					Average Error	3.38300	

TABLE IX

N_{oy}, P_G, P_L AND ERROR FOR CASE III

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	L $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	G $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	Case III - Axial Mixing in Gas and Liquid Phases				
			N_{oy}	P_G	P_L	Error x 10^4	AAPD
22	2865.0	5.0214	0.60014	49.96641	60.00216	8.35977	5.2421
23	2865.0	6.2814	0.44136	49.94777	60.00227	8.24823	4.6500
24	2865.0	7.4051	0.34587	47.84424	59.69597	5.94951	3.2008
32	3580.0	5.0214	0.95166	49.97676	60.00234	8.61063	5.5688
33	3580.0	6.2184	0.74182	49.96849	60.00251	3.58456	3.1611
34	3580.0	7.4051	0.76032	49.92450	60.00611	5.56014	3.9250
42	4300.0	5.0214	1.27791	49.99173	60.00099	8.26868	6.7186
43	4300.0	6.2184	0.94951	49.97902	60.00213	5.05402	3.9470
44	4300.0	7.4051	3.38000	50.00000	60.00000	5.41584	4.5085
52	5020.0	5.0214	2.01639	49.99879	60.00010	8.20683	8.0182
53	5020.0	6.2184	1.58286	49.98900	60.00145	5.42167	5.2949
54	5020.0	7.4051	0.97274	49.98430	60.00158	3.40332	3.4197

TABLE IX (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	Case III - Axial Mixing in Gas and Liquid Phases				
			N_{oy}	P_G	P_L	Error x 10^4	AAPD
62	5680.0	5.0214	1.89100	50.00000	60.00000	2.17184	3.6619
63	5680.0	6.2184	1.30207	49.99041	60.00112	12.13042	7.8394
64	5680.0	7.4051	1.37000	50.00001	60.00000	8.30773	6.3246
					Average Error	6.5797	

APPENDIX D

APPARENT AND TRUE MASS TRANSFER COEFFICIENTS AND HEIGHT OF TRANSFER UNITS FOR VARIOUS PACKING SIZES AND PACKING HEIGHTS

TABLE X

APPARENT AND TRUE MASS TRANSFER COEFFICIENTS AND HEIGHT OF TRANSFER UNITS FOR VARIOUS LIQUID AND GAS RATES

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	L $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	G $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	$K_G^a a$	$K_G^t a$	$K_L^a a$	$K_L^t a$	$(H.T.U.)_{OL}^a$	$(H.T.U.)_{OL}^t$
22	2865.0	5.0047	0.03038	0.03158	16.01158	16.63943	2.87304	2.76463
23	2865.0	6.1977	0.04225	0.04229	22.23633	22.25807	2.06877	2.06675
24	2865.0	7.3805	0.04296	0.03648	22.60851	19.19972	2.03472	2.39597
32	3580.0	5.0047	0.03538	0.03691	18.65315	19.45688	3.08164	2.95434
33	3580.0	6.1977	0.05004	0.05194	26.38066	27.38235	2.17896	2.09925
34	3580.0	7.3805	0.06343	0.06461	33.67195	34.29417	1.70713	1.67615
42	4300.0	5.0047	0.06422	0.06467	34.08922	34.32887	2.02536	2.01122
43	4300.0	6.1977	0.07947	0.08299	42.26804	44.14319	1.63346	1.56407
44*	4300.0	7.3805	0.07319	0.07392	38.47205	38.85304	1.79463	1.77703
52	5020.0	5.0047	0.06946	0.07164	36.45952	37.60213	2.21077	2.14359
53	5020.0	6.1977	0.07709	0.07735	40.36226	40.49449	1.99701	1.99048
54	5020.0	7.3805	0.08419	0.08600	44.07980	45.02463	1.82858	1.79021

TABLE X (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	$K_G^a a$	$K_G^t a$	$K_L^a a$	$K_L^t a$	$(H.T.U.)_{OL}^a$	$(H.T.U.)_{OL}^t$
62	5680.0	5.0047	0.06311	0.06406	33.08961	33.58820	2.75618	2.71527
63	5680.0	6.1977	0.98149	0.08299	42.66570	43.44972	2.13757	2.09900
64	5680.0	7.3805	0.10611	0.10745	55.55316	56.25786	1.64169	1.62112

*Not used for mathematical correlations.

TABLE XI

APPARENT AND TRUE MASS TRANSFER COEFFICIENTS AND HEIGHT OF TRANSFER UNITS FOR VARIOUS LIQUID AND GAS RATES

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	$K^a_G a$	$K^t_G a$	$K^a_L a$	$K^t_L a$	$(H.T.U.)^a_{OL}$	$(H.T.U.)^t_{OL}$
22	2865.0	5.0214	0.04938	0.05247	26.22372	27.86447	1.75421	1.65092
23	2865.0	6.2280	0.04821	0.04695	25.54619	24.88078	1.80073	1.84889
24	2865.0	7.3805	0.04260	0.03984	22.39452	20.94563	2.05416	2.19625
32*	3580.0	5.0214	0.09845	0.09835	52.08879	52.03223	1.10355	1.10474
33*	3580.0	6.2184	0.10866	0.11785	57.54189	62.40967	0.99897	0.92105
34*	3580.0	7.3805	0.15090	0.12334	79.32864	64.83690	0.72461	0.88657
42*	4300.0	5.1900	0.08472	0.08156	44.83035	43.15868	1.54010	1.59975
43	4300.0	6.2280	0.06019	0.05641	31.81181	29.81430	2.17036	2.31577
44	4300.0	7.5400	0.04743	0.04879	25.06313	25.78372	2.75476	2.67778
52	5020.0	5.0471	0.07563	0.07844	40.07945	41.56747	2.01110	1.93910
53	5020.0	6.2184	0.08052	0.08180	42.58177	43.25923	1.89291	1.86327
54	5020.0	7.4468	0.07630	0.07644	40.46286	40.53632	1.99204	1.98843

TABLE XI (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	$K_G^a a$	$K_G^t a$	$K_L^a a$	$K_L^t a$	$(H.T.U.)_{OL}^a$	$(H.T.U.)_{OL}^t$
62	5680.0	5.0496	0.08449	0.08572	44.78647	45.43690	2.03635	2.00720
63	5680.0	6.2499	0.09246	0.09443	48.58699	49.61885	1.87707	1.83803
64	5680.0	7.4426	0.08464	0.08684	44.48067	45.63643	2.05035	1.99842

*Not used for mathematical correlations.

TABLE XII

APPARENT AND TRUE MASS TRANSFER COEFFICIENTS AND HEIGHT OF TRANSFER UNITS FOR VARIOUS LIQUID AND GAS RATES

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	L lb./hr.sq.ft.	G lb./hr.sq.ft.	$K^a_G a$	$K^t_G a$	$K^a_L a$	$K^t_L a$	$(H.T.U.)^a_{OL}$	$(H.T.U.)^t_{OL}$
22*	2865.0	5.0471	0.09873	0.11284	52.05159	59.48750	0.88378	0.77330
23	2865.0	6.2499	0.03994	0.04265	21.05544	22.48604	2.18480	2.04580
24*	2865.0	7.4426	0.08315	0.10193	44.00912	53.95253	1.04528	0.85264
32	3580.0	5.0471	0.04547	0.04786	24.09412	25.35938	2.38574	2.26671
33	3580.0	6.2499	0.03976	0.04116	20.94511	21.68178	2.74443	2.65118
34	3580.0	7.4426	0.03949	0.04104	20.75285	21.56490	2.76985	2.66555
42	4300.0	5.0471	0.06987	0.07149	36.67615	37.52385	1.88250	1.83998
43	4300.0	6.2499	0.05758	0.06006	30.42917	31.73865	2.26898	2.17536
44*	4300.0	7.4430	0.08381	0.08364	44.49092	44.40359	1.55185	1.55490
52*	5020.0	5.0471	0.08533	0.08757	45.30214	46.48743	1.77925	1.73388
53	5020.0	6.2499	0.05099	0.05249	27.13937	27.93993	2.96999	2.88489
54	5020.0	7.4430	0.07292	0.07570	38.81573	40.29564	2.07657	2.00031

TABLE XII (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	$K^a_G a$	$K^t_G a$	$K^a_L a$	$K^t_L a$	$(H.T.U.)^a_{OL}$	$(H.T.U.)^t_{OL}$
62*	5680.0	5.0740	0.08261	0.08430	43.85698	44.75197	2.07951	2.03792
63	5680.0	6.2499	0.07274	0.07542	38.44159	39.86119	1.37246	2.28796
64	5680.0	7.4430	0.06758	0.06996	35.72977	36.98749	2.55252	2.46572

*Not used for mathematical correlations.

TABLE XIII

APPARENT AND TRUE MASS TRANSFER COEFFICIENTS AND HEIGHT OF TRANSFER UNITS FOR VARIOUS LIQUID AND GAS RATES

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	$K^a_G a$	$K^t_G a$	$K^a_L a$	$K^t_L a$	$(H.T.U.)^a_{OL}$	$(H.T.U.)^t_{OL}$
22	2865.0	5.0214	0.02014	0.02103	10.51630	10.98176	4.37434	4.18894
23	2865.0	6.2184	0.01848	0.01948	9.65413	10.17481	4.76500	4.52116
24*	2865.0	7.4051	0.13807	0.10782	72.11017	56.31448	0.63794	0.81688
32	3580.0	5.0214	0.03172	0.03292	16.75966	17.39767	3.42980	3.30402
33	3580.0	6.2184	0.03066	0.03177	16.08997	16.67278	3.57256	3.44767
34	3580.0	7.4051	0.03896	0.04049	20.30965	21.10973	2.83030	2.72302
42	4300.0	5.0214	0.04210	0.04386	21.94637	22.86221	3.14599	3.01996
43	4300.0	6.2184	0.03902	0.04025	20.34425	20.98535	3.39373	3.29006
44*	4300.0	7.4051	0.16183	0.12342	86.28177	65.80086	0.80020	1.04927
52*	5020.0	5.0214	0.06540	0.06758	34.28368	35.42363	2.35108	2.27542
53	5020.0	6.2184	0.06457	0.06604	33.66609	34.43207	2.39421	2.34095
54	5020.0	7.4051	0.04748	0.04881	24.88777	25.58524	3.23868	3.15040

TABLE XIII (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	$K_G^a a$	$K_G^t a$	$K_L^a a$	$K_L^t a$	$(H.T.U.)_{OL}^a$	$(H.T.U.)_{OL}^t$
62	5680.0	5.0214	0.06127	0.06214	32.39505	32.85616	2.81527	2.77576
63	5680.0	6.2184	0.05308	0.05494	27.67296	28.64430	3.29567	3.18391
64	5680.0	7.4051	0.06705	0.06803	34.95508	35.46804	2.60909	2.57133

*Not used for mathematical correlations.

TABLE XIV

EXPERIMENTAL MASS TRANSFER COEFFICIENTS AGAINST PUBLISHED VALUES

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	L $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	G $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	$K_L^a a$	$K_L^t a$	$K_L^a a$ Brittan (1966)	$K_L^t a$ Brittan (1966)	$K_L^a a$ Allen (1940)
22	2865.0	5.0214	26.22372	27.86447	36.80130	35.54300	47.83664
23	2865.0	6.2280	25.54619	24.88078	36.80130	35.54300	47.83664
24	2865.0	7.3805	22.39452	20.94563	36.80130	35.54300	47.83664
32	3580.0	5.0214	52.08879	52.03223	39.43286	39.06427	53.95232
33	3580.0	6.2184	57.54189	62.40967	39.43286	39.06427	53.95232
34	3580.0	7.3805	79.32864	64.83690	39.43286	39.06427	53.95232
42	4300.0	5.1900	44.83035	43.15868	41.73782	42.22055	49.56433
43	4300.0	6.2280	31.81181	29.81430	41.73782	42.22055	59.56433
44	4300.0	7.5400	25.06313	25.78372	41.73782	42.22055	59.56433
52	5020.0	5.0471	40.07945	41.56747	43.78976	45.08498	64.75798
53	5020.0	6.2184	42.58177	42.25923	43.78976	45.09498	64.75798
54	5020.0	7.4468	40.46286	40.53632	43.78976	45.08498	64.75793

TABLE XIV (CONTINUED)

Run	L $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	G $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	$K_L^a a$	$K_L^t a$	$K_L^a a$ Brittan (1966)	$K_L^t a$ Brittan (1966)	$K_L^a a$ Allen (1940)
62	5680.0	5.0498	44.78647	45.43690	45.49907	47.50912	69.22476
63	5680.0	6.2499	48.58699	49.61885	45.49907	47.50912	69.22476
64	5680.0	7.4426	44.48067	45.63643	45.49907	47.50912	69.22476

Runs 11, 12, 12, 21, 31 are not included as data are not considered reliable.

TABLE XV

EXPERIMENTAL HEIGHT OF TRANSFER UNITS AGAINST PUBLISHED VALUES

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	L lb./hr.sq.ft.	G lb./hr.sq.ft.	$(H.T.U.)^a_{OL}$	$(H.T.U.)^t_{OL}$	$(H.T.U.)^a_{OL}$ Brittan (1966)	$(H.T.U.)^t_{OL}$ Brittan (1966)	$(H.T.U.)^a_{OL}$ Allen (1940)
22	2865.0	5.0214	1.75421	1.65092	1.25001	1.29426	0.06165
23	2865.0	6.2280	1.80073	1.84889	1.25001	1.29426	0.96165
24	2865.0	7.3805	2.05416	2.19625	1.25001	1.29426	0.96165
32	3580.0	6.0214	1.10355	1.10474	1.45773	1.47148	1.06543
33	3580.0	6.2184	0.99897	0.92105	1.45773	1.47148	1.06543
34	3580.0	7.3805	0.72461	0.88657	1.45773	1.47148	1.06543
42	4300.0	5.1900	1.54010	1.59975	1.65421	1.63529	1.15913
43	4300.0	6.2280	2.17036	2.31577	1.65421	1.63529	1.15913
44	4300.0	7.5400	2.75476	2.67778	1.65421	1.63529	1.15913
52	5020.0	6.0471	2.01110	1.93910	1.84070	1.78782	1.24469
53	5020.0	6.2184	1.89291	1.86327	1.84070	1.78782	1.24469
54	5020.0	7.4468	1.99204	1.98843	1.84070	1.78782	1.24469

TABLE XV (CONTINUED)

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	$(H.T.U.)^a_{OL}$	$(H.T.U.)^t_{OL}$	$(H.T.U.)^a_{OL}$ Brittan (1966)	$(H.T.U.)^t_{OL}$ Brittan (1966)	$(H.T.U.)^a_{OL}$ Allen (1940)
62	5680.0	5.0496	2.03635	2.00720	2.00446	1.91965	1.31746
63	5680.0	6.2499	1.87707	1.83803	2.00446	1.91965	1.31746
64	5680.0	7.4426	2.05035	1.99842	2.00446	1.91965	1.31746

Runs 11, 12, 13, 21, and 31 are not included as data are not considered reliable.

APPENDIX E

MASS TRANSFER COEFFICIENTS - EXPERIMENTAL VS. CALCULATED

TABLE XVI

MASS TRANSFER COEFFICIENTS - EXPERIMENTAL VS. CALCULATED

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	L $\frac{lb.}{hr.sq.ft.}$	G $\frac{lb.}{hr.sq.ft.}$	$K_L^a a$ Experimental	$K_L^a a$ Eq. (6.1)	$K_L^t a$ Experimental	$K_L^t a$ Eq. (6.5)
22	2865.0	5.0047	16.01158	15.78749	16.63943	16.00545
23	2865.0	6.1977	22.23633	21.54262	22.25807	21.30966
24	2856.0	7.3805	22.60851	27.24854	19.19972	26.56853
32	3580.0	5.0047	18.65315	21.97696	19.45688	22.51030
33	3580.0	6.1977	26.38066	27.73209	27.38235	27.81451
34	3580.0	7.3805	33.67195	33.43800	34.29417	33.07338
42	4300.0	5.0047	34.08922	28.20972	34.32887	29.06065
43	4300.0	6.1977	42.26804	33.96484	44.14319	34.36487
52	5020.0	5.0047	36.45952	34.44246	37.60213	35.61099
53	5020.0	6.1977	40.36226	40.19759	40.49449	40.91521
54	5020.0	7.3805	44.07980	45.90350	45.02463	46.17407
62	5680.0	5.0047	33.08961	40.15582	33.58820	41.61548
63	5680.0	6.1977	42.66570	45.91095	43.44972	46.91969
64	5680.0	7.3805	55.55316	51.61687	56.25786	52.17856

TABLE XVII

MASS TRANSFER COEFFICIENTS - EXPERIMENTAL VS. CALCULATED

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	L $\frac{\text{lb.}}{\text{hr.sq.ft.}}$	$K_L^a a$ Experimental	$K_L^a a$ Eq. (6.2)	$K_L^t a$ Experimental	$K_L^t a$ Eq. (6.6)
22	2865.0	26.22372	23.59193	27.86447	23.22551
23	2865.0	25.54619	23.59193	24.88078	23.22551
24	2865.0	22.39452	23.59193	20.94563	23.22551
43	4300.0	31.81181	34.17603	29.81430	34.30641
44	4300.0	25.06313	34.17603	25.78372	34.36041
52	5020.0	40.07945	39.36322	41.56747	39.80768
53	5020.0	42.58177	39.36322 1	43.25923	39.80768
54	5020.0	40.46286	39.36322	40.53632	39.80768
62	5680.0	44.78647	44.06104	45.43690	44.82312
63	5680.0	48.58699	44.06104	49.61885	44.82312
64	5680.0	44.48067	44.06104	45.63643	44.82312

TABLE XVIII

MASS TRANSFER COEFFICIENTS - EXPERIMENTAL VS. CALCULATED

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	L $\frac{lb.}{hr.sq.ft.}$	$K_L^a a$ Experimental	$K_L^a a$ Eq. (6.2)	$K_L^t a$ Experimental	$K_L^t a$ Eq. (6.6)
23	2865.0	21.05544	19.37589	22.48605	20.42462
32	3580.0	24.09412	24.96955	25.35938	25.18080
33	3580.0	20.04510	24.96955	21.68178	25.18080
34	3580.0	20.75285	24.96955	21.56490	25.18080
42	4300.0	36.67615	28.77095	37.52385	29.91226
43	4300.0	30.42017	28.77095	31.73865	29.91226
53	5020.0	27.13937	33.45154	27.93993	34.59589
54	5020.0	38.81573	33.45154	40.29564	34.59589
63	5680.0	38.44159	37.72643	39.86119	38.85347
64	5680.0	35.72977	37.72643	36.98749	38.85347

TABLE XIX

MASS TRANSFER COEFFICIENTS - EXPERIMENTAL VS. CALCULATED

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	L $\frac{lb.}{hr.sq.ft.}$	$K_L^a a$ Experimental	$K_L^a a$ Eq. (6.2)	$K_L^t a$ Experimental	$K_L^t a$ Eq. (6.6)
22	2865.0	10.51630	11.18881	10.98176	11.72077
23	2865.0	9.65413	11.18881	10.17481	11.72007
32	3580.0	16.75966	15.97421	17.39767	16.71930
33	3580.0	16.08997	15.97421	16.67278	16.71930
34	3580.0	10.30965	15.97421	21.10973	16.71930
42	4300.0	21.94637	21.40965	22.86221	22.39354
43	4300.0	20.34425	21.40965	20.98535	22.39354
53	5020.0	33.66609	27.41968	34.43207	28.66382
54	5020.0	24.88770	27.41968	25.58524	28.66382
62	5680.0	32.39505	33.40373	32.85616	34.90392
63	5680.0	27.67296	33.40373	28.64430	34.90392
64	5680.0	34.95508	33.40373	35.46840	34.90392

APPENDIX F

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE INTERVAL FOR VARIOUS CASES

TABLE XX

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE INTERVALS FOR CASE I

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Std. Deviation x 10	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)
22	0.56461	0.17427	0.10147	0.58491	0.54432
23	0.63404	0.32657	0.21241	0.67652	0.59156
24	0.54133	0.46223	0.16038	0.59341	0.48926
32	0.65749	0.27651	0.12094	0.68168	0.63330
33	0.75088	0.22136	0.16189	0.78326	0.71850
34	0.79933	0.10806	0.16605	0.18325	0.76612
42	1.19339	0.07928	0.10754	1.21490	1.17190
43	1.19242	0.40576	0.33477	1.25940	1.12550
44	0.92231	0.32744	0.26253	0.97481	0.86980
52	1.29074	1.30120	0.39603	1.37000	1.21150
53	1.15683	0.48652	0.27108	1.21100	1.10260
54	1.06091	0.29860	0.24127	1.10920	1.01270

TABLE XX (CONTINUED)

Run	N_{oy}	Variance $(y) \times 10^4$	N_{oy} Std. Deviation $\times 10$	N_{oy} 95% Confidence Interval (+)	(-)
62	1.17271	0.37359	0.17035	1.20680	1.13860
63	1.22285	0.14948	0.13857	1.25060	1.19520
64	1.33705	0.37941	0.31705	1.40050	1.27360

TABLE XXI

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE INTERVALS FOR CASE I

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Std. Deviation x 10	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)
22	0.91461	1.03680	0.48556	1.01170	0.81749
23	0.71984	0.58213	0.35358	0.79056	0.64913
24	0.53680	0.10910	0.12463	0.56173	0.51188
32	1.82344	0.16341	0.42148	1.90770	1.73910
33	1.62503	0.22666	0.59347	0.17437	0.15063
34	1.90152	0.220123	0.61929	2.0254	1.77770
42	1.51816	0.54710	0.41654	1.60150	1.43480
43	0.89885	0.42731	0.22667	0.94418	0.85352
44	0.58501	0.25181	0.12796	0.61061	0.55942
52	1.39360	0.11997	0.42527	1.47870	1.30850
53	1.20419	0.15585	0.16495	0.12372	0.11712
54	0.95290	0.18410	0.52924	0.96348	0.94231

TABLE XXI (CONTINUED)

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Std. Deviation x 10	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)
62	1.55607	0.14039	0.14507	1.58510	1.52710
63	1.37588	0.30792	0.23442	1.42280	1.32900
64	1.05760	0.24005	0.18366	1.09430	1.02090
11	0.25097	0.17604	0.67106	0.26439	0.23755
12	1.22498	0.95013	0.10350	1.43200	1.01800
21	1.16279	0.13170	0.16908	1.19660	1.12900
31	1.92000	0.21950	0.31869	1.98370	1.85630
533	0.97021	0.12690	0.11366	0.99295	0.94748
544	1.00508	0.10568	0.13639	1.03240	0.97780

TABLE XXII

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE INTERVALS FOR CASE I

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Std. Deviation x 10	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)
22	1.81931	0.13554	0.51970	1.92330	1.71540
23	0.59430	0.69713	0.18632	6.51560	5.37040
24	1.03899	0.93687	1.02750	1.24450	0.83348
32	0.83739	0.79699	0.27441	0.89278	0.78301
33	0.59167	0.67113	0.20993	0.63366	0.54969
34	0.49350	0.68121	0.20722	0.53495	0.45206
42	1.28950	0.30318	0.23167	1.33380	1.24120
43	0.85677	0.57283	0.24756	0.90628	0.80725
44	1.04715	0.29577	0.31818	1.11080	0.98351
52	1.57239	0.45401	0.30544	1.63350	1.51130
53	0.75871	0.80310	0.21707	0.80212	0.71530
54	0.91119	0.37326	0.22483	0.95615	0.86622

TABLE XXII (CONTINUED)

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Std. Deviation x 10	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)
62	1.51416	0.25626	0.19111	1.55240	1.47590
63	1.08237	0.69414	0.26316	1.13500	1.02970
64	0.84441	0.24568	0.14126	0.87266	0.81615

TABLE XXIII

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE INTERVALS FOR CASE I

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Std. Deviation x 10	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)
22	0.61253	0.87477	0.22032	0.66570	0.57737
23	0.46075	0.89831	0.19995	0.50074	0.42076
24	2.88999	0.50076	0.10117	3.09230	2.68760
32	0.97903	0.84366	0.29904	1.03880	0.91922
33	0.76417	0.34468	0.18091	0.80035	0.72799
34	0.81539	0.55239	0.33315	0.88202	0.74876
42	1.29954	0.77990	0.32260	1.36710	1.23500
43	0.97265	0.49313	0.23204	1.01910	0.92624
44	3.38741	0.40402	0.87452	3.56230	3.21250
52	2.01886	0.78424	0.47762	2.11440	1.92330
53	1.60956	0.50109	0.38971	1.6875	1.53160
54	0.99380	0.30224	0.19425	1.0326	0.95495

TABLE XXIII (CONTINUED)

Run	N_{oy}	Variance x 10^4	N_{oy} Std. Deviation x 10	95% Confidence Interval (+)	(-)
62	1.89135	0.16129	0.16859	1.92510	1.85760
63	1.32303	0.12015	0.37674	1.39840	1.24770
64	1.40337	0.83977	0.4407	1.49220	1.31460

TABLE XXIV

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE II

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	N_{oy}	Variance	N_{oy}			P_G	P_G		
			Standard Deviation	95% Confidence Interval			Standard Deviation	95% Confidence Interval	
		(y) x 10^5	(N_{oy}) x 10^2	(+)	(-)		(P_G) x 10^2	x 10^3 (+)	x 10^2 (-)
22	0.58675	3.07290	1.60060	0.61876	0.55474	99.47832	0.41044	0.18157	0.17391
23	0.63466	0.42484	2.61970	0.68706	0.58227	84.86902	0.59305	0.20347	0.33746
24	0.45972	0.43222	1.97790	0.49927	0.42016	7.88721	0.01098	0.01088	0.05692
32	0.67744	0.45641	1.85150	0.72285	0.64879	84.13800	0.63527	0.25984	0.05733
33	0.77939	0.40286	2.49200	0.82923	0.72955	91.54670	0.34700	0.16095	0.22146
34	0.81410	0.18605	2.31100	0.86032	0.76788	100.11421	0.34778	0.16967	0.30559
42	1.20178	0.13553	1.54500	1.23270	1.17090	88.50962	0.24659	0.13783	0.39192
43	1.24532	0.64501	4.58750	1.31750	1.13400	84.19711	0.42419	0.18325	0.13576
44	0.93144	0.43631	3.25210	0.99648	0.86640	95.46814	0.56334	0.20814	0.17199
52	1.33119	0.19498	0.54560	1.44030	1.22210	84.96104	0.45210	0.17538	0.05458
53	1.16062	0.64059	0.33983	0.12286	0.10927	84.97129	0.51656	0.18828	0.18340
54	1.08365	0.47060	0.33247	1.15010	1.01720	90.75262	0.37929	0.16661	0.14895

TABLE XXIV (CONTINUED)

Run	N_{oy}	Variance (y) x 10^5	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^{-2}	P_G 95% Confidence Interval x 10^{-3}(+)	P_G 95% Confidence Interval x 10^{-2}(-)
62	1.19038	0.56225	0.23405	1.23720	1.14360	91.75947	0.42475	0.17671	0.06809
63	1.24532	0.32763	0.22964	1.29670	1.20490	84.19711	0.28776	0.15076	0.35658
64	1.35402	0.54419	0.40743	0.14328	0.12698	90.98505	0.42659	0.17658	0.05945

TABLE XXV

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE II

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	N_{oy}	Variance (y) x 10^5	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^{-2}	P_G 95% Confidence Interval x 10^{-3}(+)	P_G 95% Confidence Interval x 10^{-2}(-)
22	0.97183	15.61200	6.69780	1.10580	0.83788	157.09258	0.87085	0.33126	-0.17077
23	0.70109	7.41150	3.99790	0.78105	0.62113	83.48677	0.73609	0.23071	-0.63732
24	0.50207	0.61823	0.90162	0.52011	0.48404	19.02805	0.01943	0.02291	0.15143
32	1.82146	3.74130	6.29650	1.94740	1.69550	88.12171	0.23819	0.13576	0.40483
33	1.7625	1.41680	5.61530	1.87480	1.65020	28.40931	0.02870	0.03415	0.22670
34	1.55415	4.60010	11.72900	1.78870	1.31960	83.34756	0.29372	0.42090	0.24604
42	1.46155	5.48790	4.16600	1.54490	1.37820	28.30795	0.06679	0.04167	0.14951
43	0.84241	3.39410	2.02800	0.88297	0.80185	17.57450	0.02823	0.02322	0.11928
44	0.60184	3.88890	1.86550	0.63914	0.56453	83.96037	0.42208	0.16838	-0.00456
52	0.144534	19.16900	6.03480	1.56600	1.32460	104.49573	0.54027	0.21255	-0.03558
53	1.22335	2.80710	2.43770	1.27210	1.17460	86.84836	0.28600	0.14405	0.29647
54	0.95463	0.39851	0.84720	0.97157	0.93769	88.23839	0.16468	0.12117	0.55302

TABLE XXV (CONTINUED)

Run	N_{oy}	Variance (y) x 10^5	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^{-2}	P_G 95% Confidence Interval x 10^{-3}(+)	P_G 95% Confidence Interval x 10^{-2}(-)
62	1.57867	2.80140	2.24070	1.62350	1.53390	107.54863	0.36322	0.18019	0.34904
63	1.40510	5.16660	3.35670	1.47220	1.33800	104.24669	0.44348	0.19294	0.15550
64	1.08508	4.09950	2.69430	1.13900	1.03120	114.26855	0.49529	0.21333	0.15210
11	0.26689	2.69800	1.05750	0.28804	0.24574	147.03145	0.88613	0.32426	-0.30195
12	0.88033	12.80500	18.95100	1.25930	0.50130	154.39563	1.50970	0.45633	-1.47540
13	4.21247	0.89851	139.19000	6.99640	1.42860	1.50579	0.07456	0.00165	0.01357
21	1.18129	2.45940	2.51370	1.23160	1.13100	83.69253	0.25798	0.13529	0.32096
31	1.94827	3.98010	4.56960	2.03970	1.85690	99.25568	0.33931	0.16712	0.31393
533	0.98353	2.15890	1.66870	1.01690	0.95016	89.85968	0.32219	0.15430	0.25421
544	1.00027	1.34210	1.64510	1.03320	0.96737	85.03970	0.30391	0.14582	0.24258

TABLE XXVI

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE II

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	N_{oy}	Variance (y) x 10^5	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^3 (+)	P_G 95% Confidence Interval x 10^2 (-)
22	2.07922	0.75533	5.88340	2.19690	1.96150	35.65594	0.03554	0.42763	0.28549
23	0.63468	10.42800	4.08080	0.71629	0.55306	146.47620	0.88368	0.32321	-0.30261
24	1.27374	9.51670	18.18100	1.63740	0.91011	13.34211	0.02948	0.19238	0.74459
32	0.90151	12.67000	4.03630	0.96262	0.80116	83.53611	0.64300	0.24863	-0.85723
33	0.61248	10.15900	3.08570	0.68780	0.56437	83.20775	0.81458	0.29805	-0.27786
34	0.51281	9.89490	3.01540	0.58704	0.46643	89.43554	1.08780	0.37834	-0.56781
42	1.31726	5.58290	3.48470	1.38700	1.24760	86.14331	0.32492	0.15113	0.21159
43	0.89364	9.84350	3.73610	0.96836	0.81892	88.18715	0.40147	0.16848	0.78928
44	1.04509	3.91230	3.74300	1.12000	0.97023	86.64175	0.44967	0.17658	-0.32921
52	1.61353	8.50820	4.61400	1.70580	1.52130	99.86582	0.35192	0.16051	0.19739
53	0.78109	12.44200	3.19370	0.85864	0.73089	86.54074	0.73190	0.17427	-0.18491
54	0.94593	6.53390	3.37730	1.01350	0.87838	99.86582	0.43665	0.18720	0.12535

TABLE XXVI (CONTINUED)

Run	N_{oy}	Variance (y) x 10^5	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^{-2}	P_G 95% Confidence Interval x 10^{-3} (+)	P_G 95% Confidence Interval x 10^{-2} (-)
62	1.54506	5.06410	2.96200	1.60430	1.48580	99.09005	0.36144	0.17138	0.26803
63	1.12234	12.00000	3.95580	1.20150	1.04320	91.07285	0.41334	0.17374	0.84058
64	0.87413	4.78610	2.28530	0.91983	0.82842	97.93285	0.38802	0.17554	0.20329

TABLE XXVII

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE II

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	N_{oy}	Variance (y) x 10^5	$\overline{N_{oy}}$ Standard Deviation (N_{oy}) x 10^2	$\overline{N_{oy}}$ 95% Confidence Interval (+)	$\overline{N_{oy}}$ 95% Confidence Interval (-)	P_G	$\overline{P_G}$ Standard Deviation (P_G) x 10^{-2}	$\overline{P_G}$ 95% Confidence Interval x 10^{-3} (+)	$\overline{P_G}$ 95% Confidence Interval x 10^{-2} (-)
22	0.64905	0.12383	3.25950	0.72799	0.59761	86.07501	0.36493	0.16324	0.17270
23	0.48560	0.11985	2.97370	0.56233	0.44338	84.10892	0.56372	0.23103	0.05541
24	2.25694	0.10079	24.66800	2.47610	1.48940	79.50160	0.45958	0.18761	0.03774
32	1.01630	0.11969	4.29660	0.11257	0.95388	84.39420	0.50343	0.22526	0.23886
33	0.79185	0.50950	2.63750	0.85190	0.74640	83.44920	0.33245	0.15936	0.26883
34	0.84751	0.75016	4.39270	0.93537	0.75966	81.28302	0.57316	0.19591	-0.33348
42	1.35377	0.11834	4.64360	1.44660	1.26090	90.15008	0.30975	0.15210	0.28200
43	1.00330	0.71254	3.30670	1.07860	0.94632	84.14994	0.34829	0.16412	0.24807
44	2.58333	0.76288	22.35500	3.20380	2.30960	81.97402	0.45032	0.16964	-0.10485
52	2.08599	0.11439	6.53540	2.21670	1.95530	88.53156	0.30730	0.14999	0.27071
53	1.64618	0.72701	5.25470	1.76300	1.55280	81.88517	0.33952	0.16750	0.31689
54	1.02165	0.44958	2.79370	1.08930	0.97753	84.38106	0.41735	0.20173	0.34790

TABLE XXVII (CONTINUED)

Run	N_{oy}	Variance (y) x 10^5	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^{-2}	P_G 95% Confidence Interval x 10^{-3} (+)	P_G 95% Confidence Interval x 10^{-2} (-)
62	1.91830	0.27836	2.48240	1.96790	1.86860	88.93275	0.21173	0.13138	0.46587
63	1.36947	0.16794	5.29780	1.50210	1.29020	85.19678	0.52973	0.23233	0.20436
64	1.42398	0.11662	5.80860	1.55080	1.31840	84.10498	0.32314	0.15021	0.20949

TABLE XXVIII

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE III

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^{-2} (+)	P_G 95% Confidence Interval x 10^{-2} (-)
22	0.55507	0.41668	1.11130	0.57755	0.53310	49.98093	0.29825	0.49988	0.49976
23	0.62553	0.57728	2.13150	0.66807	0.58281	49.99121	0.99511	0.50011	0.49971
24	0.54130	0.70042	2.54650	0.59295	0.49109	50.00000	1.50200	0.50032	0.49972
32	0.64813	0.64359	1.34540	0.67480	0.62098	49.98509	0.21617	0.49989	0.49980
33	0.73766	0.54765	1.87620	0.77457	0.69952	49.97938	0.60507	0.49990	0.49966
34	0.78801	0.28209	2.19250	0.83091	0.74321	49.98358	0.01113	0.50004	0.49960
42	1.19113	0.20725	1.49100	1.22060	1.16100	49.99850	0.18170	0.50002	0.49995
43	1.17872	0.91675	4.09090	1.25870	1.09510	49.98905	1.16150	0.50010	0.49964
44	0.91574	0.60776	2.83410	0.97165	0.85829	49.99169	1.03930	0.50011	0.49970
52	1.28591	2.58610	8.61610	0.14569	0.11123	49.99905	0.24C10	0.50004	0.49994
53	1.15304	0.87551	3.02090	1.21330	1.09240	49.99759	0.44873	0.50006	0.49988
54	1.05145	0.66059	2.83920	1.10770	0.99410	49.99102	0.74850	0.50005	0.49975

TABLE XXVIII (CONTINUED)

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^{-2} (+)	P_G 95% Confidence Interval x 10^{-2} (-)
62	1.16959	0.78421	0.15599	1.20080	1.13840	50.00055	0.047484	0.50001	0.50000
63	1.21867	0.47545	0.23111	1.26450	1.17200	49.99915	0.17320	0.50002	0.49995
63	1.33505	0.76909	0.38148	1.40590	1.25330	49.99839	0.78875	0.50015	0.49984

TABLE XXIX

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE III

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	P_L	Standard Deviation (P_L) x 10^2	95% Confidence Interval (P_L) x 10^{-2}	
			(+)	(-)
22	60.00010	0.09945	0.60003	0.59999
23	60.00052	0.27190	0.60006	0.59995
24	60.00000	0.35484	0.60007	0.59993
32	60.00099	0.08632	0.60003	0.59999
33	60.00146	0.19748	0.60005	0.59998
34	60.00012	0.30792	0.60007	0.59995
42	60.00016	0.07251	0.60002	0.59999
43	60.00117	0.40279	0.60009	0.59993
44	60.00072	0.33239	0.60007	0.59994
52	60.00009	0.06928	0.60002	0.59999
53	60.00028	0.17667	0.60004	0.59997
54	60.00089	0.26583	0.60006	0.59996

TABLE XXIX (CONTINUED)

Run	P_L	Standard Deviation (P_L) x 10	95% Confidence Interval (P_L) x 10^{-2} (+)	(-)
62	59.99994	0.03417	0.60001	0.59999
63	60.00009	0.06930	0.60002	0.59999
64	60.00018	0.28788	0.60000	0.59994

TABLE XXX

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE III

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^{-2}(+)	P_G 95% Confidence Interval x 10^{-2}(-)
22	0.87050	2.20570	5.19490	0.97203	0.76424	49.94310	1.97940	0.49979	0.49900
23	0.64440	1.04750	3.10980	0.70569	0.53220	49.94460	1.52030	0.49975	0.49914
24	0.53755	0.12015	1.03540	0.55844	0.51702	50.00176	0.60593	0.50014	0.49990
32	1.81482	0.58988	8.57070	1.97830	1.63550	49.99440	3.12830	0.50051	0.49926
33	1.65374	0.24772	31.7130	0.222210	0.95245	50.02240	18.44700	0.50330	0.49592
34	1.92157	0.59274	12.98200	2.18120	1.66190	50.40738	0.12201	0.50651	0.50163
42	1.52579	0.76615	4.47250	1.61520	1.43630	50.00074	0.79039	0.50017	0.49985
43	0.89900	0.55936	2.00910	0.93939	0.85903	50.00027	0.46317	0.50010	0.49991
44	0.57755	0.52165	1.31580	0.60366	0.55103	49.98574	0.36892	0.49993	0.49978
52	1.38747	2.60900	8.16140	1.54940	1.22290	49.99825	0.32719	0.50004	0.49991
53	1.20050	0.40727	2.22360	1.24460	1.15570	49.99697	0.36208	0.50004	0.49989
54	0.94838	0.07389	0.82532	0.96464	0.93163	79.99480	0.21503	0.49999	0.49990

TABLE XXX (CONTINUED)

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^{-2} (+)	P_G 95% Confidence Interval x 10^{-2} (-)
62	1.55600	0.45381	1.38640	1.58370	1.52830	50.00000	0.03915	0.50001	0.49999
63	1.37429	0.76125	3.51170	1.44380	1.30340	49.99957	0.31840	0.50006	0.49993
64	1.04923	0.61127	2.33150	1.09540	1.00210	49.99225	0.41957	0.50000	0.49983
11	0.24529	0.36366	0.65100	0.25827	0.23223	49.96984	0.22891	0.49974	0.49965
12	1.23200	1.69520	19.20000	1.60180	0.8385	50.00000	31.93700	0.50660	0.49382
13	0.48308	2.1792	17.06900	0.91221	0.22944	50.07083	24.23300	0.50817	0.49848
21	1.15705	0.35890	2.26920	1.20210	1.11140	59.99515	0.54187	0.50008	0.49986
31	1.91900	0.61860	5.78480	2.03430	1.80290	50.00000	0.70850	0.50013	0.49985
53	0.96472	0.31511	1.42320	0.99280	0.93587	49.99444	0.20303	0.49998	0.49990
54	1.00356	0.19468	1.45850	1.02900	0.97064	60.00015	0.39210	0.50008	0.49992

TABLE XXXI

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE III

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	P_L	Standard Deviation (P_L) x 10^2	95% Confidence Interval (P_L) x 10^{-2}	
			(+)	(-)
22	60.00476	0.62074	0.60017	0.59993
23	60.00315	0.40973	0.60011	0.59995
24	59.99992	0.14335	0.60003	0.59997
32	60.00075	0.95211	0.60021	0.59982
33	59.99712	4.00670	0.59988	0.59828
34	59.93360	2.70200	0.59988	0.59880
42	59.99985	0.28366	0.60006	0.59994
43	59.99998	0.17050	0.60003	0.59997
44	60.00078	0.12189	0.60003	0.59998
52	60.00018	0.10483	0.60002	0.59998
53	60.00032	0.13973	0.60003	0.59998
54	60.00047	0.07664	0.60002	0.59999

TABLE XXXI (CONTINUED)

Run	P_L	Standard Deviation (P_L) x 10^2	95% Confidence Interval (P_L) x 10^{-2}	
			(+)	(-)
62	60.00000	0.02952	0.60001	0.59999
63	60.00005	0.12146	0.60003	0.59998
64	60.00077	0.16236	0.60004	0.59998
11	60.00053	0.05361	0.60002	0.59999
12	60.00000	5.44600	0.60106	0.59888
13	59.99479	3.78510	0.60063	0.59912
21	60.00051	0.19612	0.60004	0.59996
31	60.00000	0.22352	0.60005	0.59996
53	60.00051	0.08253	0.60002	0.59999
54	60.00015	0.13863	0.60003	0.59997

TABLE XXXII

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE III

Packing Size-1/2 in., Packing Height - 3 ft.

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^{-2}(+)	P_G 95% Confidence Interval x 10^{-2}(-)
22	1.87760	0.14783	7.42380	2.02610	0.17291	49.87586	5.11240	0.49973	0.49774
23	0.57212	1.44420	2.91850	0.62851	0.51177	49.95451	1.30160	0.49976	0.49924
24	1.03890	1.43170	16.82700	1.37140	0.69835	50.00000	16.02200	0.50306	0.49665
32	0.82304	1.72960	3.01440	0.88267	0.76210	49.98028	0.60138	0.49991	0.49967
33	0.57826	1.38830	2.13030	0.62042	0.53521	49.9756	0.58693	0.49986	0.49963
34	0.48004	1.86060	2.03360	0.52027	0.43893	49.96872	0.72016	0.49982	0.49953
42	1.28224	0.77796	3.23190	1.34620	1.21700	49.99645	0.41173	0.50004	0.49988
43	0.84307	1.29510	0.27866	0.89813	0.78666	49.98209	0.61910	0.49993	0.49969
44	1.04587	0.54776	3.75010	1.12050	0.97050	49.99875	0.15848	0.50030	0.49967
52	1.57200	1.18250	6.95540	1.70980	1.43160	50.00000	0.31940	0.50006	0.49993
53	0.74769	1.70220	2.39380	0.79520	0.69944	49.98913	0.28634	0.49994	0.49983
54	0.89788	0.90463	2.65410	0.95027	0.84410	49.98361	0.67022	0.49996	0.49969

TABLE XXXII (CONTINUED)

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^{-2} (+)	P_G 95% Confidence Interval x 10^{-2} (-)
62	1.51400	0.74783	0.66410	0.15472	0.14807	50.00000	0.040495	0.50001	0.49999
63	1.07317	1.59520	0.34967	1.14250	1.00270	49.99369	0.27059	0.49999	0.49988
64	0.83258	0.65872	1.76340	0.86983	0.79930	49.98515	0.27353	0.49993	0.49983

TABLE XXXIII

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE III

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	P_L	Standard Deviation (P_L) x 10^2	95% Confidence Interval (P_L) x 10^{-2}	
			(+)	(-)
22	60.01850	1.26940	0.60044	0.59993
23	60.00235	0.35459	0.60010	0.59995
24	60.00000	3.51520	0.60072	0.59931
32	60.00161	0.22964	0.60006	0.59997
33	60.00136	0.19519	0.60005	0.59998
34	60.00134	0.20780	0.60006	0.59997
42	60.00040	0.16041	0.60004	0.59997
43	60.00148	0.22972	0.60006	0.59997
44	60.00012	0.48741	0.60010	0.59990
52	60.00000	0.09331	0.60003	0.59998
53	60.00085	0.12215	0.60003	0.59998
54	60.00142	0.24057	0.60006	0.59997

63	60.00063	0.11367	0.60003	0.59998
64	60.00123	0.11055	0.60003	0.59999

TABLE XXXIV

NUMBER OF TRANSFER UNITS,VVARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE III

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	(-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^{-2} (+)	x 10^{-2} (-)
22	0.60014	1.39330	1.69840	0.63344	0.56551	49.96641	0.53395	0.49976	0.49954
23	0.44136	1.37470	1.43830	0.46961	0.41208	49.94777	0.58924	0.49958	0.49934
24	0.34587	0.82988	24.66500	3.95200	2.96540	47.84424	81.98700	0.49484	0.46204
32	0.95166	1.43510	2.63560	1.00320	0.89775	49.97676	0.62677	0.49988	0.49963
33	0.74182	0.59743	1.52730	0.77170	0.71061	49.96849	0.54593	0.49978	0.49956
34	0.76032	0.92669	0.27435	0.81309	0.70335	49.92450	1.44020	0.49950	0.49892
42	1.27791	1.37810	0.33878	1.34440	1.20890	49.99173	0.43519	0.500000	0.49982
43	0.94951	0.84234	2.05940	0.98984	0.90746	49.97902	0.51661	0.49988	0.49968
44	3.38000	0.90264	27.21800	3.90990	2.82120	50.00000	37.93500	0.50791	0.49274
52	2.01639	1.36780	16.98400	2.34880	1.66950	49.99879	0.77524	0.50013	0.49982
53	1.58286	0.90360	4.26850	1.66590	1.49520	49.98900	0.87562	0.50005	0.49970
54	0.97274	0.56722	1.82520	1.00850	0.93547	49.98430	0.50303	0.49993	0.49973

TABLE XXXIV (CONTINUED)

Run	N_{oy}	Variance (y) x 10^4	N_{oy} Standard Deviation (N_{oy}) x 10^2	N_{oy} 95% Confidence Interval (+)	N_{oy} 95% Confidence Interval (-)	P_G	P_G Standard Deviation (P_G) x 10^2	P_G 95% Confidence Interval x 10^{-2} (+)	P_G 95% Confidence Interval x 10^{-2} (-)
62	1.89100	0.36197	1.21970	1.91530	1.86650	50.00000	0.05223	0.50001	0.49999
63	1.30207	2.02170	4.21880	1.38520	1.21640	49.99041	0.35731	0.49997	0.49983
64	1.37000	1.38460	4.32550	1.45500	1.28200	50.00001	0.98089	0.50018	0.49979

TABLE XXXV

NUMBER OF TRANSFER UNITS, VARIANCE, STANDARD DEVIATION AND CONFIDENCE LIMITS FOR CASE III

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	P_L	Standard Deviation (P_L) x 10^2	95% Confidence Interval (P_L) x 10^{-2}	
			(+)	(-)
22	60.00216	0.17740	0.60006	0.59999
23	60.00227	0.16496	0.60006	0.59999
24	59.69597	3.41210	0.59764	0.59628
32	60.00234	0.23338	0.60007	0.59998
33	60.00251	0.17781	0.60006	0.59999
34	60.00611	0.40387	0.60014	0.59998
42	60.00099	0.16954	0.60004	0.59998
43	60.00213	0.18983	0.60006	0.59998
44	60.00000	4.30610	0.60080	0.59908
52	60.00010	0.12300	0.60003	0.59998
53	60.00145	0.30542	0.60008	0.59996
54	60.00158	0.18026	0.60005	0.59998

TABLE XXXV (CONTINUED)

Run	P_L	Standard Deviation (P_L) x 10^2	95% Confidence Interval (P_L) x 10^{-2}	
			(+)	(-)
62	60.00000	0.03619	0.60001	0.59999
63	60.00112	0.13826	0.60004	0.59998
64	60.00000	0.35262	0.60007	0.59993

APPENDIX G

EXPERIMENTAL AND CALCULATED CONCENTRATION PROFILES

TABLE XXXVI

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE I

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.19093	0.18783	0.17307	0.16244	0.14908	0.13246
	y(Cal)	0.18923	0.18027	0.17057	0.16006	0.14868	0.13634
23	y(Exp)	0.18295	0.18186	0.17362	0.16009	0.16024	0.13325
	y(Cal)	0.19060	0.18270	0.17365	0.16328	0.15140	0.13778
24	y(Exp)	0.18794	0.17385	0.17237	0.16587	0.16490	0.14424
	y(Cal)	0.19189	0.18534	0.17768	0.16874	0.15829	0.14608
32	y(Exp)	0.19266	0.18101	0.17165	0.15582	0.13772	0.12163
	y(Cal)	0.18714	0.17622	0.16471	0.15257	0.13978	0.12630
33	y(Exp)	0.19015	0.17989	0.17472	0.15812	0.14563	0.12091
	y(Cal)	0.18856	0.17863	0.16762	0.15539	0.14182	0.12676
34	y(Exp)	0.18825	0.18577	0.17304	0.15955	0.15144	0.12764
	y(Cal)	0.19027	0.18179	0.17815	0.16018	0.14649	0.13043
42	y(Exp)	0.17990	0.16690	0.15534	0.13630	0.11440	0.09521
	y(Cal)	0.18267	0.16714	0.15084	0.133373	0.11579	0.09696
43	y(Exp)	0.18641	0.17871	0.16743	0.15064	0.11984	0.10286
	y(Cal)	0.18592	0.17303	0.15868	0.14270	0.12491	0.10510

TABLE XXXVI (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.18499	0.17958	0.16788	0.16216	0.13006	0.12014
	y(Cal)	0.18823	0.17773	0.16583	0.15235	0.13707	0.11977
52	y(Exp)	0.17958	0.16486	0.15567	0.14232	0.10084	0.07487
	y(Cal)	0.17972	0.16174	0.14357	0.12519	0.10661	0.08782
53	y(Exp)	0.17324	0.16582	0.15376	0.14072	0.12631	0.09282
	y(Cal)	0.18347	0.16861	0.15288	0.13620	0.11855	0.09984
54	y(Exp)	0.18439	0.17686	0.15688	0.14642	0.13686	0.10288
	y(Cal)	0.18612	0.17359	0.15979	0.14459	0.12785	0.10941
62	y(Exp)	0.18206	0.16405	0.14551	0.13146	0.09664	0.08802
	y(Cal)	0.17875	0.16025	0.14202	0.12404	0.10631	0.08882
63	y(Exp)	0.18474	0.17000	0.15052	0.13086	0.11380	0.08825
	y(Cal)	0.18140	0.16481	0.14771	0.13009	0.11193	0.09321
64	y(Exp)	0.18256	0.17072	0.15326	0.12951	0.12761	0.09080
	y(Cal)	0.18385	0.16903	0.15295	0.13550	0.11675	0.09602

TABLE XXXVII

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE I

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.20019	0.19332	0.18145	0.16733	0.15360	0.11351
	y(Cal)	0.19480	0.18429	0.17229	0.15859	0.14295	0.11351
23	y(Exp)	0.20680	0.19882	0.18951	0.16293	0.15001	0.14648
	y(Cal)	0.19987	0.19153	0.18176	0.17032	0.15693	0.14125
24	y(Exp)	0.18839	0.18474	0.17839	0.16677	0.15339	0.14980
	y(Cal)	0.19188	0.18355	0.17769	0.16878	0.15838	0.14625
32	y(Exp)	0.19238	0.18218	0.16571	0.16461	0.11952	0.09139
	y(Cal)	0.19161	0.17723	0.16053	0.14225	0.11865	0.09252
33	y(Exp)	0.18914	0.18015	0.16815	0.15178	0.13361	0.10452
	y(Cal)	0.19568	0.18521	0.17205	0.15548	0.13463	0.10840
34	y(Exp)	0.18774	0.18136	0.17682	0.16578	0.14858	0.11455
	y(Cal)	0.19290	0.18622	0.17653	0.16244	0.14199	0.11229
42	y(Exp)	0.19139	0.17327	0.15493	0.13975	0.10160	0.10119
	y(Cal)	0.19119	0.17420	0.15595	0.13634	0.11528	0.09266
43	y(Exp)	0.19400	0.17498	0.16668	0.15898	0.12918	0.12726
	y(Cal)	0.19537	0.18277	0.16911	0.15430	0.13825	0.12086

TABLE XXXVII (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.21457	0.20220	0.18629	0.17352	0.15747	0.14801
	y(Cal)	0.20595	0.19610	0.18540	0.17352	0.15747	0.14801
52	y(Exp)	0.20045	0.18007	0.17051	0.13680	0.11812	0.07631
	y(Cal)	0.19448	0.17464	0.15447	0.13397	0.11313	0.09195
53	y(Exp)	0.19088	0.17540	0.15908	0.13736	0.12854	0.09768
	y(Cal)	0.18957	0.17419	0.15780	0.14035	0.12174	0.10192
54	y(Exp)	0.20216	0.19236	0.17700	0.15982	0.14176	0.12454
	y(Cal)	0.20312	0.19010	0.17581	0.16015	0.14297	0.12414
62	y(Exp)	0.19887	0.17041	0.14569	0.12866	0.10271	0.07921
	y(Cal)	0.19206	0.16943	0.14712	0.12511	0.10340	0.08199
63	y(Exp)	0.19441	0.18180	0.16281	0.14672	0.11435	0.09045
	y(Cal)	0.19608	0.17748	0.15819	0.13816	0.11738	0.09581
64	y(Exp)	0.19885	0.18541	0.17185	0.15772	0.13914	0.10706
	y(Cal)	0.20008	0.18520	0.16927	0.15222	0.13399	0.11447
11	y(Exp)	0.20551	0.20428	0.19373	0.18780	0.17972	0.16816
	y(Cal)	0.20225	0.19713	0.19161	0.18564	0.17921	0.17227
12	y(Exp)	0.20344	0.20324	0.19787	0.19151	0.17006	0.16919
	y(Cal)	0.20231	0.19944	0.19457	0.18634	0.17240	0.14879

TABLE XXXVII (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
13	y(Exp)	0.18565	0.18522	0.18192	0.17634	0.16363	0.16323
	y(Cal)	0.20099	0.19703	0.19200	0.18540	0.17683	0.16570
21	y(Exp)	0.19289	0.18441	0.16855	0.15198	0.12607	0.10781
	y(Cal)	0.19413	0.18004	0.16462	0.14775	0.12928	0.10907
31	y(Exp)	0.18807	0.17144	0.15387	0.12404	0.10889	0.07283
	y(Cal)	0.18909	0.16918	0.14822	0.12615	0.10291	0.07845
533	y(Exp)	0.20331	0.18800	0.17640	0.15080	0.13355	0.11754
	y(Cal)	0.20081	0.18585	0.17007	0.15344	0.13590	0.11741
544	y(Exp)	0.20496	0.19446	0.17409	0.15686	0.13797	0.12487
	y(Cal)	0.20298	0.18974	0.17516	0.15911	0.14143	0.12195

TABLE XXXVIII

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE I

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.20239	0.19367	0.17802	0.16095	0.13997	0.10709
	y(Cal)	0.20598	0.15996	0.18201	0.16439	0.14148	0.11170
23	y(Exp)	0.20713	0.20333	0.19631	0.18725	0.17351	0.17077
	y(Cal)	0.20665	0.19828	0.18874	0.17789	0.16554	0.15147
24	y(Exp)	0.20968	0.19008	0.18562	0.17492	0.16967	0.13222
	y(Cal)	0.20930	0.20292	0.19423	0.18251	0.16657	0.14494
32	y(Exp)	0.20644	0.19522	0.18440	0.16447	0.15229	0.11410
	y(Cal)	0.20192	0.18896	0.17507	0.16017	0.14419	0.12705
33	y(Exp)	0.20588	0.20027	0.18956	0.18325	0.16500	0.13428
	y(Cal)	0.20490	0.19501	0.18426	0.17257	0.15986	0.14605
34	y(Exp)	0.20705	0.19947	0.19798	0.18741	0.17542	0.14405
	y(Cal)	0.20653	0.19829	0.18919	0.17916	0.16809	0.15588
42	y(Exp)	0.19648	0.18097	0.16623	0.14827	0.12806	0.09285
	y(Cal)	0.19755	0.18024	0.16203	0.14286	0.12269	0.10147
43	y(Exp)	0.20804	0.19051	0.18534	0.16621	0.14922	0.11699
	y(Cal)	0.20216	0.18937	0.17554	0.16060	0.14445	0.12700

TABLE XXXVIII (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.20069	0.18919	0.18305	0.15850	0.15481	0.12299
	y(Cal)	0.20421	0.19286	0.17970	0.16445	0.14677	0.12629
52	y(Exp)	0.19849	0.17887	0.15537	0.13919	0.10763	0.07726
	y(Cal)	0.19368	0.17296	0.15185	0.13034	0.10842	0.08607
53	y(Exp)	0.20392	0.19964	0.18193	0.16700	0.14368	0.11699
	y(Cal)	0.20114	0.18772	0.17374	0.15915	0.14394	0.12808
54	y(Exp)	0.20608	0.18981	0.17978	0.16723	0.14933	0.11677
	y(Cal)	0.20232	0.18954	0.17559	0.16033	0.14365	0.12543
62	y(Exp)	0.19931	0.17462	0.14892	0.12941	0.10167	0.07903
	y(Cal)	0.19156	0.16938	0.14747	0.12582	0.10442	0.08328
63	y(Exp)	0.20559	0.19052	0.16981	0.15267	0.12402	0.09866
	y(Cal)	0.19758	0.18065	0.16320	0.14522	0.12668	0.10760
64	y(Exp)	0.20653	0.19297	0.17719	0.15985	0.14336	0.11852
	y(Cal)	0.20106	0.18739	0.17294	0.15768	0.14154	0.12450

TABLE XXXIX

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE I

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	Height(ft.)	0.5	1.0	1.5	2.0	2.5	3.0	4.0	4.5	5.0
22	y(Exp)	0.20041	0.19912	0.19417	0.19290	0.18421	0.17862	0.16209	0.14329	0.12261
	y(Cal)	0.19880	0.19331	0.18753	0.18144	0.17503	0.16828	0.15366	0.14576	0.13744
23	y(Exp)	0.20210	0.19769	0.19730	0.19449	0.19142	0.18661	0.17518	0.15831	0.13431
	y(Cal)	0.20001	0.19579	0.19130	0.18655	0.18150	0.17615	0.16446	0.15808	0.15131
24	y(Exp)	0.20052	0.20032	0.19940	0.19816	0.19510	0.19077	0.17987	0.16316	0.14689
	y(Cal)	0.20366	0.10310	0.20217	0.20066	0.19818	0.19411	0.17650	0.15855	0.12912
32	y(Exp)	0.20003	0.197171	0.19655	0.17770	0.17578	0.16305	0.14144	0.12378	0.10247
	y(Cal)	0.19687	0.18939	0.18155	0.17332	0.16469	0.15563	0.13616	0.12571	0.11474
33	y(Exp)	0.19623	0.19179	0.18919	0.18225	0.17973	0.17254	0.15707	0.14001	0.12048
	y(Cal)	0.19855	0.19275	0.18657	0.179980	0.17296	0.16547	0.14900	0.13995	0.13030
34	y(Exp)	0.19803	0.19754	0.19170	0.18803	0.18598	0.18422	0.16226	0.14172	0.12734
	y(Cal)	0.19958	0.19473	0.18938	0.18351	0.17705	0.16994	0.15353	0.14407	0.13368
42	y(Exp)	0.19926	0.19159	0.18556	0.16864	0.16549	0.14946	0.12788	0.10096	0.08443
	y(Cal)	0.19454	0.18480	0.17478	0.16446	0.15384	0.14290	0.12006	0.10813	0.09586
43	y(Exp)	0.19521	0.18802	0.18731	0.17518	0.17490	0.16818	0.14146	0.12499	0.10546
	y(Cal)	0.19701	0.18967	0.18195	0.17383	0.16529	0.15632	0.13696	0.12653	0.11557

TABLE XXXIX (CONTINUED)

Run	Height(ft.)	0.5	1.0	1.5	2.0	2.5	3.0	4.0	4.5	5.0
44	y(Exp)	0.20132	0.20097	0.19810	0.19037	0.18143	0.17443	0.15020	0.12695	0.01133
	y(Cal)	0.20184	0.19896	0.19513	0.19002	0.18323	0.17419	0.14613	0.12479	0.09640
52	y(Exp)	0.19288	0.18546	0.17480	0.15366	0.15047	0.13435	0.10357	0.07024	0.06352
	y(Cal)	0.19124	0.17835	0.16531	0.15213	0.13881	0.12535	0.09798	0.08407	0.07001
53	y(Exp)	0.19478	0.18897	0.18365	0.16547	0.15785	0.15378	0.12461	0.09479	0.08484
	y(Cal)	0.19486	0.18527	0.17520	0.16465	0.15358	0.14196	0.11699	0.10358	0.08951
54	y(Exp)	0.20147	0.19849	0.18677	0.17192	0.17088	0.16477	0.13412	0.12900	0.11084
	y(Cal)	0.19719	0.18999	0.18238	0.17434	0.16585	0.15688	0.13738	0.12680	0.11562
62	y(Exp)	0.19263	0.17749	0.16025	0.14521	0.14129	0.12562	0.09426	0.07828	0.06318
	y(Cal)	0.18967	0.17551	0.16151	0.14767	0.13399	0.12046	0.09387	0.08081	0.06789
63	y(Exp)	0.20164	0.19969	0.18440	0.16443	0.16303	0.14966	0.12138	0.10954	0.10806
	y(Cal)	0.19381	0.18342	0.17283	0.16202	0.15101	0.13978	0.11666	0.10476	0.09262
64	y(Exp)	0.19887	0.19408	0.18147	0.17293	0.17189	0.13377	0.13221	0.11433	0.08745
	y(Cal)	0.19562	0.18679	0.17750	0.16772	0.15743	0.14660	0.12319	0.11055	0.09724

TABLE XL

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE II

Packing Size - 1/4 in., Packed Height - 3 ft.

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.19093	0.18783	0.17307	0.16244	0.14908	0.13246
	y(Cal)	0.18835	0.17924	0.16936	0.15863	0.14699	0.13560
23	y(Exp)	0.18295	0.18186	0.17362	0.16099	0.16024	0.13325
	y(Cal)	0.18999	0.18202	0.17289	0.16245	0.15050	0.13802
24	y(Exp)	0.18794	0.17385	0.17237	0.16587	0.16490	0.14424
	y(Cal)	0.18715	0.18034	0.17270	0.16432	0.15599	0.15119
32	y(Exp)	0.19266	0.18101	0.17165	0.15582	0.13772	0.12163
	y(Cal)	0.18618	0.17508	0.16336	0.15100	0.13794	0.12527
33	y(Exp)	0.19015	0.17989	0.17472	0.15812	0.14563	0.12091
	y(Cal)	0.18758	0.17750	0.16630	0.15384	0.13998	0.12617
34	y(Exp)	0.18825	0.18577	0.17304	0.15955	0.15144	0.12764
	y(Cal)	0.18964	0.18105	0.17096	0.15912	0.14522	0.13028
42	y(Exp)	0.17990	0.16690	0.15534	0.13630	0.11440	0.09521
	y(Cal)	0.18152	0.16597	0.14967	0.13257	0.11464	0.09735
43	y(Exp)	0.18641	0.17871	0.16743	0.15064	0.11984	0.10286
	y(Cal)	0.18496	0.17195	0.15746	0.14131	0.12333	0.10492

TABLE XL (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.18499	0.17958	0.16788	0.16216	0.13006	0.12014
	y(Cal)	0.18749	0.17689	0.16489	0.15130	0.13590	0.11984
52	y(Exp)	0.17958	0.16486	0.15567	0.14232	0.10084	0.07487
	y(Cal)	0.17770	0.15971	0.14153	0.12314	0.10454	0.08784
53	y(Exp)	0.17324	0.16582	0.15376	0.14072	0.12631	0.09282
	y(Cal)	0.18234	0.16748	0.15175	0.13510	0.11748	0.10037
54	y(Exp)	0.18439	0.17686	0.15688	0.14642	0.13686	0.10288
	y(Cal)	0.18505	0.17240	0.15848	0.14313	0.12623	0.10933
62	y(Exp)	0.18206	0.16405	0.14551	0.13146	0.09664	0.08802
	y(Cal)	0.17716	0.15873	0.14055	0.12263	0.10495	0.08901
63	y(Exp)	0.18474	0.17000	0.15052	0.13086	0.11380	0.08825
	y(Cal)	0.18017	0.16352	0.14637	0.12869	0.11047	0.09310
64	y(Exp)	0.18256	0.17072	0.15326	0.12951	0.12761	0.09080
	y(Cal)	0.18268	0.16779	0.15165	0.13414	0.11515	0.09629

TABLE XLI

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE II

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	Height (ft.)	0.5	0 1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.20019	0.19332	0.18145	0.16733	0.15360	0.11351
	y(Cal)	0.19398	0.18331	0.17107	0.15703	0.14092	0.12405
23	y(Exp)	0.20680	0.19882	0.18951	0.16293	0.15001	0.14648
	y(Cal)	0.19922	0.19082	0.18103	0.16965	0.15640	0.14234
24	y(Exp)	0.18839	0.18474	0.17839	0.16677	0.15339	0.14980
	y(Cal)	0.18993	0.18321	0.17547	0.16657	0.15647	0.14841
32	y(Exp)	0.19238	0.18218	0.16571	0.14641	0.11952	0.10914
	y(Cal)	0.19034	0.17578	0.15894	0.13948	0.11698	0.09343
33	y(Exp)	0.18914	0.18015	0.16815	0.19178	0.13361	0.10452
	y(Cal)	0.19374	0.18282	0.16902	0.15159	0.12960	0.10790
34	y(Exp)	0.18774	0.18136	0.17682	0.16578	0.14858	0.11455
	y(Cal)	0.19121	0.18335	0.17272	0.15833	0.13884	0.11539
42	y(Exp)	0.19139	0.17327	0.15493	0.13975	0.10160	0.10119
	y(Cal)	0.18802	0.17120	0.15324	0.13406	0.11362	0.10963
43	y(Exp)	0.19400	0.17498	0.16668	0.15898	0.12918	0.12726
	y(Cal)	0.19165	0.17924	0.16590	0.15158	0.13642	0.12519

TABLE XLI (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.21457	0.20220	0.18629	0.17352	0.15747	0.14801
	y(Cal)	0.20497	0.19499	0.18412	0.17228	0.15939	0.14677
52	y(Exp)	0.20045	0.18007	0.17051	0.13680	0.11812	0.07631
	y(Cal)	0.19246	0.17256	0.15233	0.13176	0.11085	0.09172
53	y(Exp)	0.19088	0.17540	0.15908	0.13736	0.12854	0.19678
	y(Cal)	0.18826	0.17282	0.15637	0.13884	0.12018	0.10207
54	y(Exp)	0.20216	0.19236	0.17700	0.15982	0.14176	0.12454
	y(Cal)	0.20219	0.18912	0.17479	0.15909	0.14190	0.12454
62	y(Exp)	0.19887	0.17041	0.14569	0.12866	0.10271	0.07921
	y(Cal)	0.19043	0.16789	0.14565	0.12372	0.10209	0.08231
63	y(Exp)	0.19441	0.18180	0.16281	0.14672	0.11435	0.09045
	y(Cal)	0.19461	0.17597	0.15661	0.13653	0.11569	0.09580
64	y(Exp)	0.19885	0.18541	0.17185	0.15772	0.13914	0.10706
	y(Cal)	0.19895	0.18395	0.16788	0.15068	0.13227	0.11409
11	y(Exp)	0.20551	0.20428	0.19373	0.18780	0.17972	0.16816
	y(Cal)	0.20173	0.19645	0.19074	0.18456	0.17786	0.17125
12	y(Exp)	0.20344	0.20324	0.19787	0.19151	0.17006	0.16919
	y(Cal)	0.20115	0.19715	0.19118	0.18225	0.16890	0.15080

TABLE XLI (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
13	y(Exp)	0.18565	0.18522	0.18192	0.17634	0.16363	0.16323
	y(Cal)	0.18856	0.18452	0.17962	0.17371	0.16666	0.16087
21	y(Exp)	0.19289	0.18441	0.16855	0.15198	0.12607	0.10781
	y(Cal)	0.19292	0.17873	0.16320	0.14622	0.12764	0.10920
31	y(Exp)	0.18807	0.17144	0.15387	0.12404	0.10889	0.07283
	y(Cal)	0.18759	0.16767	0.14671	0.12465	0.10144	0.07897
533	y(Exp)	0.20331	0.18800	0.17640	0.15080	0.13355	0.11754
	y(Cal)	0.19961	0.18458	0.16875	0.15205	0.13444	0.11744
544	y(Exp)	0.20496	0.19446	0.17409	0.15686	0.13797	0.12487
	y(Cal)	0.20207	0.18880	0.17420	0.15816	0.14051	0.12261

TABLE XLII

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE II

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.20239	0.19367	0.17802	0.16095	0.13997	0.10709
	y(Cal)	0.20486	0.19428	0.18025	0.16162	0.13692	0.11009
23	y(Exp)	0.20713	0.20333	0.19631	0.18725	0.17351	0.14077
	y(Cal)	0.20595	0.19740	0.18762	0.17643	0.16361	0.15026
24	y(Exp)	0.20968	0.19008	0.18562	0.17492	0.16967	0.13222
	y(Cal)	0.20711	0.20011	0.19031	0.17668	0.15847	0.14330
32	y(Exp)	0.20644	0.19522	0.18440	0.16447	0.15229	0.11410
	y(Cal)	0.20064	0.18747	0.17333	0.15814	0.14182	0.12597
33	y(Exp)	0.20588	0.20027	0.18956	0.18325	0.16500	0.13428
	y(Cal)	0.20407	0.19402	0.18307	0.17114	0.15814	0.14515
34	y(Exp)	0.20705	0.19947	0.19798	0.18741	0.17542	0.14405
	y(Cal)	0.20587	0.19748	0.18819	0.17791	0.16653	0.15494
42	y(Exp)	0.19648	0.18097	0.16623	0.14827	0.12806	0.09285
	y(Cal)	0.19592	0.17854	0.16025	0.14101	0.12076	0.10153
43	y(Exp)	0.20804	0.19051	0.18534	0.16621	0.14922	0.11699
	y(Cal)	0.20072	0.18775	0.17371	0.15852	0.14209	0.12634

TABLE XLII (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.20069	0.18919	0.18305	0.15850	0.15481	0.12299
	y(Cal)	0.20337	0.19191	0.17865	0.16333	0.14560	0.12680
52	y(Exp)	0.19849	0.17887	0.15537	0.13919	0.10763	0.07726
	y(Cal)	0.19166	0.17096	0.14986	0.12835	0.10644	0.08631
53	y(Exp)	0.20392	0.19964	0.18193	0.16700	0.14368	0.11699
	y(Cal)	0.20092	0.18645	0.17230	0.15752	0.14210	0.12726
54	y(Exp)	0.20608	0.18981	0.17978	0.16723	0.14933	0.11677
	y(Cal)	0.20111	0.18818	0.17402	0.15852	0.14155	0.12480
62	y(Exp)	0.19931	0.17462	0.14892	0.12941	0.10167	0.07903
	y(Cal)	0.18966	0.16756	0.14571	0.12413	0.10280	0.08351
63	y(Exp)	0.20559	0.19052	0.16981	0.15267	0.12402	0.09866
	y(Cal)	0.19570	0.17867	0.16110	0.14299	0.12432	0.10715
64	y(Exp)	0.20653	0.19297	0.17719	0.15985	0.14336	0.11852
	y(Cal)	0.19972	0.18589	0.17127	0.15581	0.13945	0.12383

TABLE XLIII

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE II

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	Height(ft.)	0.5	1.0	1.5	2.0	2.5	3.0	4.0	4.5	5.0
22	y(Exp)	0.20041	0.19912	0.19417	0.19290	0.18421	0.17862	0.16209	0.14329	0.12261
	y(Cal)	0.19804	0.19246	0.18657	0.18036	0.17381	0.16689	0.15189	0.14376	0.13633
23	y(Exp)	0.20210	0.19769	0.19730	0.19449	0.19142	0.18661	0.17518	0.15831	0.13431
	y(Cal)	0.19934	0.19508	0.19049	0.18560	0.18041	0.17489	0.16278	0.15614	0.15008
24	y(Exp)	0.20052	0.20032	0.19940	0119816	0.19510	0.19077	0.17987	0.16316	0.14689
	y(Cal)	0.20306	0.20183	0.20003	0.19741	0.19360	0.18804	0.16816	0.15100	0.12989
32	y(Exp)	0.20003	0.19717	0.19655	0.17770	0.17578	0.16305	0.14144	0.12378	0.10247
	y(Cal)	0.19587	0.18831	0.18036	0.17202	0.16325	0.15404	0.13423	0.12357	0.11386
33	y(Exp)	0.19623	0.19179	0.18919	0.18225	0.17973	0.17254	0.15707	0.14001	0.12048
	y(Cal)	0.19781	0.19193	0.18566	0.17896	0.17181	0.16418	0.14735	0.13808	0.12948
34	y(Exp)	0.19803	0.19754	0.19170	0.18803	0.18598	0.18422	0.16226	0.14172	0.12734
	y(Cal)	0.19898	0.19406	0.18864	0.18266	0.17607	0.16880	0.15196	0.14222	0.13296
42	y(Exp)	0.19926	0.19159	0.18556	0.16865	0.16549	0.14946	0.12788	0.10096	0.08443
	y(Cal)	0.19277	0.18297	0.17288	0.16249	0.15180	0.14079	0.11779	0.10578	0.09564
43	y(Exp)	0.19521	0.18802	0.18731	0.17518	0.17490	0.16818	0.14146	0.12499	0.10546
	y(Cal)	0.19608	0.18865	0.18084	0.17262	0.16397	0.15487	0.13522	0.12462	0.11489

TABLE XLIII (CONTINUED)

Run)	Height(ft.)	0.5	1.0	1.5	2.0	2.5	3.0	4.0	4.5	5.0
44	y(Exp)	0.20132	0.20097	0.19810	0.19037	0.18143	0.17443	0.15020	0.12695	0.11320
	y(Cal)	0.20004	0.19578	0.19051	0.18398	0.17589	0.16587	0.13810	0.11907	0.19976
52	y(Exp)	0.19288	0.18546	0.17480	0.15366	0.15047	0.13435	0.10357	0.07024	0.06352
	y(Cal)	0.18913	0.17625	0.16322	0.15005	0.13675	0.12330	0.09596	0.08208	0.07031
53	y(Exp)	0.19478	0.18897	0.18365	0.16547	0.15785	0.15378	0.12461	0.09479	0.08484
	y(Cal)	0.19365	0.18400	0.17388	0.16326	0.15212	0.14043	0.11530	0.10181	0.08974
54	y(Exp)	0.20147	0.19849	0.18677	0.17192	0.17088	0.16477	0.13412	0.12900	0.11084
	y(Cal)	0.19629	0.18902	0.18133	0.17320	0.16460	0.15552	0.13575	0.12500	0.11509
62	y(Exp)	0.19263	0.17749	0.16025	0.14521	0.14129	0.12562	0.09426	0.07828	0.06318
	y(Cal)	0.18773	0.17367	0.15978	0.14604	0.13245	0.11902	0.09261	0.07963	0.06858
63	y(Exp)	0.20164	0.19969	0.18440	0.16443	0.16303	0.14966	0.12138	0.09544	0.08061
	y(Cal)	0.19242	0.18195	0.17127	0.16038	0.14927	0.13794	0.11460	0.10259	0.09190
64	y(Exp)	0.19887	0.19408	0.18147	0.17293	0.17189	0.13377	0.13221	0.11433	0.08745
	y(Cal)	0.19453	0.18566	0.17632	0.16649	0.15615	0.14526	0.12175	0.10906	0.09741

TABLE XLIV

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE III

Packing Size - 1/4 in., Packing Height - 3 ft.

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.19093	0.18783	0.17307	0.16244	0.14908	0.13246
	y(Cal)	0.18832	0.17944	0.16986	0.15952	0.14836	0.13779
23	y(Exp)	0.18295	0.18186	0.17362	0.16099	0.16024	0.13325
	y(Cal)	0.18972	0.18178	0.17275	0.16246	0.15075	0.13910
24	y(Exp)	0.18794	0.17385	0.17237	0.16587	0.16490	0.14424
	y(Cal)	0.19114	0.18451	0.17679	0.16783	0.15741	0.14684
32	y(Exp)	0.19266	0.18101	0.17165	0.15582	0.13772	0.12163
	y(Cal)	0.18695	0.17528	0.16396	0.15205	0.13953	0.12795
33	y(Exp)	C.19015	0.17989	0.17472	0.15812	0.14563	0.12091
	y(Cal)	0.18751	0.17762	0.16672	0.15468	0.14139	0.12854
34	y(Exp)	0.18825	0.18577	0.17304	0.159551	0.15144	0.12764
	y(Cal)	0.18928	0.18070	0.17073	0.15913	0.14565	0.13198
42	y(Exp)	0.17990	0.16690	0.15534	0.13630	0.11440	0.09521
	y(Cal)	0.18108	0.16573	0.14967	0.13285	0.11525	0.09904
43	y(Exp)	0.18641	0.17871	0.16743	0.15064	0.11984	0.10286
	y(Cal)	0.18450	0.17163	0.15740	0.14166	0.12426	0.10739

TABLE XLIV (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.18499	0.17958	0.16788	0.16216	0.13006	0.12014
	y(Cal)	0.18705	0.17651	0.16464	0.15128	0.13624	0.12143
52	y(Exp)	0.17958	0.16486	0.15567	0.14232	0.10084	0.07487
	y(Cal)	0.17796	0.16036	0.14257	0.12460	0.10643	0.09023
53	y(Exp)	0.17324	0.16582	0.15376	0.14072	0.12631	0.09282
	y(Cal)	0.18193	0.16723	0.15171	0.13531	0.11799	0.10189
54	y(Exp)	0.18439	0.17686	0.15688	0.14642	0.13686	0.10288
	y(Cal)	0.18477	0.17229	0.15861	0.14362	0.12720	0.11143
62	y(Exp)	0.18206	0.16405	0.14551	0.13146	0.09664	0.08802
	y(Cal)	0.17695	0.15888	0.14106	0.12347	0.10612	0.09099
63	y(Exp)	0.18474	0.17000	0.15052	0.13086	0.11380	0.08825
	y(Cal)	0.17973	0.16342	0.14663	0.12935	0.11157	0.09544
64	y(Exp)	0.18256	0.17072	0.15326	0.12951	0.12761	0.09080
	y(Cal)	0.18226	0.16753	0.15164	0.13447	0.11592	0.09833

TABLE XLV

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE III

Packing Size - 3/8 in., Packing Height - 3 ft.

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.20019	0.19332	0.18145	0.16733	0.15360	0.11351
	y(Cal)	0.19364	0.18316	0.17135	0.15801	0.14298	0.12814
23	y(Exp)	0.20680	0.19882	0.18951	0.18293	0.15001	0.14648
	y(Cal)	0.19893	0.19064	0.18114	0.17025	0.15778	0.14539
24	y(Exp)	0.18839	0.18474	0.17839	0.16677	0.15339	0.14980
	y(Cal)	0.19114	0.18450	0.17680	0.16787	0.15750	0.14699
32	y(Exp)	0.19238	0.18218	0.16571	0.14641	0.11952	0.09139
	y(Cal)	0.18981	0.17522	0.15850	0.13933	0.11735	0.09526
33	y(Exp)	0.18914	0.18015	0.16815	0.15178	0.13361	0.10452
	y(Cal)	0.19411	0.18317	0.16970	0.15312	0.13272	0.11085
34	y(Exp)	0.18774	0.18136	0.17682	0.16578	0.14858	0.11455
	y(Cal)	0.19167	0.18425	0.17382	0.15917	0.13857	0.11353
42	y(Exp)	0.19139	0.17327	0.15493	0.13975	0.10160	0.10119
	y(Cal)	0.18935	0.17247	0.15441	0.13508	0.11440	0.09494
43	y(Exp)	0.19400	0.17498	0.16668	0.15898	0.12918	0.12726
	y(Cal)	0.19402	0.18146	0.16790	0.15324	0.13741	0.12239

TABLE XLV (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.21457	0.20220	0.18629	0.17352	0.15747	0.14801
	y(Cal)	0.20493	0.19515	0.18455	0.17307	0.16062	0.14879
52	y(Exp)	0.20045	0.18007	0.17051	0.13680	0.11812	0.07631
	y(Cal)	0.19254	0.17311	0.15337	0.13333	0.11297	0.09473
53	y(Exp)	0.19088	0.17540	0.15908	0.13736	0.12854	0.09768
	y(Cal)	0.18796	0.17273	0.15655	0.13938	0.12113	0.10410
54	y(Exp)	0.20216	0.19236	0.17700	0.15982	0.14176	0.12454
	y(Cal)	0.20172	0.18873	0.17456	0.15908	0.14218	0.12600
62	y(Exp)	0.19887	0.17041	0.14569	0.12866	0.10271	0.07921
	y(Cal)	0.18989	0.16783	0.14605	0.12455	0.10334	0.08482
63	y(Exp)	0.19441	0.18180	0.16281	0.14672	0.11435	0.09045
	y(Cal)	0.19419	0.17588	0.15691	0.13726	0.11691	0.09834
64	y(Exp)	0.19885	0.18541	0.17185	0.15772	0.13914	0.10706
	y(Cal)	0.19854	0.18380	0.16808	0.15132	0.13346	0.11672
11	y(Exp)	0.20551	0.20428	0.19373	0.18780	0.17972	0.16816
	y(Cal)	0.20175	0.19669	0.19125	0.18539	0.17909	0.17316
12	y(Exp)	0.20344	0.20324	0.19787	0.19151	0.17006	0.16919
	y(Cal)	0.20166	0.19822	0.19267	0.18371	0.16926	0.14938

TABLE XLV (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
13	y(Exp)	0.18565	0.18522	0.18192	0.17634	0.16363	0.16323
	y(Cal)	0.20090	0.19707	0.19186	0.18475	0.17506	0.16367
14	y(Exp)	0.19289	0.18441	0.16855	0.15198	0.12607	0.10781
	y(Cal)	0.19260	0.17857	0.16329	0.14665	0.12853	0.11120
31	y(Exp)	0.18807	0.17144	0.15387	0.12404	0.10889	0.07283
	y(Cal)	0.18702	0.16738	0.14677	0.12515	0.10247	0.11120
533	y(Exp)	0.20331	0.18800	0.17460	0.15080	0.13355	0.11754
	y(Cal)	0.19927	0.18449	0.16893	0.15258	0.13537	0.11946
544	y(Exp)	0.20496	0.19446	0.17409	0.15686	0.13797	0.12487
	y(Cal)	0.20154	0.18834	0.17387	0.15800	0.14061	0.12390

TABLE XLVI

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE III

Packing Size - 1/2 in., Packing Height - 3 ft.

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
22	y(Exp)	0.20239	0.19367	0.17802	0.16095	0.13997	0.10709
	y(Cal)	0.20540	0.19355	0.17953	0.16158	0.13860	0.11302
23	y(Exp)	0.20713	0.20333	0.19631	0.18725	0.17351	0.14077
	y(Cal)	0.20576	0.19742	0.18801	0.17740	0.16543	0.15363
24	y(Exp)	0.20968	0.19008	0.18562	0.17492	0.16967	0.13222
	y(Cal)	0.20061	0.18782	0.17416	0.15955	0.14395	0.12932
32	y(Exp)	0.20644	0.19522	0.18440	0.16447	0.15229	0.11410
	y(Cal)	0.20061	0.18782	0.17416	0.15955	0.14395	0.12932
33	y(Exp)	0.20588	0.20027	0.18956	0.18325	0.16500	0.13428
	y(Cal)	0.20391	0.19413	0.18354	0.17208	0.15968	0.14791
34	y(Exp)	0.20705	0.19947	0.19798	0.18741	0.17542	0.14405
	y(Cal)	0.20570	0.19753	0.18857	0.17874	0.16795	0.15758
42	y(Exp)	0.19648	0.18097	0.16623	0.14827	0.12806	0.09285
	y(Cal)	0.19578	0.17869	0.16076	0.14195	0.12220	0.10396
43	y(Exp)	0.20804	0.190511	0.18534	0.16621	0.14922	0.11699
	y(Cal)	0.20085	0.18819	0.17456	0.15989	0.14410	0.12920

TABLE XLVI (CONTINUED)

Run	Height (ft.)	0.5	1.0	1.5	2.0	2.5	3.0
44	y(Exp)	0.20069	0.18919	0.18305	0.15850	0.15481	0.12299
	y(Cal)	0.20288	0.19140	0.17820	0.16302	0.14555	0.12799
52	y(Exp)	0.19849	0.17887	0.15537	0.13919	0.10763	0.07726
	y(Cal)	0.19162	0.17131	0.15064	0.12959	0.10816	0.08890
53	y(Exp)	0.20392	0.19964	0.18193	0.16700	0.14368	0.11699
	y(Cal)	0.19982	0.18663	0.17291	0.15826	0.14375	0.13014
54	y(Exp)	0.20608	0.18981	0.17978	0.16723	0.14933	0.11677
	y(Cal)	0.20098	0.18830	0.17450	0.15950	0.14319	0.12762
62	y(Exp)	0.19931	0.17462	0.14892	0.12941	0.10167	0.07903
	y(Cal)	0.18943	0.16779	0.14639	0.12524	0.10432	0.08604
63	y(Exp)	0.20559	0.19052	0.16981	0.15267	0.12402	0.09866
	y(Cal)	0.19591	0.17928	0.16217	0.14456	0.12643	0.11000
64	y(Exp)	0.20653	0.19297	0.17719	0.15985	0.14336	0.11852
	y(Cal)	0.19968	0.18619	0.17197	0.15698	0.14118	0.12654

TABLE XLVII

EXPERIMENTAL AND CALCULATED GAS PROFILES FOR CASE III

Packing Size - 3/8 in., Packing Height - 5 ft.

Run	Height(ft.)	0.5	1.0	1.5	2.0	2.5	3.0	4.0	4.5	5.0
22	y(Exp)	0.20041	0.19912	0.19417	0.19290	0.18421	0.17862	0.16209	0.14329	0.12261
	y(Cal)	0.19782	0.19240	0.18671	0.18073	0.17446	0.16787	0.15369	0.14607	0.13967
23	y(Exp)	0.20210	0.19769	0.19730	0.19449	0.19142	0.18661	0.17518	0.15831	0.13431
	y(Cal)	0.19927	0.19509	0.16067	0.18601	0.18109	0.17588	0.16458	0.15845	0.15328
24	y(Exp)	0.20052	0.20032	0.19940	0.19816	0.19510	0.19077	0.17987	0.16316	0.14689
	y(Cal)	0.20350	0.20282	0.20172	0.1994	0.19706	0.16241	0.17275	0.15317	0.12917
32	y(Exp)	0.20003	0.19717	0.19655	0.17770	0.17578	0.16305	0.14144	0.12378	0.10247
	y(Cal)	0.19551	0.18811	0.18038	0.17229	0.16383	0.15499	0.13607	0.12598	0.11751
33	y(Exp)	0.19623	0.19179	0.18919	0.18225	0.17973	0.17254	0.15707	0.14001	0.12048
	y(Cal)	0.19747	0.19169	0.18555	0.17903	0.17212	0.16479	0.14874	0.13998	0.13256
34	y(Exp)	0.19803	0.19754	0.19170	0.18803	0.18598	0.18422	0.16226	0.14172	0.12734
	y(Cal)	0.19859	0.19367	0.18831	0.18247	0.17612	0.19621	0.15349	0.14459	0.13687
42	y(Exp)	0.19926	0.19159	0.18556	0.16864	0.16549	0.14946	0.12788	0.10096	0.08443
	y(Cal)	0.19280	0.18321	0.17337	0.16326	0.15286	0.14219	0.11994	0.10838	0.09882
43	y(Exp)	0.19521	0.18802	0.18731	0.17518	0.17490	0.16818	0.14146	0.12499	0.10546
	y(Cal)	0.19566	0.18838	0.18074	0.17274	0.16436	0.15557	0.13672	0.12662	0.11814

TABLE XLVII (CONTINUED)

Run	Height(ft.)	0.5	1.0	1.5	3.0	2.5	3.0	4.0	4.5	5.0
44	y(Exp)	0.20132	0.20097	0.19810	0.19037	0.18143	0.17443	0.15020	0.12695	0.11329
	y(Cal)	0.20050	0.19674	0.19195	0.18584	0.17806	0.16813	0.13933	0.11879	0.09806
52	y(Exp)	0.19288	0.18546	0.17480	0.15366	0.15047	0.13435	0.10357	0.07024	0.06352
	y(Cal)	0.18895	0.17634	0.16359	0.15072	0.13772	0.12459	0.09793	0.08441	0.07338
53	y(Exp)	0.19478	0.18897	0.18365	0.16547	0.15785	0.15378	0.12461	0.09479	0.08484
	y(Cal)	0.19305	0.18351	0.17355	0.16314	0.15226	0.14088	0.11658	0.10361	0.09272
54	y(Exp)	0.20147	0.19849	0.18677	0.17192	0.17088	0.16477	0.13412	0.12900	0.11084
	y(Cal)	0.19584	0.18868	0.18113	0.17319	0.16483	0.15602	0.13699	0.12673	0.11808
62	y(Exp)	0.19263	0.17749	0.16025	0.14521	0.14129	0.12562	0.09426	0.07828	0.06318
	y(Cal)	0.18723	0.17347	0.15986	0.14639	0.13307	0.11989	0.09396	0.08122	0.07100
63	y(Exp)	0.20164	0.19969	0.18440	0.16443	0.16303	0.14996	0.12138	0.09544	0.08061
	y(Cal)	0.19198	0.18180	0.17143	0.16087	0.15012	0.13917	0.11667	0.10512	0.09565
64	y(Exp)	0.19887	0.19408	0.18147	0.17293	0.17189	0.13377	0.13221	0.11433	0.08745
	y(Cal)	0.19396	0.18519	0.17599	0.16635	0.15625	0.14565	0.12290	0.11070	0.10044

APPENDIX H

GAS COMPOSITIONS IN THE RADIAL DIRECTION

Details of the radial gas composition tables:

(i) The radial gas compositions are given as mole fractions of CO_2.

(ii) The seven radial values (across the page) at each sampling cross-section are at an interval of 1/2 inch measured along the diameter from the column wall, the first and the seventh values each being at a distance of 1/2 inch from the wall of the column.

(iii) The axial positions corresponding to each set of seven radial readings are listed vertically in the tables. The locations measured from the base of the packings are as follows.

For 3 ft. packed column:

Sample Position -	P1	P2	P3	P4	P5	P6
Axial Location -	0.5	1.0	1.5	2.0	2.5	3.0

For 5 ft. packed column:

Sample Position -	P1	P2	P3	P4	P5	P6	P7	P8	P9
Axial Location -	0.5	1.0	1.5	2.0	2.5	3.0	4.0	4.5	5.0

Compositions corresponding to positions P7 and P10 are exit gas compositions for 3 ft. and 5 ft. packed columns, respectively.

(iv) Runs are numbered as follows: Five water rates of 1490, 2865, 3580, 4300, 5020 and 5680 lb./hr.sq.ft. and four gas rates of 3.92, 5.0, 6.2 and 7.4 lb./hr.sq.ft. were used. The first digit of the run number indicates the number corresponding to the water flow rate and the second digit corresponds to the gas rate. For the duplicate runs a third digit (corresponding to the appropriate gas rate) has been added.

TABLE XLVIII

RADIAL GAS COMPOSITION, MOL. FRACTION CO_2
Packing Size - 1/4 in., Packing Height - 3 ft.

Run 22	L = 2865.0		G = 5.0047		P_T = 733.6		y_{in} = 0.1975
P1	--	0.19117	--	--	0.19551	--	0.18612
P2	0.18806	0.18996	0.18996	0.18996	--	0.18591	0.18314
P3	0.18548	0.17559	0.17392	0.16824	0.17131	0.17093	0.16602
P4	0.16630	--	0.16787	0.15849	0.15824	--	0.16176
P5	0.16092	--	--	--	0.14078	0.15084	0.14377
P6	0.15233	--	--	--	--	--	0.11258
P7	0.12983						

Run 23	L = 2865.0		G = 6.1977		P_T = 733.6		y_{in} = 0.1975
P1	--	0.17937	0.17783	--	--	0.18758	0.18701
P2	--	0.18355	--	--	--	0.18188	0.18015
P3	0.17883	0.17365	0.17410	--	--	--	0.16790
P4	0.16383	--	--	--	0.15648	--	0.16265
P5	0.16619	0.16052	--	--	--	0.15402	--
P6	0.15044	--	--	--	0.12889	0.12555	0.12813
P7	0.13538						

Run 24	L = 2865.0		G = 7.3805		P_T = 734.6		y_{in} = 0.1975
P1	--	0.18701	0.19042	0.18640	--	--	--
P2	0.17458	--	0.17536	--	--	0.17422	0.17122
P3	0.17687	0.17378	0.17093	--	--	--	0.16790
P4	0.17064	--	--	0.16480	0.16421	--	0.16383
P5	0.17151	--	--	--	--	0.15828	--
P6	0.15839	--	0.14147	--	--	--	0.13286
P7	0.14044						

TABLE XLVIII (CONTINUED)

Run 32	L = 3580.0		G = 5.0047		P_T = 733.3		y_{in} = 0.1975
P1	--	0.19210	--	0.19322	--	--	--
P2	0.18257	0.18716	0.17705	--	--	0.18358	0.17467
P3	0.17852	0.17935	0.17395	--	--	--	0.15479
P4	0.16319	--	0.15976	0.15038	0.14408	0.14590	0.15160
P5	0.15160	--	--	--	--	0.12384	--
P6	0.13309	0.12521	--	--	--	0.10659	--
P7	0.11294						

Run 33	L = 3580.0		G = 6.1977		P_T = 733.3		y_{in} = 0.1975
P1	--	0.18747	0.18696	0.19602	--	--	--
P2	0.17538	0.18631	0.17989	--	--	0.17910	0.17878
P3	0.17865	--	0.17747	--	--	--	0.16805
P4	--	--	0.16684	--	0.15336	--	0.15417
P5	0.15179	--	--	--	--	0.13947	--
P6	0.13969	--	0.12158	0.12054	--	0.11497	0.10779
P7	0.12609						

Run 34	L = 3580.0		G = 7.3805		P_T = 728.3		y_{in} = 0.1975
P1	--	0.19100	0.18543	0.18646	0.18599	--	0.18599
P2	0.18913	--	0.18944	0.18777	0.18100	0.18543	0.18184
P3	--	--	--	--	--	--	0.17304
P4	0.17923	--	0.12909	--	--	0.16195	0.16793
P5	--	--	--	--	--	0.15144	--
P6	--	0.13999	0.11928	--	--	--	0.12364
P7	0.12959						

TABLE XLVIII (CONTINUED)

Run 42	L = 4300.0		G = 5.0047		P_T = 728.3		y_{in} = 0.1975
P1	0.17486	0.17526	0.18347	0.18633	0.17957	--	--
P2	0.16955	0.16914	0.16619	--	0.16562	0.16677	0.16411
P3	--	--	--	--	--	--	0.15534
P4	0.14210	--	--	--	0.13628	--	0.13051
P5	--	--	--	--	--	0.11440	--
P6	0.10922	--	--	0.10894	--	0.08095	0.08700
P7	0.09622						

Run 43	L = 4300.0		G = 6.1977		P_T = 726.8		y_{in} = 0.1975
P1	--	0.19051	--	0.18231	--	--	--
P2	0.18104	0.18367	--	--	0.17636	0.17443	0.17806
P3	--	0.16618	--	--	--	--	0.16868
P4	0.15784	--	0.15105	0.14995	0.14573	--	0.14864
P5	--	--	--	--	--	0.11984	--
P6	0.12438	--	--	0.09545	--	0.09417	0.09743
P7	0.10629						

Run 44	L = 4300.0		G = 7.3805		P_T = 735.5		y_{in} = 0.1975
P1	0.18499	--	--	--	--	--	--
P2	0.17860	0.17605	0.17714	0.18529	--	--	0.18081
P3	--	--	0.16389	--	--	--	0.17187
P4	0.16422	--	--	0.15896	--	--	0.16331
P5	--	0.12899	0.12590	0.13256	0.13279	--	--
P6	0.13582	0.12289	--	--	--	0.11061	0.11123
P7	0.12207						

TABLE XLVIII (CONTINUED)

Run 52	L = 5020.0	G = 5.0047		P_T = 736.5		y_{in} = 0.1975	
P1	--	0.18392	0.16961	0.18520	--	--	--
P2	--	0.15552	0.16529	0.16998	--	0.17018	0.16335
P3	0.15697	--	0.15436	--	--	--	--
P4	0.14567	--	--	0.13694	--	--	0.14434
P5	--	--	--	--	--	0.10084	--
P6	0.08911	--	0.07354	0.07063	0.06621	--	--
P7	0.07760						

Run 53	L = 5020.0	G = 6.1977		P_T = 738.4		y_{in} = 0.1975	
P1	--	0.17267	0.17381	--	--	--	--
P2	--	0.16193	0.16825	--	0.17137	0.17075	0.15681
P3	0.15441	--	0.15647	--	--	0.15040	--
P4	0.14024	--	0.13805	0.14386	--	--	--
P5	0.12631	--	--	--	--	--	--
P6	--	--	0.09282	--	--	--	--
P7	0.09002						

Run 54	L = 5020.0	G = 7.3805		P_T = 738.4		y_{in} = 0.1975	
P1	--	0.18299	--	0.17863	0.19154	--	--
P2	--	0.17817	0.17381	--	0.17817	0.17756	0.17661
P3	0.16623	--	0.15320	--	--	--	0.15122
P4	0.15400	--	0.14666	0.15023	--	--	0.13477
P5	0.13686	--	--	--	--	--	--
P6	0.09714	--	0.10791	--	--	--	--
P7	0.10577						

TABLE XLVIII (CONTINUED)

Run 62	L = 5680.0		G = 5.0047		P_T = 737.3		y_{in} = 0.1975
P1	--	0.18359	0.17834	0.18425	--	--	--
P2	0.16053	0.16519	0.16909	--	--	0.16554	0.15989
P3	0.14942	--	0.14695	--	--	0.14017	--
P4	0.12749	--	--	0.14215	0.12474	--	--
P5	--	--	--	0.09664	--	--	--
P6	0.08802	--	--	--	--	--	--
P7	0.08365						
Run 63	L = 5680.0		G = 6.1977		P_T = 738.4		y_{in} = 0.1975
P1	--	0.18471	0.18486	0.18464	--	--	--
P2	--	0.16661	0.17285	--	--	0.17159	0.16894
P3	0.15523	--	0.15548	--	--	0.14085	--
P4	0.13462	--	--	0.12872	0.12925	--	--
P5	0.11380	--	--	--	--	--	--
P6	0.08221	--	--	--	--	0.04948	--
P7	0.07972						
Run 64	L = 5680.0		G = 7.3805		P_T = 738.4		y_{in} = 0.1975
P1	--	0.18196	0.18403	0.18170	--	--	--
P2	--	0.16771	0.17037	--	--	0.17301	0.17179
P3	0.15806	--	--	--	--	0.14846	--
P4	0.09316	0.15577	--	--	0.13960	--	--
P5	0.12761	--	--	--	--	--	--
P6	0.09824	--	--	0.8336	--	--	--
P7	0.09458						

TABLE XLIX

RADIAL GAS COMPOSITION, MOL. FRACTION CO_2
Packing Size - 3/8 in., Packing Height - 3 ft.

Run 22	L = 2865.0		G = 5.0214		P_T = 728.0		y_{in} = 0.204
P1	--	--	0.20011	0.20008	0.20038	--	--
P2	0.19294	0.19413	0.19530	--	--	--	0.19092
P3	0.18506	--	0.18322	--	--	0.17915	0.17838
P4	0.16841	--	--	--	0.16801	--	0.16557
P5	0.15551	0.15769	--	0.15488	--	--	0.14630
P6	--	--	--	--	0.11793	--	0.10909
P7	0.12299						
Run 23	L = 2865.0		G = 6.228		P_T = 729.5		y_{in} = 0.207
P1	--	0.20687	--	--	--	0.20673	--
P2	0.20049	0.19492	0.19626	0.20240	--	--	0.20005
P3	0.18762	0.19169	--	--	0.18862	0.19159	0.18803
P4	0.18648	--	--	0.16385	0.15649	0.15215	0.15568
P5	--	--	0.15326	--	--	--	0.14675
P6	--	--	0.15326	--	--	--	0.14675
P7	0.13002						
Run 24	L = 2865.0		G = 7.3805		P_T = 735.4		y_{in} = 0.1975
P1	0.18247	0.18901	0.19310	--	0.19437	0.18706	0.18433
P2	0.18466	0.18466	0.18846	--	0.18911	0.17680	--
P3	0.17326	--	0.17646	0.18404	0.18047	0.17771	--
P4	0.16728	0.17133	0.17177	--	0.15851	0.16497	--
P5	0.16600	--	0.13736	0.15953	0.15522	0.14745	--
P6	0.16535	--	--	--	0.13425	--	--
P7	0.14588						

TABLE XLIX (CONTINUED)

Run 32	L = 3580.0		G = 5.0214		P_T = 730.7		y_{in} = 0.204
P1	--	--	0.19220	0.19302	0.19192	--	--
P2	0.17867	0.18661	0.18551	--	--	0.18137	0.17876
P3	--	0.16822	0.16634	--	--	0.16258	--
P4	--	0.14823	--	--	--	0.14459	--
P5	--	0.12855	--	0.11998	0.11458	0.11815	0.11632
P6	0.10662	--	--	--	0.09056	0.08510	0.08337
P7	0.09747						

Run 33	L = 3580.0		G = 6.2184		P_T = 730.0		y_{in} = 0.204
P1	--	--	0.18903	0.18933	0.18906	--	--
P2	0.17939	0.18370	0.18260	--	0.17725	0.17779	--
P3	--	0.17085	0.17069	--	0.17031	0.16827	0.16063
P4	0.15770	--	--	0.15044	0.14974	0.14923	--
P5	--	0.14090	--	0.13099	0.13318	--	0.12937
P6	0.12553	--	--	0.9831	0.09762	0.09660	--
P7	0.10911						

Run 34	L = 3580.0		G = 7.3805		P_T = 735.4		y_{in} = 0.1975
P1	--	--	0.18341	0.19048	0.19113	--	0.18594
P2	0.17821	--	--	--	0.18361	0.18227	--
P3	0.17958	--	0.17376	0.17754	0.17640	--	--
P4	0.16728	--	0.16428	--	--	--	--
P5	0.15920	--	0.14530	--	--	0.14123	--
P6	--	--	--	0.11455	--	--	--
P7	0.13460						

TABLE XLIX (CONTINUED)

Run 42	L = 4300.0		G = 5.1900		P_T = 730.6		y_{in} = 0.207
P1	--	--	--	--	--	0.19139	--
P2	0.17707	0.17440	0.16823	0.17339	--	--	--
P3	0.16056	0.16140	--	--	0.15660	0.15025	0.14584
P4	0.14504	--	--	0.13446	--	--	--
P5	--	--	--	--	--	0.10361	0.09958
P6	0.10777	0.11001	0.10595	0.09620	--	0.08604	--
P7	0.08076						

Run 43	L = 4300.0		G = 6.2280		P_T = 731.5		y_{in} = 0.207
P1	--	--	--	0.19470	--	0.19329	--
P2	0.17698	0.17972	0.17028	0.17430	0.17130	0.17730	--
P3	0.16569	0.16767	--	--	--	--	--
P4	0.15898	--	--	--	--	--	--
P5	--	--	0.12679	0.13157	--	--	--
P6	0.12912	0.12540	--	--	--	--	--
P7	0.12597						

Run 44	L = 4300.0		G = 7.5400		P_T = 731.6		y_{in} = 0.215
P1	--	--	--	--	--	0.21457	--
P2	0.20451	0.20109	0.20665	--	0.20188	--	0.19688
P3	0.18640	0.19202	--	--	0.18632	0.18047	--
P4	0.18542	--	--	--	--	0.16897	0.16616
P5	--	--	--	0.15747	--	--	--
P6	0.15633	0.15359	0.16071	0.14357	--	0.12583	--
P7	0.12798						

TABLE XLIX (CONTINUED)

Run 52	L = 5020.0		G = 5.0471		P_T = 729.5		y_{in} = 0.214
P1	--	--	0.20490	--	0.19599	--	--
P2	0.18521	0.18184	0.18489	--	0.16834	--	--
P3	0.16973	--	--	--	0.17128	--	--
P4	0.14792	--	--	--	0.13229	0.13020	--
P5	0.12207	0.12198	0.12076	0.11300	0.11278	--	--
P6	--	--	0.08033	--	--	0.07088	0.07773
P7	0.08353						
Run 53	L = 5020.0		G = 6.2184		P_T = 731.0		y_{in} = 0.204
P1	--	--	0.19348	0.19128	0.19293	0.18906	0.18764
P2	0.17622	0.17723	0.17639	--	0.17152	0.17548	0.17554
P3	0.16528	0.16853	0.15920	--	--	0.15063	0.15177
P4	0.14398	0.14258	--	--	--	0.13692	0.12555
P5	0.12682	0.13411	0.13023	0.12654	--	0.13351	0.12004
P6	0.11808	--	--	0.09484	0.09156	0.08624	--
P7	0.09663						
Run 54	L = 5020.0		G = 7.4468		P_T = 729.0		y_{in} = 0.215
P1	0.20157	--	0.20091	--	0.20362	0.20252	--
P2	0.19507	--	--	0.19507	0.19214	--	0.18715
P3	0.18185	0.17879	0.17991	--	0.17400	0.17047	--
P4	0.16808	--	--	0.16574	0.15957	0.15073	0.15498
P5	0.14324	--	--	0.14028	--	--	--
P6	0.13467	0.13153	0.13301	0.12417	--	0.09933	--
P7	0.10855						

TABLE XLIX (CONTINUED)

Run 62	L = 5680.0		G = 5.0496	P_T = 729.3		y_{in} = 0.215
P1	0.20133	--	--	--	--	0.19641	--
P2	0.17359	--	0.17183	0.17199	0.16968	--	0.16498
P3	0.15045	0.15260	--	--	0.14203	0.13766	--
P4	--	--	0.12866	--	--	--	--
P5	0.10271	--	--	--	--	--	--
P6	0.08795	0.08540	0.08772	0.07492	--	0.06008	--
P7	0.07266						

Run 63	L = 5680.0		G = 6.2499	P_T = 735.7		y_{in} = 0.214
P1	--	--	0.19539	--	0.19343	--	--
P2	0.18629	--	--	--	0.18184	0.17515	0.18390
P3	--	--	0.16653	0.16442	0.16163	0.15865	--
P4	0.15124	0.15062	--	0.13828	--	--	--
P5	--	--	--	0.11899	0.11319	--	0.11088
P6	0.10430	0.09804	--	--	--	0.08293	0.07653
P7	0.09224						

Run 64	L = 5680.0		G = 7.4426	P_T = 735.6		y_{in} = 0.214
P1	--	--	0.20031	0.19739	--	--	--
P2	0.18874	0.19070	--	0.18133	--	0.18144	0.18483
P3	--	--	0.17320	--	0.17039	0.17196	--
P4	0.16426	--	--	--	--	0.16146	0.14744
P5	--	0.14774	--	0.13934	0.13897	--	0.13049
P6	0.12385	0.11974	--	--	--	0.10616	0.07850
P7	0.10188						

TABLE XLIX (CONTINUED)

Run 11	L = 1490.0		G = 3.9392		P_T = 729.4		y_{in} = 0.207
P1	--	--	0.20443	0.20675	--	0.20536	--
P2	0.20738	0.21077	0.20340	0.20653	0.20357	0.20363	--
P3	0.19925	0.19668	--	--	0.19333	--	0.18564
P4	0.19077	--	--	0.18890	--	0.19093	0.18058
P5	--	--	0.18140	0.18179	--	--	0.17596
P6	0.17475	0.7734	0.17507	0.16759	--	0.14607	--
P7	0.14848						
Run 12	L = 1490.0		G = 5.0214		P_T = 731.0		y_{in} = 0.204
P1	0.20325	--	--	--	--	0.20324	0.20383
P2	0.20520	--	0.20223	0.20304	0.20248	--	--
P3	0.19987	0.20146	--	0.19906	0.19510	0.19746	0.17429
P4	0.19418	--	0.19660	0.19186	0.19234	0.18860	0.18546
P5	--	--	--	--	--	0.17057	0.16955
P6	0.17950	0.17864	0.17917	--	--	0.16096	0.14767
P7	0.16244						
Run 13	L = 1490.0		G = 6.2184		P_T = 732.4		y_{in} = 0.204
P1	0.18394	--	--	0.18834	--	0.18468	--
P2	0.18693	--	0.18669	0.18420	0.18601	--	0.18228
P3	0.18107	0.18304	0.18182	--	0.18308	0.18058	--
P4	0.17839	--	0.17912	0.17937	--	0.17142	0.17338
P5	--	--	--	--	0.16734	--	0.15991
P6	0.16588	0.16214	0.16334	0.16156	--	--	--
P7	0.15163						

TABLE XLIX (CONTINUED)

Run 21	L = 2865.0	G = 3.9392	P_T = 728.6	y_{in} = 0.207			
P1	0.19629	--	--	0.19268	--	0.18971	--
P2	0.18419	0.18540	0.18545	--	--	--	0.18261
P3	0.17300	0.17050	--	--	0.16865	0.16721	0.16338
P4	0.15411	--	--	--	--	0.14984	--
P5	--	0.13428	0.13143	--	0.12775	0.12219	0.11470
P6	0.11682	0.11938	0.12250	0.11344	--	0.108821	0.08648
P7	0.09869						

Run 32	L = 3580.0	G = 3.9412	P_T = 736.4	y_{in} = 0.208			
P1	--	--	0.19099	0.18903	--	0.18680	0.18544
P2	0.17214	0.16818	--	--	0.17274	0.17033	0.17381
P3	0.15165	0.15793	--	--	--	0.15204	--
P4	0.12878	--	--	0.12778	0.12218	0.11658	0.12489
P5	--	0.10077	--	--	--	--	0.11701
P6	0.07667	0.07502	0.06679	--	--	--	--
P7	0.07666						

Run 533	L = 5020.0	G = 6.2534	P_T = 728.9	y_{in} = 0.215			
P1	0.20790	--	--	0.20282	--	0.20942	0.19308
P2	0.18934	--	--	0.18708	0.18818	--	0.18741
P3	0.17952	0.17943	--	--	0.17827	0.16838	--
P4	0.15772	--	0.15501	0.15478	0.14786	0.14739	0.13328
P5	--	0.13328	--	0.13381	--	--	--
P6	0.12442	0.12014	0.11961	0.11526	0.10828	--	--
P7	0.10067						

TABLE XLIX (CONTINUED)

Run 544	L = 5020.0		G = 7.4468		P_T = 731.0		y_{in} = 0.215
P1	--	--	--	0.20588	0.20632	0.20268	--
P2	0.19465	--	--	--	0.19525	--	0.19347
P3	0.17000	--	0.18038	0.17878	0.18042	0.16820	0.16385
P4	--	--	0.16026	0.16008	0.15313	0.15397	--
P5	--	0.13797	--	--	--	--	--
P6	0.12617	0.12514	0.12454	0.11533	--	0.13319	--
P7	0.10661						

TABLE L

RADIAL GAS COMPOSITION, MOL. FRACTION CO_2
Packing Size - 1/2 in., Packing Height - 3 ft.

Run 22	L = 2865.0		G = 5.047		P_T = 733.3		y_{in} = 0.214
P1	--	0.20698	0.20579	0.20058	--	0.19874	0.20037
P2	0.19586	--	0.19541	--	--	0.19134	0.19205
P3	0.18197	0.18417	0.17633	0.17661	0.17661	--	0.17273
P4	0.16574	0.16427	0.16187	--	0.15836	0.15450	--
P5	0.15156	0.14638	0.13453	0.12741	--	--	--
P6	0.11642	0.11314	0.10596	0.10490	--	0.10163	0.10127
P7	0.10545						

Run 23	L = 2865.0		G = 6.2499		P_T = 733.3		y_{in} = 0.214
P1	0.20924	0.20953	0.20829	0.20737	--	0.20079	0.20755
P2	0.20302	--	0.20643	--	0.20157	-.20305	0.20258
P3	0.19558	0.10783	--	0.19733	0.19757	--	0.19324
P4	0.18848	0.18869	0.18680	0.18480	--	--	--
P5	0.18130	0.17780	0.17025	0.16467	--	--	--
P6	0.17253	0.14367	0.14189	--	--	0.13088	0.13491
P7	0.14644						

Run 24	L = 2865.0		G = 7.4426		P_T = 730.4		y_{in} = 0.214
P1	0.20720	0.21069	0.21026	0.21081	0.20946	--	--
P2	--	--	0.18963	--	--	0.19044	0.19019
P3	0.18052	0.18996	0.18742	0.18894	0.18046	--	0.18643
P4	0.17963	0.17694	0.17433	--	0.17188	--	0.17182
P5	0.17842	0.17100	0.16842	0.16083	--	--	--
P6	0.15356	0.14637	0.13787	0.12340	0.11900	0.11916	0.12615
P7	0.13258						

TABLE L (CONTINUED)

Run 32	L = 3580.0	G = 5.0471	P_T = 729.6		y_{in} = 0.214		
P1	--	0.20493	0.20918	0.20591	0.20708	--	0.20244
P2	0.19248	--	0.19450	0.19620	--	0.20014	0.19280
P3	0.18468	0.18823	--	0.18409	0.18708	--	0.17790
P4	0.17053	0.16915	0.16483	--	0.16436	--	0.15346
P5	0.16215	0.15422	0.14052	--	--	--	--
P6	0.12869	0.11365	0.11268	--	--	0.10886	0.10663
P7	0.11197						

Run 33	L - 3580.0	G = 6.2499	P_T = 733.9		y_{in} = 0.214		
P1	--	0.20692	0.20699	--	0.20402	--	--
P2	0.20004	--	--	0.19360	--	0.20292	0.20453
P3	0.18968	0.18982	--	0.18806	0.18885	--	0.19141
P4	0.18631	0.18645	0.18342	--	--	0.18154	0.17853
P5	0.18297	0.17231	0.16623	0.15469	0.14882	--	--
P6	0.15166	0.13791	0.12954	--	--	--	0.11799
P7	0.13379						

Run 34	L - 3580.0	G = 7.4426	P = 735.7		y = 0.214		
P1	0.20733	--	--	--	0.20973	--	0.20409
P2	0.20003	--	--	0.20328	0.19268	0.20099	0.20037
P3	--	--	--	0.19849	0.19881	--	0.19666
P4	0.19141	0.18822	--	--	0.18259	--	--
P5	0.18644	0.17827	0.16849	0.16847	--	--	--
P6	0.15025	0.15169	0.14616	--	--	--	--
P7	0.14115						

TABLE L (CONTINUED)

Run 42 L = 4300.0 G = 5.0471 P_T = 736.5 y_{in} = 0.214

P1	0.18783	0.19787	0.20355	0.19768	0.19549	--	--
P2	0.17940	--	--	0.18228	--	--	0.18125
P3	--	--	--	0.17192	0.16904	--	0.15772
P4	0.15276	--	--	--	--	0.14379	--
P5	0.14136	0.13602	0.12239	0.11326	--	--	--
P6	0.09789	0.09798	0.09835	--	--	0.08382	0.08620
P7	0.08528						

Run 43 L = 4300.0 G = 6.2499 P_T = 731.5 y_{in} = 0.214

P1	--	--	0.20630	0.20978	--	--	--
P2	0.18749	--	--	--	--	0.20136	0.18266
P3	--	--	--	0.18760	0.18308	--	--
P4	0.16953	0.16539	--	--	0.17151	--	0.15839
P5	0.16248	0.15359	0.14527	--	0.13554	--	--
P6	0.12629	0.11894	0.11537	--	--	--	0.10738
P7	0.11573						

Run 44 L = 4300.0 G = 6.2499 P_T = 728.2 y_{in} = 0.214

P1	0.19943	0.19809	0.20341	0.20517	0.19733	--	--
P2	0.19040	--	--	--	--	--	0.18797
P3	--	--	--	0.18048	0.18602	--	0.18266
P4	--	--	--	--	--	0.15072	0.16628
P5	0.17103	0.15902	0.15102	0.13817	--	--	--
P6	0.13012	0.12578	0.12209	--	--	--	0.11395
P7	0.12501						

TABLE L (CONTINUED

Run 52	L = 5020.0		G = 5.0471		P_T = 728.2		y_{in} = 0.214
P1	--	0.19527	0.20144	0.19876	--	--	--
P2	0.18367	0.17696	--	--	--	--	0.17597
P3	0.15206	--	--	0.15178	0.16028	--	0.15734
P4	0.15335	--	--	--	0.13502	--	--
P5	0.12564	0.11978	0.09385	0.09126	--	--	--
P6	0.08962	0.08519	0.07993	--	--	0.06210	0.07073
P7	0.07598						

Run 53	L = 5020.0		G = 6.2499		P_T = 726.3		y_{in} = 0.214
P1	--	--	0.20392	--	--	--	--
P2	0.19520	--	--	--	--	0.20261	0.20111
P3	0.18280	--	--	--	0.18105	--	--
P4	0.17199	0.17098	--	--	0.15804	--	--
P5	0.15579	0.15343	0.13675	0.12875	--	--	--
P6	0.12213	0.11346	0.11540	--	--	--	--
P7	0.11025						

Run 54	L = 5020.0		G = 7.4430		P_T = 726.3		y_{in} = 0.214
P1	--	0.20500	--	--	--	--	0.20245
P2	0.20076	--	--	--	--	0.19706	0.17160
P3	0.18056	--	--	0.18115	0.17764	--	--
P4	0.16925	0.16520	--	--	--	--	--
P5	0.16166	0.15642	0.14416	--	--	--	0.13506
P6	--	0.13152	0.11827	--	0.11546	0.10184	--
P7	0.11989						

TABLE L (CONTINUED)

Run 62	L = 5680.0	G = 5.0740	P_T = 728.2		y_{in} = 0.214		
P1	--	0.20026	0.20350	--	0.19409	--	--
P2	0.17903	--	--	--	--	0.17020	--
P3	0.15410	--	--	0.14824	0.14443	--	--
P4	0.13695	0.13275	--	--	0.11854	--	--
P5	0.12164	0.10918	0.08934	0.08652	--	--	--
P6	0.08456	--	0.07350	--	--	--	--
P7	0.07393						

Run 63	L = 5680.0	G = 6.2499	P_T = 731.5		y_{in} = 0.214		
P1	--	0.21093	0.20849	--	0.19734	--	--
P2	0.19117	--	--	--	--	0.18987	--
P3	0.17078	0.17289	--	0.16754	0.16802	--	--
P4	0.15621	0.15814	--	--	0.14365	--	--
P5	0.14292	0.13910	0.11531	--	0.11307	--	0.10972
P6	0.10291	--	0.09441	--	--	--	--
P7	0.09275						

Run 64	L = 5680.0	G = 7.4430	P_T = 731.2		y_{in} = 0.214		
P1	--	0.20653	--	--	--	--	--
P2	0.18791	--	--	--	--	0.19707	0.19394
P3	0.18647	--	--	0.17839	0.17322	0.17069	--
P4	0.16822	0.16087	--	--	--	0.15046	--
P5	0.15750	0.15608	0.13699	0.13329	--	--	0.13293
P6	0.12783	0.11708	0.11065	--	--	--	--
P7	0.10602						

TABLE LI

RADIAL GAS COMPOSITION, MOL. FRACTION CO_2
Packing Size - 3/8 in., Packing Height - 5 ft.

Run 22	L = 2865.0		G = 5.0214	P_T = 740.2		y_{in} = 0.204
P1	0.19870	0.20093	0.20159	--	--	--	--
P2	0.19766	--	0.20058	--	--	--	--
P3	0.19533	0.19242	--	--	0.19477	--	--
P4	--	0.19359	0.19242	--	0.19420	--	0.19137
P5	0.18065	0.18074	--	0.18401	0.18623	0.18849	0.18513
P6	--	--	--	0.17952	0.17789	0.17845	--
P7	0.16883	--	--	0.16341	0.16677	0.16300	0.14842
P8	0.14189	0.14170	0.14222	0.14309	0.14755	--	--
P9	0.11990	0.11816	0.11229	0.11664	0.12269	0.13360	0.13502
P10	0.12088						

Run 23	L = 2865.0		G = 6.2184	P_T = 740.2		y_{in} = 0.204
P1	--	0.19410	--	--	0.20259	--	--
P2	0.19870	--	0.19694	--	0.19742	--	--
P3	--	0.19410	--	--	0.20259	--	--
P4	--	0.19364	0.19590	--	0.19421	--	0.19421
P5	0.18964	0.18905	0.18904	0.19186	0.19077	0.19364	0.19597
P6	--	--	--	0.18736	0.18568	0.18679	--
P7	0.17223	--	--	--	0.17489	0.17936	0.17423
P8	0.15772	0.15676	0.15441	--	0.15815	--	0.16450
P9	0.13420	0.13239	--	0.13320	0.12901	0.13118	0.14586
P10	0.14586						

TABLE LI (CONTINUED)

Run 24	L = 2865.0		G = 7.4051		P_T = 740.2		y_{in} = 0.204
P1	--	--	0.19789	0.19852	0.20283	--	0.20283
P2	0.20370	--	--	--	0.19694	--	--
P3	--	0.19917	0.20148	0,19962	0.19734	--	--
P4	--	0.20037	0.19710	--	--	--	0.19702
P5	0.19172	0.19359	0.19471	0.20047	0.19702	0.19639	0.19179
P6	--	--	--	0.18791	0.19426	0.19013	--
P7	0.17423	--	--	--	0.18009	0.18117	0.18397
P8	0.15951	0.16028	0.16475	0.16318	0.16808	--	--
P9	0.14405	0.14369	0.13747	0.14488	0.14755	0.15489	0.15570
P10	0.14549						

Run 32	L = 3580.0		G = 5.0214		P_T = 731.6		y_{in} = 0.204
P1	0.19779	0.20195	0.20014	--	0.20069	--	0.19957
P2	--	--	--	--	0.17861	--	--
P3	--	--	--	--	0.19655	--	--
P4	--	0.17861	--	--	0.17457	--	0.17991
P5	0.17502	0.15993	--	0.16843	0.18162	0.18313	0.18653
P6	--	--	0.15833	--	0.16777	--	--
P7	0.13377	0.12506	0.14061	0.14588	0.14525	0.14955	0.14996
P8	0.11854	0.11712	0.11545	0.11858	0.12804	0.13269	0.13601
P9	0.09604	0.10055	--	--	0.09320	0.10540	0.11717
P10	0.09954						

TABLE LI (CONTINUED)

Run 33 L = 3580.0 G = 6.2184 P_T = 736.6 y_{in} = 0.204

P1	0.19362	0.19128	0.19952	0.19836	--	--	0.19836
P2	0.19298	0.19294	--	--	0.18946	--	--
P3	--	--	--	0.18946	0.18892	--	--
P4	0.18693	0.18051	0.17930	--	--	--	--
P5	0.17654	0.17473	--	--	0.18253	0.18233	0.18253
P6	--	--	--	0.17005	--	0.17502	--
P7	0.14884	0.14759	--	0.15675	0.15582	0.16797	0.16547
P8	0.12979	0.13574	0.13093	0.13702	0.13677	0.15650	0.15333
P9	0.11663	0.11513	--	0.11387	0.11967	0.12343	0.13414
P10	0.11945						

Run 34 L = 3580.0 G = 7.4051 P_T = 741.5 y_{in} = 0.204

P1	0.19779	0.19907	0.19716	0.19540	0.20075	--	--
P2	--	--	--	--	0.19754	--	--
P3	--	--	--	--	0.19170	--	--
P4	--	0.18751	0.18854	--	--	--	--
P5	0.18421	--	--	0.17938	0.18526	0.19011	0.19093
P6	--	--	--	0.18316	0.18476	0.18473	--
P7	0.15743	--	--	0.16263	0.16498	0.16662	0.15965
P8	0.14199	0.13945	0.13808	0.13864	0.15044	--	--
P9	--	0.12323	0.12027	0.11649	0.12693	0.13779	0.13930
P10	0.13282						

TABLE LI (CONTINUED)

Run 42	L = 4300.0	G = 5.0214		P_T = 741.6		y_{in} = 0.204
P1	0.19998	0.20144	0.19840	0.19832	0.19832	0.19910	--
P2	--	0.18664	0.19450	--	0.19363	--	--
P3	--	--	--	--	0.18556	--	--
P4	--	0.16467	--	0.17261	--	--	--
P5	0.15999	0.15757	--	--	0.16654	0.17107	0.17230
P6	--	--	--	0.14857	0.15035	--	--
P7	0.12496	--	--	0.12305	0.12879	0.12879	0.12879
P8	0.10058	0.09879	0.09546	0.10009	0.10989	--	--
P9	0.09226	0.07863	--	0.7583	0.07643	0.08678	0.09663
P10	0.08563						

Run 43	L = 4300.0	G = 6.2184		P_T = 741.5		y_{in} = 0.204
P1	--	--	0.19256	0.19541	0.19766	--	--
P2	--	0.18802	--	0.18150	--	--	--
P3	--	--	--	--	0.18731	--	--
P4	--	0.15877	0.18140	--	0.18537	--	--
P5	0.17072	0.16711	--	--	0.17664	0.17664	0.18341
P6	--	--	--	0.16596	0.17040	--	--
P7	0.13161	0.12771	--	0.14434	0.14235	0.14846	0.15426
P8	0.13157	0.11617	0.11419	0.11797	0.12904	--	0.14099
P9	0.109761	0.09241	--	0.10442	0.10492	0.11537	0.11803
P10	0.10730						

TABLE LI (CONTINUED)

Run 44	L = 4300.0		G = 7.4051		P_T = 725.1		y_{in} = 0.204
P1	0.19835	0.19898	0.19949	0.20186	0.19658	--	--
P2	--	--	--	--	0.19772	--	--
P3	--	--	--	--	0.19125	--	--
P4	0.17808	0.17895	0.18003	--	--	--	--
P5	0.13457	0.12733	--	0.13317	0.13457	0.13853	0.13631
P6	--	--	--	0.10398	0.10931	--	--
P7	0.06718	0.08086	--	0.0972	0.09367	0.09688	0.09603
P8	0.06575	--	0.06172	0.06258	0.06963	0.07456	0.07688
P9	0.04344	0.03417	--	0.04564	0.04733	0.05111	0.05192
P10	0.04418						

Run 52	L = 5020.0		G = 5.0214		P_T = 737.5		y_{in} = 0.204
P1	--	0.18353	0.19060	0.19664	0.19656	--	0.19709
P2	--	0.18123	--	--	0.18969	--	--
P3	--	--	--	--	0.17480	--	--
P4	--	0.14544	0.15366	--	--	--	--
P5	--	0.13763	0.14712	--	0.15888	--	0.15826
P6	--	--	--	0.13274	0.13596	--	--
P7	0.09318	0.09201	--	0.10491	0.10580	0.11143	0.11407
P8	0.07760	0.07384	0.07224	0.08159	0.09103	--	0.09627
P9	0.05845	0.05565	--	0.05662	0.06247	0.07330	0.07463
P10	0.06338						

TABLE LI (CONTINUED)

Run 53 L = 5020.0 G = 6.2184 P_T = 741.5 y_{in} = 0.204

P1	--	0.19535	0.19590	--	0.19690	--	0.19098
P2	--	--	--	--	0.18897	--	--
P3	--	--	--	--	0.18365	--	--
P4	--	0.16568	0.16526	--	--	--	--
P5	0.15198	--	0.14453	--	0.16722	0.16766	--
P6	--	--	--	--	0.15378	--	--
P7	--	--	0.11539	0.12734	--	0.12700	0.12869
P8	0.09229	0.09728	--	--	--	--	--
P9	--	0.09210	0.07577	0.07869	0.08510	0.09013	0.09723
P10	0.08528						

Run 54 L = 5020.0 G = 7.4051 P_T = 737.5 y_{in} = 0.204

P1	--	--	--	0.20275	0.20194	0.19939	0.20180
P2	0.18856	--	--	--	0.20841	--	--
P3	--	--	--	--	0.18677	--	--
P4	0.16676	0.16821	--	--	0.18078	--	--
P5	0.16758	0.16356	--	--	0.17496	0.17743	--
P6	--	--	--	0.16477	--	--	--
P7	0.13155	0.13043	--	0.14685	0.15043	0.14228	0.10357
P8	0.12816	0.12692	0.11863	0.12727	0.13100	--	0.14202
P9	0.10233	0.10055	--	0.11894	--	--	0.12155
P10	0.10412						

TABLE LI (CONTINUED)

Run 62	L = 5680.0		G = 5.0214		P_T = 731.2		y_{in} = 0.204
P1	--	0.18492	0.19776	0.19486	0.19298	--	--
P2	--	--	--	--	0.17749	--	--
P3	--	--	--	--	0.16025	--	--
P4	--	0.14148	--	--	0.14894	--	--
P5	0.12965	--	--	--	0.14245	0.14434	0.14872
P6	--	--	--	--	0.12562	--	--
P7	0.07760	0.07932	--	0.09575	0.10022	0.10278	0.10990
P8	0.07396	0.07291	0.07481	0.08191	0.08779	--	--
P9	0.05745	0.05615	--	0.05932	0.06251	0.06925	0.07437
P10	0.06253						

Run 63	L = 5680.0		G = 6.2184		P_T = 741.5		y_{in} = 0.204
P1	--	--	0.20198	0.19900	0.20393	--	--
P2	--	--	--	--	0.19969	--	--
P3	--	--	--	--	0.18400	--	--
P4	0.15642	0.15991	0.17696	--	--	--	--
P5	0.15285	--	--	--	0.16791	0.16833	--
P6	--	--	--	--	0.14966	--	--
P7	0.10450	--	--	--	--	0.13244	0.12721
P8	0.09757	0.08540	0.08684	0.09548	0.11193	--	--
P9	0.07596	0.07458	0.07246	0.06980	0.06824	--	0.12263
P10	0.08153						

TABLE LI (CONTINUED)

Run 64	L = 5680.0		G = 7.4051		P_T = 741.5		y_{in} = 0.204
P1	--	--	0.19637	0.19989	0.20034	--	--
P2	--	--	--	--	0.19408	--	--
P3	--	--	--	0.18149	0.18145	--	--
P4	0.16047	--	0.17870	--	--	--	0.17961
P5	0.16638	--	--	--	0.17263	0.17367	0.17486
P6	--	--	--	--	0.13377	--	--
P7	0.12695	--	--	0.13317	0.13650	--	--
P8	0.10686	0.11279	0.11333	0.11181	0.12686	--	--
P9	--	0.08788	0.08149	0.08794	0.09250	--	--
P10	0.09463						

APPENDIX I

COMPUTER PROGRAMS FOR LEAST SQUARES CURVE - FIT OF AXIAL CONCENTRATION PROFILE FOR CASE I, CASE II AND CASE III

A. Data Input Format for Computer Programs

1. For 3 ft. Packing Height (Six Sampling Positions):

	Column No.	Variable
1st card	1-10	Total height of the packing in ft.
	11-70	Height of the probe in packing in ft. (Ten columns per probe position)
2nd card	1-10	Run number
	11-20	Liquid flow rate lb./hr.sq.ft.
	21-30	Gas flow rate lb./hr.sq.ft.
	31-40	Henry's law constant
	41-50	Total pressure, mm Hg
	51-60	Inlet gas composition mole fraction
3rd card	1-60	Gas composition at six probes positions in mole fraction. Ten columns per composition.

2. For 5 ft. Packing Height (Nine Sampling Positions):

1st card	1-10	Total height of the packing in ft.
	11-80	Height of the probe in packing in ft. (Eight columns per probe position in ft.

	Column No.	Variable
2nd card	Same as for 3 ft.	packing height
3rd card	1-72	Gas composition at nine probe positions in mole fraction. Eight columns per composition.

C. COMPUTER PROGRAM FOR CASE I

```
C      NON LINEAR REGRESSION ANALYSIS FOR CASE I.
C      TO DETERMINE THE VALUE OF PARAMETER NOY
       IMPLICIT REAL*8(A-H,0-Z)
       DIMENSION Y(10),HE(10),B(10),A(10),Z(10),CY(10),YE(10),YDCA
       2L(10),CYCAL(10),YCAL(10)
       WRITE(3,1111)
 1111  FORMAT(/10X,'3/8 INCH PACKING, H=3FT')
C      NUMBER OF DATA POINTS
       II=6
C      HEIGHT OF THE PROBES IN THE PACKING
       READ(1,1201)HT,(HE(I),I=1,II)
 1201  FORMAT(7F10.3)
       DO 101 NN=1,30
C      N=RUN NO., VS=LIQUID FLOW RATE, VG=GAS FLOW RATE, H=HENRY LAW
C      CONSTANT, YIN=INLET GAS COMPOSITION, MOL. FRACTION,P=TOTAL PRESS.
       READ(1,1205)N,VS,VG,H,P,YIN
 1205  FORMAT(I10,5F10.5)
       WRITE(3,1204)N,VS,VG,H,P
 1204  FORMAT(/6X,'RUN NO.'=,I10,5X,'VS=',F10.5,4X,'VG=',F10.5,4X,'H=',F
      210.5,4X,'P,F10.5)
C      COMPOSITIONS AT VARIOUS HEIGHTS
       READ(1,1202)(Y(I),I=1,II)
 1202  FORMAT(6F10.5)
       XIN=0.0
       EM=H*760.0/P
       MWT=44.0*YIN+28.0*(1.0-YIN)
       F=(VG*H*760.0*18.0)/(MWT*P*VS)
       WRITE(3,1021)HT,(HE(I),I=1,II)
 1021  FORMAT(//6X,'HEIGHT OF TOWER HT=',F10.5,/6X,'H(1)=',F10.5,4X,'H(2)
      2=',F10.5,4X,'H(3)=',F10.5,4X,'H(4)=',F10.5,4X,'H(5)=',F10.5,4X,
       3H(6)=',F10.5)
       WRITE(3,1022)YIN,XIN,(Y(I),I=1,II)
 1022  FORMAT(/6X,'GAS IN YIN=',F7,4,4X,'GAS IN LIQUID IN XIN=',F7.4,/6X,
      2'Y(1)=',F10.5,4X,'Y(2)=',F10.5,4X,'Y(3)=',F10.5,4X,'Y(4)=',F10.5,4
      3X,'Y(5)=',F10.5,4X,'Y(6)=',F10.5)
       DO 1203 I=1,II
       Z(I)= HE(I)/HT
       CY(I) = Y(I)/YIN
       CX1=0.0
C      LEFT HAND SIDE OF EQUATION 4.1
 1203  YE(I)=(CY(I)-CX1*EM)/(1.0=CX1*EM)
C      STARTING VALUE OF NOY (TO)
       TO=1.0
   39  DO 50 J=1,II
C      TERM OF EQUATION 4.1
       G==TO*(1-F)
       A0=1.0/(1.0-F*DEXP(G))
       BO=-F*DEXP(G)/(1.0-F*DEXP(G))
       DG=-(1.0-F)
C      DERIVATIVES WITH RESPECT TO NOY (T)
       DA0=-(F*DEXP(G)*(1.0-F))/(1.0=F*DEXP(G))**2
```

```
DBO=(-(F*DEXP(G)*DG*(1.0-F*DEXP(G)))-(DEXP(G)*DEXP(G)*F*F*DG))/((1
     2.0-F*DEXP(G))**2)
      A(J)=AO*DEXP((G)*Z(J))+BO
   50 B(J)=(DAO*DEXP(G*Z(J))+A)*Z(J)*DG*DEXP(G*Z(J)))+DBO
C     SUMMATION OF TERMS FOR EQUATION NO. A.16
      SMYEB=0
      DO 60 K=1,II
YYEB=YE(K)*B(K)
      SMYEB=SMYEB + YYEB
   60 CONTINUE
      SMAB = 0.0
      DO 70 L=1,II
      YAB = A(L)*B(L)
   70 SMAB=SMAB+YAB
      SMBB=0.0
      DO 80 N=1,II
      SBB=B(N)*B(N)
   80 SMBB=SMBB+YBB
      DELT =(SMYEB=SMAB)/SMBB
      DO 65 I=1,II
C     CALCULATED COMPOSITION AT TO
   65 SDCAL(I)=AO*DEXP(G*Z(I))+BO
      S=0.0
      SUMR=0.0
      DO 90 I=1,II
      CYCAL*I)=YDCAL(I)
      YCAL(I) =CYCAL(I)*YIN
C     SQUARE OF THE DIFFERENCE BETWEEN EXPERIMENTAL AND CALCULATED COM
C     POSITION AT A POINT
      YDIFF =(Y(I)-YCAL(I))**2
      FD=(Y(I)=YCAL(I))/Y(I)
      SUMR=SUMR+DABS(FD)
C     SUM OF THE SQUARES OF ERRORS
   90 S=DABS(YDIFF)+S
      ROT=DABS((DELT)/TO)
C     AVERAGE ABSOLUTE PERCENTAGE DEVIATION
      AAPD=(100*SUMR)/II
C     VARIANCE FOR Y (SIGMA**2)
      SIGMAY=S/(PT=1.0)
C     VARIANCE FOR NOY(T),(SIGMA**2)
      SIGMTT=SIGMAY/SMBB
C     STANDARD DEVIATION FOR NOY (SIGMA)
      SIGMAT=DSQRT(SIGMTT)
C     CONFIDENCE LIMITS
      CONFLP=TO+2.0*DSQRT(SIGMTT)
      CONFLM=TO-2.0*DSQRT(SIGMTT)
      IF(ROT=.0001)12,12,14
C     T=NEW VALUE OF NOY
   14 T=TO + DELT/10.0
      TO=T
      GO TO 39
   12 PT=II*1.0
      WRITE(3.500)TO,S,AAPD,ROT
  500 FORMAT(//6X,'TO'=D18,8,/6X,'ERROR='D18.8,/6X,'AAPD(CY)='D18.8,/6X,
     2'ROT=',D18.8)
```

```
      WRITE(3,333)(YCAL(I),I=1,II)
      WRITE(3,222)(Y(I),I=1,II)
  333 FORMAT(//6X,'CAL.COMP.Y(I)=',6D18.8)
  222 FORMAT(6X,EXP,COMP.Y(I)=',6D18.8)
      WRITE(3,600)SIGMTT,SIGMAY
      WRITE(3,900)SIGMAT
      WRITE(3,700)CONFLP
      WRITE(3,800)CONFLM
  600 FORMAT(/6X,'VARIANCE FOR T=',D18.8,/6X,'VARIANCE FOR Y=',D18.8)
  900 FORMAT(6X,'STANDARD DEVIATION FOR NOY=',D18.8)
  700 FORMAT(6X'CON. INT. 95 P.C. (TO+SIGMA(T))=',D18. 8)
  800  FORMAT(6X,'CON. INT. 95 P.C. (TO-SIGMA(T))=',D18.8)
  101 CONTINUE
      STOP
      END
```

D. COMPUTER PROGRAM FOR CASE II

```
C      NON LINEAR REGRESSION ANALYSIS FOR CASE 2
C      TO DETERMINE THE VALUES OF PARAMETER NOY AND Y PG
       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION Y(10),HE(10),Z(10),CY(10),YDCAL(10),DTYDC(10),DPYDC(10),
      2YEDTX(10),YCDTX(10),YDTTX(10),SDTPY(10),YEDPY(10),YCDPY(10),YDPPY
       (310),YE(10),CYCAL(10),YCAL(10)
       WRITE(3,1111)
 1111  FORMAT(/10X,'3/8 INCH PACKING, H=5FT')
C      NUMBER OF DATA POINTS
       II=9
C      HEIGHT OF THE PROBES IN THE PACKING
       READ(1,1201)HT,(HE(I),I=1,II)
 1201  FORMAT(10F8.3)
       DO 101 NN-1,110
C      N=RUN NO., VS=LIQUID FLOW RATE, VG=GAS FLOW RATE, H=HENRY LAW
C      CONSTANT, YIN=INLET GAS COMPOSITION, MOL. FRACTION, P= TOTAL PRESS.
       READ(1,1205)N, VS,VG,H,P,YIN
 1205  FORMAT(I10.5F10.5)
       WRITE(3.1204)N,VS,VG,H,P
 1204  FORMAT(/6X,'RUN NO.=',I10.4X,'VS=',F10.5,4X,'VG=',F10.5,4X,'H=',F
      210.5,4X,'P=',F10.5)
C      COMPOSITIONS AT VARIOUS HEIGHTS
       READ(1,1201)(Y(I),I=1,II)
 1202  FORMAT(9F8.3)
       YIN=0.0
       EM=H*760.0/P
       MWT=44,0*YIN+28.0*(1.0-YIN)
       F=(VG*H*760.0*18.0)/(MWT*P*VS)
       WRITE(3,1021)HT,(HE(I),I=1,II)
 1021  FORMAT(//6X,'HEIGHT OF TOWER HT=',F10.5,/6X,'H(1)=',F8.5,1X,'H(2)=
      2',F8.5,1X,'H(3)=',F8.5,1X,'H(4)=',F8.5,1X,'H(5)=',F8.5,1X,'H(6)=
      3',F8.5,1X,'H(7)=',F8.5,1X,'H(8)=',F8.5,1X,'H(9)=',F8.5)
       WRITE(3,1022)YIN,YIN,(Y(I),I=1,II)
 1022  FORMAT(/6X,'GAS IN YIN=',F7.3,4X,'GAS IN LIQUID IN YIN=',F7.3,/6X,
      2'Y(1)=',F8.5,1X,'Y(2)=',F8.5,1X,'Y(3)=',F8.5,1X,'Y(4)=',F8.5,1X,
      3'Y(5)=',F8.5,1X,'Y(6)=',F8.5,1X,'Y(7)=',F8.5,1X,'Y(8)=',F8.5,1X,
      4'Y(9)=',F8.5)
       DO 1203 I=1,II
       Y(I)=HE(I)/HT
       CY(I)=Y(I)/YIN
       CX1-0.0
C      LEFT HAND SIDE OF EQUATION 4.5
TE(I)=(CY(I)=CX1*EM)/(1.0=CX1*EM)
 1203  CONTINUE
       READ(1,1024)TO
 1024  FORMAT(F15.5)
C      STARTING VALUE OF PG (PO)
       PO=20.0
C      TERM OF EQUATION 4.5
   50  A=PO+F*TO
       B=(1.0-F)*TO*PO
```

```
      G2=A/2.0+DSQRT((A/2.0)**2+B)
      G3=A/2.0-DSQRT((A/2.0)**2+B)
      IF(G2-81.8)11,11,15
   11 F2=1.0+G2/TO-((G2**2)/(PO*TO))
      F3=1.0+G3/TO=((G3**2)/(PO*TO))
      DF1=F3*G2*DEXP(G2))*DEXP(G3)-F2*G3*DEXP(G2)*DEXP(G3)
      DF2=G3*DEXP(G3)
      DF3=-G2*DEXP(G2)
      DF=DF1+(DF2-(G2*DF2)/PO)+(DF3-(G3*DF3)/PO)
      F11=DF1/DF
      F22=DF2/DF
      F33=DF3/DF
C     DERIVATIVES WITH RESPECT TO NOX
      DTA=F
      DTB=(1.0-F)*PO
      DTG2=DTA/2.+((1.0/DSQRT((A/2.0)**2+B))*(A*DTA/2.+DTB))/2.0
      DTG3=DTA/2.-((1.0/DSQRT((A/2.0)**2+B))*(ADTA/2.+DTB))/2.0
      DTF2=((TO*DTG2-G2)/TO**2)-(2.0*G2*TO*DTG2=G2**2)/((TO**2)*PO)
      DTF3=((TO*DTG3-G3)/TO**2)-((2.0*G3*DTG3*TO-G3**2)/(PO*(TO**2)))
      DTDF2=DTG3*DEXP(G3)+G3*DEXP(G3)*DTG3
      DTDF3=-(DTG2*DEXP(G2)+G2*DEXP(G2)*DEXP(G2)*DTG2)
      DTDF1=-(DTF3*DEXP(G3)+F3*DEXP(G3)*DTG3)*DF3=(F3*DEXP(G3)*
     2DTDF3)-((DTF2*DEXP(G2)+F2*DEXP(G2)*DTG2)*DF2+F2*DEXP(G2)*DTDF2)
      DTDF=DTDF1+DTDF2-((DTG2*DF2)+G2*DTDF2)/PO+DTDF3-(DTG3*DF3+G3*DTDF3
     2)/PO
      DTF11=(DF*DTDF1-DF1*DTDF)/DF**2
      DTF22=(DF*DTDF2-DF2*DRDF)/DF**2
      DTF33=(DF*DTDF3-DF3*DTDF)/DF**2
C     DERIVATIVES WITH RESPECT TO PXB
      DPA=1.0
      DPB=(1.0-F)*TO
      DPG2=DPZ/2.0+(1.0/DSQRT((A/2.0)**2+B))*((A*DPA/2.)+DPB)/2.0
      DPG3=DPA/2.0-(1.0/(DSQRT((A/2.0)**2+B))*((A*DPA/2.)+DPB))/2.0
      DPF2=DPG2/TO-(PO*2.0*G2*DPG2-G2**2)/(TO*(PO**2))
      DPF3=DPG3/TO-(PO*2.0*G3*DPG3-G3**2)/(TO*(PO**2))
      DPDF2=DPG3*DEXP(G3)+G3*DEXP(G3)*DPG3
      DPDF3=-(DPG2*DEXP(G2)+G2*DEXP(G2)*DPG2)
      DPDF1=-(DPF3*DEXP(G3)  F3*DEXP(G3)*DPG3)*DF3=(F38DEXP(G3)*
     2DPDF3)-((DPF2*DEXP(G2)+F2*DEXP(G2)*DPG2)*DPG2)*DF2+(F2*DEXP(G2)*DPDF2))
      DPDF=DPDF1+DPDF2-(PO*(G2*DPDF2+DF2*DPG2)-G2*DF2)/PO**2+(DPDF3)-(PO
     2*(G3*DPDF3+DPG3)-G3*DF3)/PO**2
      DPF11=(DF*DPDF1=DF1*DPDF)/DF**2
      DPF22=(DF*DPDF2-DF2*DPDF)/DF**2
      DPF33=(DF*DPDF3-DF3*DPDF)/DF**2
C     SUMMATION TO FORM COEFFICIENTS OF EQUATION (IN LEAST SQUARE SENSE)
      SMTC1=0.0
      SMTC2=0.0
      SUMDTY=0.0
      SDTDPY=0.0
      SMPC1=0.0
      SMPC2=0.0
      SDPPY=0.0
      DO 100 I=1,II
C     CALCULATED COMPOSITION AT TO AND PO
```

```
      YDCAL(I)=F11+F22*DEXP(G2*Z(I))+F33*DEXP(G3*Z(I))
      DTYDC(I)=DTF11+F22*DEXP(G2*Z(I))*Z(I)*DTG2+DTF22*DEXP(G2*Z(I))+F33
     2*DEXP(G3*Z(I))*Z(I))*Z(I)*DTG3+DTF33*DEXP(G3*Z(I))
      DPYDC(I)=DPF11+F22*DEXP(G2*Z(I))*Z(I)*DPG2+DPF22*DEXP(G2*Z(I))+F33
     2*DEXP(G3*Z(I))*Z(I)*DPG3+DPF33*DEXP(G3*Z(I))
      XEDTY(I)=YE(I)*DTYDC(I)
      SMTC1=SMTC1+XEDTY(I)
      XCDTY(I)=YDCAL(I)*DTYDC(I)
      SMTC2=SMTC2+XCDTY(I)
      YDTTY(I)=DTYDC(I)*DTYDC(I)
      SUMDTY=SUMDTY+YDTTY(I)
      XDTPY(I)=DTYDC(I)*DPYDC(I)
      SDTDPY=SDTDPY+XDTPY(I)
      YEDPX(I)=YE(I)*DPYDC(I)
      SMPC1=SMPC1+YEDPX(I)
      YCDPY(I)=YDCAL(I)*DPYDC(I)
      SMPC2=SMPC2+YCDPY(I)
      YDPPY(I)=DPYDC(I)*DPYDC(I)
  100  SDPPY=SDPPY+YDPPY(I)
C     COEFF. OF EQS.
      A1DT=SUMDTY
      B1DP=SDTDPY
      C1=SMTC1-SMTC2
      A2DT=SDTDPY
      B2DP=SDPPY
      C2=SMPC1-SMPC2
      DELT=(C1*B2DP-C2*B1DP)/(A1DT*B2DP-A2DT*B1DP)
      DELP=(C2*A1DT-C1*A2DT)/(A1DT*B2DP-A2DT*B1DP)
      S=0.0
      SUMR=0.0
      DO 90 I=1,II
      CYCAL(I)=YDCAL(I)
      YCAL(I)=CYCAL(I)*YIN
C     SQUARE OF THE DIFFERENCE BETWEEN EXPERIMENTAL AND CALCULATED COM
C     POSITION AT A POINT
      YDIFF=(Y(I)-YCAL(I))**2
      FD=(Y(I)-YCAL(I))/Y(I)
      SUMR=SUMR+DABS(FD)
C     SUM OF THE SQUARES OF ERRORS
  90  S=DABS(YDIFF)+S
      HC=(A1DT*B2DP-B1DP*A2DT)
      DIMC11=B2DP/HC
      DIMC22=A2DT/HC
      ROT=DABS(DELT/TO)
      ROP=DABS(DELP/PO)
      IF(ROT=0.001)12,12,14
  12  IF(ROP-0.001)15,15,14
C     T=NEW VALUE OF NOY,P=NEW VALUE OF PG
  14  T=TO+DELT/10.0
      P=PO+DELP/10.0
      TO=T
      PO=P
      GO TO 50
  15  PT=II*1.0
```

```
C     AVERAGE ABSOLUTE PERCENTAGE DEVIATION
      AAPD=(100*SUMR)/II
C     VARIANCE FOR Y,(SIGMA**2)
      SIGMAY=S/(PT-2.0)
C     VARIANCE FOR NOY(T),(SIGMA**2)
      SIGMTT=SIGMAY*DIMC11
C     STANDARD DEVIATION FOR NOY (SIGMA)
      SIGMAT=DSQRT(DABS(SIGMTT))
C     VARIANCE FOR (PG)(SIGMA**2)
      SIGMPP=SIGMAY*DIMC22
C     STANDARD DEVIATION FOR PG (SIGMA)
      SIGMAP=DSQRT(DABS(SIGMPP))
C     CONFIDENCE LIMITS
      CONFTP=TO+2.0*SIGMAT
      CONFTM=TO-2.0*SIGMAT
      CONFPP=P0+2.0*SIGMAP
      CONFPM=P0-2.0*SIGMAP
      WRITE(3,150)TO,PO
  150 FORMAT(//12X,'TO=',D18.8,6X,'PO=',D18.8)
      WRITE(3,51)G2,G3
   51 FORMAT(//10X,'G2=',D18.8,'G3-',D18.8)
      WRITE(3,200)ROT,ROP
  200 FORMAT(/6X,'ROT=',D18.8,/6X,'ROP=',D18.8)
      WRITE(3,500)S,AAPD
      WRITE(3,555)(YCAL(I),I=1,II)
      WRITE(3,222)(Y(I),I=1,II)
  333 FORMAT(//6X,'CAL. COMP. Y(I)=',9D12.6)
  222 FORMAT(6X,'EXP. COMP. Y(I)=',9D12.6
      WRITE(3,600)SIGMTT, SIGMAY
      WRITE(3,601)SIGMPP
      WRITE(3,900)SIGMAT
      WRITE(3,901)SIGMAP
      WRITE(3,700)CONFTP
      WRITE(3,800)CONFTM
      WRITE(3,701)CONFPP
      WRITE(3,801)CONFPM
  500 FORMAT(//6X,'ERROR='D18.8,/6X,'AAPD='D18.8)
  600 FORMAT(/6X,'VARIANCE FOR T=',D18.8,/6X,'VARIANCE FOR Y=',D18.8)
  601 FORMAT(/6X,'VARIANCE FOR P=',D18.8)
  900 FORMAT(6X,'STANDARD DEVIATION FOR T=',D18.8)
  901 FORMAT(6X,'STANDARD DEVIATION FOR P=',D18.8)
  700 FORMAT(6X,'CON. INT. 95 P.C. (TO+SIGMA(T))=',D18.8)
  701 FORMAT(6X,'CON. INT. 95 P.C. (PO+SIGMA(P))=',D18.8)
  800 FORMAT(6X,'CON. INT. 95 P.C. (TO-SIGMA(T))=',D18.8)
  801 FORMAT(6X,'CON. INT. 95 P.C. (PO-SIGMA(T))=',D18.8)
  101 CONTINUE
      STOP
      END
```

E. COMPUTER PROGRAM FOR CASE III

```
C      NON-LINEAR REGRESSION ANALYSIS FOR CASE 3
C      TO DETERMINE THE VALUE OF PARAMETER NOY, PG AND PL
       IMPLICIT  REAL*8(A-H,O-Z)
       DIMENSION Y(10),HE(10),Z(10),CY(10),YE(10),YDCAL(10),CYCAL(10),YCA
      2L(10),DIYDC(10),DPYDC(10),DRYDC(10),YEDTY(10),YCDTY(10),YEDPY(10),
      3YCDPY(10),YDPPY(10),YDPRY(10),YEDRY(10),YCDRY(10),YDTTY(10),YDTPY
      4(10),YDTRY(10),YDRRY(10),S(50)
       IR=5
       IW=6
       WRITE(IW,1111)
 1111  FORMAT(/10X,'1/4 INCH PACKING, H=4FT')
C      NUMBER OF DATA POINTS
       II=6
C      HEIGHT OF THE PROBES IN THE PACKING
       READ(IR,1201)HT,(HE(I),I=1,II)
 1201  FORMAT(7F10.3)
       DO 101 NN=1,20
C      CONSTANT, YIN=INLET GAS COMPOSITION,MOL. FRACTION,P= TOTAL PRESS.
       READ(IR,1205)N,VS,VG,H,P,YIN
 1205  FORMAT(I10,5F10.5)
       WRITE(IW,1204) N,VS,VG,H,P
 1204  FORMAT(/6X,'RUN NO.=',I10,4X,'VS=',F10.5,4X,'VG=',F10.5,4X,'H=',F
      210.5,4X,'P=',F10.5)
C      COMPOSITIONS AT VARIOUS HEIGHT
       READ(IR,1202)(Y(I),I=1,II)
 1202  FORMAT(6F10.5)
       XIN=0.0
       EM=H*760.0/P
       MWT=44.0*YIN=28.0*(1.0-YIN)
       F=(VG*H*760.0*18.0)/(MWT*P*VS)
       WRITE(IW,1201)HT,(HE(I),I=1,II)
 1021  FORMAT(//6X,'HEIGHT OF TOWER HT=',F10.5,/6X,'H(1)=',F10.5,4X,'H(2)
      2=',F10.5,4X,'H(3)=',F10.5,4X,'H(4)=',F10.5,4X,'H(5)=',F10.5.4X,
      3H(6)=',F10.5)
       WRITE(IW,1022)YIN,XIN,(Y(I),I=1,II)
 1022  FORMAT(/6X,'GAS IN YIN=',F7.5,4X,'GAS IN LIQUID IN XIN=',F7.5,/6X,
      2'Y(1)=',F10.5,4X,'Y(2)=',F10.5,4X,Y(3)=',F10.5,4X,'Y(4)=',F10.5,4
      3X,'Y(5)=',F10.5,4X,'Y(6)=',F10.5)
       DO 1203 I=1,II
       Z(I)=HE(I)/HT
       CY(I)=Y(I)/YIN
       CX1=0.0
 1203  YE(I)=(CY(I)-CX1*EM)/(1.0-CX1*EM)
       READ(IR,1024)TO
 1024  FORMAT(F15.5)
C      STARTING VALUES FOR PG AND PL
       PO=50.0
       RO=60.0
       DO 102 J=1,50
```

```
C     TERMS OF THE EQUATION
      A=PO-RO
      B=TO*PO+PO*RO+TO*RO*F
      G=TO*PO*RO*(1-F)
      P=(A/3.0)**2+B/3.0
      Q=(A/3.0)**3+(A&B/6.0)+G/2.0
      1F(P-2)1,101,101
      U=DARCOS(Q/P**1.5)
      PI=3.1415926536
      G1=0.0
      G2=A/3.0 + 2.0*DSQRT(P)*DCOS(U/3.0)
      G3=A/3.0 + 2.0*DSQRT(P)*DCOS(U/3.0+2,O*PI/3.0)
      G4=A/3.0 + 2.0*DSQRT(P)*DCOS(U/3.0+4.0*PI/3.0)
      A1=1.0+G1/TO-(G1**2)/(TO*PO)
      A2=1.0+G2/TO-(G2**2)/(TO*PO)
      A3=1.0+G3/TO-(G3**2)/(TO*PO)
      A4=1.0+G4/TOO(G4**2)/(TO*PO)
      D2=G2*A2
      D3=G3*A3
      D4=G4*A4
      D5=G2*DEXP(G2)
      D6=G3*DEXP(G3)
      D7=G4*DEXP(G4)
      D8=A2*DEXP(G2)
      D9=A3*DEXP(G3)
      D1=A4*DEXP(G4)
      DA4=-(D2*D6-D3*D5)
      DA3=(D2*D7-D4*D5)
      DA2=-(D3(D7-D4*D6)
      DA1=D2*((D6*(1.0+G4/$O)*D1)-(D7*(1.0+G3/RO)*D9))-D3*((D5*(1.0+G4/R
     20)*D1)-(D7*(1.0+G2/RO)*D8))+D4*(1.0+G3/RO)*D9)-(D6*(1.0+G2/RO
     3)*D8))
      DA=DA1-((1.0-G2/PO)*((D3*D7-D4*D6))-( 1.0-G3 /PO)*(D2*D7-D4*D5)+
      (21.0-G4 /PO)*(D2*D6-D3*D5))
      A11=DA1/DA
      A22=DA2/DA
      A33=DA3/DA
      A44=DA4/DA
C     DERIVATIVES WITH RESPECT TO NOX
      DTA=0.0
      DTB= PO+RO*F
      DTG= PO*RO*(1.0-F)
      DTP= 2.0*(A/3.0)*(DTA/3.0)+ DTB/3.0
      DTQ= 3.*((A/3.0)**2)*(DTA/3.0)+(DTA*B+ DTB*A)/6.0+DTG/2.0
      DTU=-(1.0 DSQRT(1.0-(Q**2/P**3)))*((P**1.5)*DTQ-1.5*(P**0.5)*Q*DTP
     2)/P**3
      DTG1=0.0
      DTG2=DTA/3.0+ 2.0*((DTP*DCOS(U/3,0))/2(2.0*P**0.5)-(P**0.5*DSIN(U/3
     2.0)*DTU/3.0)
      DTG3=DTA/3.0+ 2.0*((DTP*DCOX(U/3.0+2.0*PI/3.0) /(2.0*P**0.5))-(P**
     20.5*DSIN(U/3.0+2.0*PI?3.0)*DTU/3.0))
      DTG4=DTA/3.0+ 2.0*((DTP *DCOS(U/3.0+4.0*PI/3.0) /(2,0*P**0.5))-(P*
     2*0.5*DSIN(U/3.0+4.0*PI/3.0)*DTU/3.0))
```

```
      DTA1=(DTG1*TO-G1)/TO**2 -(2.0*G1*DTG1*TO-G1**2)/(PO*TO**2)
      DTA2=(DTG2*TO-G2)/TO**2 -  (2.0*G2*DTG2*TO-G2**2)/(PO*TO**2)
      DTA3=(DTG3*TO-G3)/TO**2 -(2.0*G3*DTG3*TO-G3**2)/(PO*TO**2)
      DTA4=(DTG4*TO-G4)/TO**2 -(2.0*G4*DTG4*TO-G3**2)/(PO*TO**2)
      DTD2=G2*DTA2+A2*DTG2
      DTD3=G3*DTA3+A3*DTG3
      DTD4=G4*DTA4+A4*DTG4
      DTD5-G2*DEXP(G2)*DTG2+DTG2*DEXP(G2)
      DTD6=G3*DEXP(G3)*DTG3+DTG3*DEXP(G3)
      DTD7=G4*DEXP(G4)*DTG4+DTG4*DEXP(G4)
      DTD8=A2*DEXP(G2)*DTG2+DTA2*DEXP(G2)
      DTD9=A3*DEXP(G3)*DTG3+DTA3*DEXP(G3)
      DTD1=A4*DEXP(G4)*DTG4+DTA4*DEXP(G4)
      W1=(D6*D1*DTD2+D2*D1*DTD6+D1*D6*DTD1)
      W2=(D6*D1*G4*DTD1+D2*D1*G4*DTD6+D2*D6+G4*DTD1+D2*D6*D1*DTG4)/RO
      W3=-(D7*D9*DTD2+D2*D9*DTD7+D2*D7*DTD9)
      W4=-(D7*D9*G3*DTD2+D2*D9*G3*DTD7+D2*D7*G3*DTD9+D2*D7*DTG38D9)/RO
      W5=-(D5*D1*DTD3+D3*D1*DTD5+D3*D5*DTD1)
      W6=-(D5*D1*G4*DTD3+D3*D1*G4*DTD5+D3*D5*G4*DTD1+D3*D5¼D1*DTG4)/RO
      W7= {D7*D8*DTD3+D3*D8*DTD7+D3*D7*DTD8)
      W8= (D7*D8*G2*DTD3+D3*D8*G2*DTD7+D3*D7*G2*DTD8+D3*D7*D8*DTG2)/RO
      W9= (D5*D9*DTD4+D4*D9*DTD5+D5*DTD9)
      W10=(D5*D9*G3*DTD4+D4*D9*G3*DTD5+D4*D5*G3*DTD9+D4*D5*D9*DTG3)/RO
      W11=-(D6*D8*DTD4+D4*D8*DTD6+D4*D6*DTD8)
      W12=-(D6*D8*G2*DTD4+D4*D8*G2*DTD6+D4*D6*G2*DTD8+D4*D6*D8*DTG2)/RO
      DTDA1=W1+W2+W3+W4+W5+W6+W7+W8+W9+W10+W11+W12
      DTDA2=-((DTD3*D7+DTD7*De)-(DTD4*D6+DTD6*D4))
      DTDA3= ((DTD2*D7+DTD7*D2)-(DTD4*D5+DTD5*D4))
      DTDA4=-((DTD2*D6+DTD6*D2)-(DTD3&D5+DTD5*D3))
      T1=DTDA1
      T2=-(D3*DTD7+DTD3*D7)
      T3= (D7*G2*DTD3+D3*G2*DTD7+D3*D7*DTG2)/PO
      T4= (D4*DTD6+DTD4*D6)
      T5=-(D6*G2*DTD4+Dr*G2*DTD6+D4*D6*DTG2)/PO
      T6= (D7*DTD2+D2*DTD7)
      T7=-(D7*G3*DTD2+D2*G3*DTD7+D7+D2*DTG3)/PO
      T8=-(D5*DTD4+D4*DTD5)
      T9= (D5*G3*DTD4+D4*G3*DTD5+D5*D4*DTG3)/PO
      T10=-(D6*DTD2+D2*DTD6)
      T11= (D6*G4*DTD2+D2*G4*DTD6+D2*D6*DTG4)/PO
      T12= (D5*DTD3+D3*DTD5)
      T13=-(D5*G4*DTD3+D3*G4*DTD5+D3*D5*DTG4)/PO
      DTDA=T1+T2+T3+T4+T5+T6+T7+T8+T9+T10+T11+T12+T13
      DTA11=DTDA1/DA-DA1*DTDA/DA**2
      DTA22=DTDA2/DA-DA2*DTDA/DA**2
      DTA33=DTDA3/DA-DA3*DTDA/DA**2
      DTA44=DTDA4/DA-DA4*DTDA/DA**2
C     DERIVATIVES WITH RESPECT TO PG
      DPA=1.0
      DPB=TO*RO
      DPG=TO*RO*(1.0 -F)
      DPP=2.0*A*DPA/9.0-DPB/3.0
      DPQ=(A/3.0)**2*DPA-(DPA*B+DPB*A)/6.0+DPB/2.0
      DPU=-(1.0/DSQRT(1.0-Q**2/P**3))*P**1.5*DPQ-1.5*P**0.5*DPP)/P**3
```

```
 DPG1=0.0
 DPG2=DPA/3.0+2.*((DPP*DCOS(U/3.0)/(P**0.5*2.0))-DSIN(U/3.0)*P**0.5
2*DPU/3.0)
 DPG3=DPZ/3.0+2.0*((DPP*DCOS(U/3.0+2.0*PI/3.0)/(P**0.5*2.0))-DSIN(
2U/3.0+2.0*PI/3.0)*P**0.5*DPU/3.0)
 DPG4=DPA/3.0+2.0*((DPP*DCOS(U/3.0+4.0*PI/3.0)/(P**0.5*2.0))-DSIN(
2U.3.0+2.0*PI/3.0)*P**0.5*DPU/3.0)
 DPA1=DPG1/TO-(2.0*G1*DPG1*P)-G1**2)/(TO*PO**2)
 DPA2=DPG2/TO-(2.0*G2*DPG2*PO-G2**2)/(TO*PO**2)
 DPA3=DPG3/TO-(2.0*G3*DPG3*PO-G3**2)/(TO*PO**2)
 DPA4=DPG4/TO-(2.0*G4*DPG3*PO-G4**2)/(TO*PO**2)
 DPD2 =G2*DPA2+A2*DPG2
 DPD3 =G3*DPA3+A3*DPG3
 DPD4 =G4*DPA4+A4*DPG4
 DPD5=G2*DEXP(G2)*DPG2+DPG2+DEXP(G2)
 DPD6=G3*DEXP(G3)*DPG3+DPG3*DEXP(G3)
 DPD7=G4*DEXP(G4)*DPG4+DPG4*DEXP(G4)
 DPD8=A2*DEXP(G2)*DPG2+DPA2*DEXP(G2)
 DPD9=A3*DEXP(G3)*DPG3+DPA3*DEXP(G3)
 DPD1=A4*DEXP(G4)*DPG4+DPA4*DEXP(G4)
 WP1=(D6*D1*DPD2+D2*D1*DPD6+D2*D6*DPD1)
 WP2=(D6*D1*G4*DPD2+D2*D1*G4*DPD6+D2*D6*G4*DPD1+D2*D6*D1*DPG4)/RO
 WP3=-(D7*D9*DPD2+D2*D9*DPD7+D2*D7*DPD9)
 WP4=-(D7*D9*G3*DPD2+D2*D9*G3*DPD7+D2*D7*G3*DPD9+D2*D7*D9*DPG3)/RO
 WP5=-(D5*D1*DPD3+D3*D1*DPD5+D3*D5*DPD1)
 WP6=0(D5*D1*G4*DPD3+D3*D1*G4*DPD5+D3*D5*G4*DPD1+D3*D5*D1*DPG4)/RO
 WP7=(D7*D8*DPD3+D3*D8*DPD7+D3*D7*DPD8)
 WP8=(D7*D8*G2*DPD3+D3*D8*DPD7*G2+D3+D7*G2*DPD8+D3*D7*D8*DPG2)/RO
 WP9=(D5*D9*DPD4+D4*D9*DPD5+D4*D5*DPD9)
 WP10=(D5*D9*G3*DPD4+D4*D9*G3*DPD5+D4*D5*G3*DPD9+D4*D5*D9*DPG3)/RO
 WP11=-(D6*D8*DPD4+D4*D8*DPD6+Dr*Dy*DPD8)
 WP12=-(D6*D8*G2*DPG4+D4*D8*G2*DPD6+Dr*D6*G2*DPD8+D4*D6*D8*DPG2)/RO
 DPDA1=WP1+WP2+WP3+WP4+WP5+WP6+WP7+WP8+WP9+WP10+WP11+WP12
 DPDA2=-((DPD3*D7+DPD7*D3)-(DPD4*D6+DPD6*D4))
 DPDA3= ((DPD2*D7+DPD7*D2)-(DPD4*D5+DOD5*D4))
 DPDA4=-((DPD2*D6+DPD6*D2)-(DPD3*D5+DPD5*D3))
 S1=DPDA1
 S2=-(D3*DPD7+DPD3*D7)
 S3= (D7*G2*DPD3+D3*G2*DPD7+D3*D7*DPG2)/PO-(D3*D7*G2)/PO**2
 S4= (D4*DPD6+DPD4*D6)
 S5=-((D6*G2*DPD4+D4*G2*DPD6+D4*D6*DPG2)/PO-(D6*D4*G2)/PO**2
 S6= (D7*DPD2+D2*DPD7)
 S7=-((D7*G3*DPD2+D2*G3*DPD7+D7*D2*DPG3)/PO-(D7*G3*D2)/PO**2)
 S10=-(D6*DPD2+D2*DPD6)
 S8=-(D5*DPD4+D4*DPD5)
 S9= (D5*G3*DPD4+D4*G3*DPD5+D5*D4*DPG3)/PO-(D5*G3*D4)/PO**2
 S11=(D6*G4*DPD2+D2*G4*DPD6+D2*D6*DPG3)/PO-(D6*G4*D2)/PO**2
 S12= (D5*DPD3+D3*DPD5)
 S13=-((D5*G4*DPD3+D3*G4+DPD5+D3*D5*DPG4)/PO-(D5*G4*D3)/PO**2)
 DPDA=S1+S2+S3+S4+S5+S6+S7+S8+S9+S10+S11+S12+S13
 DPA11 =DPDA1/DA=DA1*DPDA/DA**2
 DPA22 =DPDA2/DA=DA2**DPDA/DA**2
 DPA33 =DPDA3/DA-DA3*DPDA/DA**2
 DPA44=DPDA4/DA-DA4*DPDA/DA**2
```

```
C     DERIVATIVES WITH RESPECT TO PL
      DRA=-1.0
      DRB=PO+TO*F
      DRB=PO+TO*F
      DRG=TO*PO*(1.0-F)
      DRP=2.0*A*DRA/9.0+DRB/3.0
      DRQ=(A/3.0)**2*DRA+(DRA*B+DRB*A)/6.0+DRG/2.0
      DRU=-((1./DSQRT(1.0-Q**2/P**3))*P**1.5*DRQ- P**0.5*Q*DRP*1.5))/P
     2**3
      DTG1=0.0
      DRG2=DRA/3.0+2.0*((DRP*DCOS(U/3.0)/(2.0**P*0.5))-(P**0.5*DSIN(U/3.
     20)*DRU)/3.0)
      DRG3=DRA/3.0+2.0*((DRP*DCOS(U/3.0+2.0*PI/3.0))/(2.0*P**0.5)-(P**0
     2.5*DSIN(U/3.0+2.0*PI/3.0)*DRU/3.0))
      DRG4=DRA/3.0+2.0*((DRP*DCOS(U/3.0+4.0*PI/3.0))/(2.0*P**0.5)-(P**0.
     25*DSIN(U/3.0+4.0*PI/3.0)(DRU/3.0))
      DRA1=DRG1/TO-2.0*G1*DRG1/(TO*PO)
      DRA2=DRG2/TO-2.0*G2*DRG2/(TO*PO)
      DRA3=DRG3/TO-2.0*G3*DRG3/(TO*PO)
      DRA4=DRG4/TO-2.0*G4*DRG4/(TO*PO)
      DRD2=G2*DRA2+A2*DRG2
      DRD3=G3*DRA3+A3*DRG3
      DRD4=G4*DRA4+A4*DRG4
      DRD5=G2*DEXP(G2)(DRG2+DRG2*DEXP(G2)
      DRD6=G3*DEXP(G3)*DRG3+DRG3*DEXP(G2)
      DRD7=G4*DEXP(G4)*DRG4+DRG4*DEXP(G2)
      DRD8=A2*DEXP(G2)*DRG2+DRA2*DEXP(G2)
      DRD9=A3*DEXP(G3)(DRG3+DRA3*DEXP(G3)
      DRD1=A4*DEXP(G4)(DRG4+DRA4*DEXP(G4)
      WR1=(D6*D1*DRD2+D2*D1*DRD6+D2*D6*DRD1)
      WR2=(D6*D1*G4*DRD2+D2*D1*G4*DRD6+D2*D6*Gr*DRD1+D2*D6*D1*DRG4)/RO-(
     2D6*D1*G4*D2)/RO**2
      WR3=-(D7*D9*DRD2+D2*D9*DRD7+D2*D7*DRD9)
      WR4=-((D7*D9*G3*DRD2+D2*D9*G3*DRD7+D2*D7*G3*DRD9+D3*D7*D9*DRG3)/RO
     2-(D7*D9*G3*D2)/RO**2)
      WR5=-(D5*D1*DTD3+D3*D1*DRD5+D3*D5*DRD1)
      WR6=-((D5*D1*G4*DRD3+D3*D1*Gr*DRD5*D3*D5*G4*DRD1+D3*D5*D1*DRG4)/RO
     2-(D5*D1*G4*D3)/RO**2)
      WR7=(D7*D8*DRD3+D3*D8*DRD7+D3*D7*DRD8)
      WR8=(D7*D8*G2*DRD3+D3*D8*G2*DRD7+D3*D7*G2*DRD8+D3*D7*D8*DRG2)/RO-
     2(D7*D8*G2*D3)/RO**2
      WR9=(D5*D9*DRD4+D4*D9*DRD5+D4*D5*DRD9)
      WR10=(D5*D9*G3*DRD4+D4*D9*G3*DRD5+D4*D5*G3*DRD9+D4*D5*D9*DRG3)/RO-
     2(D5*D9*G3*D4)/RO**2
      WR11=-(D6*D8*DRD4+D4*D8*DRD6+D4*D6*DRD8)
      WR12=-((D6*D8*G2*DRD4+D4*D8*G2*DRD6+D4*D6*G2*DRD8+D4*D6*D8*DTG2)/R
     20-(D6*D8*G2*Dr)/RO**2
      DRDA1=WR1+WR2+WR3+WR4+WR5+WR6+WR7+WR8+WR9+WR10+WR11+WR12
      DRDA2=-((DRD3*D7+DRD7*D3)-(DRD4*D6+DRD6*D4))
      DRDA3= ((DRD2*D7+DRD7*D2)-(DRD4*D5+DRD5*D4))
      DRDA4=-((DRD2*D6+DRD6*D2)-(DRD3*D5+DRD5*D3))
      TR1=DRDA1
      TR2=-(D3*DRD7+DRD3*D7)
      TR3=(D7*G2*DRD3+D3*G2*DRD7+D3*D7*DRG2)/PO
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```
      TR4= (D4*DRD6+DRD4*D6)
      TR5=-(D6*G2*DRD4+D4*G2*DRD6+D4*D6*DRG2)/PO
      TR6= (D7*DRD2+D2*DRD7)
      TR7=-(D7*G3*DRD2+D2*G3*DRD7+D7*D2*DRG3)/PO
      TR8=-(D5*DRD4+D4*DRD5)
      TR9= (D5*G3*DRD4+D4*G3*DRD5+D5*D4*DRG3)/PO
      TR10=-(D6*DRD2+D2*DRD6)
      TR11= (D6*G4*DRD2+D2*G4*DRD6+D2*D6*DRG3)/PO
      TR12= (D5*DRD3+D3*DRD5)
      TR13=-(D5*G4*DRD3+D3*G4*DRD5+D3*D5*DRG4)/PO
      DRDA=TR1+TR2+TR3+TR4+TR5+TR6+TR7+TR8+TR9+TR10+TR11+TR12+TR13
      DRA11=DRDA1/DA-DA1*DRDA/DA**2
      DRA22=DRDA2/DA0DA2*DRDA/DA**2
      DRA33=DRDA3/DA-DA3*DRDA/DA**2
      DRA44=DRDA4/DA-DA4*DRDA/DA**2
C     SUMMATION TO FORM COEFFICIENTS OF EQUATION (IN LEAST SQUARE SENSE)
      SMTC1=0.0
      SMTC2=0.0
      SDTDTY=0.0
      SDTDPY=0.0
      SDTDRY=0.0
      SMPC1=0.0
      SMPC2=0.0
      SDPPY=0.0
      SDPRY=0.0
      SMRC1=0.0
      SMRC2=0.0
      SDRRY=0.0
      DO 1001=1,II
C     CALCULATED COMPOSITION AT TO,PO AND RO
      YDCAL(I)=A11+A22*DEXP(G2*Z(I)+A33*DEXP(G3*Z(I))+A44DEXP(G4*Z*(I))
      DTYDC(I)=DTA11+(DTA22*DEXP(G2*Z(I))+A22*DEXP(G2*Z(I))*Z(I)*DTG2)
     2+(DTA33*DEXP(G3*Z(I))+A33*DEXP(G3*Z(I))*DTG3*Z(I))+(DTA44*
     3DEXP(G4*Z(I))+A44*DEXP(G4*Z(I))*Z*I)*DTG4)
      DPYDC(I)=DPA11+(DPA22*DEXP(G2*Z(I))+A22*DEXP(G2*Z(I))*Z*I)*DPG2)
     2+(DPA33*DEXP(G3*Z(I))+A33*DEXP(G3*Z(I))*DPG3*Z(I))+(DPA44*
     3DEXP(G4*Z(I))+A44*DEXP(G4*Z(I))*Z(I)*DPG4)
      DRYDC(I)=DRA11+(DRA22*DEXP(G2*Z(I))+A22*DEXP(G2*Z(I))*Z(I)*DRG2)
     2+(DRA33*DEXP(G3*Z(I))+A33*DEXP(G3*Z(I))*DRG3*Z(I))+(DRA44*
     3DEXP(G4*Z(I))+A44*DEXP(G4*Z(I))*Z(I)*DRG4)
      YEDTY(I)=YE(I)*DTYDC(I)
      SMTC1=SMTC1+XEDTY(I)
      YCDTY(I)=YDCAL(I)*DTYDC(I)
      SMTC2=SMTC2+YCDTY(I)
      YDTTY(I)=DTYDC(I)*DTYDC(I)
      SDTDTY=SDTDTY+YDTTY(I)
      YDTPY(I)=DTYDC(I)*DPYDC(I)
      SDTDPY=SDTDPY+YDTPY(I)
      YDTRY(I)=DTYDC(I)*DRYDC(I)
      SDTDRY=SDTDRY+YDTRY(I)
      YEDPY(I)=YE(I)*DPYDC(I)
      SMPC1=SMPC1+YEDPY(I)
      YCDPY(I)=YDCAL(I)*DPYDC(I)
      SMPC2=SMPC2+YCDPY(I)
```

```
      YDPPY(I)=DPYDC(I)*DPYDC(I)
      SDPPY=SDPPY+YDPPY(I)
      YDPRY(I)=DPYDC(I)*DRYDC(I)
      SDPRY=SDPPY+YDPRY(I)
      YEDRY(I)=YE(I)*DRXDC(I)
      SMRC1=SMRC1+YEDRY(I)
      SCDRY(I)=YDCAL(I)*DRYDC(I)
      SMRC2=SMRC2+XCDRY(I)
      YDRRY(I)=DRYDC(I)*DRYDC(I)
  100 SDRRY=SDRRY+SDRRY(I)
C     COEFF. OF EQS.
      A1DT=SDTDTY
      B1DP=SDTDPY
      C1DR=SDTDRY
      C1=SMTC1-SMTC2
      A2DT=SDTDPY
      B2DP=SDPPY
      C2DR=SDTDRY
      C2=SMPTC1=SMPC2
      A3DT=SDTDRY
      B3DP=SDPRY
      C3DR=SDRRY
      C3=SMRC2-SMRC2
      DLRN=)A3DT*C2-A2DT*C3)*(A2DT*B1DP-A1DT*B2DP)-C1*A2DT-C2*A1DT)*(A3
     2DT*B2DP-A2DT*B3DP)
      DLRM=(A2DT*B1DP-A2DT*B2DP)*(A3DT*C2DR-A2DT*C3DR)-(A3DT*B2DP-A2DT*B
     23DP)*(C1DR*A2DT-C2DR*A1DT)
      DELR= DLRN/DLRM
      DELP=))C1*A2DT-C2*A2DT)-(C1DR*A2DT-C2DR*A1DT)*DELR)/(A2DT*B1DP-A1D
     2T*B2DP)
      DELT=(C1-B1DP*DELP-C1DR*DELR)/A1DT
      SIMXD=0.0
      SUMR=0.0
      SM=0.0
      DO 90 I=1,II
      CYCAL(I)=YDCAL(I)
C     SQUARE OF THE DIFFERENCE BETWEEN EXPERIMENTAL AND CALCULATED COM
C     POSITION AT A POINT
      YDIFF=(Y(I)-YCAL(I))**2
      FD=(Y(I)-YCAL(I))/Y(I)
      SUMR=SUMR+DABS(FD)
C     SUM OF THE SQUARES OF ERRORS
   90 SM=DABS(YDIFF)+SM
      S(J)=SM
      HC=A1DT*(B2DP*C3DR-C2DR*B3DP)-B1DP*(A2DT*C3DR-A3DT*C2DR)+C1DR*(A2D
     2T*B3DP-B2DP*A3DT)
      DIMC11=(B2DP*C3DR-B3DP*C2DR)/HC
      DIMC22=(A1DI*C3Dr-A3DT*C1DR)/HC
      DIMC33=(A1DT*B2DP-A2DT*B1DP)/HC
      ROT=DABS(DELT/TO)
      ROP=DABS(DELP/PO)
      ROR=DABS(DELR/RO)
      IF(J-1)10,10,11
   11 IF(S(J)-S(J-1))10,15,15
   10 IF(ROT-0.0001)12,12,14
```

```
   12 IF(ROP-0.0001)16,16,14
   16 IF(ROR-0.0001)15,15,14
C     NEW VALUES OF NOY, PG AND PL
   14 TD=TO+DELT/100.0
      PD=PO+DELP/100.0
      RD=RO+DELR/100.0
      TO=TD
      PO=PD
      RO=RD
  102 CONTINUE
   15 PT=II*1.0
C     AVERAGE ABSOLUTE PERCENTAGE DEVIATION
      AAPD=(100*SUMR)/II
C     VARIANCE FOR Y,(SIGMA**2)
      SIGMAY=S(J-1)/(PT-3.0)
C     VARIANCE FOR NOY,(SIGMA**2)
      SIGMTT=SIGMY* DIMC11
C     STANDARD DEVIATION FOR NOY (SIGMA)
      SIGMAT=DSQRT(DABS(SIGMTT))
C     VARIANCE FOR PG,(SIGMA**2)
      SIGMPP=SIGMAY* DIMC22
C     STANDARD DEVIATION FOR PG (SIGMA)
      SIGMAP=DSQRT(DABS(SIGMPP))
C     VARIANCE OF PARAMETER PL (SIGMA**2)
      SIGMRR=SIGMAY* DIMC33
C     STANDARD DEVIATION FOR PL (SIGMA)
      SIGMAR=DSQRT(DABS(SIGMRR))
C     CONFIDENCE LIMITS
      CONFTP=TO+2.0*SIGMAT
      CONFTM=TO-2.0*SIGMAT
      CONFPP=PO+2.0*SIGMAP
      CONFPM+PO-2.0*SIGMAP
      CONFRP=RO+2.0*SIGMAR
      CONFRM=RO-2.0*SIGMAR
      WRITE(IW,150)TP,PO,RO
      WRITE(IW,200)DELT, DELP, DELR
      WRITE(IW,151)ROT,ROP,ROR
      WRITE(IW,500)S(J),AAPD
      WRITE(IW,222)(X(I),I=1,II)
      WRITE(IW,333)(XCAL(I),I=1,II)
      WRITE(IW,600)SIGMTT,SIGMAY
      WRITE(IW,601)SIGMPP
      WRITE(IW,602)SIGMRR
      WRITE(IW,900)SIGMAT
      WRITE(IW,901)SIGMAP
      WRITE(IW,902)SIGMAR
      WRITE(IW,700)CONFTP
      WRITE(IW,701)CONFPP
      WRITE(IW,702)CONFRP
      WRITE(IW,800)CONFTM
      WRITE(IW,801)CONFPM
      WRITE(IW,802)CONFRM
  150 FORMAT(//12X,'TO=',D18.8,6X,'PO=',D18.8,6X,'RO=',D18.8)
  151 FORMAT(//6X,'ROT=',D18.8,/6X,'ROP=',D18.8,/6X,'ROR=',D18.8)
```

```
200 FORMAT(/6X,'DELT=',D18.8,6X,'DELP=',D18.8,6X,'DELR=',D18.8)
500 FORMAT(//6X,'SQ=',D18.8,/6X,'AAPD=',D18.8)
600 FORMAT(/6X,'VARIANCE OF NOY=',D18.8,/6X,'VARIANCE OF Y=',D18.8)
601 FORMAT(/6X,'VARIANCE OF PG=',D18.8)
602 FORMAT(/6X,'VARIANCE OF PL=',D18.8)
900 FORMAT(6X,'STANDARD DEVIATION NOY=',D18.8)
901 FORMAT(6X,'STANDARD DEVIATION PL=',D18.8)
902 FORMAT(6X,'STANDARD DEVIATION PL=',D18.8)
700 FORMAT(6X,'CON.INT. 95 P.C. (TO+SIGMA(T))=',D18.8)
701 FORMAT(6x,'CON.INT. 95 P.C. (PO+SIGMA(P))=',D18.8)
702 FORMAT(6X,'CON.INT. 95 P.C. (RO+SIGMA(R))=',D18.8)
800 FORMAT(6X,'CON. INT. 9t P.C. (TO-SIGMA(T))=',D18.8)
801 FORMAT(6X,'CON.INT. 95 P. C. (PO-SIGMA(P))=',D18.8)
802 FORMAT(6X,'CON.INT. 95 P.C. (RO-SIGMA(R))=',D18.8)
333 FORMAT(//6X,'CAL. COMP. Y(I)=',6D12.6)
222 FORMAT(6X,'EXP. COMP. Y(I)=',6D12.6)
101 CONTINUE
    STOP
    END
```

APPENDIX J

CALIBRATION DATA FOR ROTAMETERS

TABLE LII

ROTAMETER CALIBRATION DATA FOR INLET WATER TO ABSORPTION COLUMN

Float Position	Rate of Water (lb./min.)
0.1	1.16
0.2	2.17
0.3	3.14
0.4	4.16
0.5	5.20
0.6	6.24
0.7	7.30
0.8	8.25
0.9	9.25
1.0	10.10

TABLE LIII

ROTAMETER CALIBRATION DATA FOR INLET GAS MIXTURE

20.8% CO_2 (by Volume) at 28°C and 732.4 mm Hg.

Float Position	Rate (cu.ft./min.)
40	0.0759
50	0.0969
60	0.1200
70	0.1429
80	0.1600
90	0.1856
100	0.2041
110	0.2266

TABLE LIV

ROTAMETER CALIBRATION DATA FOR INLET WATER TO HOT WATER TANK

Float Position	Rate of Water (lb./min.)
10.0	0.946
20.0	1.95
30.0	2.76
40.0	3.71
50.0	4.58
60.0	5.64
70.0	6.52
80.0	7.51
90.0	8.45
100.0	9.6

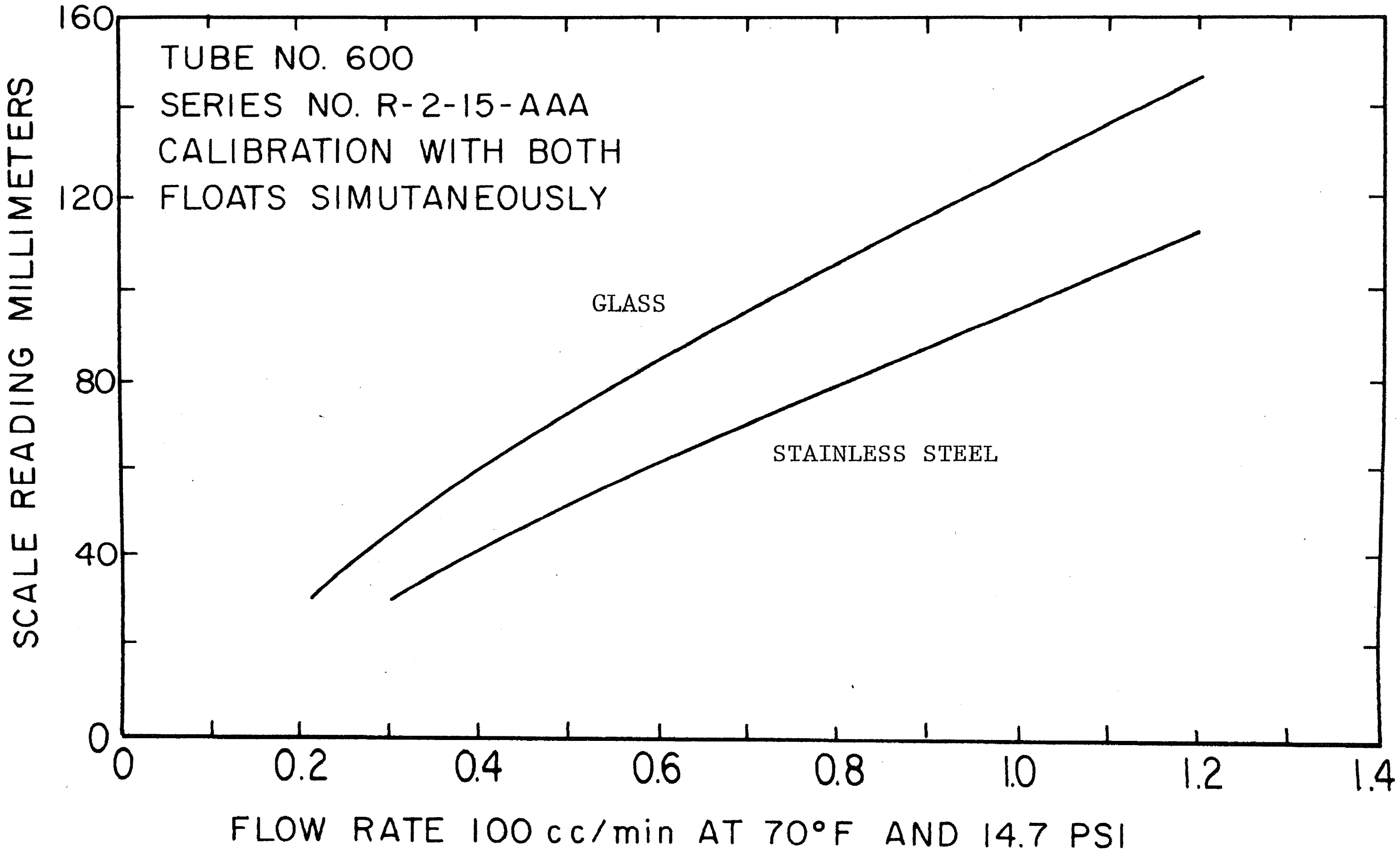

Figure 41. Rotameter Calibration for Gas Sample

APPENDIX K

SPECIFICATIONS FOR EQUIPMENT

Gas Chromatograph

Varian Aerograph

Series 1520, Serial No. 956-0010 (11/66), Part No. 1520-B

2700 Mitchell Drive, Walnut Creek, California

Recorder

10 inch Linear Potiometric, 1 m.v. full scale 10"

Beckman No 100500, Equiped with Disc integrater

Beckman Instrument Inc., Fulerton, Calif.

Wet Test Meter

Range - 0.0 to 2.5 cu.ft.

Precision Scienctific Co., Chicago, Ill.

Manometer for Gas Flow Line

Type 22-24

Serial No. 20263

Trimount Instrument Co., Chicago, Ill.

Manostat for Maintaining Vacuum in the System

Style No. 8

Serial No. 2480

Cartesian Manostat, Manostat Corporation, New York,N. Y.

Rotameter for Inlet Water Measurements to Hot Water Tank

Tube Size R-8W-25-4

Brooks Rotameter Co., Lansdate, Penn.

Rotameter for Gas Flow Rate Measurements (Gas Mixture)

No. 604

Tube Size R-6-15-A

The Matheson Co,, East Rutherford, Joilet, Ill.

Potentiometer for Temperature Measurements

Model 80220, Serial No. AG6959-2

Range 0 to 600^{o}F, CC-T

Saddle Brook, New Jersey

Rotameter for Water Inlet Measurement to Absorption Column

Tube Size 8-25-1

Brooks Rotameter Co., Lansdate, Penn.

Column Packing

Raschig Rings

Size - 1/4, 3/8 and 1/2 in., unglazed porcelain

M. A. Knight Company, Akron, Ohio

Sampling Valve

Carle Micro Volume, No. 3391

Sampling loop approximately 0.5 ml., internal volume 0.4 ml.

Carle Instrument Inc., Fulerton, Calif.

Rotameter for Gas Sample Measurements

Tube No. 600

Serial No. R-2-15 AAA

The Matheson Co., East Rutherford, Joilet, Ill.

APPENDIX L

ERROR ANALYSIS

In experimental work the study of the effects of experimental error on the final results is of great importance. For this reason an error analysis was performed to ascertain the accuracy of the results of this investigation.

(a) The gas analysis of the inlet gas mixture was provided (four significant places) by the supplier, the Matheson Co., Joilet, Ill. An analytical method is reported (Oliver, 1969) to have been used for the analysis, and, therefore, the inlet gas composition can be considered sufficiently accurate.

(b) The water rotameters were calibrated by actually weighing outlet water from the rotameters at various rotameter scale readings. The exact rotameter scale readings for which the calibration was performed were used in the experimental work. No extrapolation or interpolation was used.

(c) The gas mixture rotameter was calibrated by using a wet test meter. The dial of the meter is graduated in 250 divisions each representing 1/1000 of a cubic foot. The normal accuracy of the gas meter is 0.5 percent. Since the calibration was performed by measuring 0.5 cu. ft. of the gas at a time, calibration data can be considered sufficiently accurate. In this case, also, the exact rotameter scale readings for which the calibration was performed were used in the experimental work. No extrapolation or interpolation was used.

(d) Gas sample analysis was believed to be a major source of error in this investigation. Experiments for 3/8 inch Raschig ring packing with 5 feet packing height (L = 2865.0 lb./hr.sq.ft. and G = 7.4 lb./hr.sq.ft.) were performed to determine the reproducibility of the gas sample compositions. It was found that the sample composition at a point in the column attained steady state in about 15 minutes and after that the fluctuations were within one percent.

(e) It may be recalled that the gas phase composition in the axial direction was calculated by averaging the various radial compositions at a specific axial position. Efforts were made to evaluate the effect of error in the gas phase axial compositions on the mass transfer number (N_{oy}) and the Peclet number (P_G) as follows:

The experimentally measured gas phase axial profile data for 1/4 inch Raschig ring packing with 3 feet packing height were randomly perturbed by ±1.0 to ±5.0%. Fifteen sets of data at various liquid and gas flow rates were subjected to this study. In 80% of the cases, the variation between the values of N_{oy} and P_G calculated with and without the perturbations were below 6 and 10%, respectively. Variations were large at the low liquid rate of 2865.0 lb./hr.sq.ft. probably because of the poor gas and liquid contact. This error would not significantly affect the findings of this investigation.

(f) In some cases due to experimental difficulties composition in radial direction could be determined only at one radial sample point (see sample positions P2 and P3 on Figure 39). Though such cases are only small in number, efforts were made to make an evaluation of the possible deviation in composition at such radial points from the desired average composition at that height, and its effect on N_{oy} and P_G. As seen from Figure 39 variations in compositions at sampling positions P1 and P4 which are in the close vicinity of P2 and P3 are very small. At position P5 the maximum deviation between the composition at a sample point and the average composition is about 4.2%. It will not be too presumptuous to assume that the maximum deviations in compositions at positions P2 and P3, individually, could be about 5%. As mentioned earlier, this would result in a deviation of about 6 and 10% in calculated values of N_{oy} and P_G, respectively.

Thus, in most of such cases where composition could be determined at only one point the deviation would not exceed more than 5%. This would not have any significant effect on the findings of this investigation. However, in those few cases where the deviation is considerably higher than 5%, the axial concentration profile might have been affected causing the data to scatter.

(g) A rough estimate of the error generated by the computer during the regression analysis was made. For Case II and Case III, five computed gas compositions in the axial direction (Runs 23, 33, 43, 53 and 63 for Case II and Case III, individually) were again curve-fitted. It was expected that the error in the least square sense from curve-fitting this computed data would be near zero. The errors were found to be 10^{-14} (minimum-10^{-15}, maximum-10^{-12}) and 10^{-10} (minimum-10^{-10}, maximum-10^{-7}) for Case II and Case III, respectively. These errors are considerably less than the values encountered in curve-fitting of the experimental data which is of the order of 10^{-4}.

The criteria of stopping the iterations was that the ratios of the changes in parameters (N_{oy}, P_G and P_L) to the parameters should be less or equal to 0.0001. If the value of the ratio was further decreased, the errors might have been further reduced.

Thus, from the above it can be concluded that the computation errors involved in the regression analysis of the models are probably insignificant.

(h) In order to evaluate the effect of variations in axial gas compositions (at various radial positions) on Peclet number, axial gas phase profiles were obtained for runs numbered 32 for both 1/4 inch and 1/2 inch packings, by choosing the highest and lowest radial gas composition measurements. Peclet numbers were then calculated using Model II and the results are presented below:

	1/4 Inch Packing	1/4 Inch Packing
P_G for the axial gas phase profile using the highest radial gas compositions	86	85
P_G for the axial gas phase profile using average gas compositions	84	83
P_G for the axial gas phase profile using the lowest radial gas compositions	83	82
Variation in Peclet Number	4%	4%

The above results indicate that Peclet numbers can be obtained for these data with a precision of about 4%. This means that the values of P_G of this study are about 50 times larger than those obtained from packed bed studies with gases and liquids.