OPTIMUM FEED PLATE LOCATION FOR MULTI-COMPONENT DISTILLATION SEPARATION

By

AMORNVAT CHENBHANICH

Bachelor of Science
Chulalongkorn University
Bangkok, Thailand
1982

Master of Gas Technology
Illinois Institute of Technology
Chicago, Illinois
1984

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fufillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 1986

OPTIMUM FEED PLATE LOCATION FOR

MULTI-COMPONENT DISTILLATION

SEPARATION

Thesis Approved:

Keith C Gilson

Thesis Adviser

Mayis Seapan

Jan Wagner by KCB

Norman N. Durham

Dean of the Graduate College

ACKNOWLEDGEMENT

I would like to express my sincere appreciation and gratitude to my adviser, Dr. Ruth C. Erbar, for her advice and guidance, encouragement, patience and understanding.

I wish to thank the Faculty for introducing me to engineering theories during my graduate study, and the School of Chemical Engineering for the financial support I received during the course of the work. Special thanks are due to Iris McPherson for her suggestions about the SAS Software Package.

I am also thankful for the moral support offered by my aunt, Sumon Intudom and the unforgettable friendship, encouragement and company of Kenneth L. McNally.

Finally, I dedicate this work to my parents who appreciate the value of education. Without them, my achivement to this point would not have been reached.

ABSTRACT

The object of this thesis is to study the optimum feed plate location of a simple one-feed, two-product distillation column. The optimum feed plate location provides the reflux and boil up rates which lead to minimum duty of the column. The tool of this study is the MAXISIM simulation system program, developed in the School of Chemical Engineering, Oklahoma State University. The feed used in this study were chosen in such a way that they will be representative of the feeds that might be encountered in industry. The results are compared with those predicted by the correlations of Fenske, Winn, Kirkbride, and Akashah et al. The final result is in the form of an improved correlation that can be applied to various feed conditions and column sizes. In general, the correlation can predict optimum feed plate location better than the others for a saturated liquid feed. The new correlation also gives a satisfactory prediction when employed in the range of saturated liquid down to 50 percent liquid feed.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table		Page

Table		Page

Table Page

LIST OF FIGURES

Figure Page

Figure Page

NOMENCLATURE

b	flow rate of the light key component in the bottom product, mols/hr
b'	flow rate of the heavy key component in the bottom product, mols/hr
B	total flow rate of the bottom product, mols/hr
C1	constant value defined in Model 1
C2	constant value defined in Model 1
C3	constant value defined in Model 1
d	flow rate of the light key component in the distillate, mols/hr
d'	flow rate of the heavy key component in the distillate, mols/hr
Δd_1	difference of the feed plate location between the feeds at saturated liquid and 50 percent liquid condition
Δd_2	difference of the feed plate location between the feeds at saturated liquid and saturated vapor condition
D	total flow rate of the distillate, mols/hr
f	flow rate of the light key component in the feed, mols/hr
f'	flow rate of the heavy key component in the feed, mols/hr

F	total flow rate of the feed, mols/hr
FPL	feed plate location
FPL_K	feed plate location by the Kirkbride correlation
K_n	distribution coefficient for the light key component in plate n
K'_n	distribution coefficient for the heavy key component in plate n
K1	constant value defined in Model 2
K2	constant value defined in Model 2
K3	constant value defined in Model 2
K4	constant value defined in Model 2
K5	constant value defined in Model 2
K6	constant value defined in Model 2
L	total liquid flow rate, mols/hr
L_n	total flow rate of the liquid leaving plate n, mols/hr
N	number of plates in the column including condenser and reboiler
N_r	number of plates in the rectifying section
N_s	number of plates in the stripping section
N_T	number of plates in the column excluding condenser, reboiler and feed plate
ΔT	temperature difference between the reboiler and the condenser, F
V_n	total vapor flow rate leaving plate n, mols/hr
x_B	mole fraction of the light key component in the bottom

x'_B mole fraction of the heavy key component in the bottom

x_D mole fraction of the light key component in the distillate

x'_D mole fraction of the heavy key component in the distillate

x_F mole fraction of the light key component in the feed

x'_F mole fraction of the heavy key component in the feed

x_n mole fraction of the light key component in plate n

x'_n mole fraction of the heavy key component in plate n

XHB mole fraction of the heavy key component in the bottom

XHD mole fraction of the heavy key component in the distillate

XHF mole fraction of the heavy key component in the feed

XLB mole fraction of the light key component in the bottom

XLD mole fraction of the light key component in the distillate

XLF mole fraction of the light key component in the feed

y_n mole fraction of the light key component in the vapor leaving plate n

α_{avg}	average relative volatility in the column
α_C	relative volatility in the condenser
α_F	relative volatility in the feed
α_n	relative volatility in plate n
β	constant value in the Winn correlations
θ	constant value in the Winn correlations
ξ	additional constant in the Winn correlations

CHAPTER I

INTRODUCTION

Since the advent of high-speed computers and sophisticated techniques for convergence schemes, the complicated tray-by-tray computation in multicomponent distillation columns can be achieved both easily and quickly. Many packaged simulation programs have been developed to solve this problem rigorously. In order to reduce the calculation time, some reasonable operating variables are required as the initial input data by most (probably all) of these packages. Hence, reliable short-cut methods to predict these variables are worthy of continued study. Short-cut correlations to determine the optimum feed plate location will be presented in this work.

The optimum feed plate location can be defined in one of two ways: For a given reflux rate, the feed plate is that which will require the smallest number of theoretical contacts to achieve the desired separation, or for a given number of plates the feed plate will be that which will require the smallest reflux rate to achieve the specified separation.

The MAXISIM package simulation system, developed in the School of Chemical Engineering, Oklahoma State University, will be used to generate the optimum feed plate locations by means of tray-by-tray computations.

From the literature review in Chapter II, convenient methods to estimate optimum feed plate location are the correlations proposed by Fenske (1932), Kirkbride (1944), Winn (1958), and Akashah et al. (1979). It can be shown that the correlations obtained empirically tend to yield more accurate results than those theoretically derived correlations which are constrained by a set of assumptions. For this reason, the correlation from this work is empirically based on the results from MAXISIM simulations. The correlation is also prepared in such a way that it can be employed with various amounts of feed vaporizations.

The derivations of the Fenske (1932) and Winn (1958) correlations, the similarity between these two correlations and the Kirkbride (1944) correlation, and the final relations used in this study will be presented in Chapter III.

The procedure used in obtaining the final correlation by correlating the data from MAXISIM simulations are described in Chapter IV. Four types of feeds are introduced for evaluating the accuracy of the correlation. The predicted optimum feed plate locations are compared with those predicted by the other correlations along with the discussion are included in Chapter V.

Conclusions and recommendations drawn from this study are presented in Chapter VI.

CHAPTER II

REVIEW OF LITERATURE

The first group of equations and relationships that served as a basis to determine feed plate locations in distillation columns were developed by Fenske (1932). Certain relationships were derived so that the separation of a complex mixture may be treated as if it were the separation of a simple binary mixture of key components using the same ratios as those which occur with the key components in the complex mixture.

Four simplifying assumptions were imposed in this derivation. First, the moles of overflow and moles of vapor ascending the column were constant. Second, the operation of the column was continuous and adiabatic. Third, there was no heat of mixing of any of the components. Fourth, Raoult's law was used in determining the vapor-liquid equilibria.

The final correlations enabled the calculation of the minimum number of theoretical plates under total reflux and the minimum reflux for a column of infinite height.

An estimation of feed plate location can be made by using the Fenske correlations to calculate the number of plates in the rectifying and stripping sections separately. When applying the Fenske correlations, the relative volatility is normally assumed constant across the column. Therefore, the relative volatility for the average temperature and pressure of the column is recommended.

Ellis (1954) presented a procedure based on the Fenske relationships for a column operating at total reflux. In the Ellis procedure, the ratio of the plates in the rectifying section to the total number of theoretical plates, including the partial condenser and reboiler, is assumed to be equal to the same ratio at an operating reflux. Since the ratio at total reflux can be calculated by the Fenske correlation, the number of plates above the feed plate at operating reflux can be determined.

Winn (1958) commented that the Fenske correlations did not give reliable results since the relative volatility varies appreciably, especially in the case of widely differing top and bottom plate temperatures. Winn related the vapor-liquid equilibrium ratio, K, of one key component to the other at a fixed pressure. It is expressed by $K = \beta(K')^{\theta}$, where β and θ are constants. This equation is valid over a range of several hundred degrees of temperature and, in this range, yields an accurate value of the minimum number of theoretical plates.

Kirkbride (1944) proposed an empirical correlation for locating the feed plate in a column. It was developed on the basis that the ratio of rectifying plates to stripping plates, including the partial condenser and reboiler, is a function of:

1. the fraction of the heavy key component (in the feed) removed in the distillate,
2. the fraction of the light key component removed in the bottom,
3. the concentration of the heavy key component present in the distillate,
4. the concentration of the light key component present in the bottom.

There are other variables which affect this ratio but the proposed correlation claimed to give reasonably good results. This correlation was later recommended by many authors, e.g., Henley and Seader (1981), Sinnott (1985), Hines and Maddox (1985).

In order to cut down the tedious calculation of feed plate location, Zanker (1983) prepared a nomograph to estimate the percentage of theoretical stages below the feed plate using Kirkbride's correlation.

Akashah et al. (1979) made an extensive study of feed plate location by making tray-by-tray calculations. They concluded that the feed plate could best be estimated by using a modified form of the Kirkbride correlation. They also stated that the feed vaporization had little noticeable influence on the optimum feed plate.

Hengsteback (1968) proposed a graphical method to find the optimum feed plate location. Plots of the logarithm of the molal concentration ratio of key components, i.e., $(d/f)/(d'/f')$, versus the plate number in the column were prepared. The slope of the curve represented the relative fractionation being accomplished per stage. The optimum feed plate location occurs at the plate where the slope in the rectifying section is equal to that in the stripping section.

Another graphical procedure was developed by Maas (1973). The same plots suggested by Hengsteback (1968) were used. The optimum feed location will be on the side of the feed plate that showed the most negative slope condition.

Both graphical techniques require an initial tray-by-tray solution and do not provide an original estimation of where the first feed location trial should be.

Hanson and Newman (1977) employed the Underwood (1948) equations for calculation of distillation columns having the feed plate at the optimum location. Underwood assumed constant relative volatility and constant molal overflow. These claimed to provide a better value for the total number of stages and a reasonable choice of the feed plate location. However, this procedure is not a short-cut estimation.

Fenske (1932), Kirkbride (1944), Winn (1958), and Akashah et al. (1979) will serve as the basis in this study since they provide a quick and convenient estimation of the optimum feed plate location.

CHAPTER III

DERIVATION OF CORRELATIONS

Derivation of Feed Plate Location by the Fenske Correlations

Nomenclature used in developing the Fenske correlations was shown in Figure 1. Subscripts on all variables apply to plate numbers. For the light key component on the first or top plate,

$$y_1 = K_1 x_1 \tag{1}$$

where

y_1 = mole fraction of the light key component in the vapor leaving the first plate

x_1 = mole fraction of the light key component in the liquid leaving the first plate

K_1 = distribution coefficient for the light key component in the first plate.

Since $y_1 = x_D$ for a total condenser,

$$x_D = K_1 x_1 \tag{2}$$

where

x_D = mole fraction of the light key component in the distillate product.

An overall material balance can be written below the first

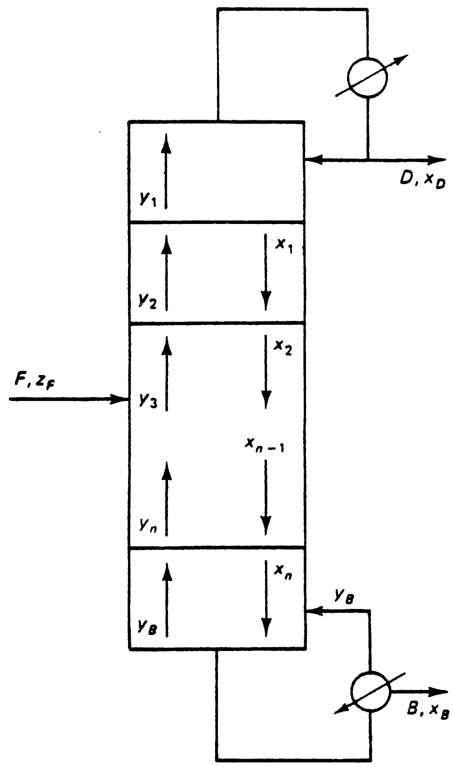


Figure 1. Nomenclature of Multicomponent Column Used in Developing the Fenske Correlations

plate and around the top column as

$$V_2 = L_1 + D \tag{3}$$

where

V_2 = total vapor flow rate leaving the second plate (flowing to the first plate)

L_1 = total liquid flow rate leaving the first plate

D = total flow rate of distillate.

Under conditions of minimum plate or total reflux, D is equal to zero. Thus

$$V_2 = L_1. \tag{4}$$

A component material balance around the first plate and the top of the column for the light key component is

$$V_2 y_2 = L_1 x_1 + D x_D. \tag{5}$$

Under the restrictions of minimum plates, Equation (5) becomes

$$y_2 = x_1. \tag{6}$$

The equilibrium relationship on the second plate is

$$y_2 = K_2 x_2. \tag{7}$$

Since $y_2 = x_1$, Equation (7) becomes

$$x_1 = K_2 x_2. \tag{8}$$

Substituting Equation (8) into Equation (2),

$$x_D = K_1 K_2 x_2. \tag{9}$$

Continuing this until the feed plate is reached

$$x_D = K_1K_2...K_Fx_F. \qquad (10)$$

Following the same development for the heavy key component

$$x'_D = K'_1K'_2...K'_Fx'_F. \qquad (11)$$

Prime symbol, ', indicates the heavy key component.
Dividing Equation (10) by Equation (11)

$$(x_D/x'_D) = (K_1K_2...K_Fx_F)/(K'_1K'_2...K'_Fx'_F). \qquad (12)$$

If a partial condenser is applied, an additional equilibrium stage is considered. Equation (12) becomes

$$(x_D/x'_D) = (K_CK_1K_2...K_Fx_F)/(K'_CK'_1K'_2...K'_Fx'_F). \qquad (13)$$

Since the ratio of the K values is equal to the relative volatility, α,

$$(K_1/K'_1) = \alpha_1. \qquad (14)$$

Equation (13) can be written as

$$(x_D/x'_D) = \alpha_C\alpha_1\alpha_2...\alpha_F(x_F/x'_F). \qquad (15)$$

Assuming that an average value of the relative volatiliy applies for all column plates. Equation (15) becomes

$$(x_D/x'_D) = \alpha_{avg}^{N_r}(x_F/x'_F) \qquad (16)$$

where

α_{avg} = average value of the relative volatility

N_r = number of plates in rectifying section plus partial condenser.

However, the molar flow rate is usually specified in multi-component separations rather than the mole fraction. Equation (16) can be expressed as

$$(d/d') = \alpha_{avg}^{N_r}(f/f') \tag{17}$$

or

$$\alpha_{avg}^{N_r} = (d/f)(f'/d') \tag{18}$$

where

f = molar flow rate of the light key component in the feed stream

f' = molar flow rate of the heavy key component in the feed stream

d = molar flow rate of the light key component in the distillate stream

d' = molar flow rate of the heavy key component in the distillate stream.

Similarly for the stripping section:

$$\alpha_{avg}^{N_s} = (f/b)(b'/f') \tag{19}$$

where

N_s = number of plates in stripping section plus reboiler

b = molar flow rate of the light key component in the bottom stream

b' = molar flow rate of the heavy key component in the bottom stream.

Derivation of Feed Plate Location by the Winn Correlations

The distribution coefficient, K, of one component to the other can be expressed by

$$K = \beta(K')^{\theta} \tag{20}$$

where

K = K value of the light key component

K' = K value of the heavy key component

β = constant

θ = constant.

Substituting Equation (20) into Equation (13)

$$\beta^{N_r} = (x_D/x_F)(x'_F/x'_D)^{\theta}. \tag{21}$$

Equation (20) can be written in terms of the molar flow rates;

$$\beta^{N_r} = (d/f)(f'/d')^{\theta}(F/D)^{1-\theta}. \tag{22}$$

Similarly,

$$\beta^{N_s} = (f/b)(b'/f')^{\theta}(B/F)^{1-\theta}. \tag{23}$$

Note that when θ equals to one, Equation (22) and Equation (23) reduce to Equation (18) and Equation (19), respectively. Hence, it can be stated that the Fenske correlations are specific cases of the Winn correlations. The determination of the constants in Winn correlations will be described in Appendix A.

Feed Plate Location by the Kirkbride Correlation

An empirical correlation for estimating feed plate location has been presented by Kirkbride (1944).

$$\log(N_r/N_s) = 0.206 \log\{(B/D)(XHF/XLF)(XLB/XHD)^2\} \quad (24)$$

where

N_r = number of plates in the rectifying section plus partial condenser

N_s = number of plates in the stripping section plus reboiler

B = total molar flow rate of the bottom product

D = total molar flow rate of the distillate product

XHF = mole fraction of the heavy key component in the feed

XLF = mole fraction of the light key component in the feed

XLB = mole fraction of the light key component in the bottom product

XHD = mole fraction of the heavy key component in the distillate product.

Note that

$$N_r + N_s = N - 1 \quad (25)$$

where

N = number of plates plus partial condenser plus reboiler

l = repetition of the feed plate.

Feed Plate Location by the Akashah Et Al. Correlation

Akashah et al. (1979) suggested that the feed plate could best be estimated by using a modified form of the Kirkbride correlation, Equation (24).

$$FPL = FPL_K + 0.5 \log(N_T) \tag{26}$$

where

FPL = feed plate location

FPL_K = feed plate location calculated by the Kirkbride correlation

N_T = number of plates not including reboiler, condenser and feed plate.

Similarities Between the Fenske and Kirkbride Correlations

There are some identical variables appearing in both the Fenske and Kirkbride correlations, which will be helpful in setting up a new set of variables for the new correlation. The comparison of the identical variables from the two correlations can be performed as the following:

Recall the Fenske correlations,

$$\alpha_{avg}^{N_r} = (d/f)(f'/d') \tag{18}$$

and

$$\alpha_{avg}^{N_s} = (f/b)(b'/f'). \tag{19}$$

Dividing Equation (18) by Equation (19),

$$\alpha_{avg}^{N_r - N_s} = (d/f)(f'/d')(b/f)(f'/b'). \qquad (27)$$

Taking logarithm of the above equation and rearranging,

$$N_r - N_s = (1/\log\alpha_{avg}) \log\{(d/f)(f'/d')(b/f)(f'/b')\}$$
$$= (const1) \log\{(f/f')(b/d')(d/f)/(b'/f')\} \qquad (28)$$

where

const1 = $1/\log \alpha_{avg}$.

Recall the Kirkbride correlation,

$$\log(N_r/N_s) = 0.206 \log\{(B/D)(XHF/XLF)(XLB/XHD)^2\} \quad (24)$$

Since,

$$XHF = f'/F$$
$$XLF = f\ /F$$
$$XLB = b\ /B$$
$$XHD = d'/D$$

Then, Equation (24) can be written as

$$\log N_r - \log N_s = 0.206 \log\{(B/D)(f'/F)(F/f)(b/B)^2(D/d')^2\}$$
$$= (const2) \log\{(f'/f)(b/d')(b/B)/(d'/D)\} (29)$$

where

const2 = 0.206.

Comparing Equation (28) and Equation (29), the two equations were set up similarly, i.e., the difference between the N_r and N_s values equals some constant multiplied by a group of variables. The common variables in these two groups are (f'/f)(b/d'). The Fenske case accounts for the rest of the variables as the ratio of the light key component in the distillate to the light key component in the feed, (d/f), divided by the ratio of the heavy key component in the bottom to the heavy key component in the feed, (b'/f'). However, Kirkbride uses the remaining variables as the ratio of the mole fraction of the light key component in the bottom, (b/B) or XLB, to the mole fraction of the heavy key component in the distillate, (d'/D) or XHD.

The Proposed Correlations

Following the Kirkbride form and employing the identical variable group, described in the previous topic, as a basis, two new correlations were introduced as Model 1 and Model 2. Model 1 is expressed as

$$\log(N_r/N_s) = \log\{(f/f')^{C1}(b/d')^{C2}(d/b')^{C3}\} \quad (30)$$

where

C1,C2,C3 = constants.

Model 2 can be expressed as,

$$\log(N_r/N_s) = \log\{(f/f')^{K1}(b/d')^{K2}(d/D)^{K3}/(b'/B)^{K3}\} \quad (31)$$

or

$$\log(N_r/N_s) = \log\{(f/f')^{K1}(b/d')^{K2}(XLD/XHB)^{K3}\} \quad (32)$$

where

K1,K2,K3 = constants

d/D = XLD; mole fraction of the light key component in the distillate

b'/B = XHB; mole fraction of the heavy key component in the bottom.

The constant estimations and the accuracies of Equation (30) and Equation (32) will be discussed in the next chapter.

CHAPTER IV

STUDY PROCEDURES

Data Manipulations of the MAXISIM Outputs and the Correlations by Fenske, Winn, Kirkbride and Akashah Et Al.

There are thirteen feeds used in testing the correlations presented by Fenske (1932), Winn (1958), Kirkbride (1944), and Akashah et al. (1979), and in generating the correlation in this work. The feeds were chosen in such a way that they will be representative of the feeds that might be encountered in industry. Feed No.1 was taken from Kirkbride (1944). Feed Nos.2 to 5 were taken from Akashah et al. (1979). They represent a deethanizer, depropanizer, debutanizer and depentanizer. Feed Nos.6, 7, and 13 were chosen from Amundson and Pontinen (1958), Erbar (1985), and Wagner (1982), respectively. Feed No.8 was first introduced by Robinson and Gilliland (1950). Later, it was modified by Lyster et al. (1959). Feed No.8 was used as the main feed composition at saturated liquid condition. Feed No.9 has the same composition as Feed No.8 but was introduced to the column at the 50 percent liquid condition. A heavy component, $C_{12}H_{26}$, was added to Feed No.8 to become feed No.10. Feed Nos.11 and 12 have the same components as

Feed No.8 but the compositions of the lightest, CH_4, and the heaviest, $C_{10}H_{22}$, components were varied. Note that the specifications for distillate and bottom streams were identical from Feed No.8 through Feed No.12.

Feed No.1 will be discussed in detail as an example. The composition and conditions of Feed No.1, together with the specified separation are shown in Table I. Tables and figures for the rest of the feeds can be found in Appendix B.

The definition used in considering the optimum feed plate location is such that for a given number of plates the optimum feed plate will be that which required the smallest reflux rate to achieve the specified separation.

The MAXISIM simulations (Erbar, 1984) were employed to perform tray-by-tray calculations. In order to vary the reflux rate in the MAXISIM output, the specified mole fraction of the key component was given as the input for the distillate specification and the bottom flow rate was given as the input for the bottom specification.

Three sizes of columns were selected in each feed, i.e., short, medium and tall columns. The terms "short", "medium", and "tall" are relative for each feed. For example, in Feed No.1, the short, medium, and tall columns refered to the 10-, 14-, and 20-plate columns, respectively. The choices of the column sizes were based on the calculation ability of MAXISIM. Frequently, the MAXISIM would not converge in performing the calculation of the tall

TABLE I

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.1

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
C3H8	54.00	51.80	2.20
nC3H10	377.00	2.70	374.30
nC5H12	60.00	54.50	436.50
Totals	491.00	54.50	436.50
Temperature,F	100.00	115.22	216.25
Pressure,psia	214.70	210.00	215.00

Feed Condition: Subcooled Liquid

column due to some numerical problem.

For each column size, the feed plate locations were varied. The reflux rates corresponding to each feed plate location were recorded. The graphs of feed plate locations versus reflux rates are plotted as Figure 2. The feed plate locations that yield the minimum reflux rates were estimated graphically. These locations represented the optimum feed plate locations. Note that some feeds at a high percentage of liquid will be treated as saturated liquid. The same procedures were repeated for the other amounts of feed vaporization, i.e., for the 50 percent liquid feed and for the saturated vapor feed. Table II shows these feed plate locations as well as the corresponding reflux rates obtained from MAXISIM outputs at various feed conditions and the column sizes for Feed No.1.

The optimum feed plate locations by the Fenske (1932), Winn (1958), Kirkbride (1944), and Akashah et al. (1979) correlations (which correspond to Equations (18) to (19), Equations (22) to (23), Equation (24), and Equation (25) in Chapter III, respectively) will be calculated next. Samples of calculations for feed plate locations will be shown in Appendix C.

In reality, the feed plate location will be reported as an integer, however, the locations obtained from graphs (such as Figure 2) or from calculations will be recorded with one digit to the right of the decimal due to the accuracy of the graphical manipulations.

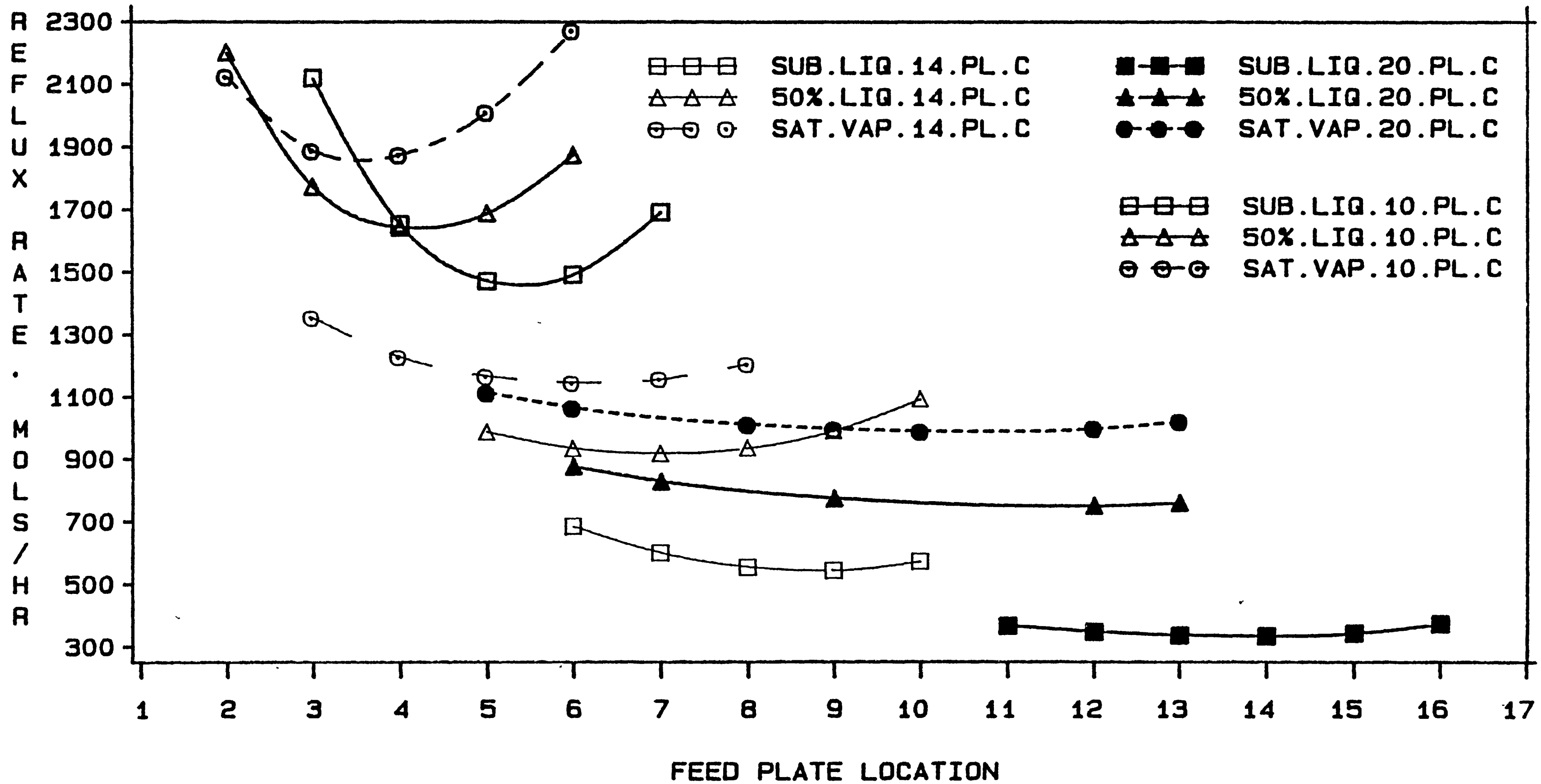


Figure 2. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.1

TABLE II

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS
FEED CONDITIONS AND COLUMN SIZES - FEED NO.1

Feed Condition	10 Theo.Pl.Col. FPL*	10 Theo.Pl.Col. Reflux (mols/hr)	14 Theo.Pl.Col. FPL	14 Theo.Pl.Col. Reflux (mols/hr)	20 Theo.Pl.Col. FPL	20 Theo.Pl.Col. Reflux (mols/hr)
Subcooled liquid	3	2120.0	6	685.1	11	365.8
	4	1652.9	7	599.7	12	346.5
	5	1470.9	8	554.1	13	335.6
	6	1492.0	9	543.4	14	332.8
	7	1691.8	10	572.9	15	342.7
					16	373.2
50% liq.	2	2201.8	5	987.6	6	876.2
	3	1773.1	6	934.4	7	829.1
	4	1642.3	7	918.4	9	774.3
	5	1688.3	8	936.2	12	750.8
	6	1874.1	9	992.0	13	760.9
			10	1093.9		
Saturated vapor	2	2123.7	3	1354.8	5	1113.0
	3	1887.5	4	1228.4	6	1064.5
	4	1874.9	5	1166.3	8	1010.7
	5	2010.5	6	1145.2	9	996.7
	6	2271.8	7	1158.0	10	989.3
			8	1205.7	12	998.6
					13	1021.3

*FPL = Feed Plate Location

The feed plate location derived from MAXISIM will be referred to as the theoretical feed plate location and the one derived from the correlation will be referred to as the calculated feed plate location.

The summary of the theoretical feed plate locations compared to the calculated values is tabulated in Table III.

For a better perception, the relationship of column sizes, theoretical feed plate locations, and calculated values are depicted as Figure 3. The same data manipulations were carried through the rest of the thirteen feeds.

Table IV, Table V, and Table VI summarized the theoretical feed plate locations for the saturated liquid, 50 percent liquid and saturated vapor feed of all thirteen feeds, respectively. Table VII summarized the calculated feed plate locations for the saturated liquid feed of all thirteen feeds.

Data Analyses

The first part of the analysis will be the study of the feed plate location when the feeds are introduced to the column at a saturated liquid condition. The accuracy test for each correlaion with the theoretical feed plate, the estimation of the constants for Model 1 (Equation (30)) and Model 2 (Equation (32)), and the final correlation will be included in this part. The second part will be the determination of the additional term which when added to the

TABLE III

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.1

Source	Feed Condition	Optimum Feed Plate Location		
		10 Pl.Col.	14 Pl.Col.	20 Pl.Col.
Fenske	Subcooled Liquid	4.3	5.9	8.3
Winn	Subcooled Liquid	3.9	5.4	7.5
Kirkbride	Subcooled Liquid	5.8	8.0	11.1
Akashah et al.	Subcooled Liquid	6.3	8.5	11.8
Theoretical Feed Plate	Subcooled Liquid	5.4	8.8	13.3
	50% liq.	4.2	7.0	11.0
	Saturated Vapor	3.5	6.0	10.0

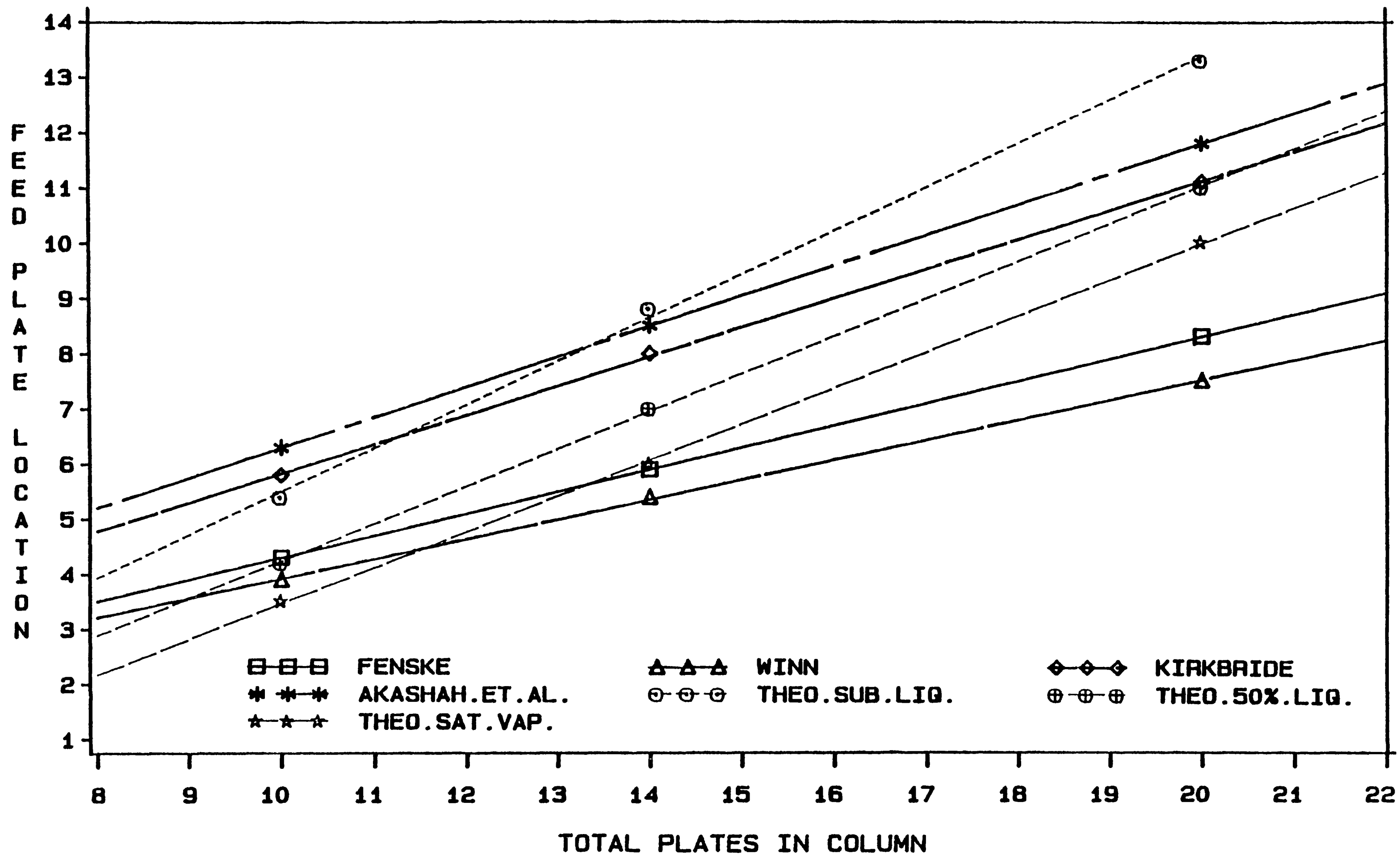


Figure 3. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.1

TABLE IV

THEORETICAL FEED PLATE LOCATIONS FOR SATURATED LIQUID FEEDS AT VARIOUS COLUMN SIZES

Feed No.	Column Size			Optimum Feed Pl. Location		
	Short	Medium	Tall	Short	Medium	Tall
1	10	14	20	5.4	8.8	13.3
2	12	16	22	8.3	10.9	14.7
3	28	34	40	16.0	18.2	20.3
4	12	22	28	6.0	10.7	13.4
5	12	22	32	4.3	9.0	14.0
6	12	15	20	6.1	8.0	11.5
7	13	15	17	9.1	10.1	11.0
8	12	16	20	8.1	10.7	13.0
9	-	-	-	-	-	-
10	12	16	20	8.1	10.5	12.9
11	12	16	20	8.4	10.8	13.0
12	12	14	16	9.5	11.0	12.4
13	15	20	25	11.5	15.0	18.0

TABLE V

THEORETICAL FEED PLATE LOCATIONS FOR 50 PERCENT LIQUID FEEDS AT VARIOUS COLUMN SIZES

Feed No.	Column Size			Optimum Feed Pl. Location		
	Short	Medium	Tall	Short	Medium	Tall
1	10	14	20	4.2	7.0	11.0
2	9	12	16	5.0	7.0	9.8
3	28	34	40	15.2	17.7	20.0
4	12	22	28	5.5	10.2	13.0
5	12	22	30	3.5	8.5	13.2
6	12	15	20	5.5	7.4	10.6
7	13	15	17	8.0	8.9	9.8
8	-	-	-	-	-	-
9	12	16	20	5.8	7.2	8.7
10	12	16	20	5.1	6.4	7.4
11	12	16	20	5.3	6.8	8.0
12	12	16	20	4.9	6.1	7.0
13	15	16	25	10.0	12.9	16.0

TABLE VI

THEORETICAL FEED PLATE LOCATIONS FOR SATURATED VAPOR FEEDS AT VARIOUS COLUMN SIZES

Feed No.	Column Size			Optimum Feed Pl. Location		
	Short	Medium	Tall	Short	Medium	Tall
1	10	14	20	3.5	6.0	10.0
2	9	12	15	4.1	5.9	7.8
3	28	34	40	14.6	17.6	20.5
4	12	22	28	5.1	9.9	12.7
5	12	22	30	2.7	7.2	10.5
6	12	15	20	4.8	6.6	9.8*
7	13	15	17	7.2	8.0	9.0
8&9	12	16	20	3.9	4.4	4.7
10	12	16	20	2.9	3.2	3.5*
11	12	16	20	3.4	4.0	4.4
12	12	16	20	3.0	3.3	3.7*
13	15	20	25	8.0	11.0	14.0

* Extrapolated

TABLE VII

CALCULATED VALUES OF OPTIMUM FEED PLATE LOCATIONS FOR SATURATED LIQUID FEED AT VARIOUS COLUMN SIZES

Feed No.	Column Size			Kirkbride			Akashah et al.			Fenske			Winn		
	S	M	T	S	M	T	S	M	T	S	M	T	S	M	T
1	10	14	20	5.8	7.9	11.1	6.3	8.5	11.7	4.3	5.9	8.3	3.9	5.4	7.5
2	12	16	22	8.8	11.5	15.5	9.3	12.1	16.2	7.5	9.7	13.2	6.9	9.0	12.2
3	28	34	40	16.7	20.1	23.5	17.4	20.9	24.3	18.1	22.1	25.9	17.0	20.5	24.0
4	12	22	28	6.7	11.9	15.0	7.3	12.6	15.7	7.8	13.8	17.4	7.5	13.2	16.7
5	12	22	32	3.4	6.1	8.7	4.0	6.8	9.5	3.9	6.8	9.8	3.5	6.2	8.9
6	12	15	20	5.8	7.1	9.3	6.3	7.7	10.0	5.4	6.6	8.7	4.7	5.8	7.6
7	13	15	17	7.7	8.8	9.9	8.2	9.4	10.5	8.7	9.9	11.1	8.0	9.2	10.3
8	12	16	20	9.3	12.2	15.1	9.9	12.8	15.7	9.2	12.1	14.9	9.4	12.3	15.2
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	12	16	20	9.4	12.3	15.2	9.9	12.9	15.9	9.2	12.1	14.9	9.5	12.5	15.3
11	12	16	20	9.4	12.3	15.1	9.9	12.8	15.8	9.2	12.1	14.9	9.4	12.3	15.2
12	12	14	16	9.4	11.0	12.3	9.9	11.4	12.9	9.2	10.7	12.1	9.5	10.9	12.4
13	15	20	25	9.6	12.7	15.7	10.2	13.3	16.4	10.8	14.1	17.5	10.5	13.8	17.1

Note: S=Short Column; M=Medium Column; T=Tall Column final correlation will enable it to predict the feed plate location at various feed vaporizations.

Saturated Liquid Feed Condition

The accuracy of each correlation has been tested by determining the sum of the absolute values of the difference between the theoretical feed plate location and the calculated feed plate location, i.e., error sum:

$$\text{error sum} = \sum_{n=1}^{13} \left| \begin{matrix}\text{Theoretical} \\ \text{feed plate}\end{matrix} - \begin{matrix}\text{Calculated} \\ \text{feed plate}\end{matrix} \right|$$

where

n = number of feeds.

A comparison of the error sums is illustrated as Figure 4. It can be interpreted that the Kirkbride correlation gives a more accurate prediction than the others and that the error sum will increase as the column size increases.

Attempts have been made to find the feed plate location as a function of the total number of plates, i.e.,

$$N_s = f(N) \tag{33}$$

where N is the number of plates in the column and N_s is the number of plates in the stripping section, which will be identical to the feed plate location if the plates are counted from the bottom up and the reboiler is considered as the zeroth plate.

The graphs of column size (or total number of plates) versus feed plate location were prepared for the theoretical

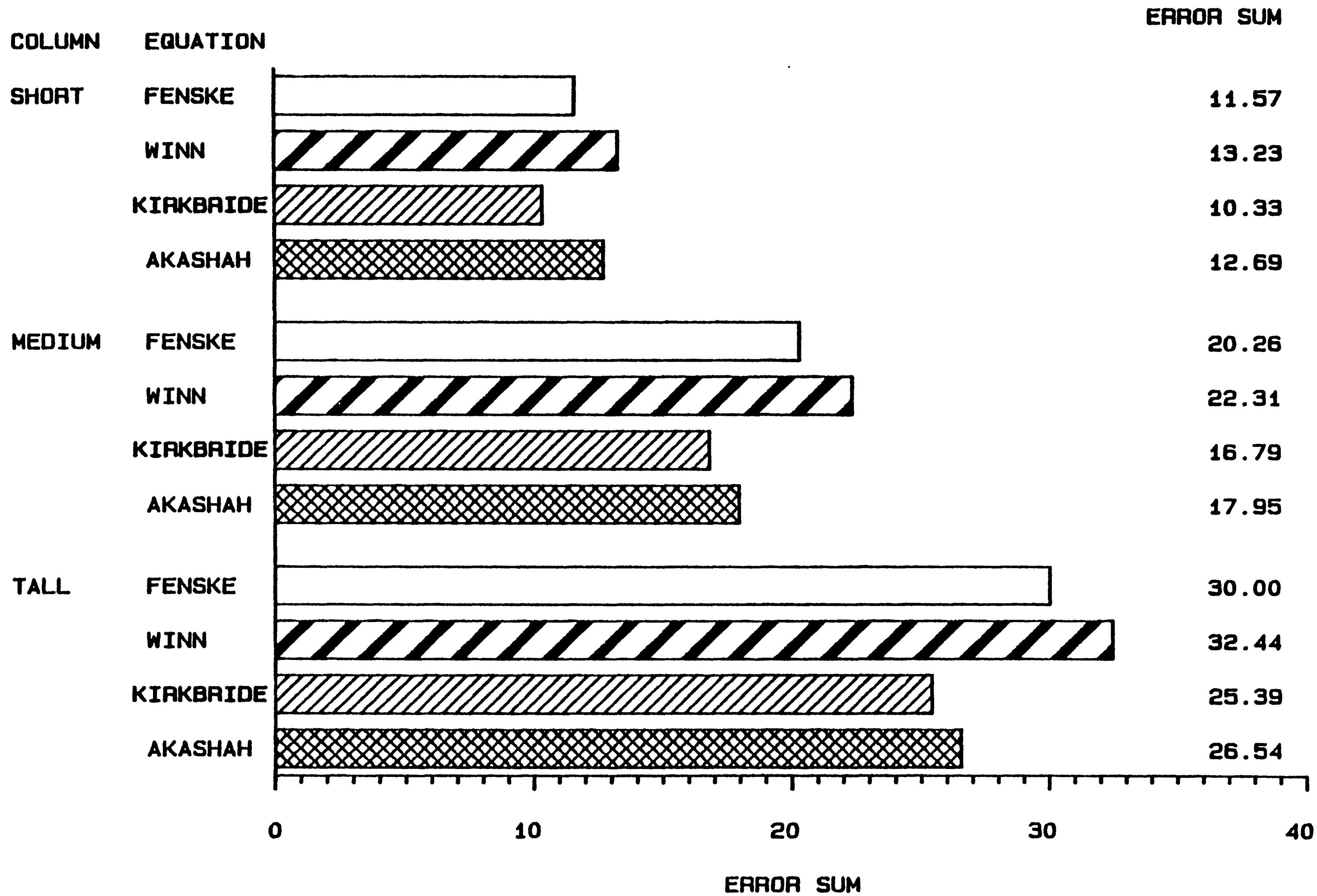


Figure 4. Comparison of the Error Sums

feed plate location and for the calculated feed plate locations from the Fenske, Winn, Kirkbride and Akashah et al. correlations. These were shown as Figures 5 to 9. The relationship in Equation (33) was first assumed to be a linear equation,

$$N_s = \text{slope } N + \text{ intercept.}$$

Linear regression analysis was carried out using the Statistical Analysis System (Helwig, 1978), SAS. The SAS input programs and printouts are shown in Appendix D. The slopes, intercepts and R-square values are tabulated as Table VIII.

The "R-square" is the value that measures how much variation in the feed plate location can be accounted for by the regression equation. R-square, which can range from zero to one, is the ratio of the sum of squares for the regressed values divided by the sum of squares for the calculated values. In general, the larger the value of R-square, the better the regression equation fits.

Some remarks can be made from Table VIII and Figure 4 as follows:

1. The slope and intercept from the Kirkbride case are the closest values to those from the theoretical case which produces the smallest error sums.
2. Since the regression equation will be justified as a good fit when the R-square is higher than 0.95, the feed plate location can not be set as a linear function of the total number of plates.

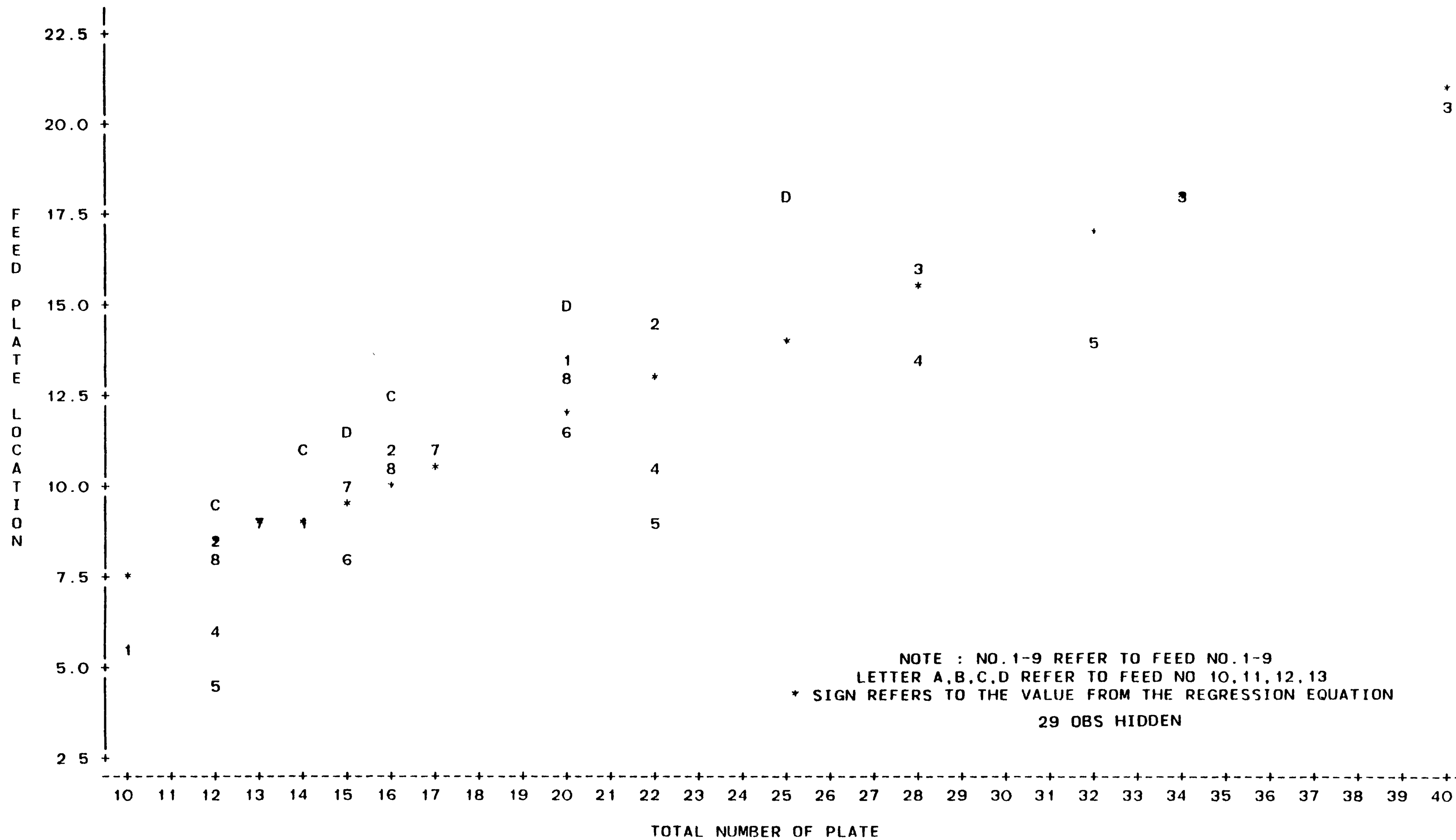


Figure 5. Effect of Column Sizes on Feed Plate Location by MAXISIM

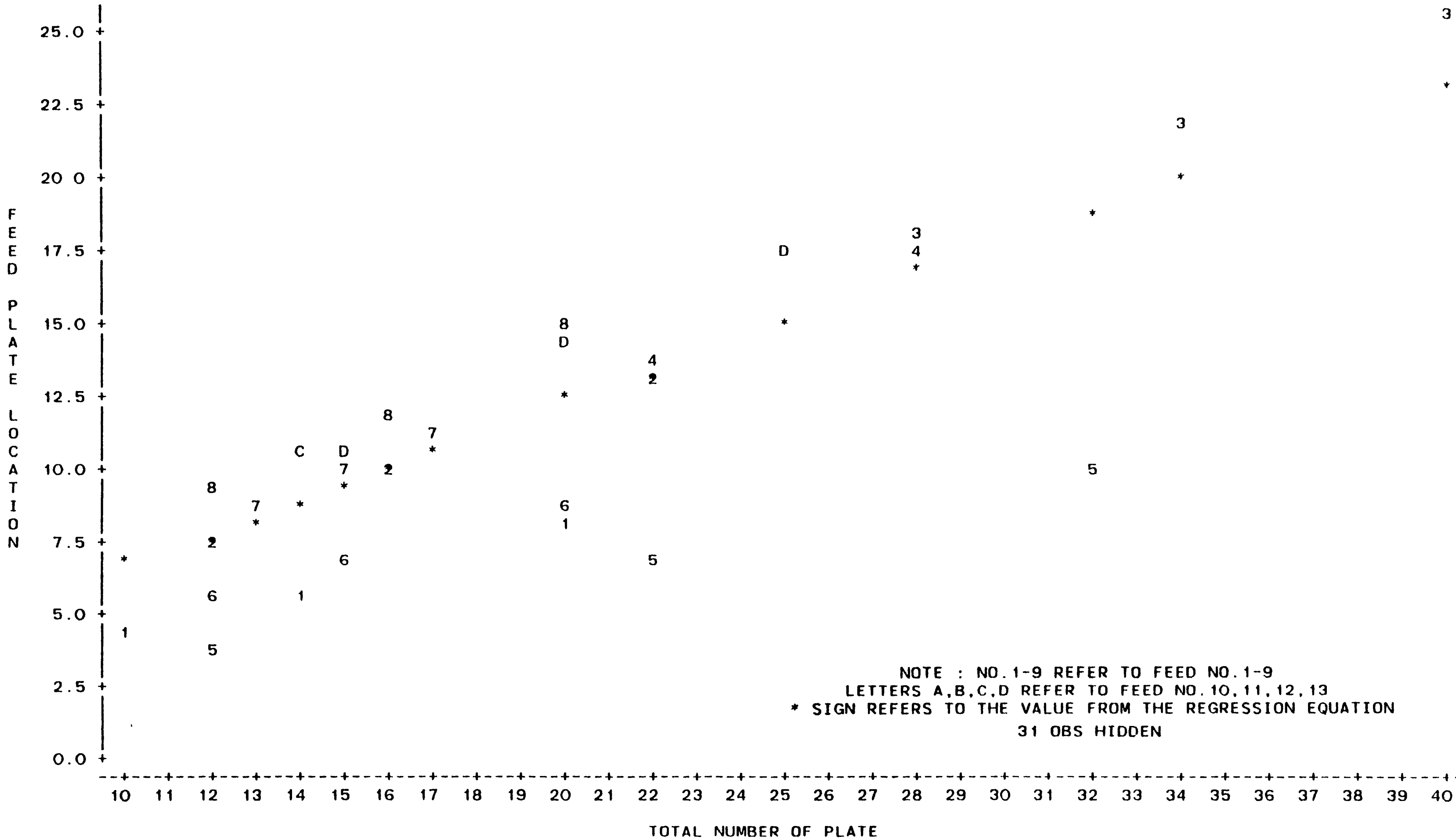


Figure 6. Effect of Column Sizes on Feed Plate Location by the Fenske Correlations

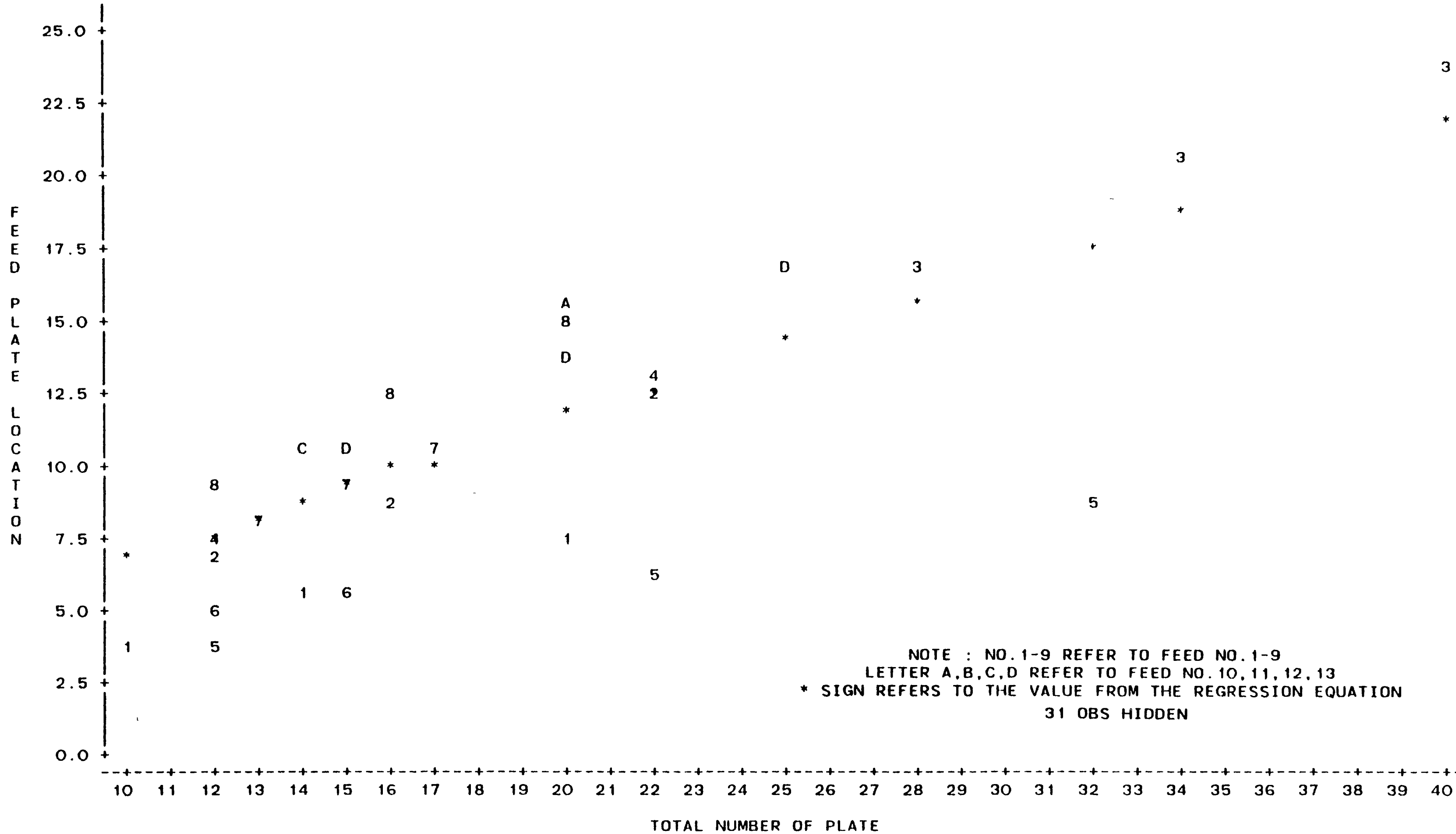


Figure 7. Effect of Column Size on Feed Plate Location by the Winn Correlations

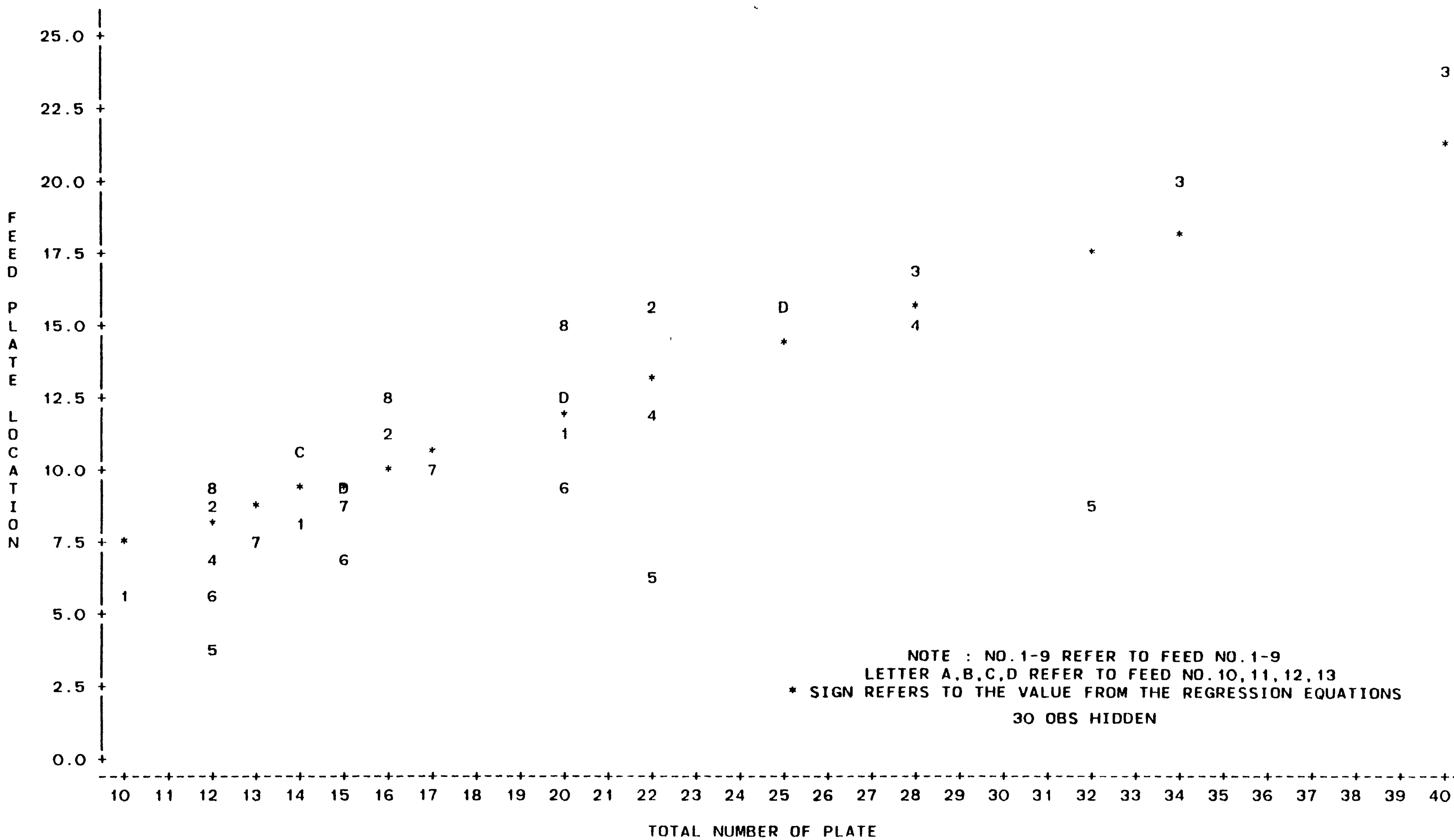


Figure 8. Effect of Column Size on Feed Plate Location by the Kirkbride Correlation

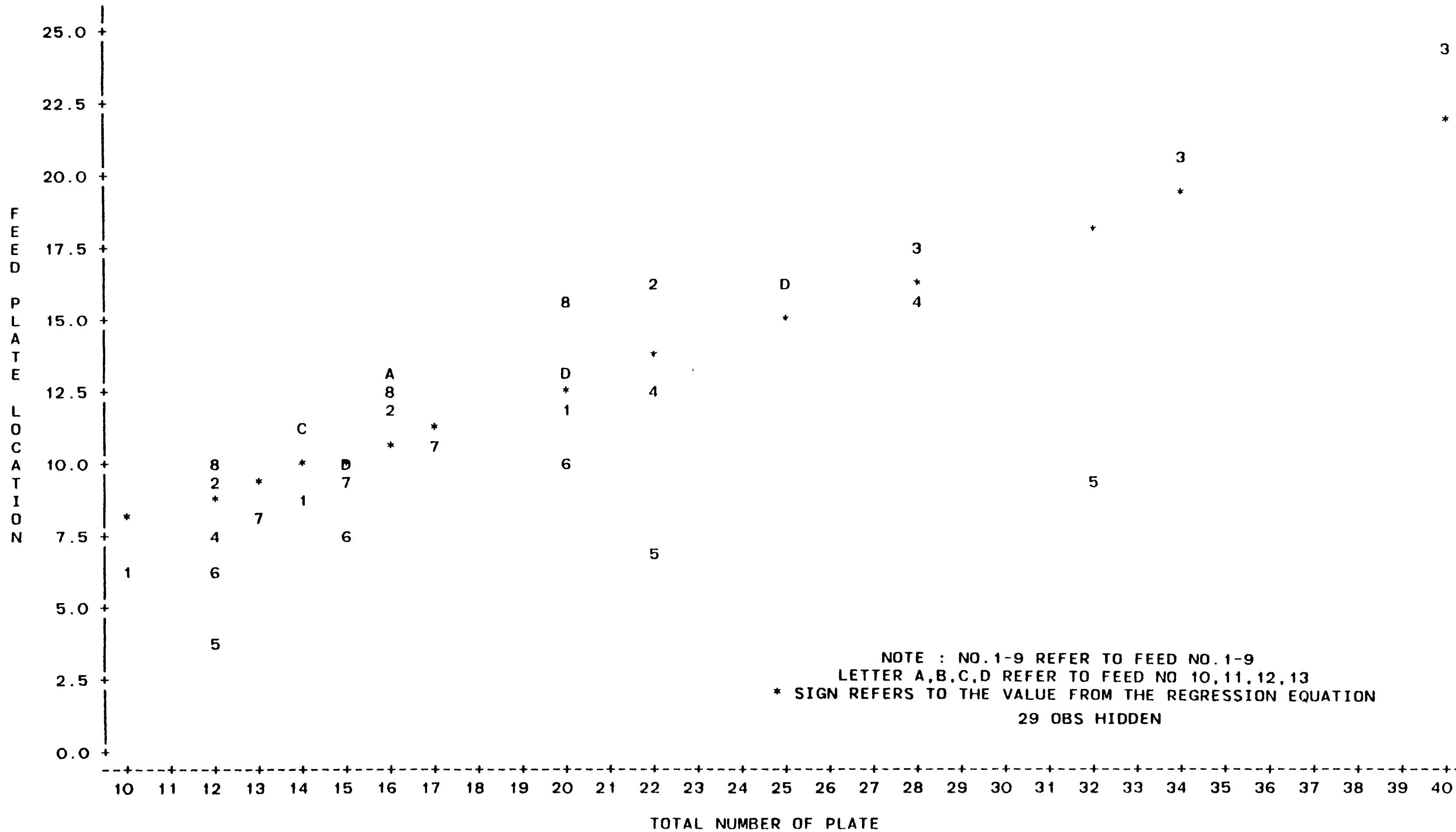


Figure 9. Effect of Column Size on Feed Plate Location by the Akashah Et Al. Correlations

TABLE VIII

COMPARISON OF THE SLOPES, INTERCEPTS, AND R-SQUARES FROM LINEAR REGRESSION ANALYSES

Source	Slope	Intercept	R-Square
Fenske	0.553	1.154	0.655
Winn	0.501	1.708	0.571
Kirkbride	0.465	2.669	0.583
Akashah et al.	0.469	3.164	0.596
Theoretical Feed Plate (MAXISIM)	0.446	2.972	0.744

However, the slope and intercept from the linear regression equation will be used to estimate the constants in Model 1.

Recall Model 1 (from Chapter III):

$$\log(N_r/N_s) = \log\{(f/f')^{C1}(b/d')^{C2}(d/b')^{C3}\} \qquad (30)$$

The constants C1, C2, and C3 are varied until the slope and intercept of the regression equation are close to those from MAXISIM determination of the theoretical feed plate location with the corresponding slopes and intercepts shown in Table XLVII of Appendix E.

The selected values of C1, C2, and C3 are 0.1, 0.1, and 0.1. These will give the slope and intercept for a regression equation from Model 1 of 0.377 and 2.049, respectively.

The error sums of Model 1 are estimated and compared with other correlations as Figure 10. It shows that Model 1 produced large error sums especially for the short column case. So far, the combinations of variables used in all correlations are related to molar flow rates of key components. There should be some new type of variable that whem combined with the group of key component variables will reduce the error sum. The temperature difference between the reboiler and the condenser, ΔT, should help in improving the feed plate prediction, since it is shown, in Figure 11, that ΔT can be related to the error sums by some function.

Model 2 with ΔT as one of the variables is the next

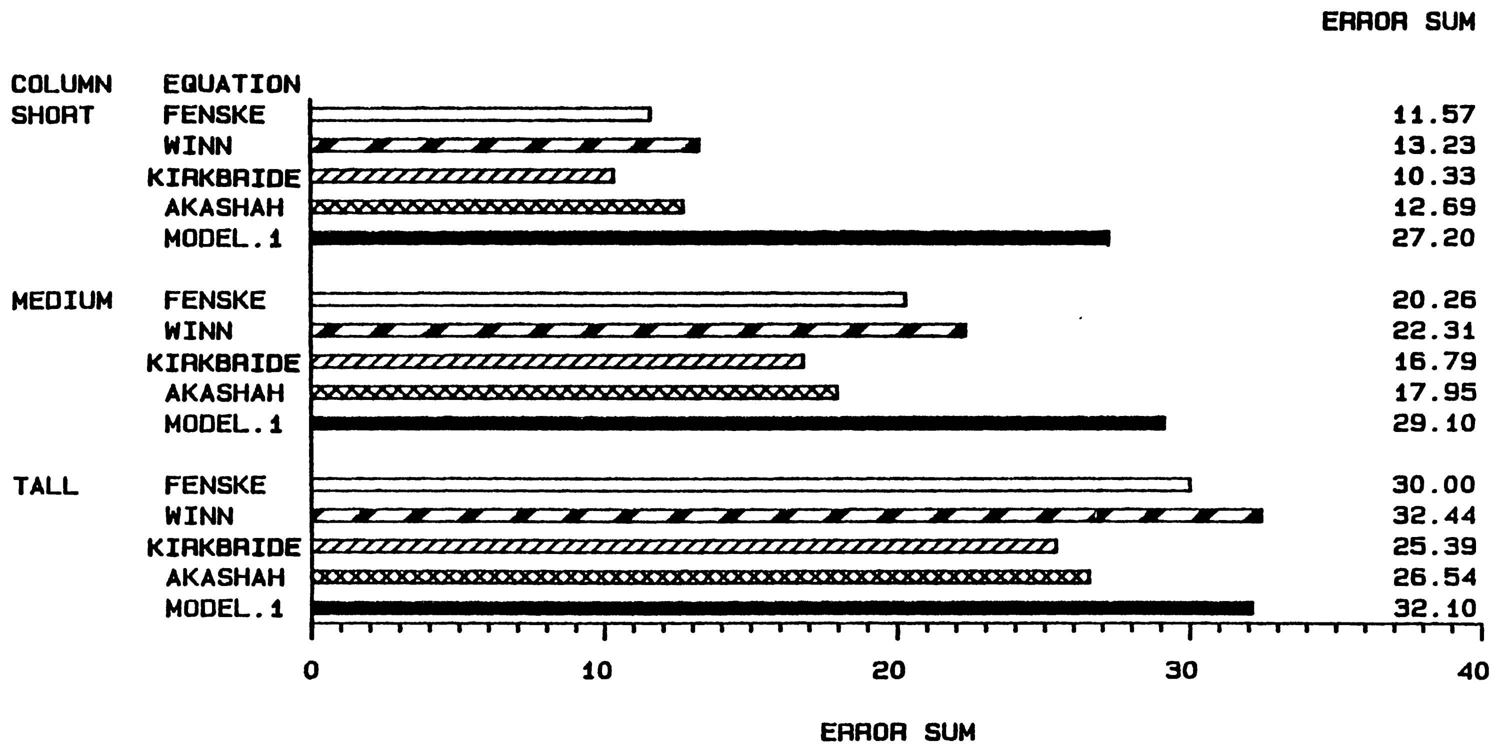


Figure 10. Error Sums from Model 1 Compared to the Other Correlations

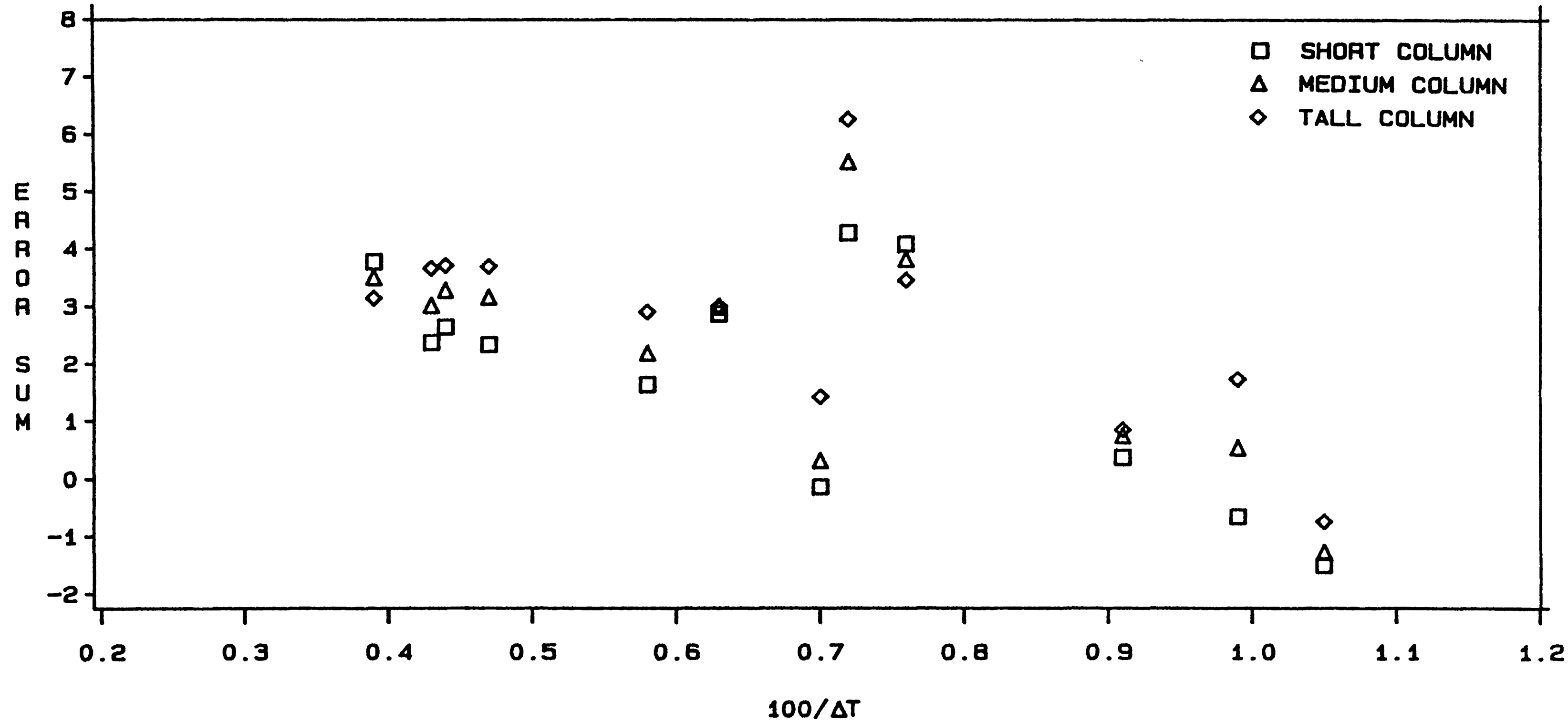


Figure 11. Effect of ΔT on Error Sums

correlation to be examined. Recall Model 2 (Equation (32) of Chapter III):

$$\log(N_r/N_s) = \log\{(f/f')^{K1}(b/d')^{K2}(XLD/XHB)^{K3}\} \quad (32)$$

The ΔT variable will be added to Model 2 as:

$$\log(N_r/N_s) = \log\{(f/f')^{K1}(b/d')^{K2}(XLD/XHB)^{K3}(100/\Delta T)^{K4}\} \quad (34)$$

where K4 is the unknown exponent. The constants K1, K2, and K3 will be assumed to be C1, C2, and C3 of Model 1 but may need to be adjusted later. The final form of Model 2 can be written as:

$$\log(N_r/N_s) = \log\{(f/f')^{0.1}(b/d')^{0.1}(XLD/XHB)^{0.1}(100/\Delta T)^{K4}\} \quad (35)$$

In order to estimate the proper value of the exponent, K4, the error sums of the short, medium, and tall column were calculated for each K4. The graphs of the error sums as functions of K4 have been prepared as Figure 12. It can be seen that when K4 equals to 0.82, the error sums of all three cases are at the minimum.

Other combinations of constants K1, K2, and K3 were attempted, yet, error analysis showed that the original constants set by Model 1 give the least error.

The accuracy of Model 2 with a ΔT variable gives the smallest error sums when compared to the other correlations as seen in Figure 13. Hence, the new proposed correlation to predict the optimum feed plate location, for saturated liquid feed, can be expressed as:

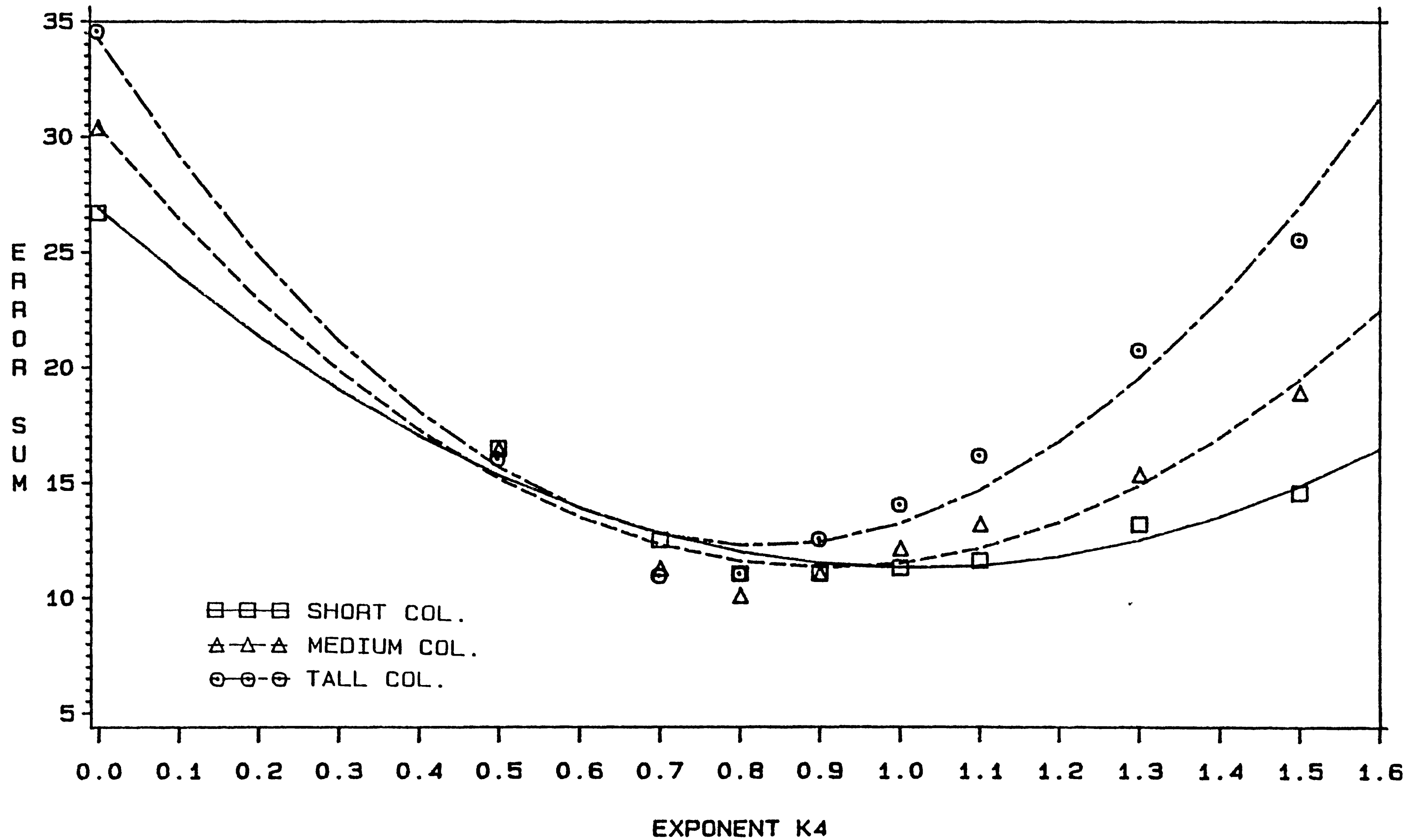


Figure 12. Effect of Exponent K4 on Error Sums

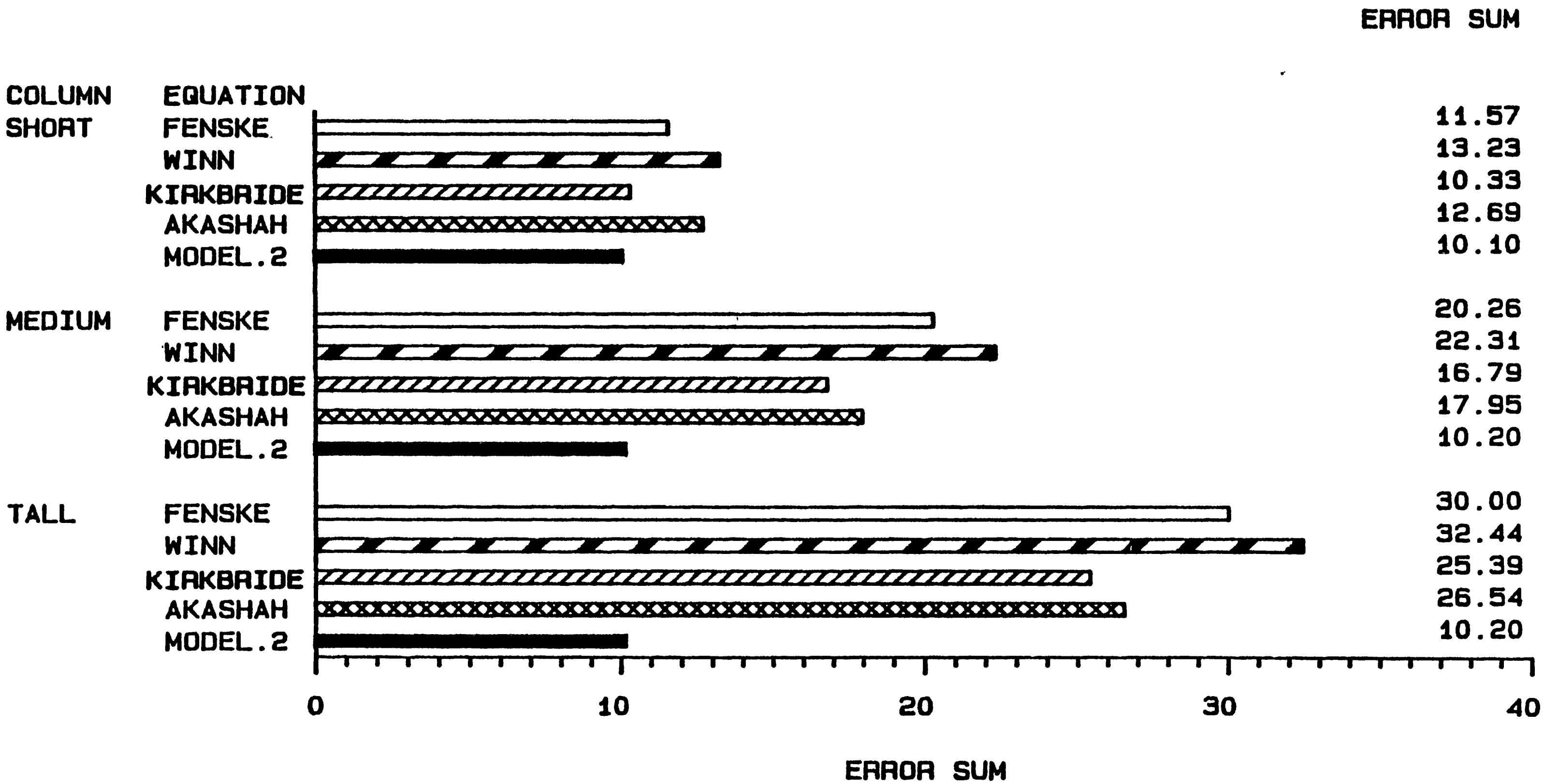


Figure 13. Error Sums from Model 2 Compared to the Other Correlations

$$\log(N_r/N_s) = \log\{(f/f')^{0.1}(b/d')^{0.1}(XLD/XHB)^{0.1}(100/\Delta T)^{0.82}\} \quad (36)$$

or

$$\log(N_r/N_s) = 0.1 \log\{(f/f')(b/d')(XLD/XHB)(100/\Delta T)^{8.2}\} \quad (37)$$

The (d/D)/(b'/B), or XLD/XHB, term in Model 2 is a stable term compared to the square of the (b/B)/(d'/D), or XLB/XHD, term in the Kirkbride correlation as shown in Table IX. The square of the XLB/XHD term can be as high as 97.22 in Feed No.5 or as low as 0.008 in Feed No.2 while the XLD/XHB term vary from 0.88 to 11.00. The highest value of XLB/XHD square causes the prediction of the feed plate location of Feed No.5 to deviate drastically from the other calculated values as seen in Figure 6.

Various Feed Vaporization Conditions

The development of some term to be added to Model 2, which served as the main correlation, in order to enable it to predict the feed plate location at various feed vaporizations, will be shown in this section. The new term should vanish when the feed is introduced at the saturated liquid condition and should increase the ratio of (N_r/N_s), since, in general, the feed plate will be lower when the percentage of liquid in the feed decreases.

A new variable related to the feed vaporization will be defined, i.e., L/F, where L is the amount of liquid in the feed. For example, L/F is equal to one if the feed is introduced to the column at the saturated liquid condition

TABLE IX

COMPARISON OF THE $\{(b/B)/(d'/D)\}^2$ AND $(d/D)/(b'/B)$ TERMS

Feed No.	Kirkbride Correlation			Model 2		
	(b/B)	(d'/D)	$\{(b/B)/(d'/D)\}^2$	(d/D)	(b'/B)	(d/D)/(b'/B)
1	0.005	0.050	0.010	0.95	0.86	1.10
2	0.003	0.034	0.008	0.94	0.37	2.54
3	0.015	0.009	2.790	0.97	0.20	4.85
4	0.048	0.024	4.000	0.61	0.21	2.90
5	0.069	0.007	97.220	0.49	0.56	0.88
6	0.009	0.013	0.476	0.85	0.47	1.81
7	0.023	0.010	5.290	0.89	0.42	2.12
8	0.003	0.022	0.020	0.39	0.04	9.75
10	0.003	0.022	0.012	0.39	0.04	9.75
11	0.003	0.021	0.014	0.37	0.04	9.25
12	0.002	0.019	0.014	0.33	0.03	11.00
13	0.047	0.063	0.563	0.91	0.27	3.37

and equal to zero if the feed is introduced at the saturated vapor condition.

The relationships between total plates in the column and feed plate location at various feed conditions have been observed in all thirteen feeds. These relationships can be seen in Figure 3 for Feed No.1, Figure 25 (in Appendix B) for Feed No.2, etc. The distances between the saturated liquid feed line and the other feed condition lines are varied. They might be close to each other as in Feed No.4 (Figure 30 in Appendix B) or far apart as in Feed Nos.8 to 12 (Figure 38, 40, 42, and 44 in Appendix B), which in the later case might be caused by the presence of the large difference in molecular weight of the components between the condenser and the reboiler. Since the temperature difference between the reboiler and the condenser, ΔT, indicates the difference in molecular weight of components in these two stages, it should be one variable that can be added to the new term.

The differences between feed plate location at saturated liquid feed and other feed conditions, Δd, and ΔT have been calculated. These differences are tabulated in Table X and depicted as Figures 14 to 16. The Δd_1 refers to the difference of the feed plate location between feeds at saturated liquid and 50 percent liquid condition and Δd_2 refers to the difference of feed plate location between feeds at saturated liquid and saturated vapor condition. The lines drawn through the coordinates in Figures 14 to 16

TABLE X

VALUES OF Δd AND ΔT AT VARIOUS COLUMN SIZES AND FEED CONDITIONS

Feed No.	L/F	Short Column FPL	Short Column $\Delta d_1, \Delta d_2$	Medium Column FPL	Medium Column $\Delta d_1, \Delta d_2$	Tall Column FPL	Tall Column $\Delta d_1, \Delta d_2$	ΔT
1	1.0	5.4		8.8		13.3		
			1.2		1.8		2.3	
	0.5	4.2		7.0		11.0		101.3
			1.9		2.8		3.3	
	0.0	3.5		6.0		10.0		
2	1.0	6.4		8.3		10.9		
			1.4		1.3		1.1	
	0.5	5.0		7.0		9.8		193.0
			2.3		2.4		2.3	
	0.0	4.1		5.9		8.6		
3	1.0	16.0		18.2		20.3		
			0.8		0.5		0.3	
	0.5	15.2		17.7		20.0		141.0
			1.4		0.6		-0.2	
	0.0	14.6		17.6		20.5		
4	1.0	6.0		10.7		13.4		
			0.5		0.5		0.4	
	0.5	5.5		10.2		13.0		111.8
			0.9		0.8		0.7	
	0.0	5.1		9.9		12.7		
5	1.0	4.3		9.0		12.2		
			0.8		0.5		-1.0	
	0.5	3.5		8.5		13.2		94.4
			1.6		1.8		1.7	
	0.0	2.7		7.2		10.5		
6	1.0	6.1		8.0		11.5		
			0.6		0.6		0.9	
	0.5	5.5		7.4		10.6		152.8
			1.3		1.4		1.7	
	0.0	4.8		6.6		9.8		

TABLE X (CONTINUED)

Feed No.	L/F	Short Column FPL	Short Column Δd_1	Short Column Δd_2	Medium Column FPL	Medium Column Δd_1	Medium Column Δd_2	Tall Column FPL	Tall Column Δd_1	Tall Column Δd_2	ΔT
7	1.0	9.1			10.1			11.0			
			1.1			1.2			1.2		
	0.5	8.0			8.9			9.8			174.0
				1.9			2.1			2.0	
	0.0	7.2			8.0			9.0			
8,9	1.0	8.1			10.7			13.0			
			2.3			3.5			4.3		
	0.5	5.8			7.2			8.7			251.1
				4.2			6.3			8.3	
	0.0	3.9			4.4			4.7			
10	1.0	8.1			10.5			12.9			
			3.0			4.1			5.5		
	0.5	5.1			6.4			7.4			275.3
				5.2			7.3			9.4	
	0.0	5.9			3.2			3.5			
11	1.0	8.4			10.8			13.0			
			3.1			4.0			5.0		
	0.5	5.3			6.8			8.0			272.5
				5.0			6.8			8.6	
	0.0	3.4			4.0			4.4			
12	1.0	9.5			11.0			12.4			
			4.6			5.5			6.3		
	0.5	4.9			5.5			6.1			311.9
				6.5			7.8			9.1	
	0.0	3.0			3.2			3.3			
13	1.0	11.5			15.0			18.0			
			1.5			2.1			2.0		
	0.5	10.0			12.9			16.0			148.7
				3.5			4.0			4.0	
	0.0	8.0			11.0			14.0			

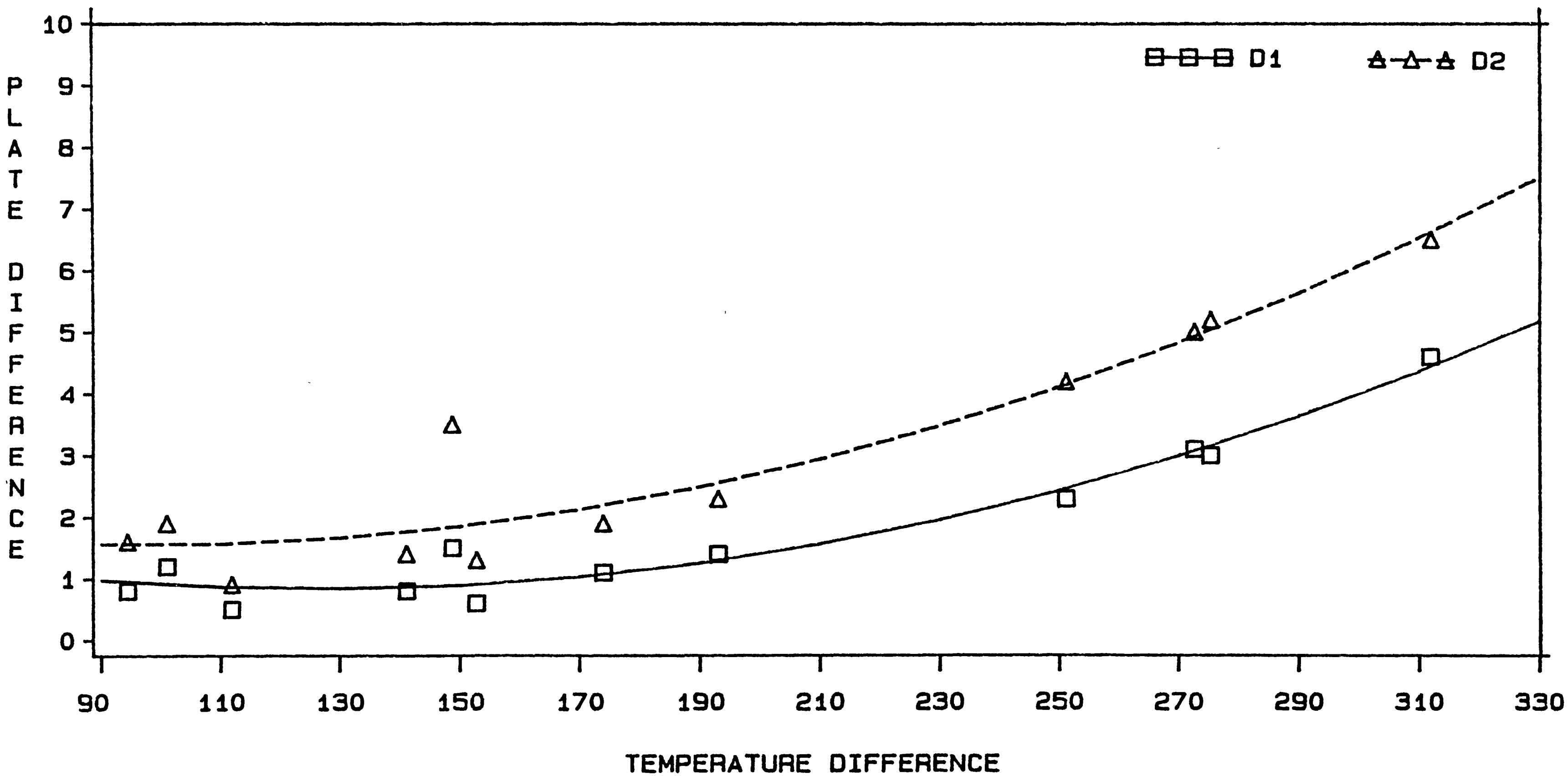


Figure 14. Effect of Temperature Difference Between Reboiler and Condenser to Feed Plate Difference - Short Column

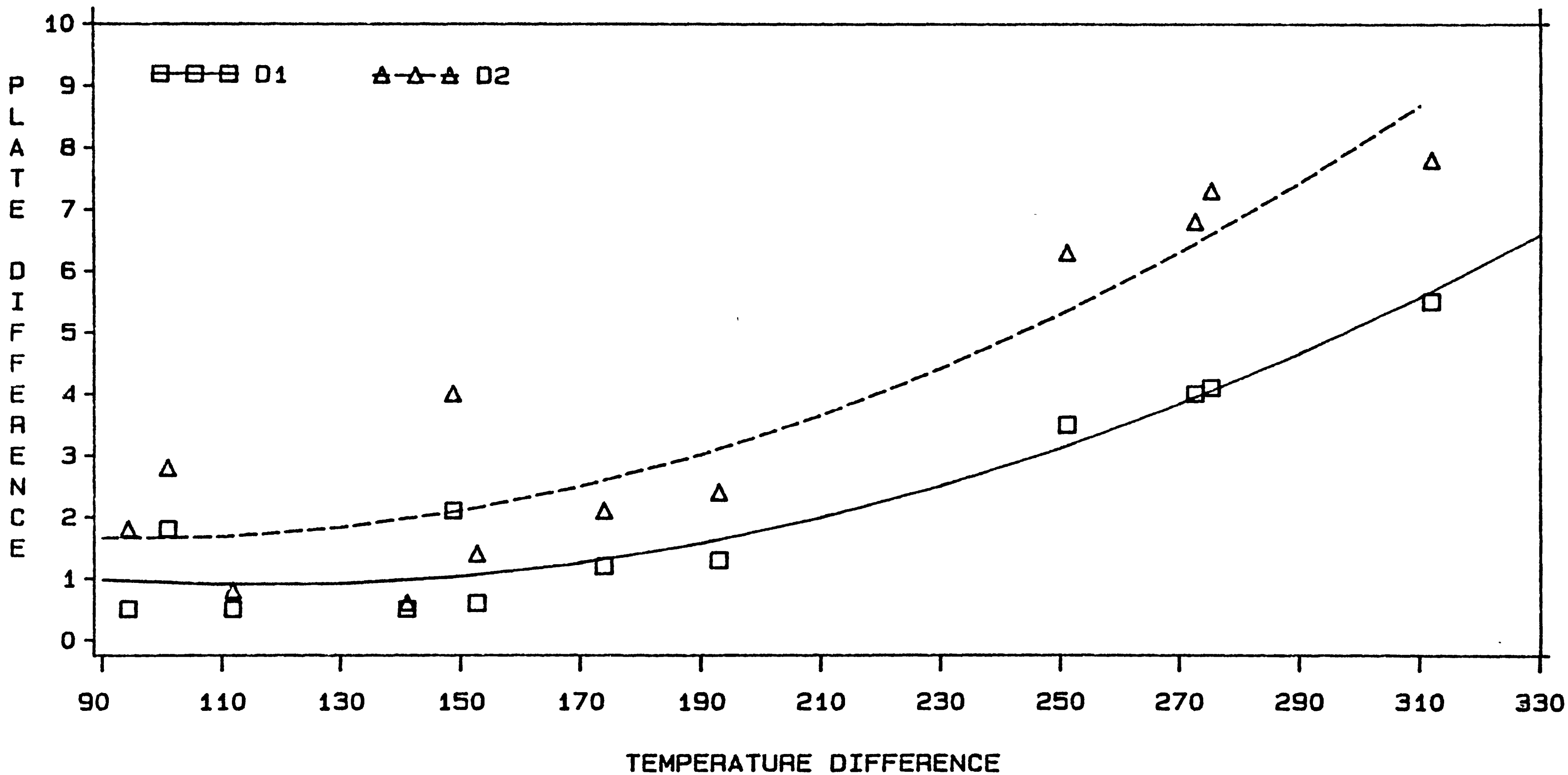


Figure 15. Effect of Temperature Difference Between Reboiler and Condenser to Feed Plate Difference - Medium Column

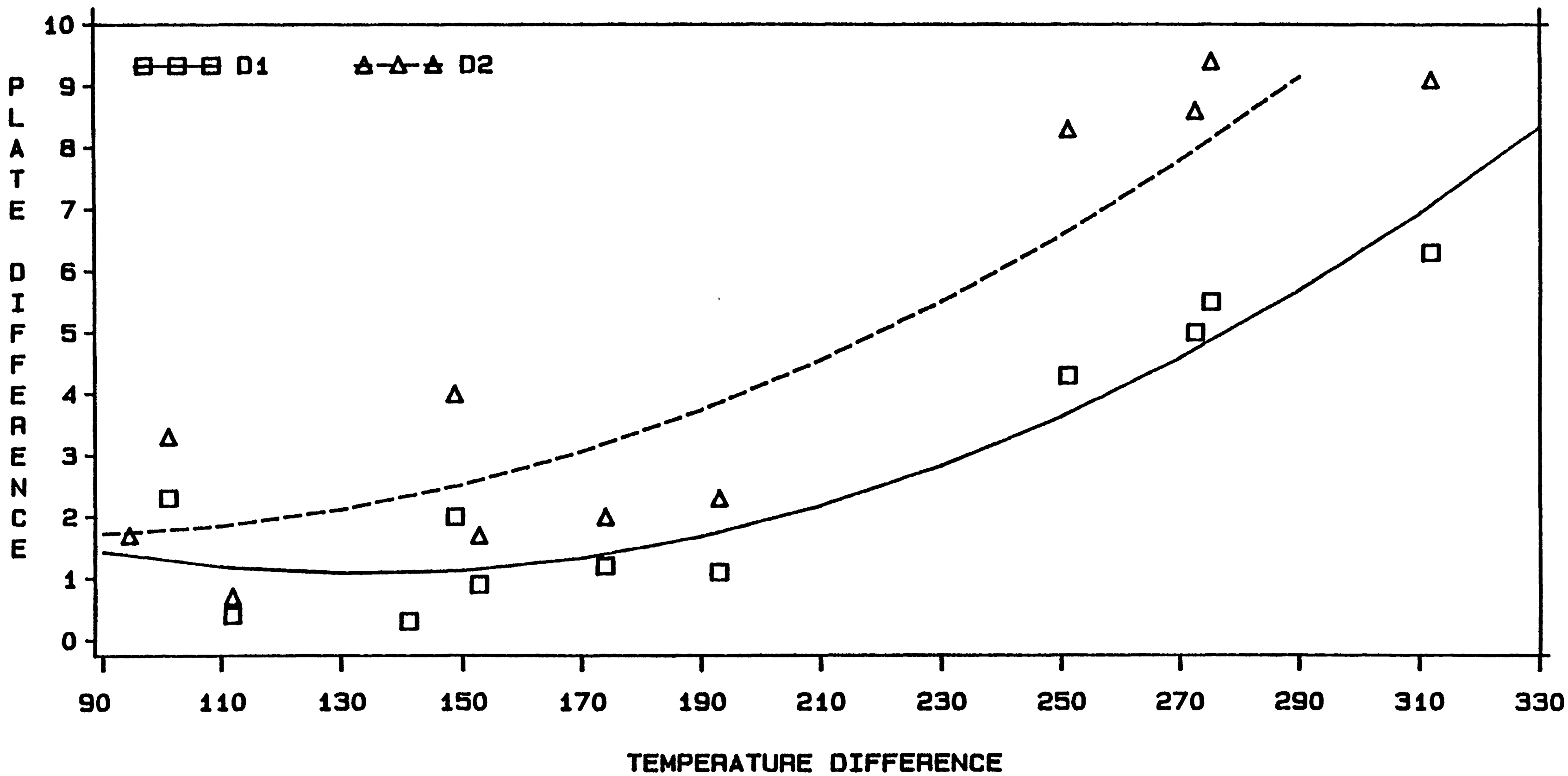


Figure 16. Effect of Temperature Difference Between Reboiler and Condenser to Feed Plate Difference - Tall Column

are the results of the curve fitting routine generated by the SAS package program. The lines are simply to help in visualizing the variations among the coordinates. The lines themselves do not have any physical or theoretical significance.

Figures 14 to 16 show that the feed plate difference can be related to some function of ΔT. Recall Model 2 :

$$\log(N_r/N_s) = 0.1 \log\{(f/f')(b/d')(XLD/XHB)(100/\Delta T)^{8.2}\} \quad (37)$$

If ΔT is added to Model 2 with the L/F variable as:

$$\log(N_r/N_s) = 0.1 \log\{(f/f')(b/d')(XLD/XHB)(100/\Delta T)^{8.2}\} + (K5)\ (1 - L/F)(\Delta T/100)^{K6} \quad (38)$$

where K5 and K6 are unknown constants. The K5 and K6 constants can be estimated by means of the minimization of the error sums as shown in Appendix F. The selected values for K5 and K6 are 0.1 and 2.1, respectively. The final correlation to estimate the optimum feed plate location for various feed vaporizations can be written as:

$$\log(N_r/N_s) = 0.1 \log\{(f/f')(b/d')(XLD/XHB)(100/\Delta T)^{8.2}\} + 0.1\ (1 - L/F)(\Delta T/100)^{2.1} \quad (39)$$

When Equation (39) is applied to the saturated liquid feed, the last term on the right hand side will equal to zero and Equation (39) will be identical to Equation (37). The accuracy test for Equation (39) will be made and compared to the other correlations in Chapter V.

CHAPTER V

TESTING OF THE PROPOSED CORRELATION

Model 2 has been proposed as a correlation to predict feed plate locations at various feed vaporizations. It will be tested for accuracy by comparison of the feed plate location from Model 2 to the feed plate location from the other correlations at the saturated liquid feed condition and by comparison of the feed plate location from Model 2 to the theoretical feed plate location (from MAXISIM simulations) at 75, 50 and 25 percent liquid and at saturated vapor conditions.

Four test feeds were selected for evaluating the proposed correlation. These feeds are referred to as Test Nos.1 to 4 and were taken from Hines and Maddox (1985), Henley and Seader (1981), King (1971), and Erbar (1980), respectively. Feed compositions, process conditions and predictions of optimum feed plate locations of all four tests will be included in Appendix F.

Determination of the theoretical and calculated feed plate locations were carried out by the same procedure as explained in the previous chapter. The difference between theoretical and calculated feed plates, from every correlation, were estimated in terms of error and percentage error and were tabulated in Table XI. Table XII contains

TABLE XI

COMPARISON OF THE OPTIMUM FEED PLATE ERRORS FROM PROPOSED CORRELATION (MODEL 2) WITH OTHER CORRELATIONS (AT SATURATED LIQUID FEED)

Test No.	Column Size	Model 2		Kirkbride		Akashah Et Al.		Fenske		Winn	
		Error	%Error	Error	%Error	Error	%Error	Error	%Error	Error	%Error
1	12	0.9	12.86	1.3	18.57	0.7	10.00	1.3	18.57	1.9	27.14
	15	1.3	14.77	1.7	19.32	1.1	12.50	1.8	20.45	2.6	29.55
	24	2.3	16.43	2.9	20.71	2.3	16.43	3.1	22.14	4.3	30.71
2	17	0.6	5.36	2.4	21.43	1.8	16.07	1.7	15.18	2.7	24.11
	26	-0.3	-1.92	2.4	15.38	1.7	10.90	1.4	8.97	2.8	17.95
	35	-1.1	-5.50	2.4	12.00	1.7	8.50	1.1	5.50	2.9	14.50
3	13	0.7	7.07	3.3	33.33	2.8	28.28	2.8	28.28	3.5	35.35
	19	0.4	2.96	4.1	30.37	3.5	26.19	3.4	25.19	4.4	32.59
	23	0.1	0.63	4.5	28.48	3.9	24.68	3.7	23.42	4.9	31.01
4	10	1.0	15.38	1.1	16.92	0.6	9.23	0.6	9.23	1.0	15.38
	15	1.1	12.22	1.1	12.22	0.5	5.56	0.4	4.44	0.9	10.00
	21	0.9	7.63	0.9	7.63	0.3	2.54	-0.1	0.85	0.7	5.93

TABLE XII

COMPARISON OF THE ERRORS BETWEEN PROPOSED CORRELATION (MODEL 2) AND MAXISIM AT VARIOUS FEED VAPORIZATIONS

Test No.	Column Size	Sat.Liq.Feed Error	Sat.Liq.Feed %Error	Feed@L/F=0.75 Error	Feed@L/F=0.75 %Error	Feed@L/F=0.5 Error	Feed@L/F=0.5 %Error	Feed@L/F=0.25 Error	Feed@L/F=0.25 %Error	Sat.Vap.Feed Error	Sat.Vap.Feed %Error
1	12	0.9	12.86	0.7	10.61	0.2	3.39	-0.1	1.85	-	-
	15	1.3	14.77	1.2	14.29	0.8	10.26	0.5	6.94	-	-
	24	2.3	16.43	2.4	17.52	2.5	18.66	2.5	19.23	-	-
2	17	0.6	5.36	0.9	8.33	1.0	9.80	1.2	12.37	-	-
	26	-0.3	-1.92	0.6	3.90	1.4	9.21	2.3	15.33	-	-
	35	-1.1	-5.50	0.0	0.00	1.8	8.91	3.5	17.50	-	-
3	13	0.7	7.07	1.0	11.24	1.2	15.38	1.6	23.53	1.9	31.67
	19	0.4	2.96	1.2	9.60	2.1	18.26	3.1	29.25	3.9	40.21
	23	0.1	0.63	1.3	8.78	2.8	20.00	4.1	31.30	5.2	42.62
4	10	1.0	15.38	0.8	13.33	0.5	9.26	0.1	2.13	-0.2	-4.88
	15	1.1	12.22	0.9	10.71	0.6	7.79	0.4	5.63	0.3	4.55
	21	0.9	7.63	0.9	8.04	0.8	7.55	0.8	8.00	0.9	9.47

the error and the percentage error of the predicted feed plate by Model 2, at saturated, 75, 50, and 25 percent liquid, and saturated vapor feed.

At the saturated liquid feed condition, Model 2 predicts the feed plate location, in general, better than the other correlations. It gives a good prediction, especially in the short column, but an error of 2 plates in tall column of Test No.1. However, as far as the minimum reflux rate accounts for the optimum feed plate location, the error of 2 plates in the tall column will result in a slight difference in the reflux rate from the optimum. As an example shown in Figure 17, the error of 2.3 plates in the tall column will lead to the error, from the minimum reflux rate, of 0.6 mole per hour. On the other hand, the same error of plate in the short column will lead to 11.6 moles per hour.

At various feed conditions, Model 2 produced no more than 20 percent error when applied to the feed with a percentage of liquid as low as 25 percent as in Test No.1 and 2 or with saturated vapor as in Test No.4. Test No.3 showed considerable error when the feed had lower than 50 percent liquid.

Comparison of optimum feed plate predictions by Model 2 to theoretical feed plate from Test Nos.1 to 4 are shown as Figures 18 to 21. The patterns of lines, orientations of line and distances between each line of various feed vaporizations, from Model 2 sometimes are agreeable

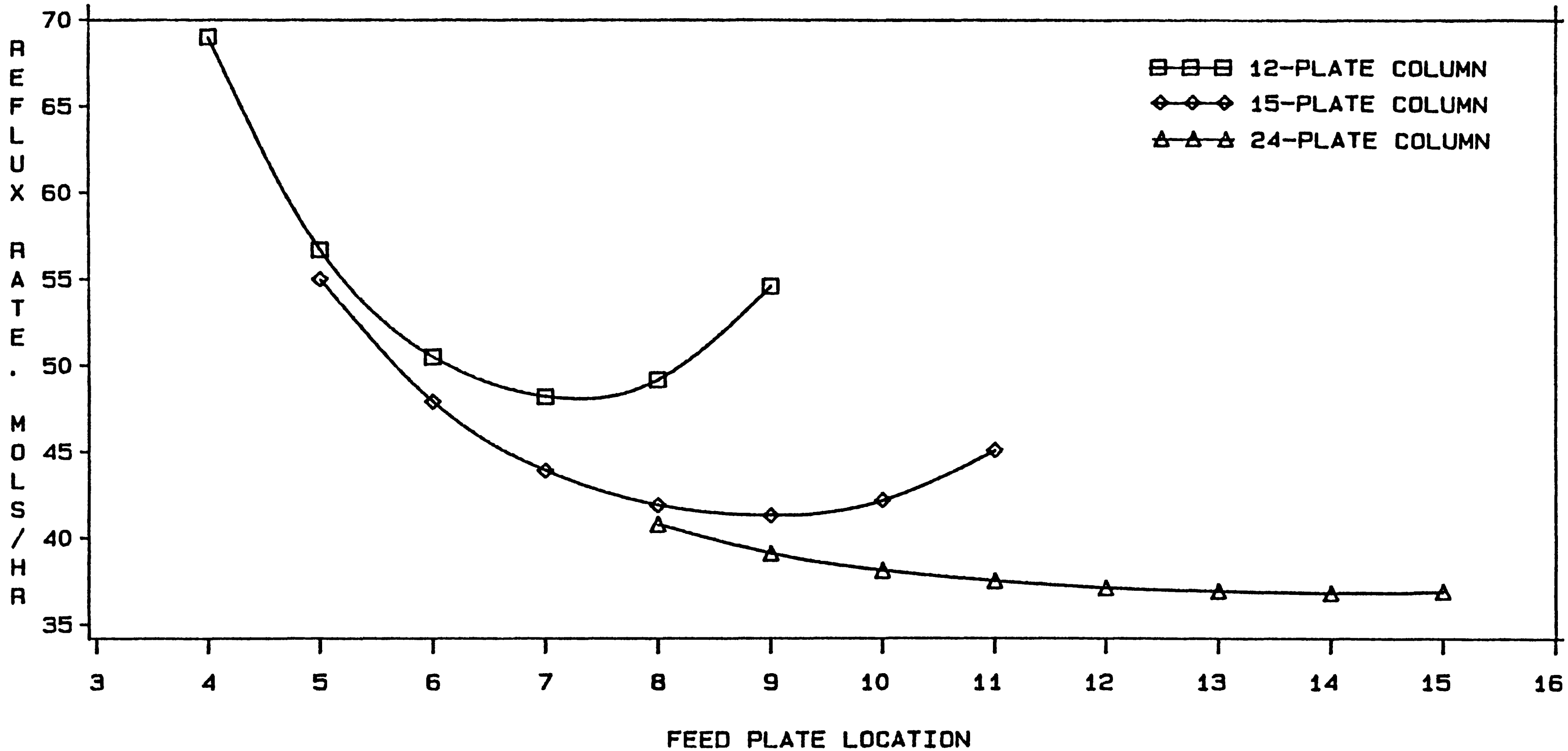


Figure 17. Effect of Feed Plate Location On Reflux Rates-Saturated Liquid Feed from Test No.1

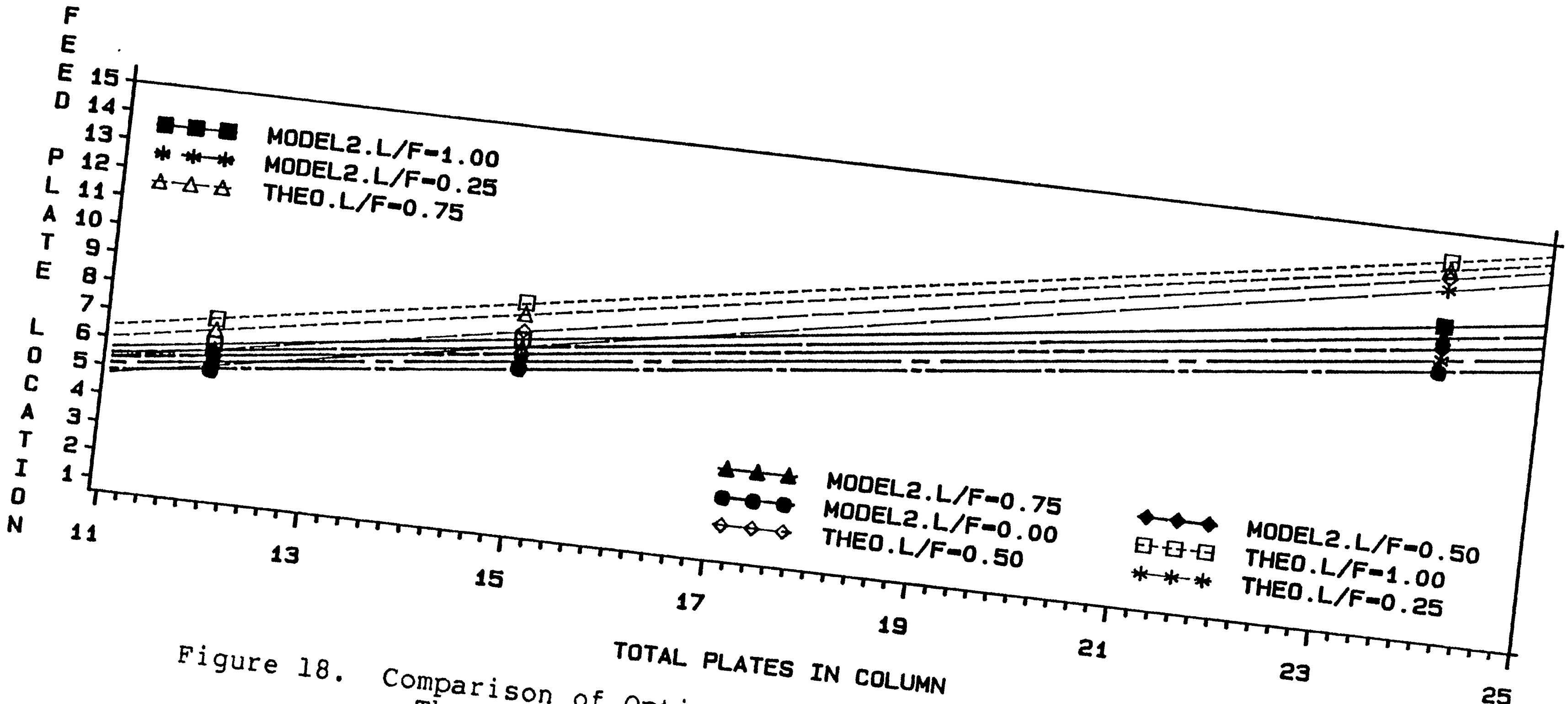


Figure 18. Comparison of Optimum Feed Plate Locations by Model 2 to Theoretical Feed Plate - Test No.1

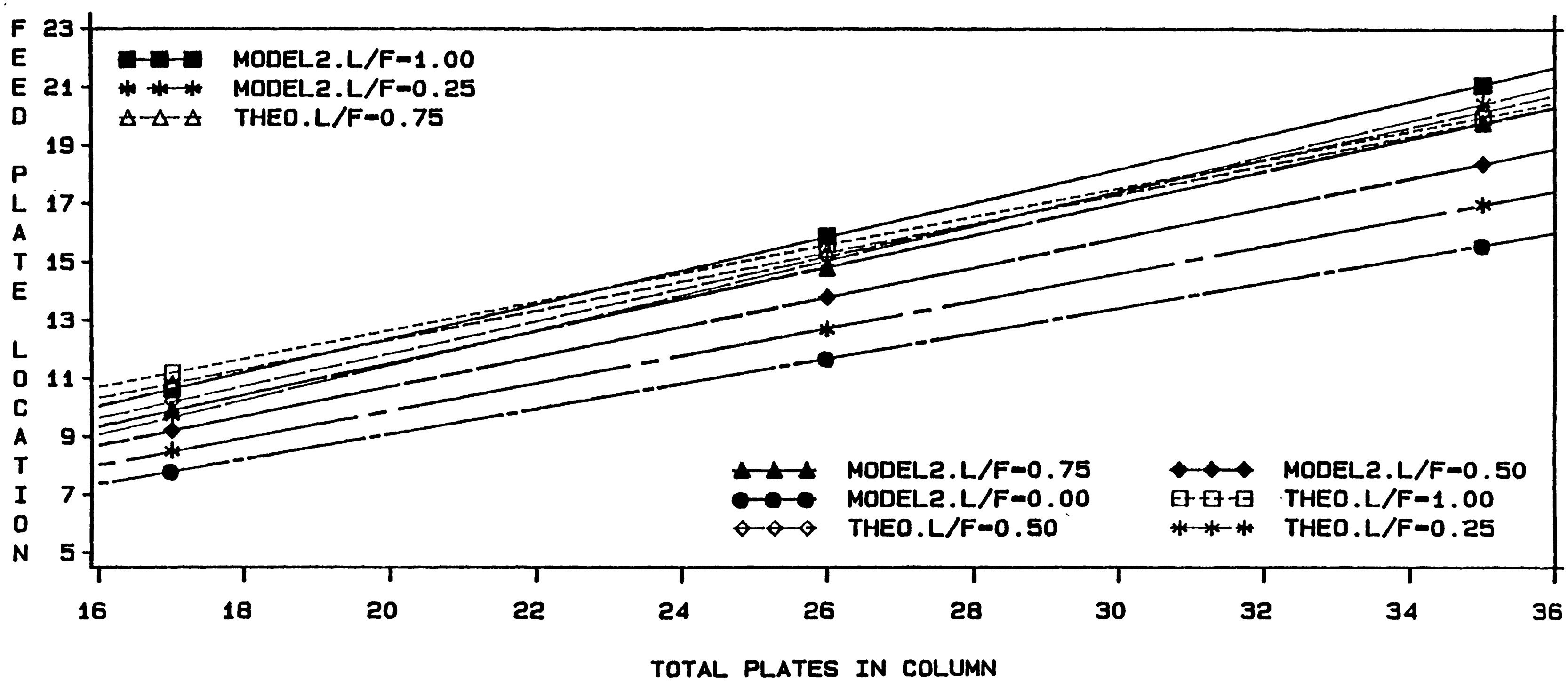


Figure 19. Comparison of Optimum Feed Plate Locations by Model 2 to Theoretical Feed Plate - Test No.2

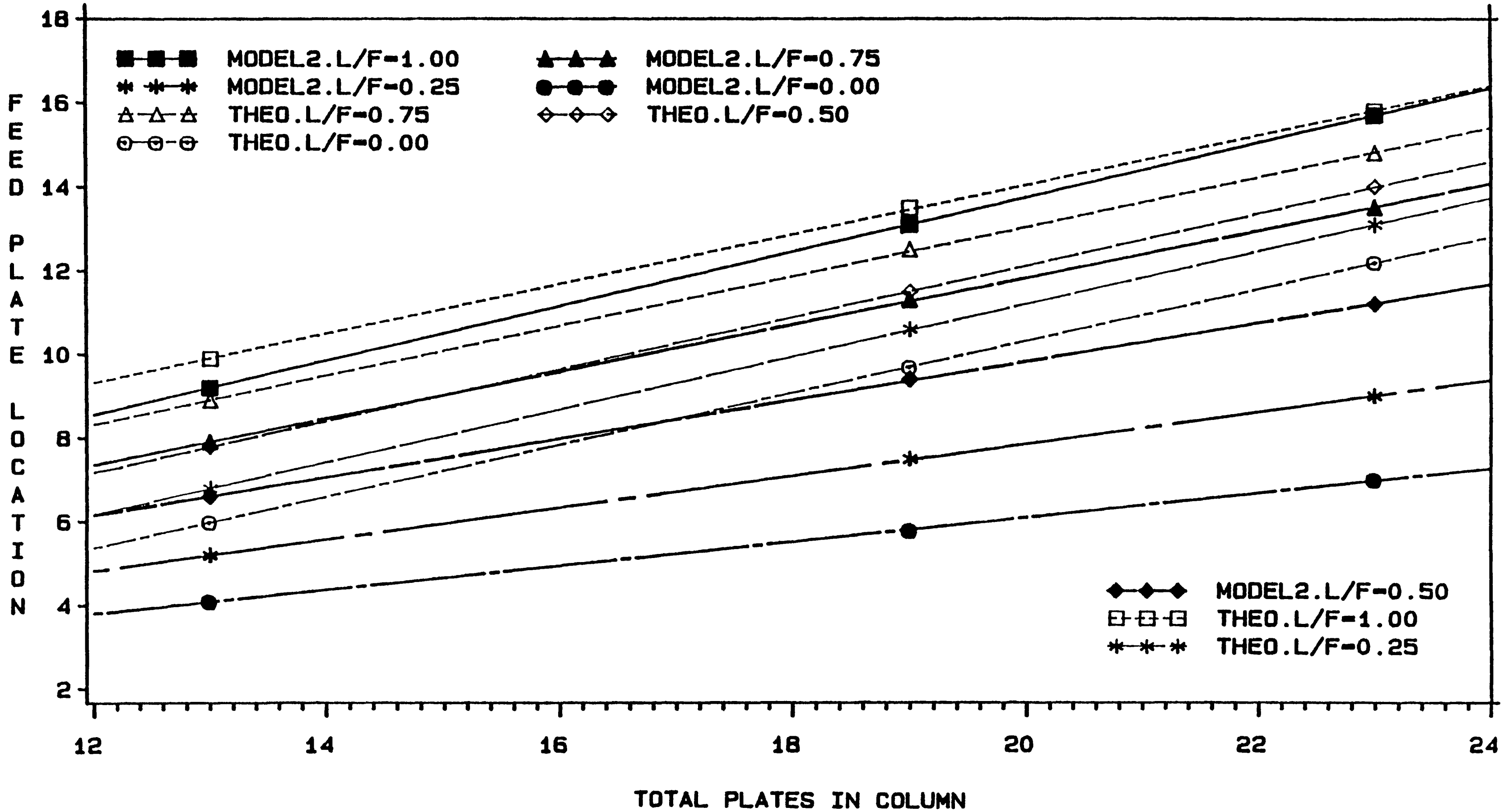


Figure 20. Comparison of Optimum Feed Plate Locations by Model 2 to Theoretical Feed Plate - Test No.3

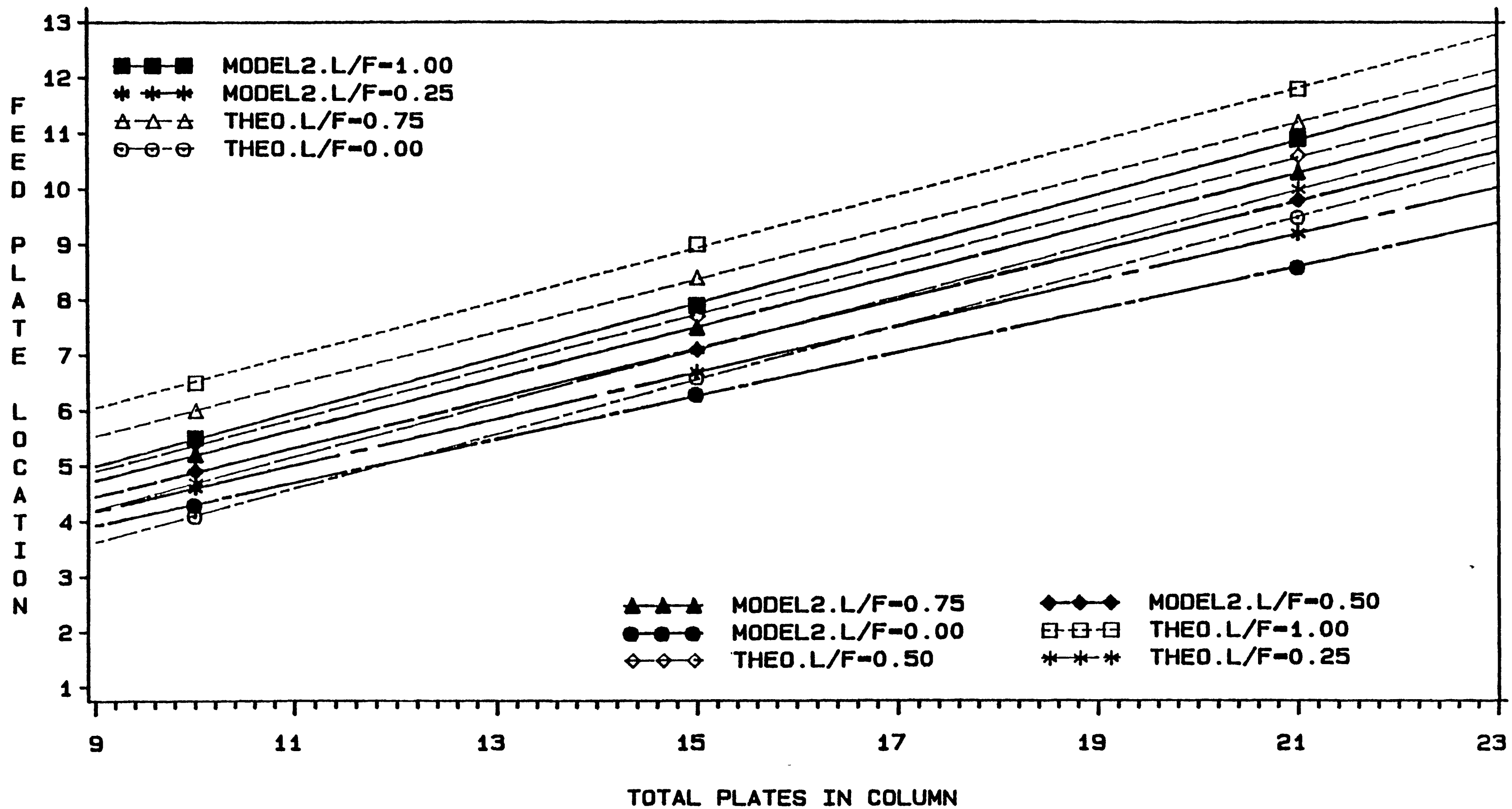


Figure 21. Comparison of Optimum Feed Plate Locations by Model 2 to Theoretical Feed Plate - Test No.4

with those from the theoretical values as in Figures 18 and 21 (Test No.1 and 4) but sometimes are not as in Figure 19 and 20 (Test No.2 and 3). The pattern of lines from theoretical value in Test No.2 reveals an irregular pattern which shows that the feed location at higher percentage vapor is higher than the location at saturated liquid, when the total number of plates in the column exceeds 26. This irregular pattern is also shown in Feed No.3 (Figure 28 in Appendix B). In Test No.3 the distances of lines from Model 2 is wider than those from Model 2.

The plot of ln(P) versus ln(K) of Feed No.3 at the temperature of 256.23°F are prepared as Figure 22. Figure 22 reveals the region where K values of heavy components are increasing when pressure is increasing, which will lead to difficulties in separation. Hence, it can be stated that the irregular pattern will take place if the column conditions were designed to operate in this region.

The high percentage error in Test No.3 might be due to the low temperature of the feed at saturated condition, which is as low as -68.57°F. This will cause the poor temperature distribution in the column (Note that the temperature of the saturated liquid feed used in generating Model 2 is ranged from 100-300°F).

Due to the presence of the irregular pattern and the high percentage error, caution should be taken when applying Model 2 to the column operating in the region cited above, or having the saturated liquid feed at a low temperature.

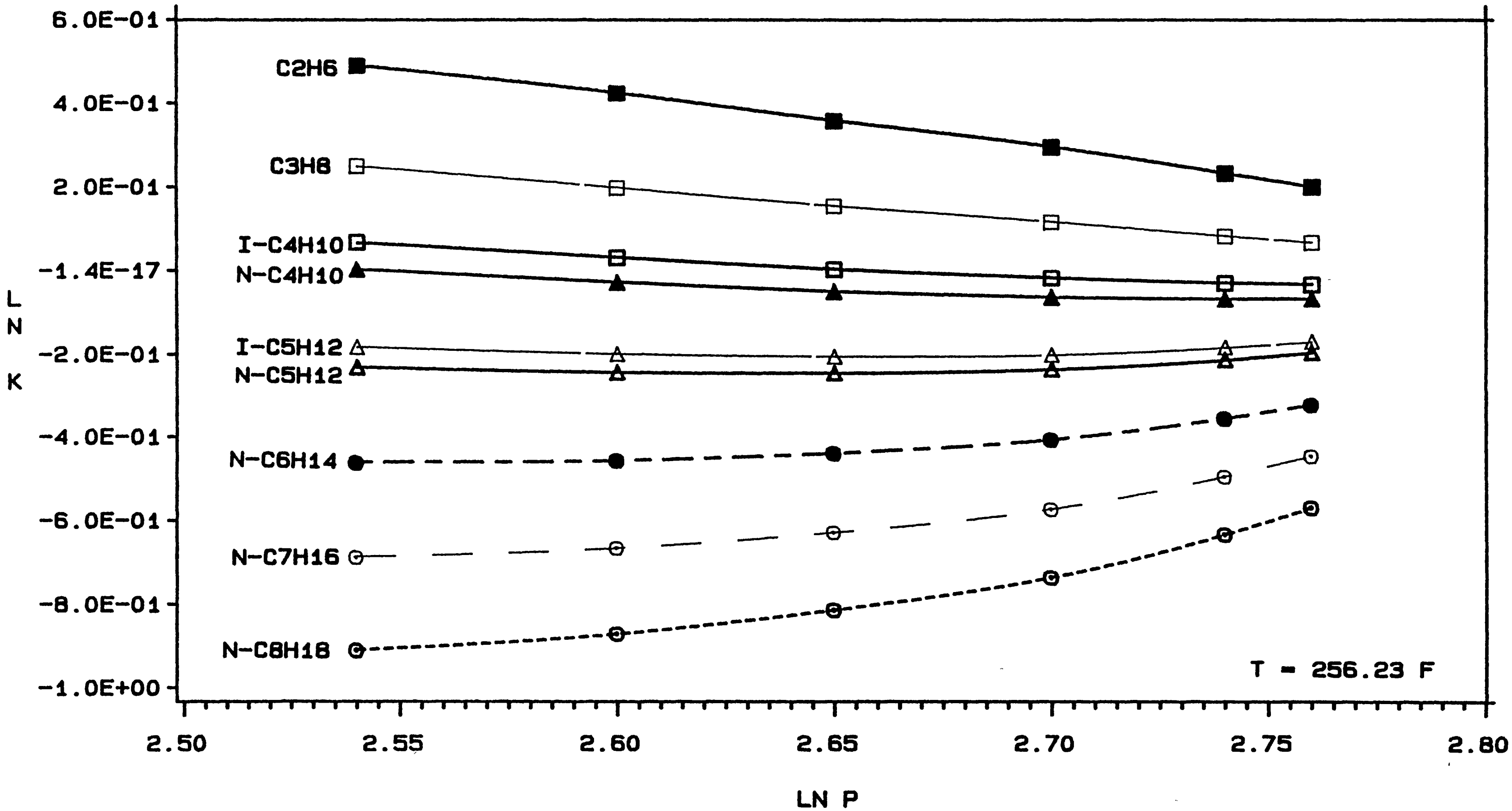


Figure 22. Effect of P on K - Feed No.3

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

A correlation to predict optimum feed plate location for multi-component distillation of a simple one-feed, two-product column has been proposed as Model 2.

$$\log(N_r/N_s) = 0.1 \log\{(f/f')(b/d')(XLD/XHB)(100/\Delta T)^{8.2}\} + 0.1\,(1 - L/F)(\Delta T/100)^{2.1}$$

where

N_r = number of plates in the rectifying section

N_s = number of plates in the stripping section

f = flow rate of the light key component in the feed, mols/hr

f' = flow rate of the heavy key component in the feed, mols/hr

b = flow rate of the light key component in the bottom product, mols/hr

d' = flow rate of the heavy key component in the distillate, mols/hr

XLD = mole fraction of the light key component in the distillate

XHB = mole fraction of the heavy key component in the bottom

ΔT = temperature difference between the reboiler and the condenser,°F

L/F = ratio of the liquid flow rate to the total flow rate of the feed

The L/F ratio can be ranged from one, saturated liquid feed, to zero, saturated vapor feed. The exponent terms in Model 2 are genereated when the feed temperatures at the saturated liquid condition range from 100-300°F, the operating pressures range from 40 to 345 psia, and the ΔT's range from 94 to 312°F.

In general, the correlation gives better feed plate location prediction when applied to saturated liquid feed, than those from Fenske (1932), Winn (1958), Kirkbride (1944), and Akashah et al. (1979). The correlation also produces satisfactory predictions when employed with various column sizes when the percentage of liquid in the feed is highter than 50 percent.

The correlation might produce considerable error when applied to the column operating in the region where K values of heavy components are increasing when pressure is increasing, or when the temperature of the feed at saturated liquid condition is far out of the range cited above.

Some variables, e.g., pressure, might be considered to add to the correlation for more precise prediction. Further study should be done to improve the prediction beyond the limited range. Future work could be done towards predicting feed plate locations for the multiple-feed columns.

SELECTED BIBLIOGRAPHY

Akashah, S. A., J. H. Erbar, and R. N. Maddox, "Optimum Feed Plate Location for Multi-Component Separations," Chem. Eng. Commun., 3(6), 461-468 (1979).

Amundson, N. R., and A. J. Pontinen, "Multicomponent Distillation Calculations on a Large Digital Computer," Ind. Eng. Chem., 50(5), 730-736 (May, 1958).

Ellis, S. R. M. "Locating Optimum Feed Tray," Pet. Ref., 33(9), 307-309 (Sep., 1954).

Erbar, J. H., "GPA*SIM Documentation," Users Manual, Gas Processors Associations, Tulsa, Oklahoma (1980).

Erbar, J. H., "MAXISIM - A Dual Purpose Complete Process Design Simulation System/Simple Equilibrium Calculation Program," R. C. Erbar, rev., Department of Chemical Engineering, Oklahoma State University, Stillwater, Oklahoma (Oct., 1984).

Erbar, R. C., Class Notes for Stagewise Operations, CHENG 5633, Oklahoma State University, Stillwater, Oklahoma (Fall 1985).

Fenske, M. R., "Fractionation of Straight-Run Pennsylvania Gasoline," Ind. Eng. Chem., 24(5), 482-485 (May, 1932).

Hanson, D. H., and J. Newman, "Calculation of Distillation Columns at the Optimum Feed Plate Location," Ind. Eng. Chem. Proc. Des. Dev., 16(2), 223-227 (1977).

Helwig, J. T., "SAS Introductory Guide," 58-69, SAS Institute, Cary, North Carolina (1978).

Hengstebeck, R. J., "Finding Feedplates from Plots," Chem. Eng., 75(16), 143-144 (Jul. 29, 1968).

Henley, E. J., and J. D. Seader, "Equilibrium - Stage Separation Operations in Chemical Engineering," 577, John Wiley and Sons, New York (1981).

Hines, A. L., and R. N. Maddox, "Mass Transfer - Fundamentals and Applications," 331-377, Prentice-Hall, Englewood Cliffs, New Jersey (1985).

King, C. J., "Separation Process," 352, Mcgraw-Hill, New York (1971).

Kirkbride, C. G., "Process Design Procedure for Multicomponent Fractionators," Pet. Ref., 23(9), 321-336 (Sep., 1944).

Lyster, W. N., S. L. Sullivan, Jr., D. S. Billingsley, and C. D. Holland, "Figure Distillation This New Way. Part 1 New Convergence Method Will Handle Many Cases," Pet. Ref., 38(6), 221-230 (Jun., 1959).

Maas, J. H., "Optimum-Feed-Stage Location in Multicomponent Distillations," Chem. Eng., 80(9), 96-98, (Apr. 16, 1973).

Robinson, C. S., and E. R. Gilliland, "Elements of Fractional Distillation," 261, 4th Edition, McGraw-Hill, New York (1950).

Sinnott, R. K., "Design - Chemical Engineering, Volume 6," 422, Coulson, J. M., and J. F. Richardson, eds., Pegamon Press, New York (1985).

Wagner, J., Class Notes for Stagewise Operations, CHENG 5633, Oklahoma State University, Stillwater, Oklahoma (1982).

Winn, F. W., "New Relative Volatility Method for Distillation Calculations," Pet. Ref., 37(5), 216-218, (May, 1958).

Zanker, A., "Easy Way to Feed-Plate Location," Process Eng. (London), 64(11), 67 (Nov., 1983).

__________, "SAS/GRAPH User's Guide,", Version 5 Edition, Chapter 24, SAS Institute, Cary, North Carolina (1985).

APPENDIXES

APPENDIX A

DETERMINATION OF THE CONSTANTS IN
THE WINN CORRELATIONS

When the slope and the intercept of the linear regression line from the relation of calculated optimum feed plate location as a function of total number of plate (or column size) are close to those obtained from MAXISIM, the error between calculated and theoretical optimum feed plate will be decreased. This can be verified by the Kirkbride correlation, as shown in Figure 4 of Chapter IV. Therefore, the slopes and the intercepts will be used as guidelines in determining the constants in Winn correlations.

Recall Winn correlations:

$$\beta^{N_r} = (d/f)(f'/d')^{\theta}(F/D)^{1-\theta} \quad (22)$$

and

$$\beta^{N_s} = (f/b)(b'/f')^{\theta}(B/F)^{1-\theta} \quad (23)$$

Introducing another constant, ξ, to the above equations,

$$\beta^{N_r} = (d/f)^{\xi}(f'/d')^{\theta}(F/D)^{1-\theta} \quad (A-1)$$

and

$$\beta^{N_s} = (f/b)^{\xi}(b'/f')^{\theta}(B/F)^{1-\theta} \quad (A-2)$$

Multiplying Equation (A-1) with Equation (A-2),

$$\beta^{N_r+N_s} = (d/b)^{\xi}(b'/d')^{\theta}(B/D)^{1-\theta} \quad (A-3)$$

Taking logarithm of Equation (A-3) and rearranging,

$$(N_r + N_s)\log\beta = \log\{(d/b)^{\xi}(b'/d')^{\theta}(B/D)^{1-\theta}\}$$

$$\log\beta = \log\{(d/b)^{\xi}(b'/d')^{\theta}(B/D)^{1-\theta}\}/(N_r + N_s)$$

Since

$$N_r + N_s = N + 2 - 1$$

therefore,

$$\log\beta = \log\{(d/b)^{\xi}(b'/d')^{\theta}(B/D)^{1-\theta}\} / (N + 2 - 1) \qquad \text{(A-4)}$$

Taking logarithm of Equation (A-2) and rearranging,

$$N_s \log\beta = \log\{(f/b)^{\xi}(b'/f')^{\theta}(B/F)^{1-\theta}\}$$

$$N_s = \log\{(f/b)^{\xi}(b'/f')^{\theta}(B/F)^{1-\theta}\}/\log\beta \qquad \text{(A-5)}$$

Substituting $\log\beta$ from Equation (A-4) into Equation (A-5)

$$N_s = \frac{(N + 2 - 1) \log \{(f/b)^{\xi}(b'/f')^{\theta}(B/F)^{1-\theta}\}}{\log\{(d/b)^{\xi}(b'/d')^{\theta}(B/D)^{1-\theta}\}} \qquad \text{(A-6)}$$

All terms but N in the right-hand side of Equation (A-6) are constants for each specific separation. Then, Equation (A-6) can be written in the linear equation form as:

$$N_s = \text{slope } N + \text{intercept}. \qquad \text{(A-7)}$$

Linear regression analysis was carried out using the SAS Package (Helwig, 1978). The values of ξ and θ will be varied until the slope and the intercept are close to those from MAXISIM, i.e., 0.446 for the slope and 2.972 for the intercept. The sample of input program was shown on page 75. The varied ξ's and θ's together with the corresponding slopes and intercepts are tabulated in Table XIII.

Two functions were set up as the followings:

$$\text{slope} = f(\xi, \theta) \qquad \text{(A-8)}$$

$$\text{intercept} = f(\xi, \theta). \qquad \text{(A-9)}$$

SAS package (SAS, 1985) was applied to interpolate the functions (A-8) and (A-9). All the values in Table XII were placed in the input program shown on page 77. The results were depicted as Figures 23 and 24.

The combination of ξ equal to 1.3 and θ equal to 2.0 was chosen. These will give a slope of 0.477 and an intercept of 1.723.

Program Listing for the Winn Correlations

```
DATA WINN (DROP=XNOPL YNOSTRIP OBSV)
     TOPLOT (KEEP=NO XNOPL YNOSTRIP OBSV);
  INPUT NO FLK FHK F DLK DHK D BLK BHK B NOP1 NOP2 NOP3;
  LIST;
  LENGTH OBSV $1 ;
   XI = 1.3 ;
   THETA = 2.0 ;
  ALPHAN = (DLK/FLK)**XI * (FHK/DHK)**THETA * (F/D)**(1.-THETA);
  ALPHAM = (FLK/BLK)**XI * (BHK/FHK)**THETA * (B/F)**(1.-THETA);
  ARRAY NOPL(3) NOP1 NOP2 NOP3;
  ARRAY NOSTRIP(3) NOS1 NOS2 NOS3;
    DO I = 1 TO 3 ;
       NOSTRIP(I)=(NOPL(I)+2.-1.)*LOG10(ALPHAM)/LOG10(ALPHAN*ALPHAM);
       XNOPL=NOPL(I);
       YNOSTRIP=NOSTRIP(I);
       OBSV=NO;
          IF NO = 10 THEN OBSV='A';
          IF NO = 11 THEN OBSV='B';
          IF NO = 12 THEN OBSV='C';
          IF NO = 13 THEN OBSV='D';
       OUTPUT TOPLOT;
    END;
  OUTPUT WINN;
  CARDS;
1 54.00 377.00 491.00 51.81 2.70 54.51 2.20 374.30 436.49 10. 14. 20.
2 17.90 20.68 72.43 16.92 0.62 18.04 0.17 20.06 54.39 12. 16. 22.
3 792.53 108.84 1318.27 784.63 7.62 808.44 7 9 101.22 509.83 28. 34. 40
4 196.43 51.00 510.55 186.62 7.24 304.54 9.81 43.76 206.01 12. 22. 28.
5 179.33 226.92 703.77 151.87 2.27 305.61 27.46 224.65 398.16 12. 22. 32
6 20.00 37.00 100.00 19.30 0.30 22.60 0.70 36.70 77.40 12. 15. 20.
7 171.37 32.98 263.85 169.66 1.97 190.63 1.71 31.01 73.22 13. 15. 17.
8 12.50 3.50 100.00 12.30 0.70 31.48 0.20 2.80 68.52 12. 16. 20.
10 12.50 3.50 110.00 12.30 0.70 31.48 0.20 2.80 78.52 12. 16. 20.
11 12.50 3.50 109.00 12.30 0.70 33.48 0.20 2.80 75.52 12. 16. 20.
12 12.50 3.50 127.00 12.30 0.70 37.48 0.20 2.80 89.52 12. 14. 16.
13 111.38 32.6 211.75 106.92 7.41 117.57 4.46 25.19 94.18 15. 20. 25.
  PROC SORT DATA=WINN;
       BY NO;
  PROC PRINT DATA=WINN;
       TITLE INPUT DATA FOR CALCULATING THE FEED PLATE LOCATION;
       TITLE2 BY WINN CORRELATIONS;
       VAR FLK FHK F DLK DHK D BLK BHK B ;
       LABEL NO='FEED NO.';
       ID NO;
       FOOTNOTE 'NOTE : SEE EXPLANATIONS OF ABBREVIATION IN APPENDIX D';
  PROC SORT DATA=TOPLOT;
       BY NO;
  PROC PRINT DATA=TOPLOT SPLIT='*';
       TITLE FEED PLATE LOCATIONS FROM WINN CORRELATIONS;
       VAR  XNOPL YNOSTRIP;
       BY NO;
       LABEL XNOPL='TOTAL NO. OF PLATES *     IN COLUMN';
       LABEL YNOSTRIP='FEED PLATE * LOCATION';
       LABEL NO='FEED NO.';
       ID NO;
       FOOTNOTE;
  PROC GLM DATA=TOPLOT;
       TITLE LINEAR REGRESSION INFORMATIONS FOR WINN CORRELATION;
       MODEL YNOSTRIP=XNOPL;
       OUTPUT OUT=NEW P=PREDICT;
  PROC PLOT DATA=NEW;
       TITLE 'EFFECT OF COLUMN SIZE ON FEED PLATE LOCATION';
       TITLE2 'BY WINN CORRELATIONS';
       PLOT YNOSTRIP*XNOPL=OBSV PREDICT*XNOPL='*'/OVERLAY;
       LABEL YNOSTRIP='FEED PLATE LOCATION';
       LABEL XNOPL='TOTAL NUMBER OF PLATE';
  FOOTNOTE1 'NOTE : NO.1-9 REFER TO FEED NO.1-9';
  FOOTNOTE2 'LETTER A,B,C,D REFER TO FEED NO.10,11,12,13';
  FOOTNOTE3 '* SIGN REFERS TO THE VALUE FROM THE REGRESSION EQUATION';
```

TABLE XIII

VALUES OF ξ, θ, SLOPES, AND INTERCEPTS USED IN DETERMINING THE CONSTANTS IN WINN CORRELATIONS

ξ	θ	Slope	Intercept
0.5	0.5	0.460	0.502
0.5	1.0	0.392	0.859
0.5	1.5	0.359	0.924
1.0	0.5	0.663	0.442
1.0	1.0	0.560	1.050
1.0	1.5	0.499	1.334
1.5	0.5	0.754	0.498
1.5	1.0	0.654	1.093
1.5	1.5	0.587	1.425

Program Listing to Interpolate Equations (A-8) and (A-9)

```
DATA WIN1PLOT;
INPUT XI THETA SLOPE INTERCEP ;
CARDS;
0.5 0.5 0.460 0.502
0.5 1.0 0.392 0.859
0.5 1.5 0.359 0.924
1.0 0.5 0.663 0.442
1.0 1.0 0.560 1.050
1.0 1.5 0.499 1.334
1.5 0.5 0.754 0.498
1.5 1.0 0.654 1.093
1.5 1.5 0.587 1.425
    GOPTIONS NOTEXT82 ;
    PROC G3GRID DATA=WIN1PLOT OUT=SPLINE;
         GRID XI * THETA = SLOPE /    AXIS1 = 0 TO 2.00 BY .10
                                      AXIS2 = 0 TO 2.00 BY .10;
    RUN;
    TITLE H=1 F=COMPLEX 'FIG.20';
    PROC G3D DATA=SPLINE;
         PLOT XI * THETA = SLOPE /  CAXIS   = BLACK
                                    TILT    = 50
                                    ROTATE  = 50
                                    CTOP    = RED
                                    CBOTTOM = GREEN ;
    RUN;
```

```
DATA WIN1PLOT;
INPUT XI THETA SLOPE INTERCEP ;
CARDS;
0.5 0.5 0.460 0.502
0.5 1.0 0.392 0.859
0.5 1.5 0.359 0.924
1.0 0.5 0.663 0.442
1.0 1.0 0.560 1.050
1.0 1.5 0.499 1.334
1.5 0.5 0.754 0.498
1.5 1.0 0.654 1.093
1.5 1.5 0.587 1.425
    GOPTIONS NOTEXT82 ;
    PROC G3GRID DATA=WIN1PLOT OUT=SPLINE;
         GRID XI * THETA = INTERCEP /    AXIS1 = 0 TO 2.00 BY .10
                                         AXIS2 = 0 TO 2.00 BY .10;
    RUN;
    TITLE H=1 F=COMPLEX 'FIG.21';
    PROC G3D DATA=SPLINE;
         PLOT XI * THETA = INTERCEP /  CAXIS   = BLACK
                                       TILT    = 80
                                       ROTATE  = 50
                                       CTOP    = RED
                                       CBOTTOM = GREEN ;
         LABEL INTERCEP='INTERCEPT';
    RUN;
```

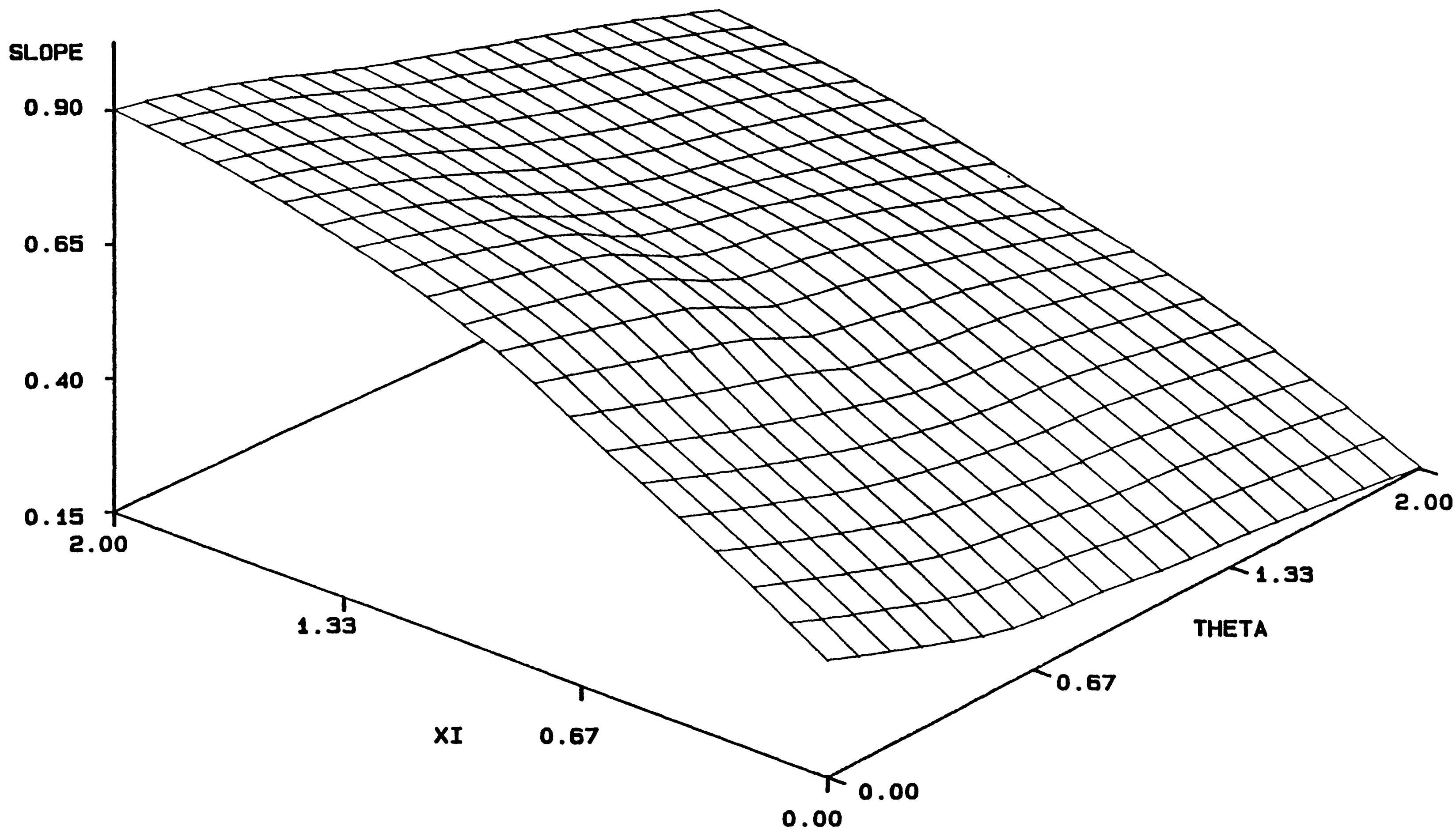


Figure 23. Effects of ξ and θ on Slope

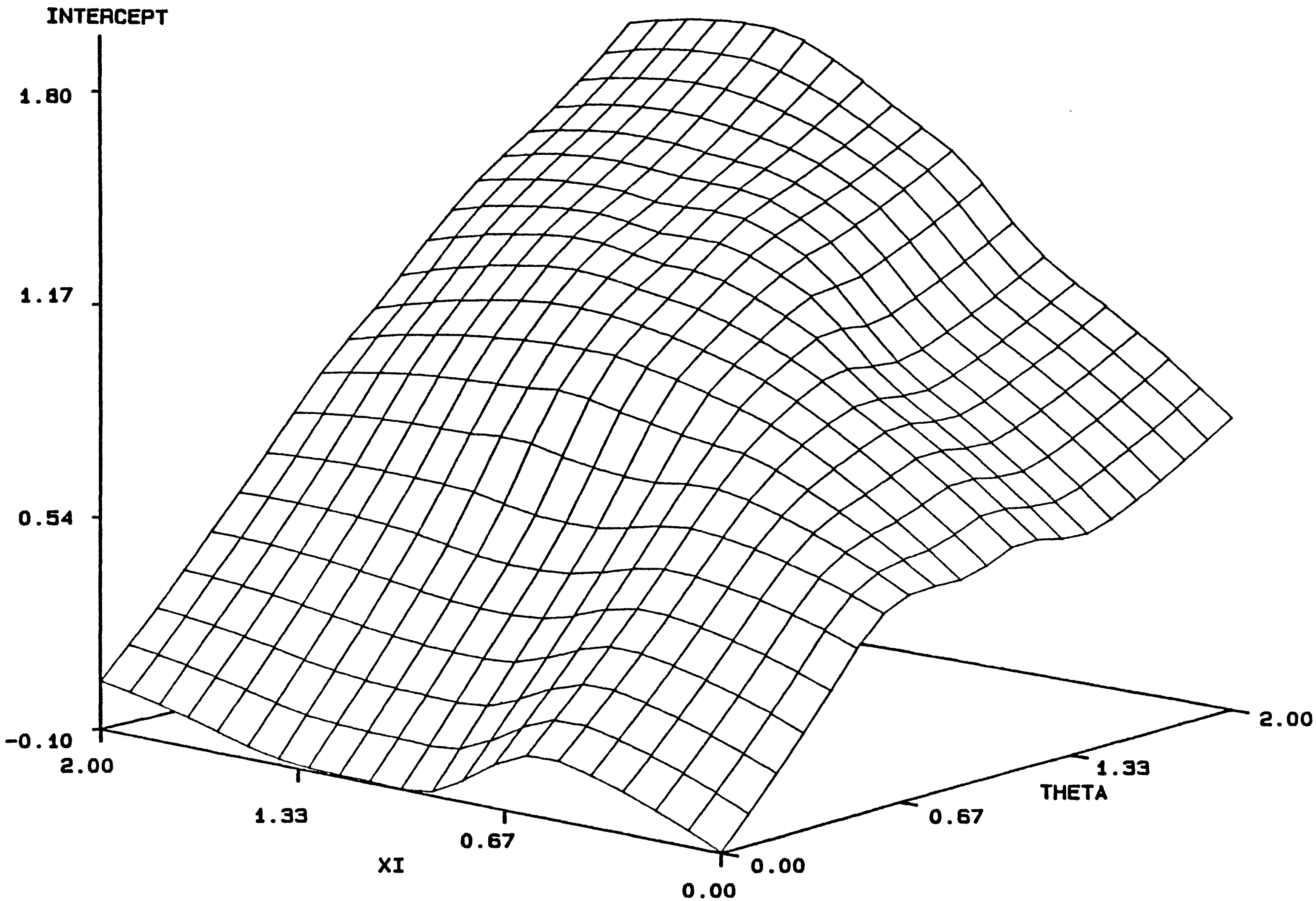


Figure 24. Effects of ξ and θ on Intercept

APPENDIX B

FEED COMPOSITIONS, PROCESS CONDITIONS AND DATA FROM MAXISIM USED IN GENERATING THE CORRELATION

TABLE XIV

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.2

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
CH4	0.50	0.50	-
C2H6	17.09	16.92	0.17
C3H8	20.68	0.62	20.06
iC4H10	4.32	-	4.32
nC4H10	9.44	-	9.44
iC5H12	3.51	-	3.51
nC5H12	3.82	-	3.82
nC6H14	2.57	-	2.57
nC7H16	10.50	-	10.50
Totals	72.43	18.04	54.39
Temperature,F	125.92	117.36	210.00
Pressure,psia	270.00	265.00	268.00
Feed Condition	96.24% liq.		

TABLE XV

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.2

Feed Condition	12 Theo.Pl.Col.		16 Theo.Pl.Col.		22 Theo.Pl.Col.	
	FPL	Reflux (mols/hr)	FPL	Reflux (mols/hr)	FPL	Reflux (mols/hr)
96% liq.	6	63.7	8	46.8	13	36.9
	7	55.8	9	43.3	14	36.5
	8	52.2	10	41.3	15	36.4
	9	53.0	10	40.5	16	36.7
	10	60.4	12	41.4	17	37.5
	11	82.5	13	44.8		
	9 Theo.Pl.Col		12 Theo.Pl.Col.		16 Theo.Pl.Col.	
50% liq.	3	168.9	5	112.5	8	94.1
	4	144.5	6	106.0	9	92.3
	5	137.9	7	104.0	10	91.8
	6	143.7	8	106.2	13	106.1
	7	162.6	9	114.2	14	126.1
			10	132.7		
	9 Theo.Pl.Col.		12 Theo.Pl.Col.		15 Theo.Pl.Col.	
Saturated vapor	2	250.1	4	199.0	6	185.4
	3	231.2	5	193.2	7	183.2
	4	224.0	6	191.8	8	182.5
	5	229.1	7	194.3	9	183.5
	6	244.7	8	201.6		
			9	205.9		

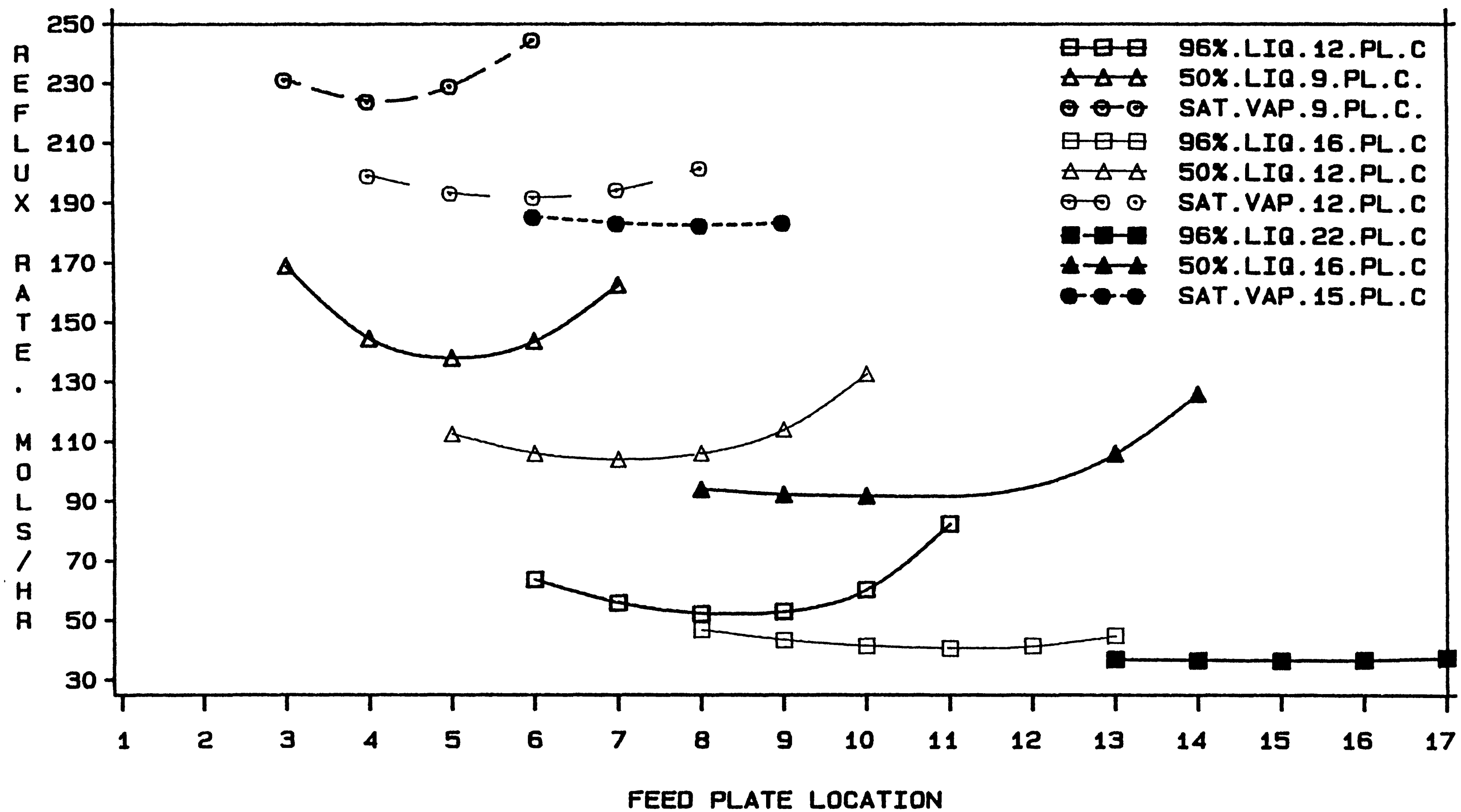


Figure 25. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.2

TABLE XVI

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.2

Source	Feed Condition	Optimum Feed Plate Location					
		9Pl.Col.	12Pl.Col.	15Pl.Col.	16Pl.Col.	22Pl.Col.	32Pl.Col.
Fenske	96% Liq.		7.4		9.7	13.0	18.7
Winn	96% Liq.		6.9		9.0	12.2	
Kirkbride	96% Liq.		8.8		11.5	15.5	22.3
Akashah et al.	96% Liq.		9.3		12.1	16.2	23.0
Theoretical Feed Plate	96% Liq.		8.3		10.9	14.7	
	50% Liq.	5.0	7.0		9.8		
	Sat.Vap.	4.1	5.9	7.8			

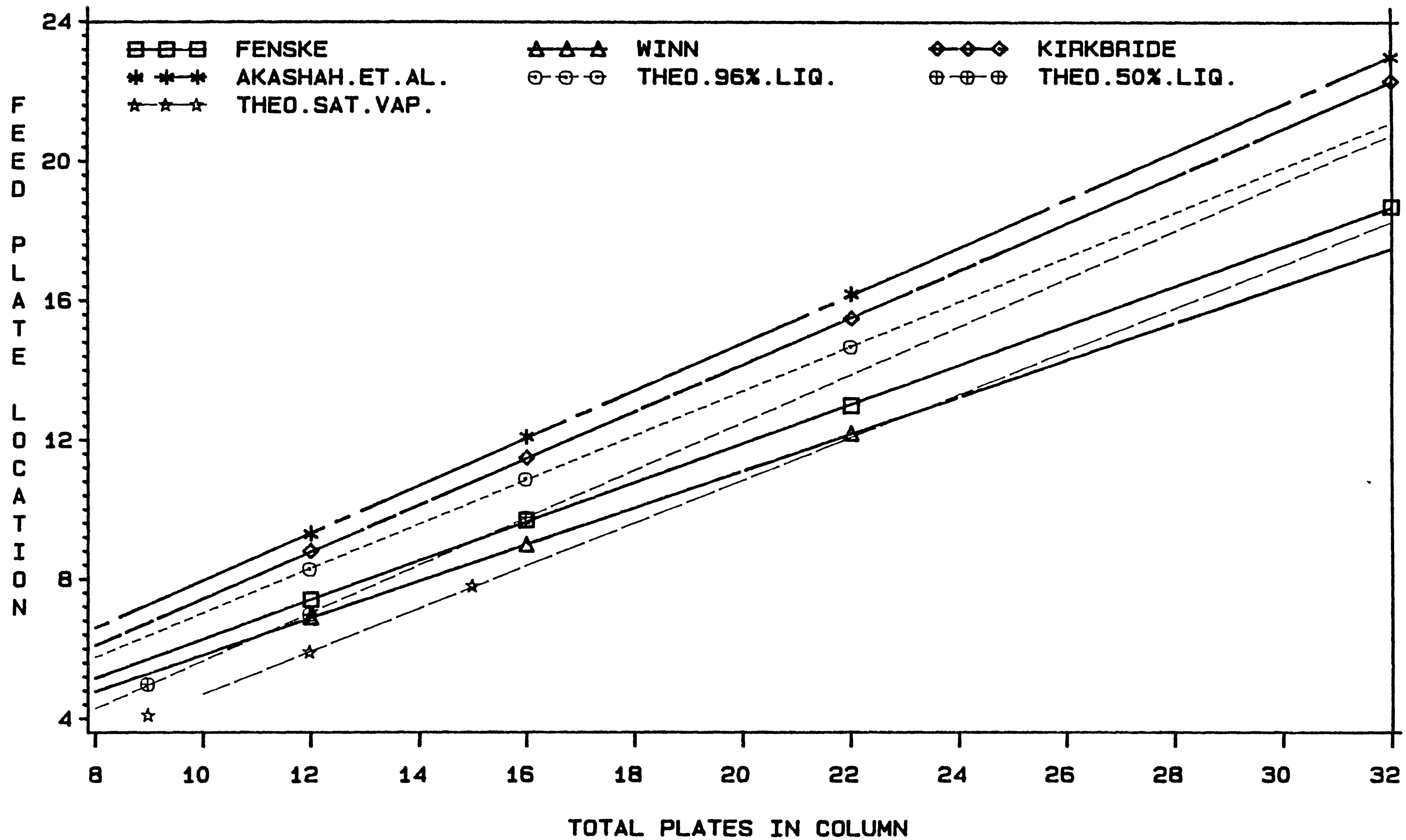


Figure 26. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.2

TABLE XVII

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.3

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
C2H6	14.94	14.94	-
C3H8	792.53	784.63	7.90
iC4H10	108.84	7.62	101.22
nC4H10	196.96	1.25	195.71
iC5H12	51.00	-	51.00
nC5H12	60.00	-	60.00
nC6H14	49.00	-	49.00
nC7H16	31.14	-	31.00
NC8H18	14.00	-	14.00
Totals	1318.27	808.44	509.83
Temperature,F	190.00	139.26	280.30
Pressure,psia	345.00	310.00	317.00
Feed Condition	97.00% liq.		

TABLE XVIII

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.3

Feed Condition	28 Theo.Pl.Col. FPL	28 Theo.Pl.Col. Reflux (mols/hr)	34 Theo.Pl.Col. FPL	34 Theo.Pl.Col. Reflux (mols/hr)	40 Theo.Pl.Col. FPL	40 Theo.Pl.Col. Reflux (mols/hr)
97% liq.	13	2051.8	15	1762.4	18	1610.0
	14	1971.2	16	1720.1	19	1598.1
	15	1927.4	17	1696.5	20	1593.6
	16	1914.0	18	1687.6	21	1595.2
	17	1929.6	19	1691.1	22	1601.3
	18	1975.5	20	1706.4		
50% liq.	12	2434.6	14	2123.4	17	1945.1
	13	2338.5	15	2068.7	18	1924.6
	14	2281.0	16	2033.9	19	1912.9
	15	2256.1	17	2015.3	20	1908.0
	16	2261.5	18	2010.6	21	1909.6
	17	2297.1	19	2018.9	22	1916.7
			20	2039.9		
Saturated vapor	11	3141.4	13	2842.4	16	2659.6
	12	3038.3	14	2780.4	17	2631.3
	13	2973.4	15	2737.0	18	2611.0
	14	2939.4	16	2709.0	19	2597.8
	15	2935.1	17	2694.1	20	2591.1
	16	2959.3	18	2691.7	21	2589.4
			19	2702.1	23	2605.2
			20	2726.0		

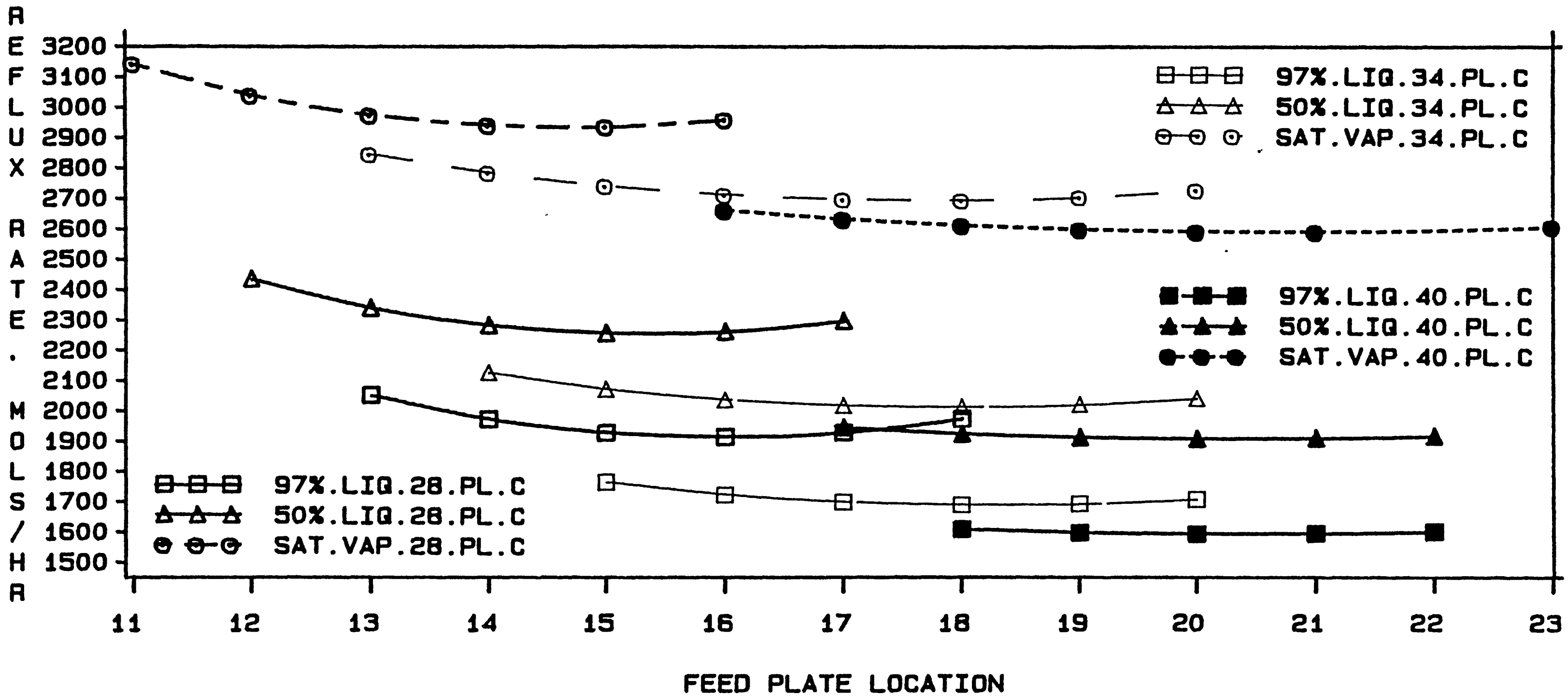


Figure 27. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.3

TABLE XIX

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.3

Source	Feed Condition	Optimum Feed Plate Location 28 Pl.Col.	34 Pl.Col.	40 Pl.Col.
Fenske	97% Liq.	18.3	22.1	25.9
Winn	97% Liq.	17.0	20.5	24.0
Kirkbride	97% Liq.	16.6	20.0	23.5
Akashah et al.	97% Liq.	17.3	20.8	24.3
Theoretical Feed Plate	97% Liq.	16.0	18.2	20.3
	50% Liq.	15.2	17.7	20.1
	Saturated Vapor	14.6	17.6	20.5

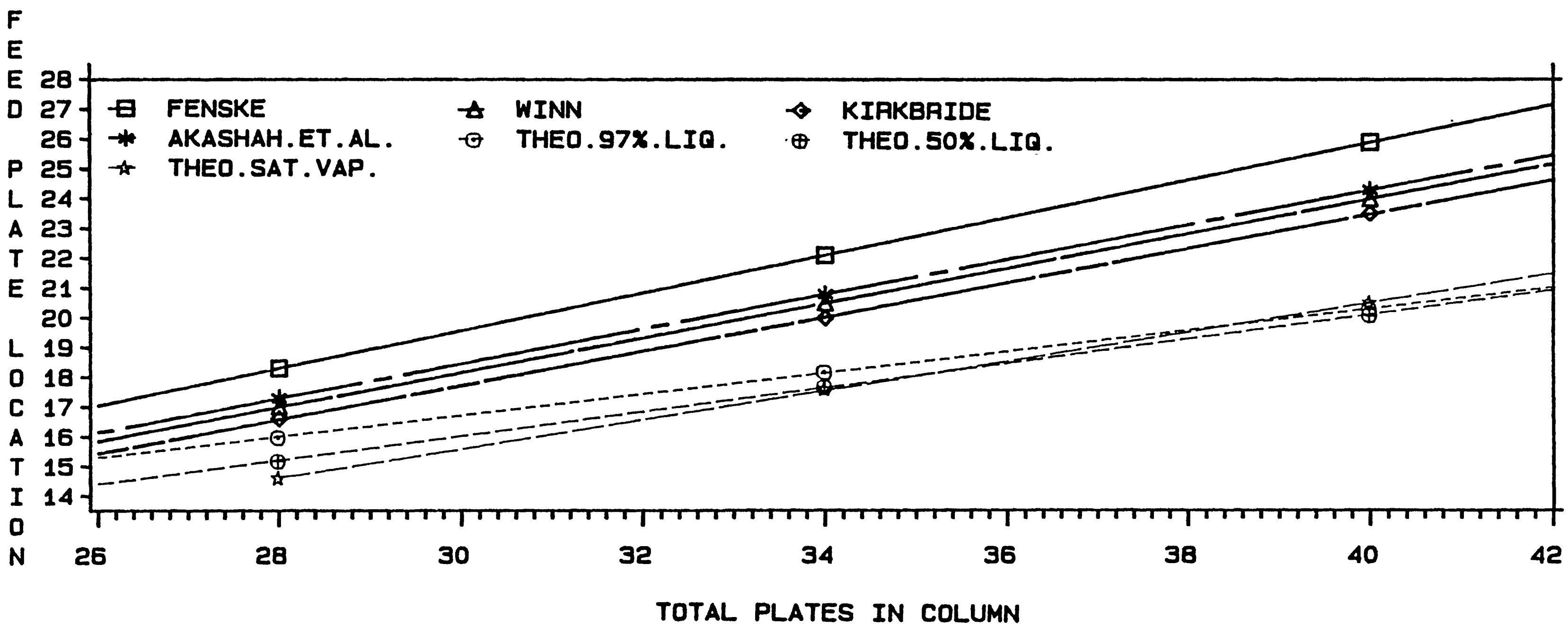


Figure 28. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.3

TABLE XX

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.4

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
C_3H_8	7.90	7.90	-
iC_4H_{10}	101.22	100.22	1.00
nC_4H_{10}	196.43	186.62	9.81
iC_5H_{12}	51.00	7.24	43.76
nC_5H_{12}	60.00	2.55	57.45
nC_6H_{14}	49.00	-	49.00
nC_7H_{16}	31.00	-	31.00
nC_8H_{18}	14.00	-	14.00
Totals	510.55	304.53	206.02
Temperature,F	280.24	139.83	251.10
Pressure,psia	317.00	100.00	105.00

Feed Condition: Saturated Liquid

TABLE XXI

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.4

Feed Condition	12 Theo.Pl.Col. FPL	12 Theo.Pl.Col. Reflux (mols/hr)	22 Theo.Pl.Col. FPL	22 Theo.Pl.Col. Reflux (mols/hr)	28 Theo.Pl.Col. FPL	28 Theo.Pl.Col. Reflux (mols/hr)
Saturated liquid	3	1357.1	7	564.6	10	492.1
	4	1113.2	8	535.8	11	484.0
	5	996.4	9	519.1	12	479.4
	6	959.2	10	511.0	13	477.6
	7	990.5	11	509.9	14	478.1
	8	1107.9	12	515.2	15	480.7
			13	527.5	16	485.6
50% liq.	3	1331.0	7	675.3	10	618.9
	4	1156.5	8	654.2	11	612.1
	5	1087.7	9	642.2	12	608.2
	6	1090.4	10	637.3	13	606.5
	7	1163.2	11	638.5	14	606.9
	8	1335.7	12	646.3	15	609.4
					16	614.5
Saturated vapor	2	1710.5	6	879.5	9	819.9
	3	1406.4	7	854.2	10	811.9
	4	1278.5	8	838.9	11	806.6
	5	1244.1	9	830.5	12	803.3
	6	1275.6	10	827.7	13	801.8
	7	1375.6	11	830.3	14	802.0
					15	804.0

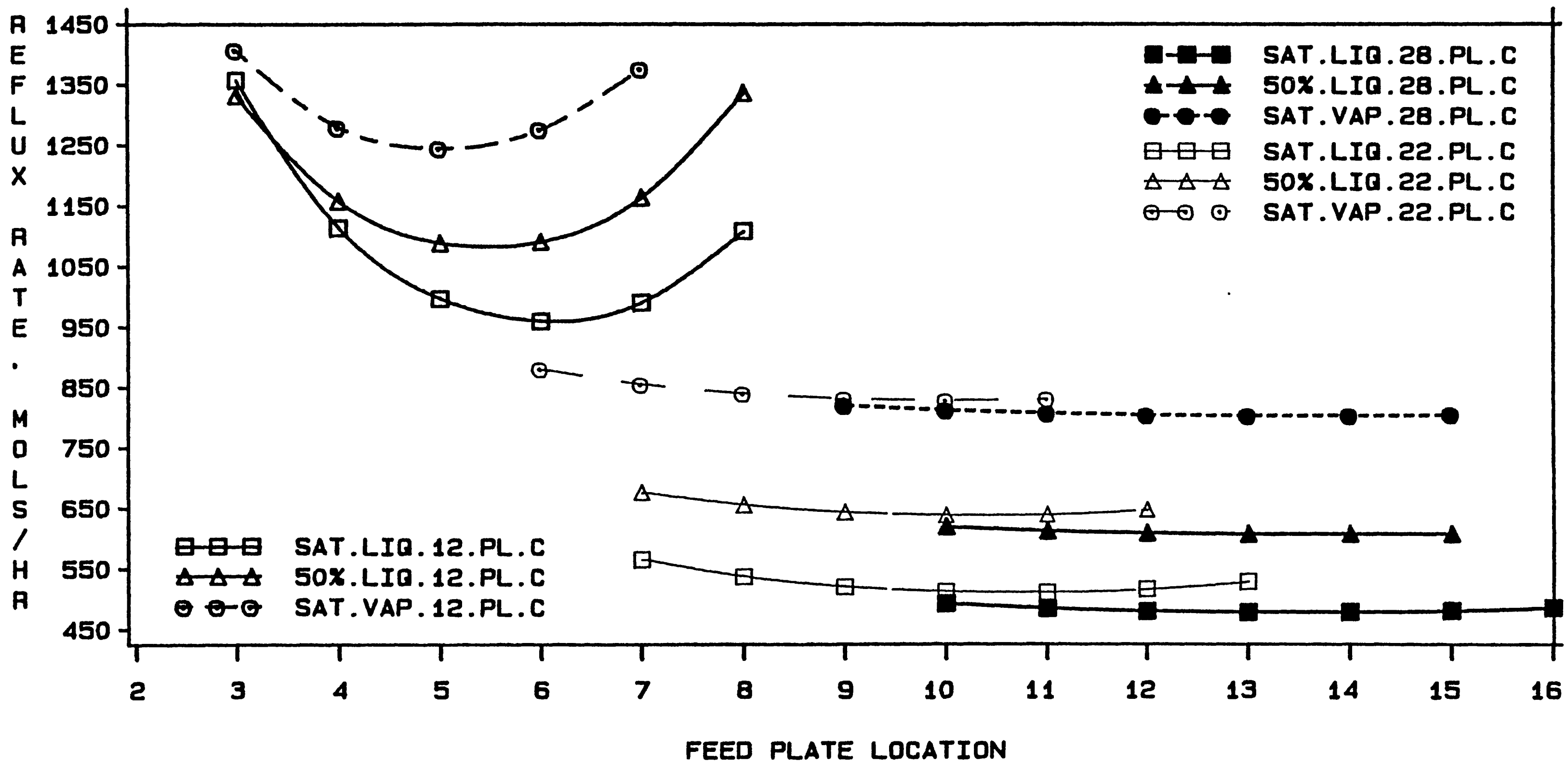


Figure 29. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.4

TABLE XXII

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.4

Source	Feed Condition	Optimum Feed Plate Location		
		12 Pl.Col.	22 Pl.Col.	28 Pl.Col.
Fenske	Saturated Liquid	7.8	13.8	17.4
Winn	Saturated Liquid	7.5	13.2	16.7
Kirkbride	Saturated Liquid	6.7	11.9	15.0
Akashah et al.	Saturated Liquid	7.2	12.6	15.8
Theoretical Feed Plate	Saturated Liquid	6.0	10.7	13.4
	50% liq.	5.5	10.2	13.0
	Saturated Vapor	5.1	9.9	12.7

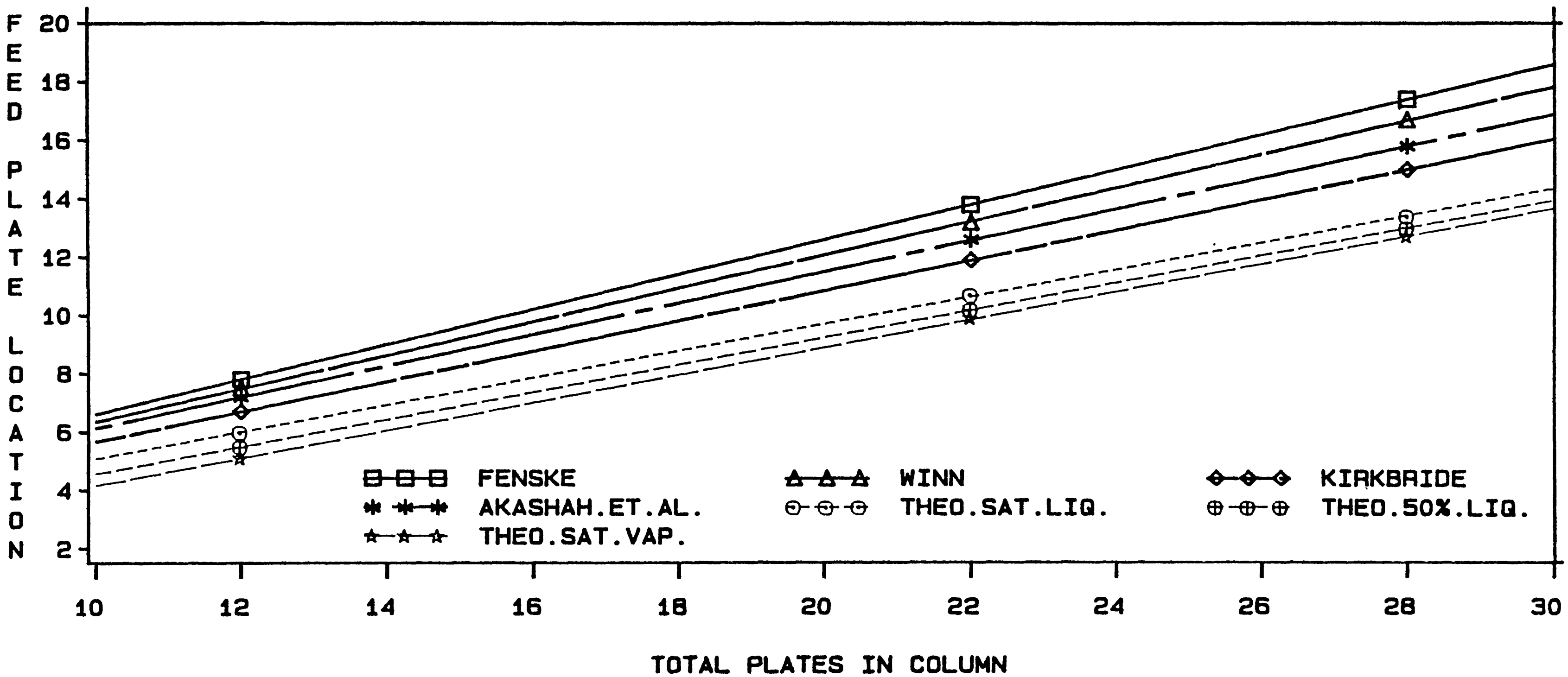


Figure 30. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.4

TABLE XXIII

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.5

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
nC4H10	20.59	20.59	-
iC5H12	136.63	130.89	5.74
nC5H12	179.33	151.86	27.47
nC6H14	226.92	2.27	224.65
nC7H16	61.40	-	61.40
nC8H18	41.22	-	41.22
nC9H20	37.68	-	37.68
Totals	703.77	305.61	398.16
Temperature,F	264.13	147.10	241.42
Pressure,psia	105.00	40.00	45.00
Feed Condition	90.00% liq.		

TABLE XXIV

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.5

Feed Condition	12 Theo.Pl.Col. FPL	12 Theo.Pl.Col. Reflux (mols/hr)	22 Theo.Pl.Col. FPL	22 Theo.Pl.Col. Reflux (mols/hr)	32 Theo.Pl.Col. FPL	32 Theo.Pl.Col. Reflux (mols/hr)
90% liq.	2	732.5	5	530.9	7	509.2
	3	644.0	6	517.4	9	501.7
	4	614.5	7	510.0	11	498.6
	5	619.1	8	506.2	13	497.3
	6	654.6	9	504.9	14	496.9
			10	505.6	16	496.6
			11	508.6	17	496.9
	12 Theo.Pl.Col.		22 Theo.Pl.Col.		30 Theo.Pl.Col.	
50% liq.	2	816.3	6	683.9	8	676.7
	3	775.0	7	680.1	9	675.1
	4	772.6	8	678.5	11	673.5
	5	799.1	9	678.4	13	673.0
	6	859.7	10	680.1	14	673.1
			11	684.0	15	673.3
Saturated vapor	2	1077.5	5	1011.8	8	1007.1
	3	1072.2	6	1009.7	9	10006.8
	4	1092.2	7	1008.9	10	1006.6
	5	1138.5	8	1009.1	11	1006.6
	6	1222.7	9	1010.2	12	1006.7
					13	1006.9

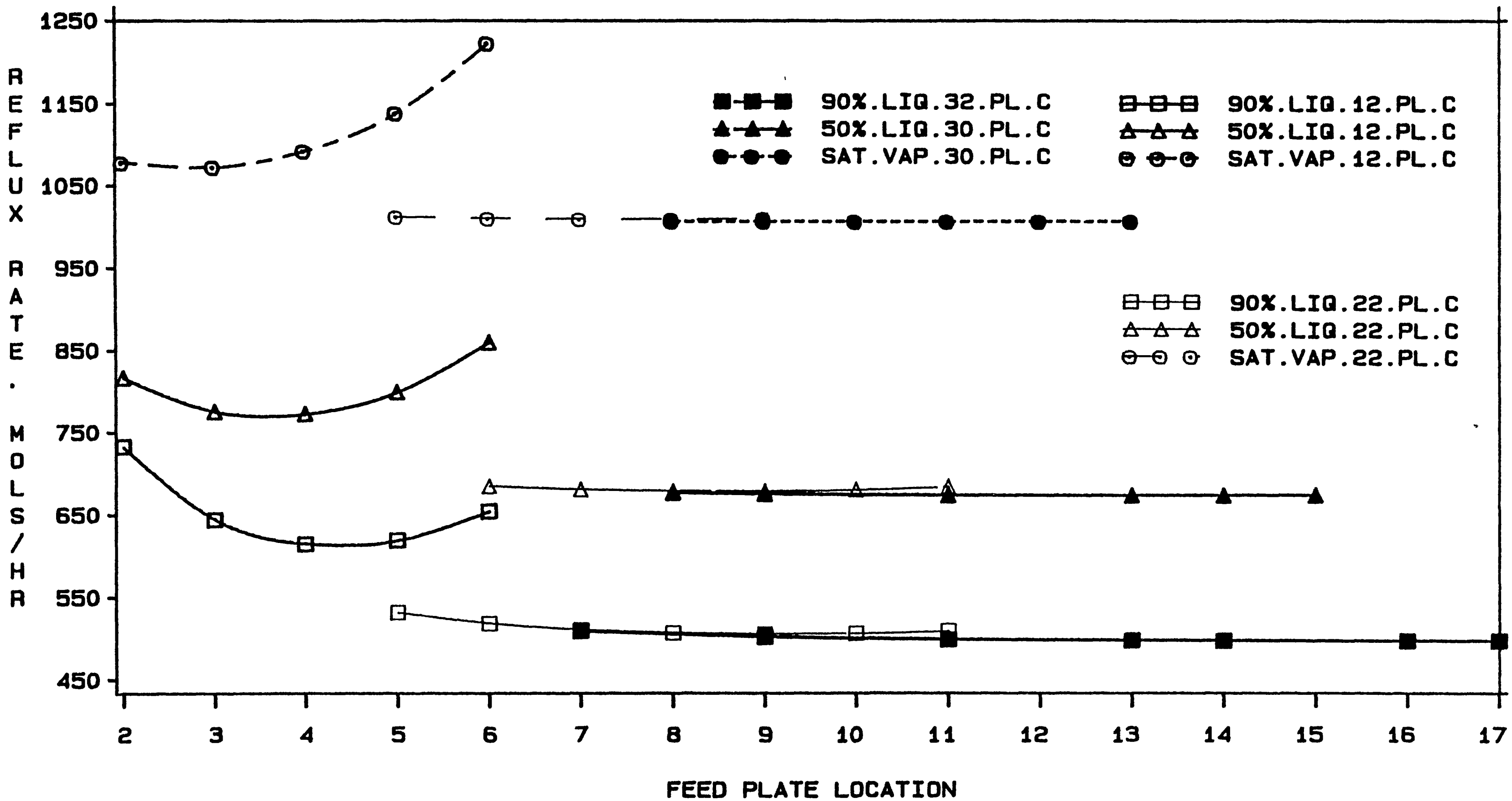


Figure 31. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.5

TABLE XXV

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.5

Source	Feed Condition	Optimum Feed Plate Location			
		12Pl.Col.	22Pl.Col.	30Pl.Col.	32Pl.Col.
Fenske	90% Liq.	3.9	6.8		9.8
Winn	90% Liq.	3.5	6.2		8.9
Kirkbride	90% Liq.	3.4	6.0		8.6
Akashah et al.	90% Liq.	3.9	6.7		9.3
Theoretical Feed Plate	90% Liq.	4.3	9.0	14.0	
	50% Liq.	3.5	8.5	12.8	
	Sat.Vap.	2.7	7.2	10.5	

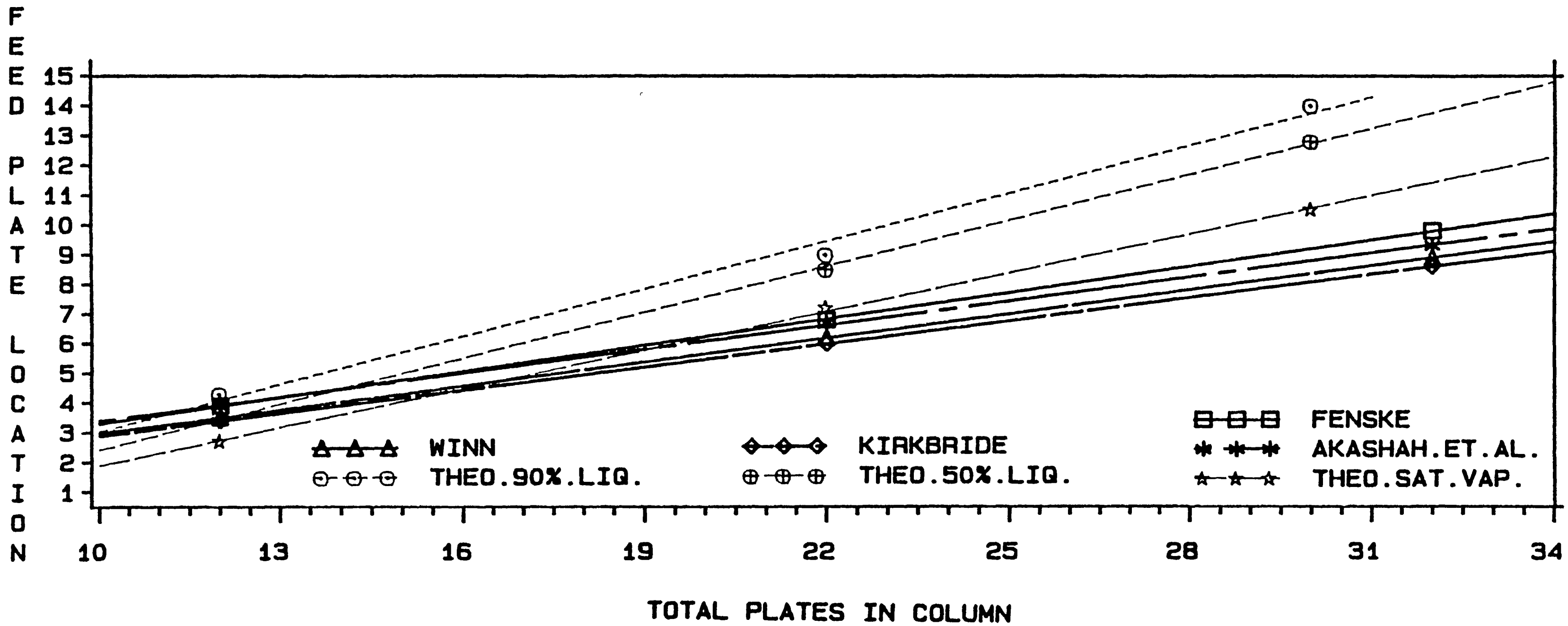


Figure 32. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.5

TABLE XXVI

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.6

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
C_2H_6	3.00	3.00	-
C_3H_8	20.00	19.30	0.70
nC_4H_{10}	37.00	0.30	36.70
nC_5H_{12}	35.00	-	35.00
nC_6H_{14}	5.00	-	5.00
Totals	100.00	22.60	77.4
Temperature,F	225.00	112.85	264.76
Pressure,psia	255.00	247.00	253.00
Feed Condition	83.60% liq.		

TABLE XXVII

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.6

Feed Condition	12 Theo.Pl.Col. FPL	12 Theo.Pl.Col. Reflux (mols/hr)	15 Theo.Pl.Col. FPL	15 Theo.Pl.Col. Reflux (mols/hr)	20 Theo.Pl.Col. FPL	20 Theo.Pl.Col. Reflux (mols/hr)
83.6%liq.	3	320.5	5	188.4	7	140.8
	4	274.6	6	166.7	9	123.8
	5	239.6	7	155.0	10	119.3
	6	228.0	8	150.6	11	116.9
	7	234.0	9	152.8	12	116.6
	8	257.7	10	162.6	13	118.7
50% liq.	2	450.5	4	231.7	7	165.1
	4	281.1	5	203.9	8	157.6
	5	260.3	6	189.0	10	149.8
	6	259.4	7	182.5	11	148.9
	7	275	8	182.6	12	150.1
	8	308.9	10	204.8	13	154.3
Saturated vapor	2	421.0	4	261.9	7	213.9
	3	346.1	5	244.9	8	*
	4	316.6	6	237.5	9	*
	5	311.2	7	236.9	10	*
	6	322.6	8	242.9	11	*
	7	349.3	9	255.9	13	*

* MAXISIM Did Not Converge in 20 Iterations

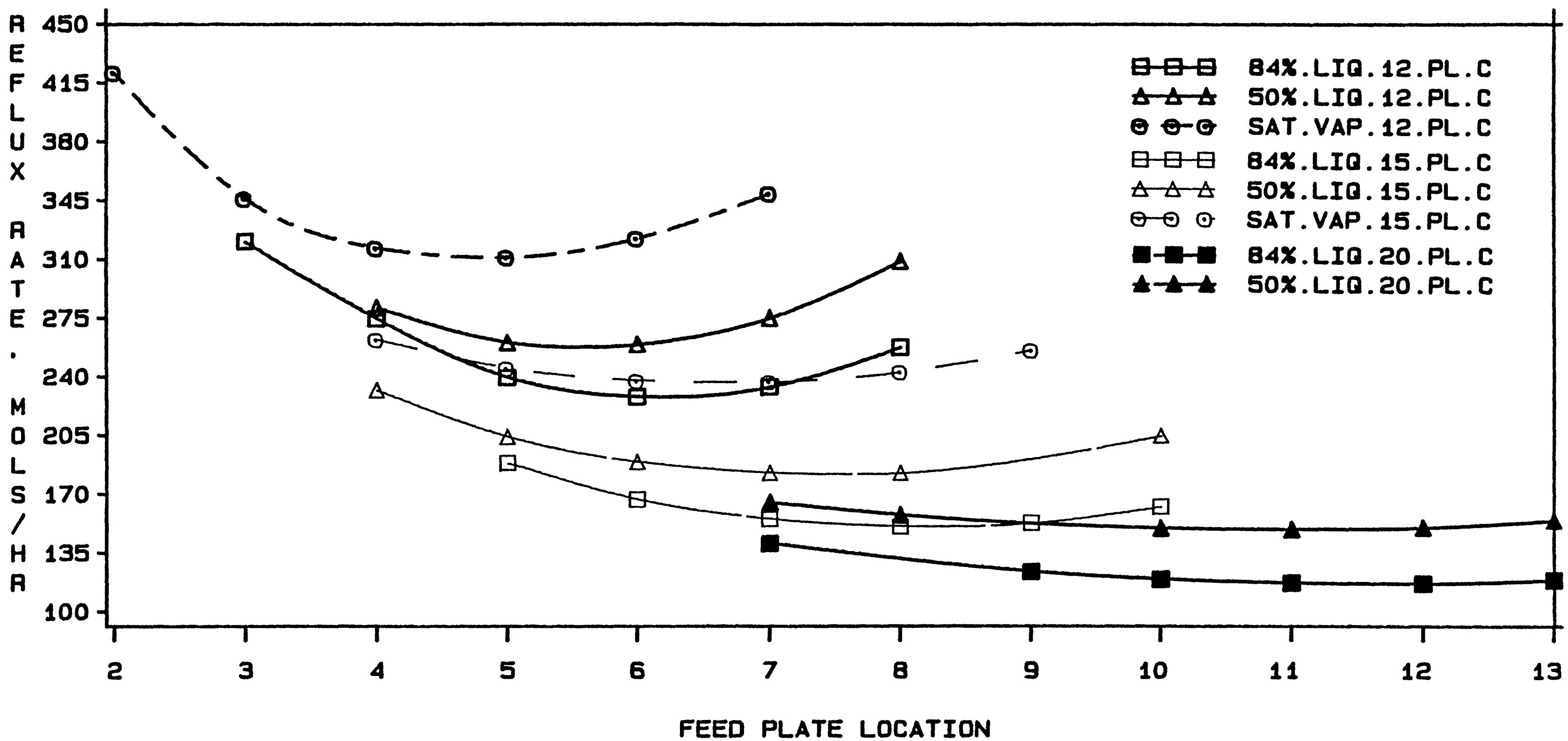


Figure 33. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.6

TABLE XXVIII

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.6

Source	Feed Condition	Optimum Feed Plate Location			
		12Pl.Col.	15Pl.Col.	20Pl.Col.	30Pl.Col.
Fenske	84% Liq.	5.4	6.6	8.7	12.8
Winn	84% Liq.	4.7	5.8	7.6	
Kirkbride	84% Liq.	5.8	7.1	9.3	13.7
Akashah et al.	84% Liq.	6.3	7.7	10.0	14.5
Theoretical Feed Plate	84% Liq.	6.1	8.0	11.5	
	50% Liq.	5.5	7.4	10.6	
	Sat.Vap.	4.8	6.6		

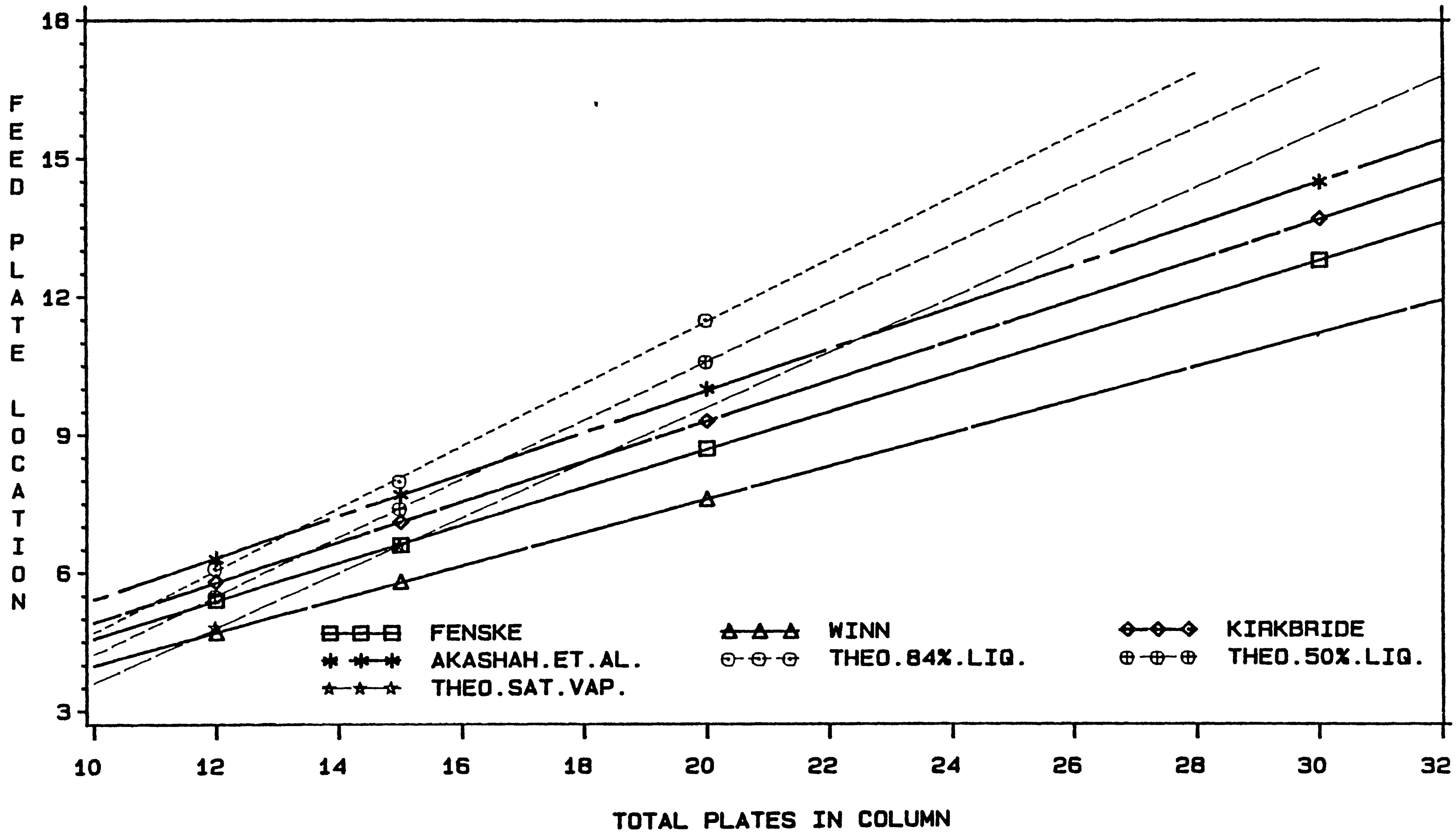


Figure 34. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.6

TABLE XXIX

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.7

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
CO2	0.40	0.40	-
C2H6	18.60	18.60	-
C3H8	171.37	169.66	1.71
nC4H10	32.98	1.97	31.01
nC5H12	19.00	-	19.00
nC6H14	21.50	-	21.50
Totals	491.00	54.50	436.50
Temperature,F	190.91	140.44	313.99
Pressure,psia	345.00	337.00	343.00
Feed Condition	50.00% liq.		

TABLE XXX

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.7

Feed Condition	13 Theo.Pl.Col. FPL	13 Theo.Pl.Col. Reflux (mols/hr)	15 Theo.Pl.Col. FPL	15 Theo.Pl.Col. Reflux (mols/hr)	17 Theo.Pl.Col. FPL	17 Theo.Pl.Col. Reflux (mols/hr)
Saturated liquid	6	675.4	6	538.9	7	397.4
	7	568.1	8	388.6	8	342.5
	8	506.1	9	355.9	9	308.7
	9	483.2	10	343.9	10	209.3
	10	501.8	13	485.9	15	457.3
	11	586.3				
50% liq.	5	679.5	6	479.9	7	387.3
	6	582.2	7	429.4	8	358.4
	7	530.7	8	403.4	9	344.3
	8	514.3	9	396.8	10	342.1
	9	533.6	10	409.2	11	351.3
	10	602.2	11	446.3	12	374.4
Saturated vapor	5	795.1	6	586.4	7	497.2
	6	720.0	7	552.2	8	479.3
	7	691.6	8	541.7	9	474.9
	8	702.0	9	551.4	10	482.8
	9	756.9	10	584.4		
	10	881.2	11	651.4		

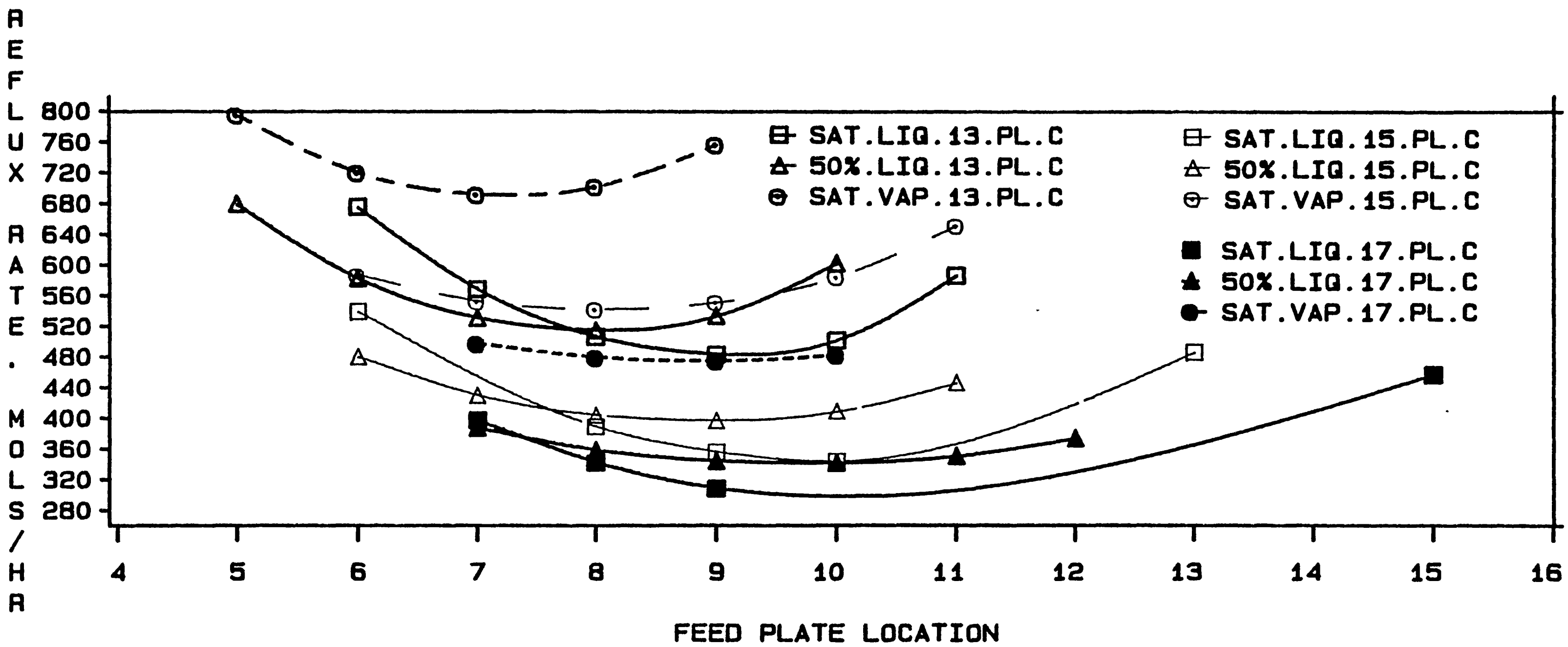


Figure 35. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.7

TABLE XXXI

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.7

Source	Feed Condition	Optimum Feed Plate Location			
		13Pl.Col.	15Pl.Col.	17Pl.Col.	19Pl.Col.
Fenske	50% Liq.	8.7	9.9	11.1	12.4
Winn	50% Liq.	8.0	9.2	10.3	
Kirkbride	50% Liq.	7.7	8.8	9.9	11.0
Akashah et al.	50% Liq.	8.2	9.4	10.5	11.6
Theoretical Feed Plate	Sat.Liq.	9.1	10.1	11.0	
	50% Liq.	8.0	8.9	9.8	
	Sat.Vap.	7.2	8.0	9.0	

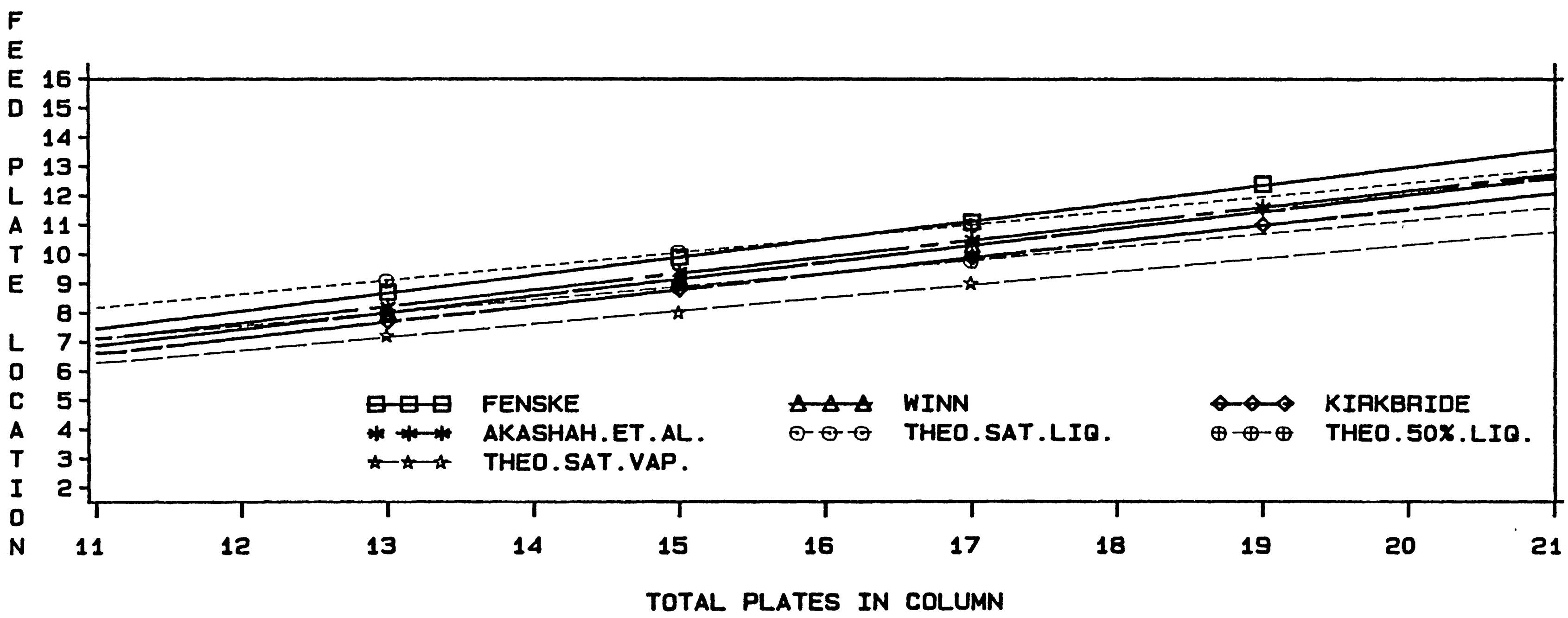


Figure 36. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.7

TABLE XXXII

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.8 AND FEED NO.9

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
CH4	2.00	2.00	-
C2H6	10.00	10.00	-
C3H6	6.00	6.00	-
C3H8	12.50	12.30	0.20
iC4H10	3.50	0.70	2.80
nC4H10	15.00	0.60	14.40
nC5H12	15.20	-	15.20
nC6H14	11.30	-	11.30
nC7H16	9.00	-	9.00
nC8H18	8.50	-	8.50
nC10H22	7.00	-	7.00
Totals	100.00	31.60	68.40
Temperature,F			
Feed No.8	172.11	96.57	347.42
Feed No.9	299.63		
Pressure,psia	270.00	262.00	267.00

Feed Condition:

Feed No.8 Saturated Liquid

Feed No.9 50.00% Liquid

TABLE XXXIII

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.8 AND FEED NO.9

Feed Condition	12 Theo.Pl.Col. FPL	12 Theo.Pl.Col. Reflux (mols/hr)	16 Theo.Pl.Col. FPL	16 Theo.Pl.Col. Reflux (mols/hr)	20 Theo.Pl.Col. FPL	20 Theo.Pl.Col. Reflux (mols/hr)
Saturated liquid (Feed No.8)	6	62.0	7	46.5	8	40.4
	7	56.5	9	40.5	10	36.3
	8	54.4	10	39.3	12	34.5
	9	55.9	11	38.9	14	34.3
	10	63.1	12	39.8	15	35.1
			13	42.7	16	36.7
50% liq. (Feed No.9)	2	186.8	5	119.9	6	110.0
	3	157.2	6	117.3	7	108.7
	4	144.3	7	116.4	8	108.2
	5	139.2	8	116.6	9	108.2
	6	139.0	9	118.1	10	108.6
	7	143.3	10	121.2	11	109.5
	8	153.0	11	126.6	12	110.9
Saturated vapor	2	250.3	2	227.2	2	215.5
	3	242.3	3	221.7	3	211.6
	4	240.9	4	220.1	4	210.3
	5	243.8	5	220.2	5	210.3
	6	250.5	6	221.4	6	211.0
			7	223.7	7	212.2
					8	213.7

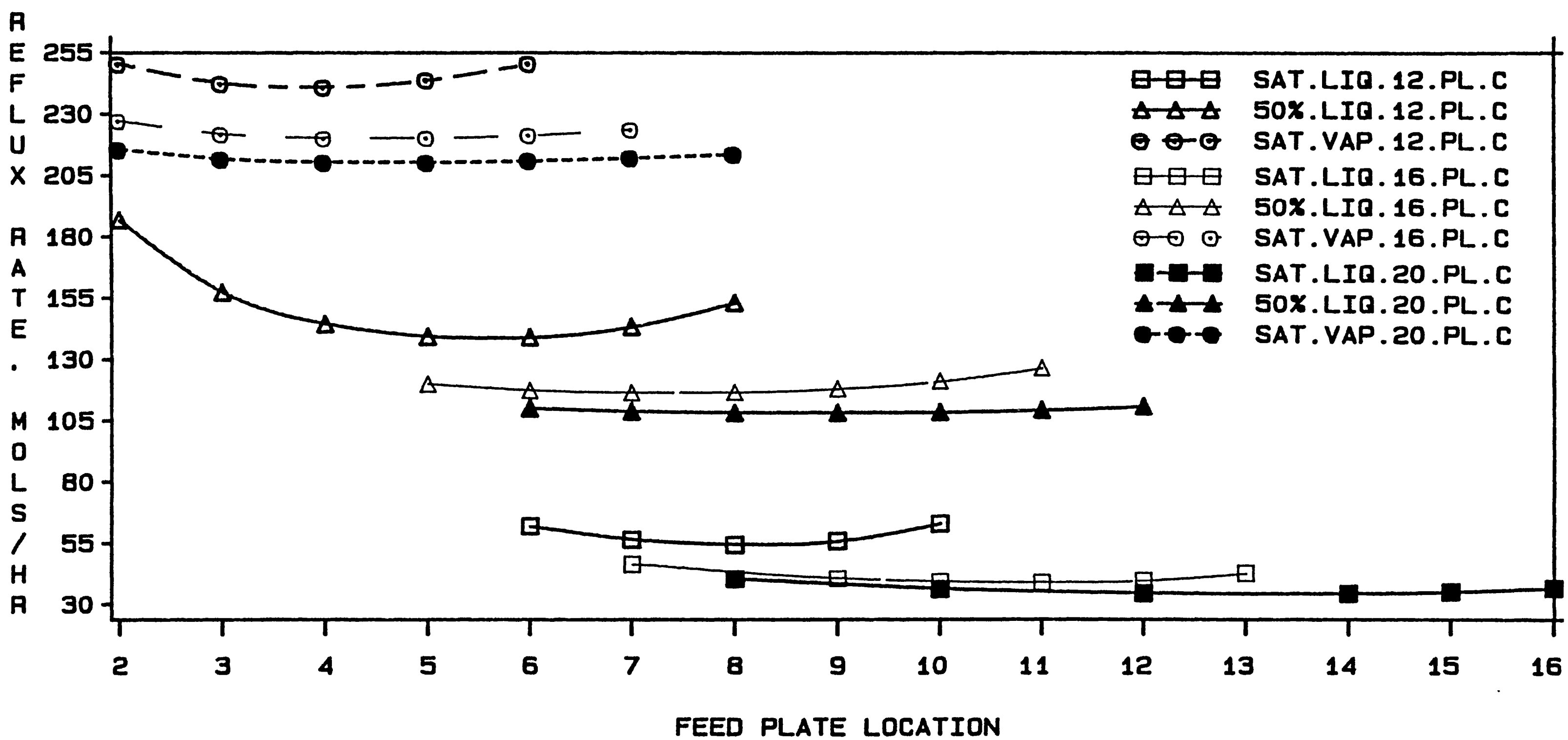


Figure 37. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.8 and No.9

TABLE XXXIV

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION
FEED NO.8 AND FEED NO.9

Source	Feed Condition	Optimum Feed Plate Location		
		12 Pl.Col.	16 Pl.Col.	20 Pl.Col.
Fenske	Saturated Liquid	9.2	12.1	14.9
Winn	Saturated Liquid	9.4	12.3	15.2
Kirkbride	Saturated Liquid	9.3	12.2	15.0
Akashah et al.	Saturated Liquid	9.8	12.8	15.7
Theoretical Feed Plate	Saturated Liquid (Feed No.8)	8.1	10.7	13.0
	50% liq. (Feed No.9)	5.8	7.2	8.7
	Saturated Vapor	3.9	4.4	4.7

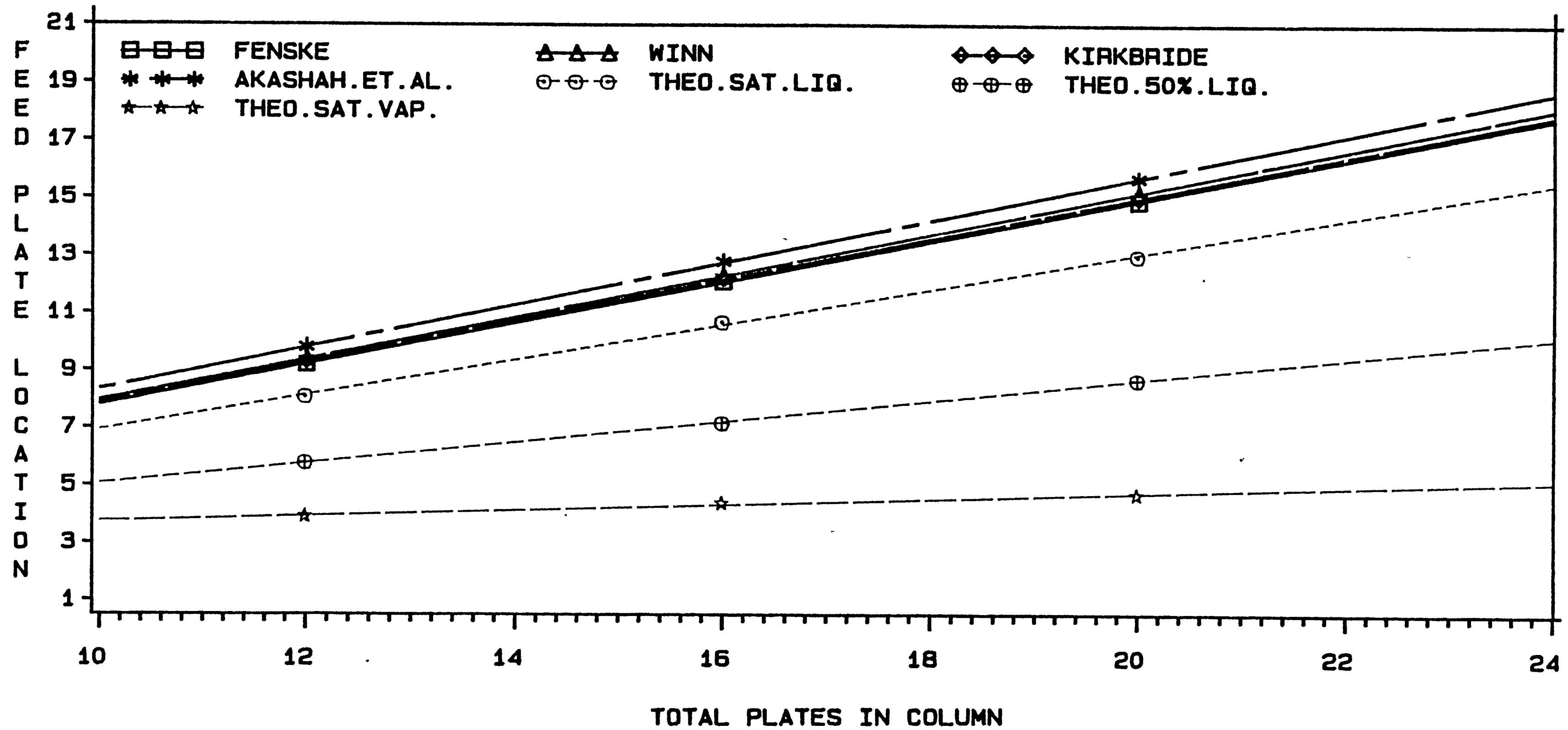


Figure 38. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.8 and No.9

TABLE XXXV

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.10

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
CH4	2.00	2.00	-
C2H6	10.00	10.00	-
C3H6	6.00	6.00	-
C3H8	12.50	12.30	0.20
iC4H10	3.50	0.70	2.80
nC4H10	15.00	0.60	14.40
nC5H12	15.20	-	15.20
nC6H14	11.30	-	11.30
nC7H16	9.00	-	9.00
nC8H18	8.50	-	8.50
nC10H20	7.00	-	7.00
nC12H26	10.00	-	10.00
Totals	110.00	31.60	78.40
Temperature,F	187.39	96.57	371.82
Pressure,psia	270.00	262.00	267.00

Feed Condition: Saturated Liquid

TABLE XXXVI

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.10

Feed Condition	12 Theo.Pl.Col. FPL	12 Theo.Pl.Col. Reflux (mols/hr)	16 Theo.Pl.Col. FPL	16 Theo.Pl.Col. Reflux (mols/hr)	20 Theo.Pl.Col. FPL	20 Theo.Pl.Col. Reflux (mols/hr)
Saturated liquid	6	70.3	5	66.8	7	47.5
	7	64.2	6	57.1	8	43.7
	8	62.2	7	50.9	9	41.1
	9	64.8	8	46.9	10	39.3
	10	74.4	10	43.1	11	38.1
	11	99.1	11	42.9	13	37.2
			12	44.2	14	37.5
			13	47.9	15	38.4
50% liq.	3	180.3	4	148.7	4	139.4
	4	170.0	5	145.0	5	136.2
	5	167.0	6	143.5	6	134.6
	6	169.0	7	143.5	7	134.1
	7	176.1	8	144.8	8	134.2
			9	147.8	9	134.9
			10	152.1	10	135.9
Saturated vapor	2	341.2	3	310.5	2	298.9
	3	336.5	4	310.8	3	*
	4	338.4	5	312.5	4	*
	5	344.9	6	315.4	5	*

* MAXISIM Did Not Converge in 20 Iterations

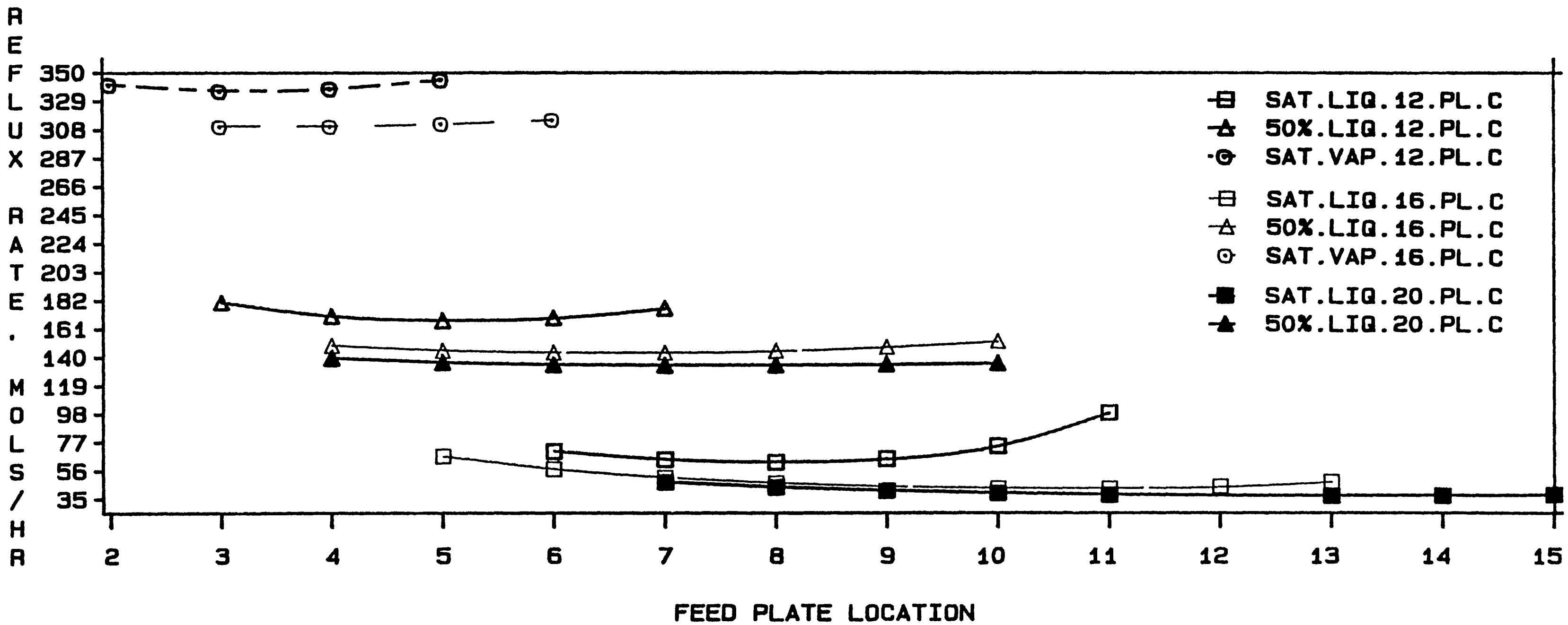


Figure 39. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.10

TABLE XXXVII

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.10

Source	Feed Condition	Optimum Feed Plate Location 12 Pl.Col.	16 Pl.Col.	20 Pl.Col.
Fenske	Saturated Liquid	9.2	12.1	14.9
Winn	Saturated Liquid	9.5	12.4	15.3
Kirkbride	Saturated Liquid	9.2	12.1	14.9
Akashah et al.	Saturated Liquid	9.8	12.7	15.6
Theoretical Feed Plate	Saturated Liquid	8.0	10.5	12.8
	50% liq.	5.1	6.4	7.4
	Saturated Vapor	2.9	3.2	

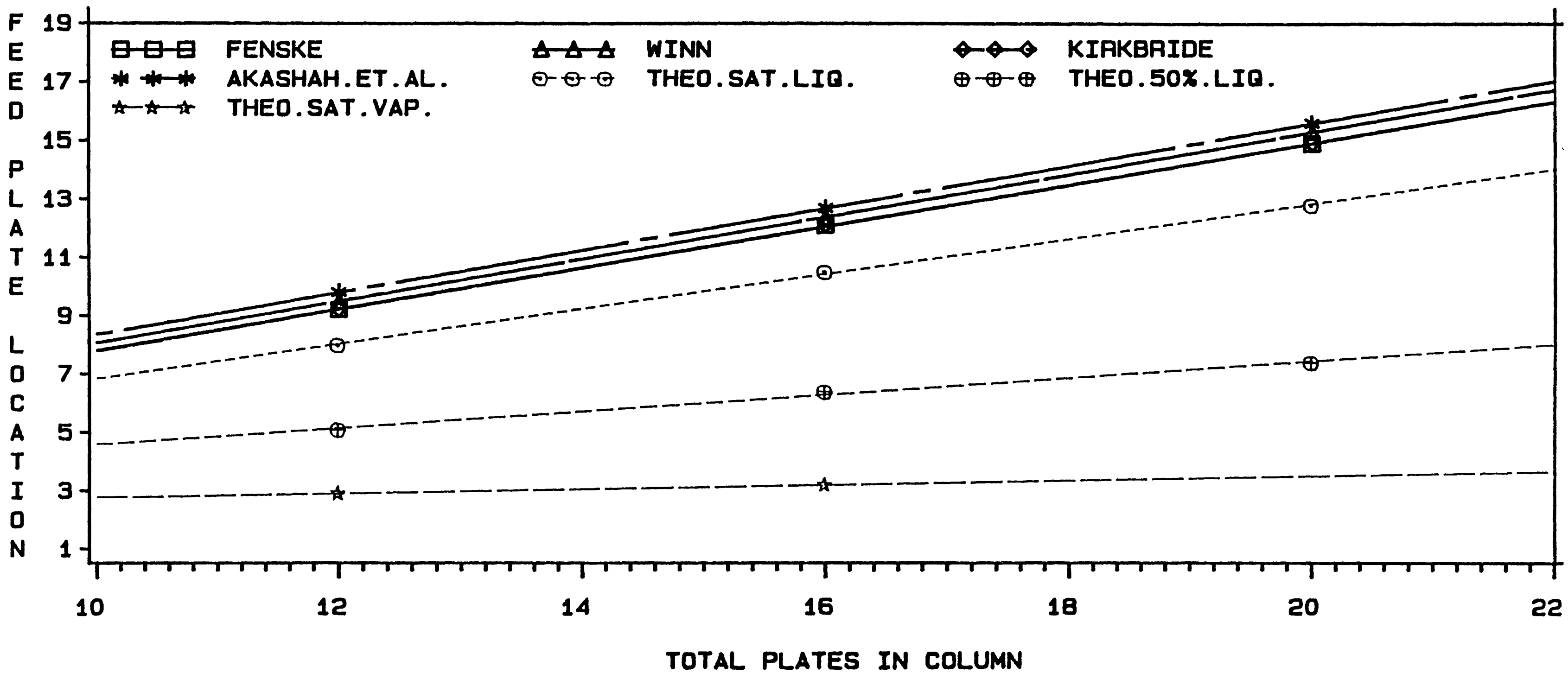


Figure 40. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.10

TABLE XXXVIII

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.11

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
CH4	4.00	4.00	-
C2H6	10.00	10.00	-
C3H6	6.00	6.00	-
C3H8	12.50	12.30	0.20
iC4H10	3.50	0.70	2.80
nC4H10	15.00	0.60	14.40
nC5H12	15.20	-	15.20
nC6H14	11.30	-	11.30
nC7H16	9.00	-	9.00
nC8H18	8.50	-	8.50
nC10H22	14.00	-	14.00
Totals	109.00	33.60	75.40
Temperature,F	147.91	91.12	363.66
Pressure,psia	270.00	262.00	267.00

Feed Condition: Saturated Liquid

TABLE XXXIX

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.11

Feed Condition	12 Theo.Pl.Col. FPL	12 Theo.Pl.Col. Reflux (mols/hr)	16 Theo.Pl.Col. FPL	16 Theo.Pl.Col. Reflux (mols/hr)	20 Theo.Pl.Col. FPL	20 Theo.Pl.Col. Reflux (mols/hr)
Saturated liquid	6	52.0	6	44.4	8	33.5
	7	46.1	7	38.8	10	29.4
	8	43.1	8	35.1	12	27.6
	9	43.1	10	31.2	13	27.2
	10	47.6	11	30.6	15	27.6
	11	62.4	13	36.5	16	28.6
50% liq.	3	156.0	5	125.2	6	116.5
	4	145.9	6	123.4	7	115.7
	5	142.3	7	123.0	8	115.5
	6	143.1	9	125.5	9	115.8
	7	148.1	10	128.9	10	116.5
					11	117.5
Saturated vapor	2	277.2	2	254.2	3	*
	3	271.0	3	250.3	4	239.1
	4	271.1	4	249.5	5	239.6
	5	275.4	5	250.3	6	240.8
	6	283.6	6	252.2	7	*
			7	255.0	8	*

* MAXISIM Did Not Converge in 20 Iterations

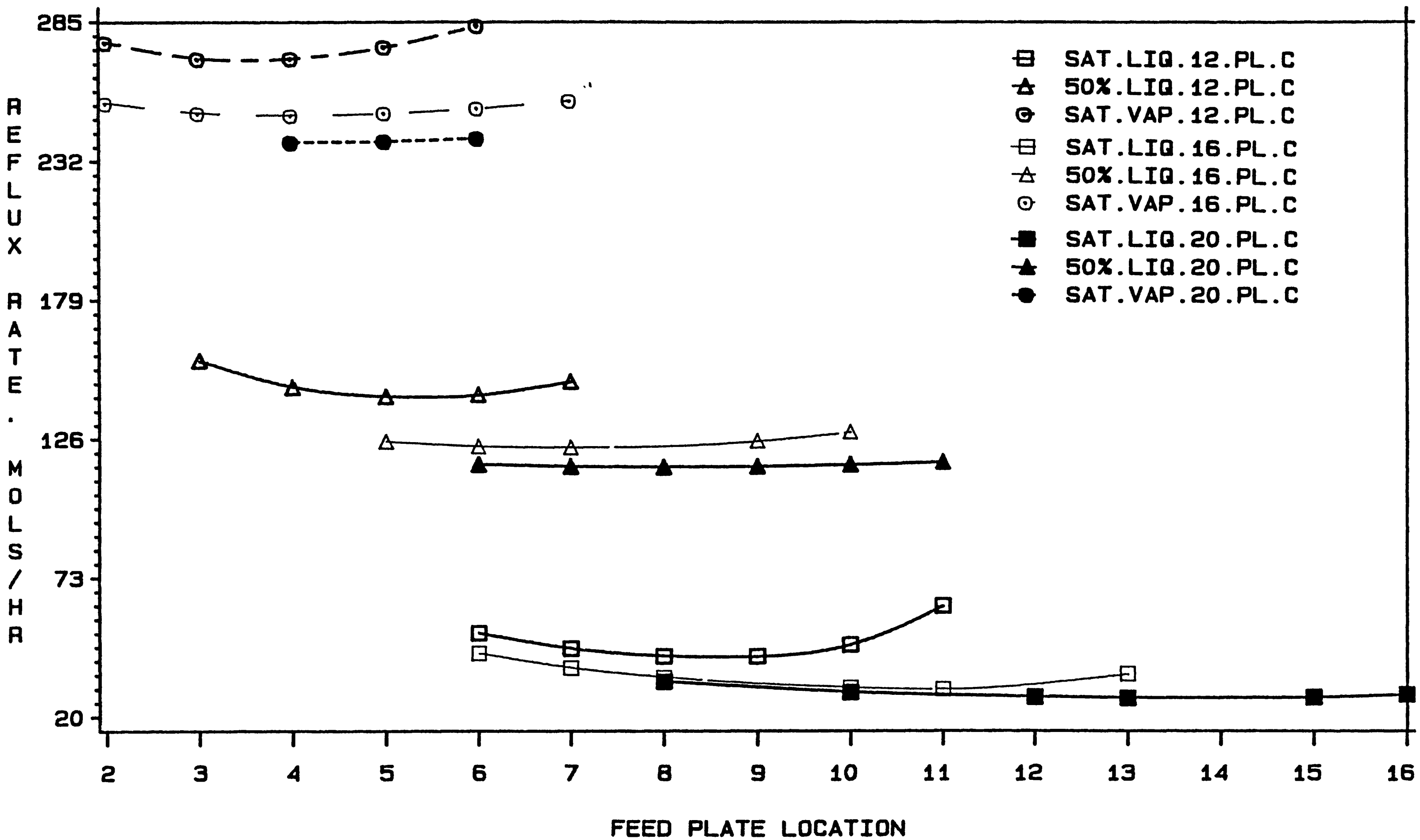


Figure 41. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.11

TABLE XL

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.11

Source	Feed Condition	Optimum Feed Plate Location		
		12 Pl.Col.	16 Pl.Col.	20 Pl.Col.
Fenske	Saturated Liquid	9.2	12.1	14.9
Winn	Saturated Liquid	9.4	12.3	15.2
Kirkbride	Saturated Liquid	9.2	12.1	14.9
Akashah et al.	Saturated Liquid	9.8	12.7	15.6
Theoretical Feed Plate	Saturated Liquid	8.4	10.8	13.0
	50% liq.	5.3	6.8	8.0
	Saturated Vapor	3.4	4.0	4.4

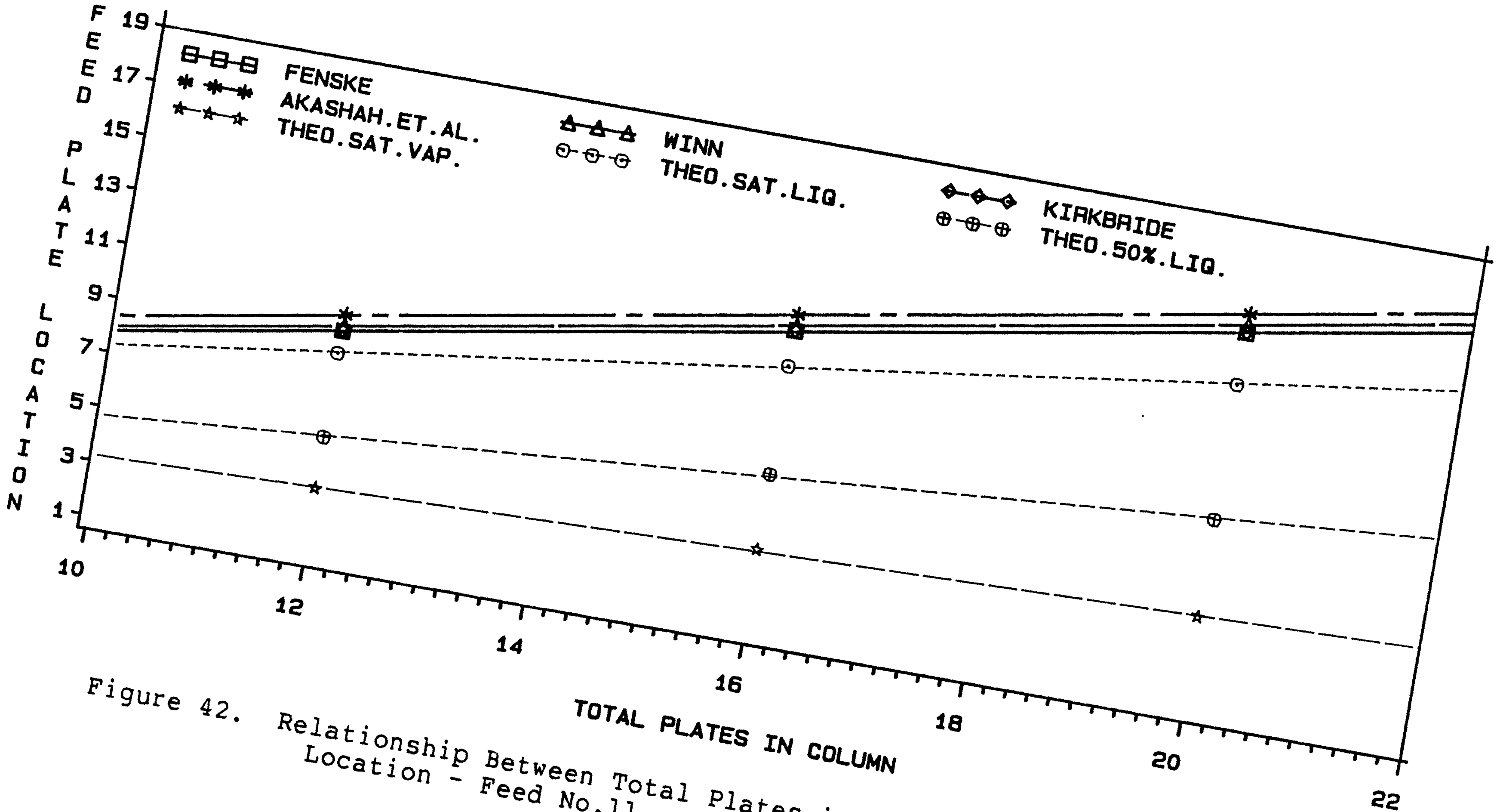


Figure 42. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.11

TABLE XLI

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.12

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
CH4	8.00	8.00	-
C2H6	10.00	10.00	-
C3H6	6.00	6.00	-
C3H8	12.50	12.30	0.20
iC4H10	3.50	0.70	2.80
nC4H10	15.00	0.60	14.40
nC5H12	15.20	-	15.20
nC6H14	11.30	-	11.30
nC7H16	9.00	-	9.00
nC8H18	8.50	-	8.50
nC9H20	28.00	-	28.00
Totals	127.00	37.60	89.40
Temperature,F	103.98	81.62	392.71
Pressure,psia	270.00	262.00	267.00

Feed Condition: Saturated Liquid

TABLE XLII

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.12

Feed Condition	12 Theo.Pl.Col. FPL	12 Theo.Pl.Col. Reflux (mols/hr)	16 Theo.Pl.Col. FPL	16 Theo.Pl.Col. Reflux (mols/hr)	20 Theo.Pl.Col. FPL	20 Theo.Pl.Col. Reflux (mols/hr)
Saturated liquid	6	32.3	8	21.6	9	19.2
	7	26.9	10	18.0	11	16.9
	8	23.5	11	17.2	12	16.3
	9	21.5	13	16.6	13	16.0
	10	21.0	14	17.2	14	15.8
	11	23.4	15	20.0		
	12	39.0				
50% liq.	3	158.8	3	145.2	4	134.0
	4	152.9	4	140.0	6	130.9
	5	151.7	5	137.8	7	130.7
	6	153.9	6	137.1	8	131.1
	7	159.8	7	137.5	9	131.8
	8	170.8	8	138.7		
Saturated vapor	2	308.2	2	290.1	2	*
	3	306.2	3	288.5	3	*
	4	308.5	4	289.1	4	*
	5	314.3	5	290.8	5	*
	6	324.1	6	293.3	6	*

* MAXISIM Did Not Converge in 20 Iterations

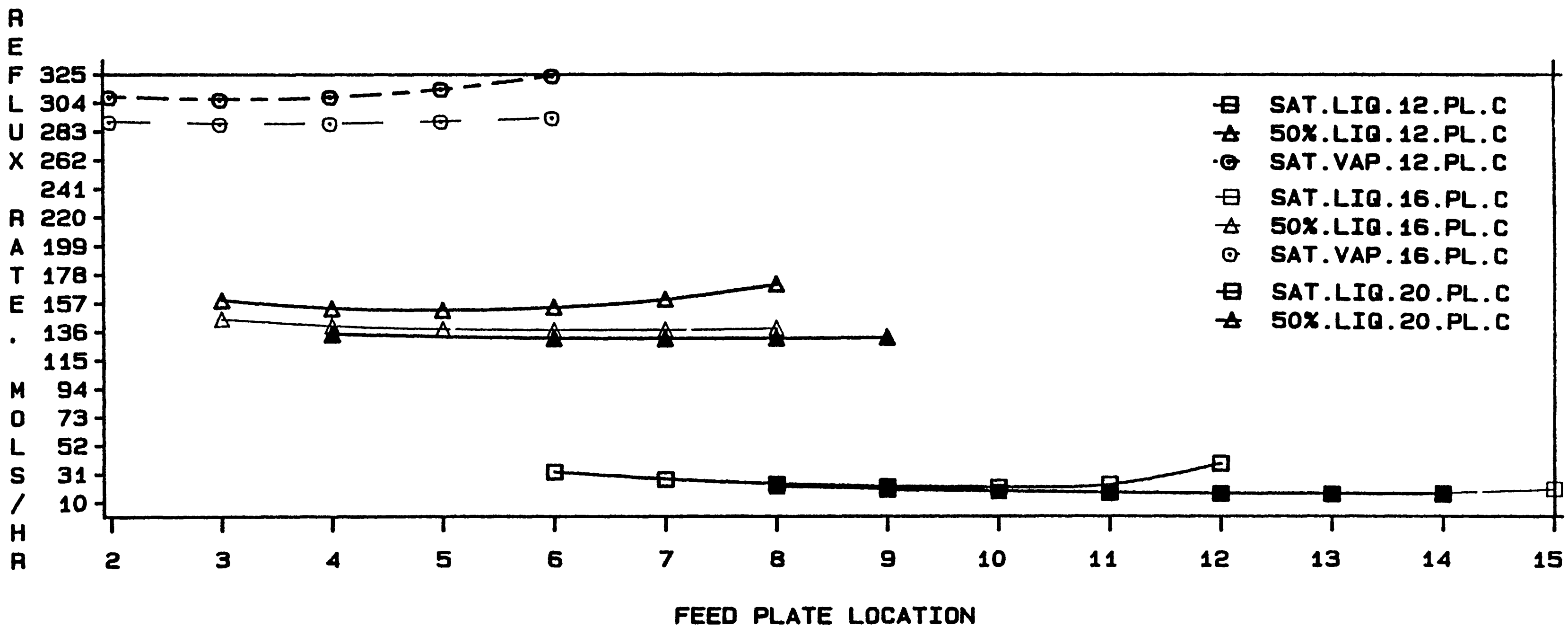


Figure 43. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.12

TABLE XLIII

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.12

Source	Feed Condition	Optimum Feed Plate Location		
		12 Pl.Col.	16 Pl.Col.	20 Pl.Col.
Fenske	Saturated Liquid	9.2	12.1	14.9
Winn	Saturated Liquid	9.5	10.9	12.4
Kirkbride	Saturated Liquid	9.5	12.5	15.4
Akashah et al.	Saturated Liquid	10.1	13.1	15.6
Theoretical Feed Plate	Saturated Liquid	9.5	12.4	15.3
	50% liq.	4.9	6.1	7.0
	Saturated Vapor	3.0	3.3	

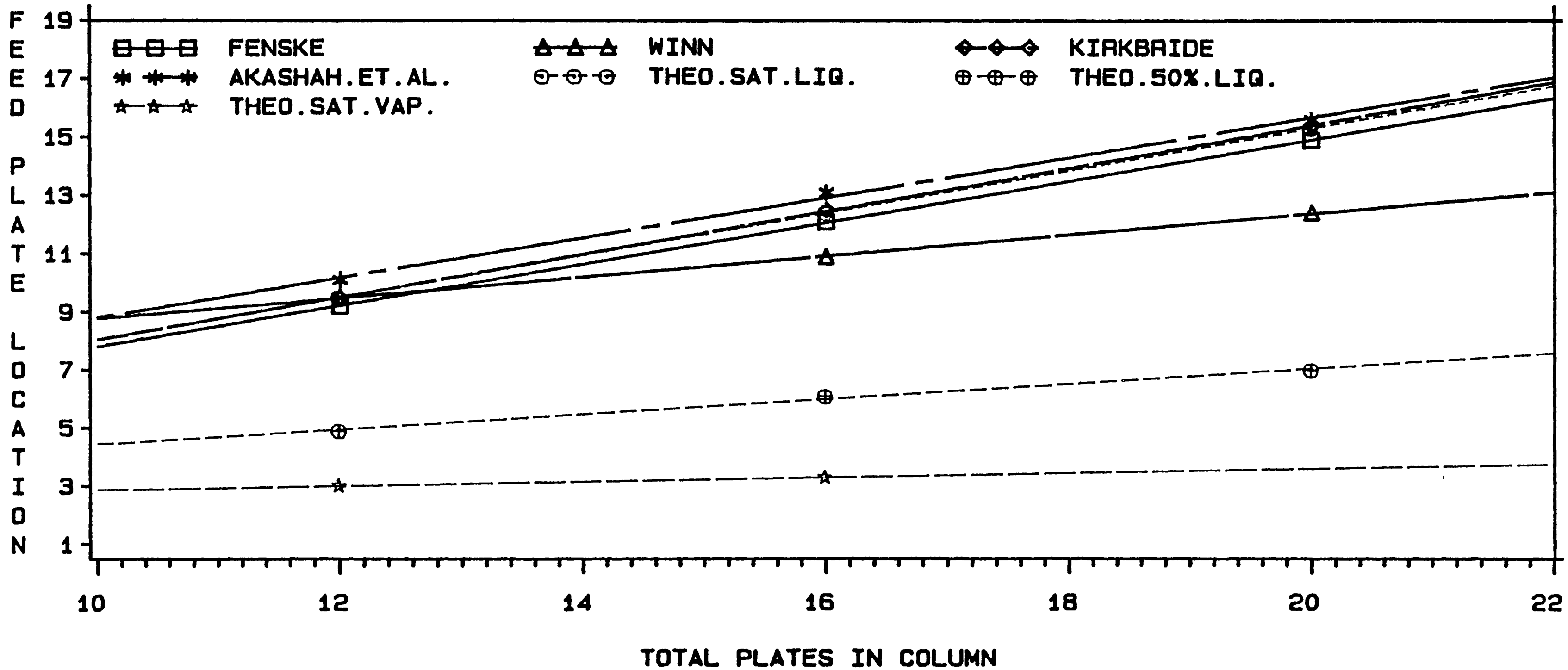


Figure 44. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.12

TABLE XLIV

FEED COMPOSITION AND PROCESS CONDITIONS - FEED NO.13

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
C2H6	1.89	1.89	-
C3H8	111.38	106.97	4.46
iC4H10	32.60	7.41	25.19
nC4H10	21.89	1.33	20.56
iC5H12	10.99	0.01	10.98
nC5H12	11.00	-	11.00
nC8H18	22.00	-	22.00
Totals	211.75	117.61	94.19
Temperature,F	200.60	155.52	304.21
Pressure,psia	343.00	343.00	353.00

Feed Condition: Saturated Liquid

TABLE XLV

FEED PLATE LOCATIONS AND REFLUX RATES FOR VARIOUS FEED CONDITIONS AND COLUMN SIZES - FEED NO.13

Feed Condition	15 Theo.Pl.Col. FPL	15 Theo.Pl.Col. Reflux (mols/hr)	20 Theo.Pl.Col. FPL	20 Theo.Pl.Col. Reflux (mols/hr)	25 Theo.Pl.Col. FPL	25 Theo.Pl.Col. Reflux (mols/hr)
Saturated liquid	7	306.2	8	266.2	12	197.6
	8	265.5	10	217.1	13	190.7
	9	238.8	12	195.0	14	185.9
	10	222.3	14	186.5	16	180.4
	12	213.0	16	187.8	18	178.6
	13	221.0			20	180.5
50% liq.	7	346.6	11	283.8	14	271.6
	8	325.2	12	280.0	15	269.9
	9	313.6	13	278.9	16	269.2
	10	309.9	14	280.5	17	269.7
	11	313.8	16	295.1	19	275.2
	12	327.3				
Saturated Vapor	5	552.7	7	499.3	10	475.2
	6	527.2	8	487.8	12	467.7
	7	514.1	9	480.7	13	465.9
	8	509.7	10	476.9	14	465.2
	9	512.4	11	475.9	15	465.7
	10	522.3	12	477.6	16	467.7
	11	540.9	13	482.4	18	477.7

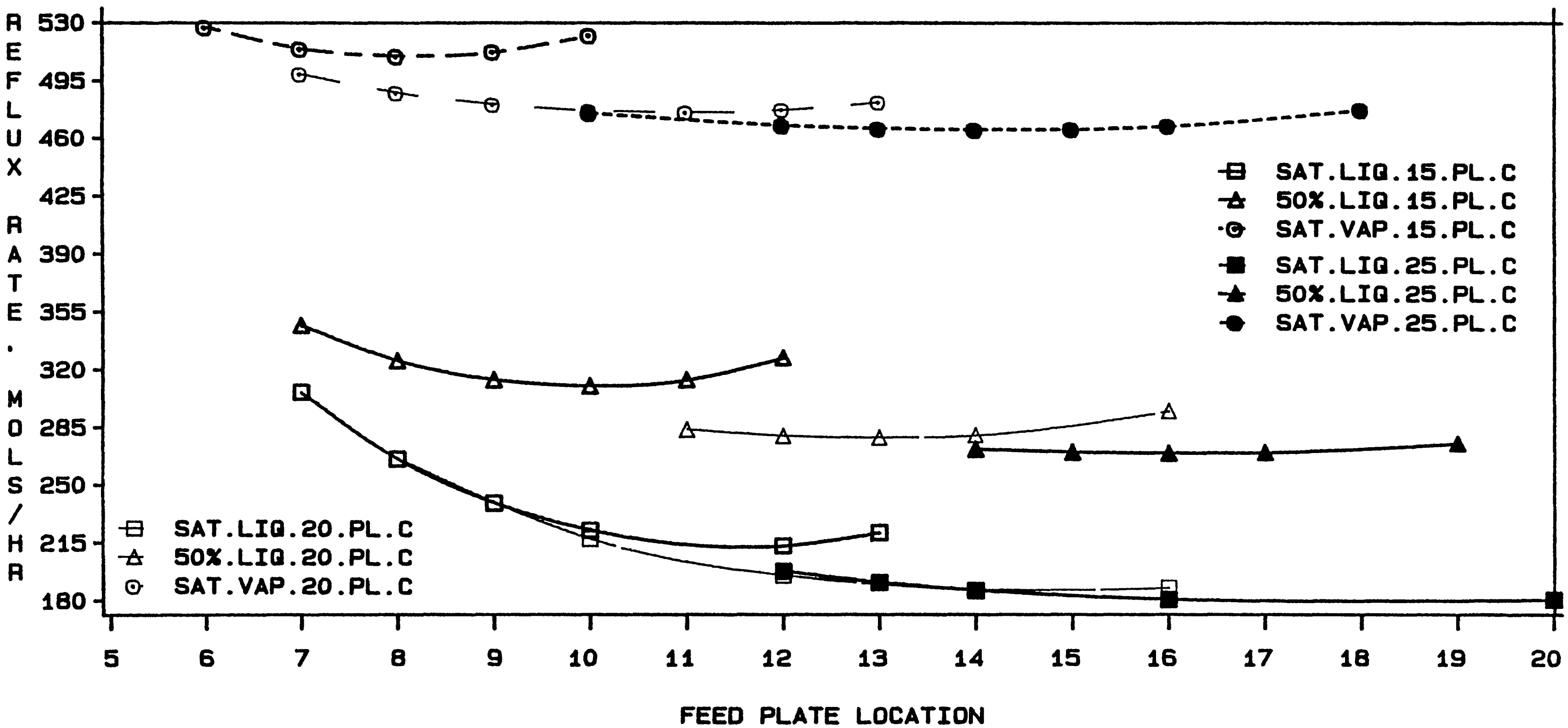


Figure 45. Effects of Feed Plate Location and Feed Vaporization on Reflux Rate - Feed No.13

TABLE XLVI

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - FEED NO.13

Source	Feed Condition	Optimum Feed Plate Location		
		15 Pl.Col.	20 Pl.Col.	25 Pl.Col.
Fenske	Saturated Liquid	10.8	14.1	17.5
Winn	Saturated Liquid	10.5	13.8	17.1
Kirkbride	Saturated Liquid	9.7	12.7	15.7
Akashah et al.	Saturated Liquid	10.2	13.3	16.4
Theoretical Feed Plate	Saturated Liquid	11.9	15.0	18.0
	50% liq.	10.0	12.9	16.0
	Saturated Vapor	8.0	11.0	14.0

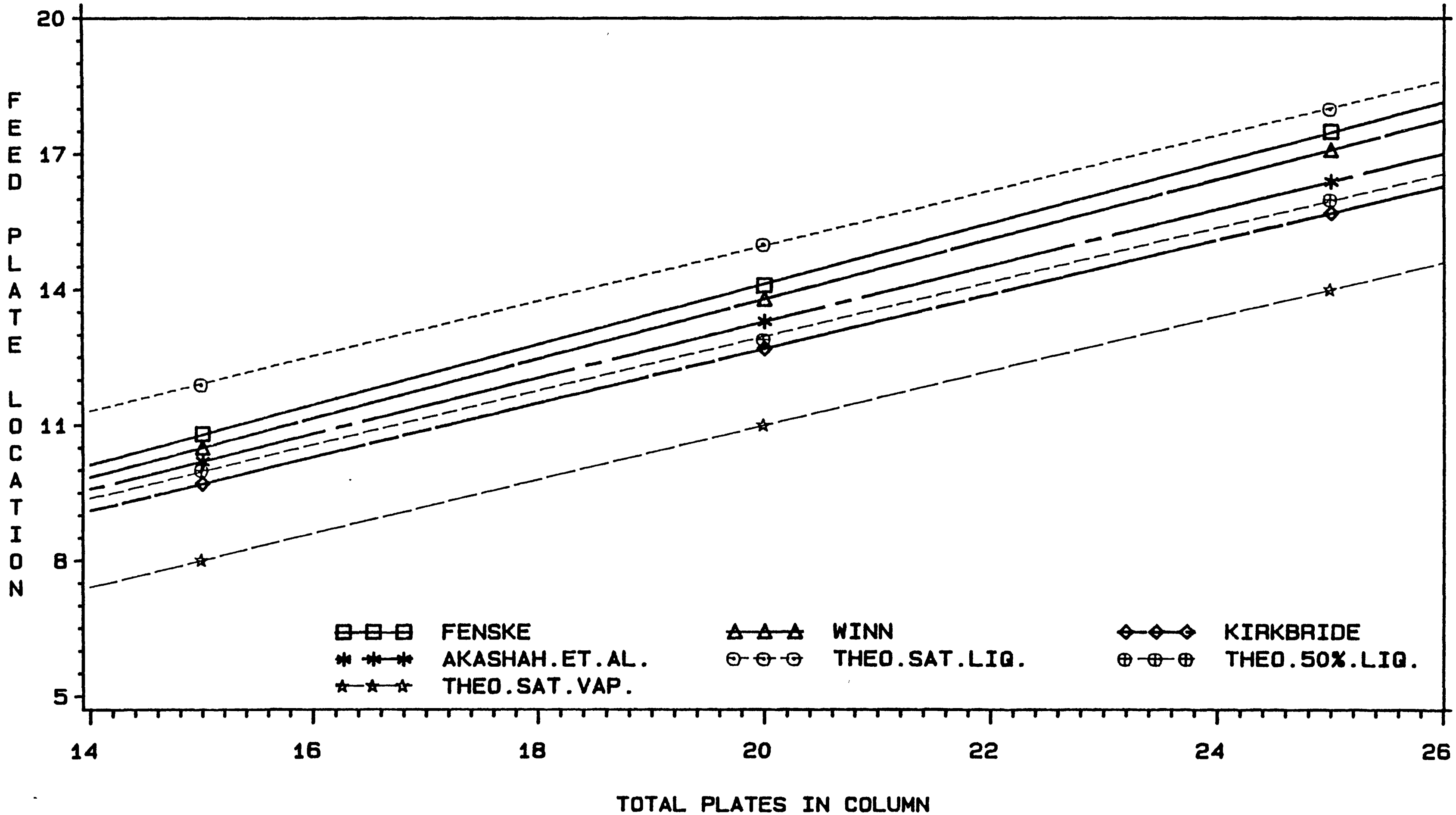


Figure 46. Relationship Between Total Plates in the Column and Feed Plate Location - Feed No.13

APPENDIX C

SAMPLES OF CALCULATIONS FOR THE FEED PLATE LOCATIONS BY THE CORRELATIONS OF FENSKE, WINN, KIRKBRIDE AND AKASHAH ET AL.

Feed No. 2 was chosen to illustrate the sample of calculations. The specific separation constants from Table XIV can be assigned as the followings:

$$f = 17.09 \text{ moles/hr}$$
$$f' = 20.68 \text{ mols/hr}$$
$$d = 16.92 \text{ mols/hr}$$
$$d' = 0.62 \text{ mols/hr}$$
$$b = 0.17 \text{ mols/hr}$$
$$b' = 20.06 \text{ mols/hr}$$
$$F = 72.43 \text{ mols/hr}$$
$$D = 18.04 \text{ mols/hr}$$
$$B = 54.39 \text{ mols/hr}$$
$$N = 12.0$$
$$XHF = f'/F = 20.68/72.43 = 0.286$$
$$XLF = f/F = 17.09/72.43 = 0.236$$
$$XLB = b/B = 0.17/54.39 = 0.003$$
$$XHD = d'/D = 0.62/18.04 = 0.034$$

Feed Plate Location by the

Fenske Correlations

Recall:

$$\alpha_{avg}^{N_r} = (d/f)(f'/d') \tag{18}$$

and

$$\alpha_{avg}^{N_s} = (f/b)(b'/f') \tag{19}$$

Substituting all known values into Equations (18) and (19),

$$\alpha_{avg}^{N_r} = (16.92/17.09)(20.68/0.62) = 33.023 \tag{C-1}$$

$$\alpha_{avg}^{N_s} = (17.09/0.17)(20.06/20.68) = 97.515 \qquad \text{(C-2)}$$

Multiplying Equation (C-1) with Equation (C-2), taking logarithm, and rearranging:

$$\alpha_{avg}^{N_r+N_s} = (33.023)(97.515)$$

$$(N_r + N_s)\ \log\alpha_{avg} = \log\{(33.023)(97.515)\}$$

$$\log\alpha_{avg} = \log\{(33.023)(97.515)\}\ /(N_r + N_s)$$

Since,

$$N_r + N_s = N + 2 - 1$$

$$= 12 + 2 - 1$$

$$= 13$$

hence,

$$\log\alpha_{avg} = \log\{(33.023)(97.515)\}\ /13$$

$$= 0.2698.$$

Taking the logarithm of Equation (C-2), rearranging, and substituting the value of $\log\alpha_{avg}$,

$$N_s\ \log\alpha_{avg} = \log(97.515)$$

$$N_s = \log(97.515)/\log\alpha_{avg}$$

$$= \log(97.515)/0.2698$$

$$= 7.5$$

Therefore, the 7.5th plate is the feed plate location calculated from Fenske correlations. The plates will be counted from the bottom up where the reboiler is considered as the zeroth plate. The system of counting will be applied throughout this work.

Feed Plate Location by the Winn Correlations

The feed plate location by the Winn correlations can be estimated from Equation (A-6)

$$N_s = \frac{(N + 2 - 1)\ \log\{(f/b)^{\xi}(b'/f')^{\theta}(B/F)^{1-\theta}\}}{\log\{(d/b)^{\xi}(b'/d')^{\theta}(B/D)^{1-\theta}\}} \qquad \text{(A-6)}$$

where

$\xi = 1.3$

$\theta = 2.0$

Substituting all known values in Equation (A-6):

$$N_s = \frac{13\ \log\{(17.09/0.17)^{1.3}(20.06/20.68)^{2.0}(54.39/72.43)^{1-2.0}\}}{\log\{(16.92/0.17)^{1.3}(20.06/0.62)^{2.0}(54.39/18.04)^{1-2.0}\}}$$

$$= 6.9$$

Feed Plate Location by the Kirkbride Correlation

Recall the Kirkbride correlation:

$$\log(N_r/N_s) = 0.206\ \log\{(B/D)(XHF/XLF)(XLB/XHD)^2\} \qquad (24)$$

Substituting,

$$\log(\frac{N_r}{N_s}) = 0.206 \log\{(54.39/18.04)(0.286/0.236)(0.003/0.034)^2\}$$
$$= -0.318$$

Taking anti-logarithm of the above equation,

$$N_r/N_s = 0.48 \qquad (C-3)$$

Since

$$N_r + N_s = 13 \qquad (C-4)$$

Solving Equations (C-3) and (C-4) for N_s, then,

$$N_s = 8.8$$

Feed Plate Location by the Akashah Et Al. Correlation

Recall the Akashah et al. correlation:

$$FPL = FPL_K + 0.5 \log(N_T) \qquad (26)$$

Note that N_T is the number of plates not including reboiler, condenser and feed plate. Substituting all known values into Equation (26)

$$FPL = 8.8 + 0.5 \log(12 - 1)$$
$$= 9.3$$

In order to expedite the calculations, the SAS input programs were prepared for each correlation. These were shown Appendix D.

APPENDIX D

LISTING OF SAS INPUT PROGRAMS AND SAMPLES OF THE PRINTOUTS

The SAS input programs presented in this appendix are capable of calculating feed plate locations for all thirteen feeds, of determining the regression equations and of displaying the graphs of feed plate location as a function of total number of plates from both correlations and regression equations. The program listings for the Fenske, Kirkbride and Akashah et al. correlations were shown on pages 144, 145, and 146, respectively. The program listing for the Winn correlations can be found on page 75 of Appendix A. Nomenclature for the programs is as follows:

NO = feed number

FLK = molar flow rate of the light key component in the feed stream

FHK = molar flow rate of the heavy key component in the feed stream

F = total molar flow rate of the feed stream

DLK = molar flow rate of the light key component in the distillate stream

DHK = molar flow rate of the heavy key component in the distillate stream

D = total molar flow rate of the distillate stream

BLK = molar flow rate of the light key component in the bottom stream

BHK = molar flow rate of the heavy key component in the bottom stream

B = total molar flow rate of the bottom stream

NOP1 = total number of plates in the short column

NOP2 = total number of plates in the medium column

NOP3 = total number of plates in the tall column

NOS1 = feed plate location for the short column

NOS2 = feed plate location for the medium column

NOS3 = feed plate location for the tall column

The input data from thirteen feeds were entered under the "CARDS" line. The feed plate location calculation will be executed in the data step. The procedure step consists of the input data listing command and the results printout command, "PROC PRINT"; the linear regression command, "PROC GLM"; and the graph plotting command, "PROC PLOT".

The printouts of the Kirkbride case were shown on pages 147 to 150.

The "XNOPL" and the "INTERCEPT" printed on the regression information page refer to the slope and the intercept of the regression equation.

Note that the numbers from one to nine shown on the printout graph represent the Feed Nos.1 to 9. The letter A, B, C, and D refer to the Feed Nos.10, 11, 12 and 13, respectively. The asterisk symbol, *, represents the feed plate location calculated from the regression equation. In some cases, there are calculated values that are close to others. All of those points but one will be omitted and will be flagged as the hidden observations.

Program Listing for the Fenske Correlations

```
DATA FENSKE (DROP=XNOPL YNOSTRIP OBSV)
     TOPLOT (KEEP=NO XNOPL YNOSTRIP OBSV);
  INPUT NO FLK FHK F DLK DHK D BLK BHK B NOP1 NOP2 NOP3;
  LIST;
  LENGTH OBSV $1 ;
    ALPHAN = (DLK/FLK)*(FHK/DHK);
    ALPHAM = (FLK/BLK)*(BHK/FHK);
  ARRAY NOPL(3) NOP1 NOP2 NOP3;
  ARRAY NOSTRIP(3) NOS1 NOS2 NOS3;
    DO I = 1 TO 3 ;
       NOSTRIP(I)=(NOPL(I)+2.-1.)*LOG10(ALPHAM)/LOG10(ALPHAN*ALPHAM);
       XNOPL=NOPL(I);
       YNOSTRIP=NOSTRIP(I);
       OBSV=NO;
          IF NO = 10 THEN OBSV='A';
          IF NO = 11 THEN OBSV='B';
          IF NO = 12 THEN OBSV='C';
          IF NO = 13 THEN OBSV='D';
       OUTPUT TOPLOT;
    END;
  OUTPUT FENSKE;
  CARDS;
1 54.00 377.00 491.00 51.81 2.70 54.51 2.20 374.30 436.49 10. 14. 20.
2 17.90 20.68 72.43 16.92 0.62 18.04 0.17 20.06 54.39 12. 16. 22.
3 792.53 108.84 1318.27 784.63 7.62 808.44 7.9 101.22 509.83 28. 34. 40.
4 196.43 51.00 510.55 186.62 7.24 304.54 9.81 43.76 206.01 12. 22  28.
5 179.33 226.92 703.77 151.87 2.27 305.61 27.46 224.65 398.16 12. 22. 32
6 20.00 37.00 100.00 19.30 0.30 22.60 0.70 36.70 77.40 12. 15. 20.
7 171.37 32.98 263.85 169.66 1.97 190.63 1.71 31.01 73.22 13. 15. 17.
8 12.50 3.50 100.00 12.30 0.70 31.48 0.20 2.80 68.52 12. 16. 20.
10 12.50 3.50 110.00 12.30 0.70 31.48 0.20 2.80 78.52 12. 16. 20.
11 12.50 3.50 109.00 12.30 0.70 33.48 0.20 2.80 75.52 12. 16. 20.
12 12.50 3.50 127.00 12.30 0.70 37.48 0.20 2.80 89.52 12. 14. 16
13 111.38 32.6 211.75 106.92 7.41 117.57 4.46 25.19 94.18 15. 20. 25.
  PROC SORT DATA=FENSKE;
       BY NO;
  PROC PRINT DATA=FENSKE;
       TITLE INPUT DATA FOR CALCULATING THE FEED PLATE LOCATION;
       TITLE2 BY FENSKE CORRELATIONS;
       VAR FLK FHK F DLK DHK D BLK BHK B ;
       LABEL NO='FEED NO.';
       ID NO;
       FOOTNOTE 'NOTE : SEE EXPLANATIONS OF ABBREVIATION IN APPENDIX D';
  PROC SORT DATA=TOPLOT;
       BY NO;
  PROC PRINT DATA=TOPLOT SPLIT='*';
       TITLE FEED PLATE LOCATIONS FROM FENSKE CORRELATIONS;
       VAR  XNOPL YNOSTRIP;
       BY NO;
       LABEL XNOPL='TOTAL NO. OF PLATES *     IN COLUMN';
       LABEL YNOSTRIP='FEED PLATE * LOCATION';
       LABEL NO='FEED NO.';
       ID NO;
       FOOTNOTE;
  PROC GLM DATA=TOPLOT;
       TITLE LINEAR REGRESSION INFORMATIONS FOR FENSKE CORRELATIONS;
       MODEL YNOSTRIP=XNOPL;
       OUTPUT OUT=NEW P=PREDICT;
  PROC PLOT DATA=NEW;
       TITLE 'EFFECT OF COLUMN SIZE ON FEED PLATE LOCATION';
       TITLE2 'BY FENSKE CORRELATIONS';
       PLOT YNOSTRIP*XNOPL=OBSV PREDICT*XNOPL='*'/OVERLAY;
       LABEL YNOSTRIP='FEED PLATE LOCATION';
       LABEL XNOPL='TOTAL NUMBER OF PLATE';
  FOOTNOTE1 'NOTE : NO.1-9 REFER TO FEED NO.1-9';
  FOOTNOTE2 'LETTERS A,B,C,D REFER TO FEED NO.10,11,12,13';
  FOOTNOTE3 '* SIGN REFERS TO THE VALUE FROM THE REGRESSION EQUATION';
```

Program Listing for the Kirkbride Correlation

```
DATA KIRKB (DROP=XNOPL YNOSTRIP OBSV)
     TOPLOT (KEEP=NO XNOPL YNOSTRIP OBSV);
  INPUT NO FLK FHK F DLK DHK D BLK BHK B NOP1 NOP2 NOP3;
  LIST;
  LENGTH OBSV $1 ;
    CONST = 0.206 ;
    XHF = FHK/F ;    XLF = FLK/F ;
    XLB = BLK/B ;    XHD = DHK/D ;
    NUM = CONST*LOG10((B/D)*(XHF/XLF)*(XLB/XHD)**2);
  ARRAY NOPL(3) NOP1 NOP2 NOP3;
  ARRAY NOSTRIP(3) NOS1 NOS2 NOS3;
    DO I = 1 TO 3 ;
       NOSTRIP(I)=(NOPL(I)+2.-1.)/(1 +10 **NUM);
       XNOPL=NOPL(I);
       YNOSTRIP=NOSTRIP(I);
       OBSV=NO;
          IF NO = 10 THEN OBSV='A';
          IF NO = 11 THEN OBSV='B';
          IF NO = 12 THEN OBSV='C';
          IF NO = 13 THEN OBSV='D';
       OUTPUT TOPLOT;
    END;
  OUTPUT KIRKB;
  CARDS;
1 54.00 377.00 491.00 51.81 2.70 54.51 2.20 374.30 436.49 10. 14. 20.
2 17.90 20.68 72.43 16.92 0.62 18.04 0.17 20.06 54.39 12. 16. 22.
3 792.53 108.84 1318.27 784.63 7.62 808.44 7.9 101.22 509.83 28. 34. 40.
4 196.43 51.00 510.55 186.62 7.24 304.54 9.81 43.76 206.01 12. 22. 28.
5 179.33 226.92 703.77 151.87 2.27 305.61 27.46 224.65 398.16 12. 22. 32
6 20.00 37.00 100.00 19.30 0.30 22.60 0.70 36.70 77.40 12. 15. 20.
7 171.37 32.98 263.85 169.66 1.97 190.63 1.71 31.01 73.22 13. 15. 17.
8 12.50 3.50 100.00 12.30 0.70 31.48 0.20 2.80 68.52 12. 16. 20.
10 12.50 3.50 110.00 12.30 0.70 31.48 0.20 2.80 78.52 12. 16. 20.
11 12.50 3.50 109.00 12.30 0.70 33.48 0.20 2.80 75.52 12. 16. 20.
12 12.50 3.50 127.00 12.30 0.70 37.48 0.20 2.80 89.52 12. 14. 16.
13 111.38 32.6 211.75 106.92 7.41 117.57 4.46 25.19 94.18 15. 20  25.
  PROC SORT DATA=KIRKB;
       BY NO;
  PROC PRINT DATA=KIRKB;
       TITLE INPUT DATA FOR CALCULATING THE FEED PLATE LOCATION;
       TITLE2 BY KIRKBRIDE CORRELATION;
       VAR FLK FHK F DLK DHK D BLK BHK B ;
       LABEL NO='FEED NO.';
       ID NO;
       FOOTNOTE 'NOTE : SEE ABBREVIATION EXPLANATIONS IN APPENDIX D';
  PROC SORT DATA=TOPLOT;
       BY NO;
  PROC PRINT DATA=TOPLOT SPLIT='*';
       TITLE FEED PLATE LOCATIONS FROM KIRKBRIDE CORRELATION;
       VAR  XNOPL YNOSTRIP;
       BY NO;
       LABEL XNOPL='TOTAL NO. OF PLATES *     IN COLUMN';
       LABEL YNOSTRIP='FEED PLATE * LOCATION';
       LABEL NO='FEED NO.';
       ID NO;
       FOOTNOTE;
  PROC GLM DATA=TOPLOT;
       TITLE LINEAR REGRESSION INFORMATION FOR KIRKBRIDE CORRELATION;
       MODEL YNOSTRIP=XNOPL;
       OUTPUT OUT=NEW P=PREDICT;
  PROC PLOT DATA=NEW;
       TITLE 'EFFECT OF COLUMN SIZE ON FEED PLATE LOCATION';
       TITLE2 'BY KIRKBRIDE CORRELATION';
       PLOT YNOSTRIP*XNOPL=OBSV PREDICT*XNOPL='*'/OVERLAY;
       LABEL YNOSTRIP='FEED PLATE LOCATION';
       LABEL XNOPL='TOTAL NUMBER OF PLATE';
  FOOTNOTE1 'NOTE : NO.1-9 REFER TO FEED NO.1-9';
  FOOTNOTE2 'LETTER A,B,C,D REFER TO FEED NO.10,11,12,13';
  FOOTNOTE3 '* SIGN REFERS TO THE VALUE FROM THE REGRESSION EQUATIONS';
```

Program Listing for the Akashah Et Al. Correlation

```
DATA AEM (DROP=XNOPL YNOSTRIP OBSV)
     TOPLOT (KEEP=NO XNOPL YNOSTRIP OBSV);
  INPUT NO FLK FHK F DLK DHK D BLK BHK B NOP1 NOP2 NOP3;
  LIST;
  LENGTH OBSV $1 ;
    CONST = 0.206 ;
    XHF = FHK/F ;    XLF = FLK/F ;
    XLB = BLK/B ;    XHD = DHK/D ;
    NUM = CONST*LOG10((B/D)*(XHF/XLF)*(XLB/XHD)**2);
  ARRAY NOPL(3) NOP1 NOP2 NOP3;
  ARRAY NOSTRIP(3) NOS1 NOS2 NOS3;
    DO I = 1 TO 3 ;
       NOSTRIP(I)=(NOPL(I)+2.-1.)/(1.+10.**NUM)
                  + 0.5*LOG10(NOPL(I)-1.);
       XNOPL=NOPL(I);
       YNOSTRIP=NOSTRIP(I);
       OBSV=NO;
          IF NO = 10 THEN OBSV='A';
          IF NO = 11 THEN OBSV='B';
          IF NO = 12 THEN OBSV='C';
          IF NO = 13 THEN OBSV='D';
       OUTPUT TOPLOT;
    END;
  OUTPUT AEM;
  CARDS;
1 54.00 377.00 491.00 51.81 2.70 54.51 2.20 374 30 436.49 10. 14. 20.
2 17.90 20.68 72.43 16.92 0.62 18.04 0.17 20.06 54.39 12. 16  22.
3 792.53 108.84 1318.27 784.63 7.62 808.44 7.9 101.22 509.83 28. 34. 40.
4 196.43 51.00 510.55 186.62 7.24 304.54 9.81 43.76 206.01 12. 22. 28.
5 179.33 226.92 703.77 151.87 2.27 305.61 27.46 224.65 398.16 12. 22. 32
6 20.00 37.00 100.00 19.30 0.30 22.60 0.70 36.70 77.40 12. 15. 20.
7 171.37 32.98 263.85 169.66 1.97 190.63 1.71 31.01 73.22 13  15. 17.
8 12.50 3.50 100.00 12.30 0.70 31.48 0.20 2.80 68.52 12. 16. 20.
10 12.50 3.50 110.00 12.30 0.70 31.48 0.20 2.80 78.52 12. 16. 20.
11 12.50 3.50 109.00 12.30 0.70 33.48 0.20 2.80 75.52 12. 16. 20.
12 12.50 3.50 127.00 12.30 0.70 37.48 0.20 2.80 89.52 12. 14. 16.
13 111.38 32.6 211.75 106.92 7.41 117.57 4.46 25.19 94.18 15. 20. 25.
  PROC SORT DATA=AEM;
       BY NO;
  PROC PRINT DATA=AEM;
       TITLE INPUT DATA FOR CALCULATING THE FEED PLATE LOCATION;
       TITLE2 BY AKASHAH ET AL. CORRELATION;
       VAR FLK FHK F DLK DHK D BLK BHK B ;
       LABEL NO='FEED NO.';
       ID NO;
       FOOTNOTE 'NOTE : SEE EXPLANATIONS OF ABBREVIATION IN APPENDIX D';
  PROC SORT DATA=TOPLOT;
       BY NO;
  PROC PRINT DATA=TOPLOT SPLIT='*';
       TITLE FEED PLATE LOCATIONS FROM AKASHAH ET AL  CORRELATION;
       VAR  XNOPL YNOSTRIP;
       BY NO;
       LABEL XNOPL='TOTAL NO. OF PLATES *      IN COLUMN';
       LABEL YNOSTRIP='FEED PLATE * LOCATION';
       LABEL NO='FEED NO.';
       ID NO;
       FOOTNOTE;
  PROC GLM DATA=TOPLOT;
    TITLE LINEAR REGRESSION INFORMATION FOR AKASHAH ET AL. CORRELATION;
    MODEL YNOSTRIP=XNOPL;
    OUTPUT OUT=NEW P=PREDICT;
  PROC PLOT DATA=NEW;
       TITLE 'EFFECT OF COLUMN SIZE ON FEED PLATE LOCATION';
       TITLE2 'BY AKASHAH ET AL. CORRELATION';
       PLOT YNOSTRIP*XNOPL=OBSV PREDICT*XNOPL='*'/OVERLAY;
       LABEL YNOSTRIP='FEED PLATE LOCATION';
       LABEL XNOPL='TOTAL NUMBER OF PLATE';
  FOOTNOTE1 'NOTE : NO.1-9 REFER TO FEED NO.1-9';
  FOOTNOTE2 'LETTER A,B,C,D REFER TO FEED NO.10,11,12,13';
  FOOTNOTE3 '* SIGN REFERS TO THE VALUE FROM THE REGRESSION EQUATION';
```

Example of the Printout from the Kirkbride Correlation

INPUT DATA FOR CALCULATING THE FEED PLATE LOCATION
BY KIRKBRIDE CORRELATION

NO	FLK	FHK	F	DLK	DHK	D	BLK	BHK	B
1	54.00	377.00	491.00	51.81	2.70	54.51	2 20	374.30	436.49
2	17.90	20.68	72.43	16.92	0.62	18.04	0 17	20.06	54.39
3	792.53	108.84	1318.27	784.63	7.62	808.44	7.90	101.22	509.83
4	196.43	51.00	510.55	186.62	7.24	304.54	9 81	43.76	206.01
5	179.33	226.92	703.77	151.87	2.27	305.61	27.46	224.65	398.16
6	20.00	37.00	100.00	19.30	0.30	22.60	0 70	36.70	77.40
7	171.37	32.98	263.85	169.66	1.97	190.63	1.71	31.01	73.22
8	12.50	3.50	100.00	12.30	0.70	31.48	0 20	2.80	68.52
10	12.50	3.50	110.00	12.30	0 70	31.48	0.20	2 80	78.52
11	12.50	3.50	109.00	12 30	0 70	33 48	0.20	2.80	75.52
12	12.50	3.50	127.00	12 30	0.70	37.48	0.20	2 80	89.52
13	111.38	32.60	211.75	106.92	7.41	117.57	4.46	25.19	94.18

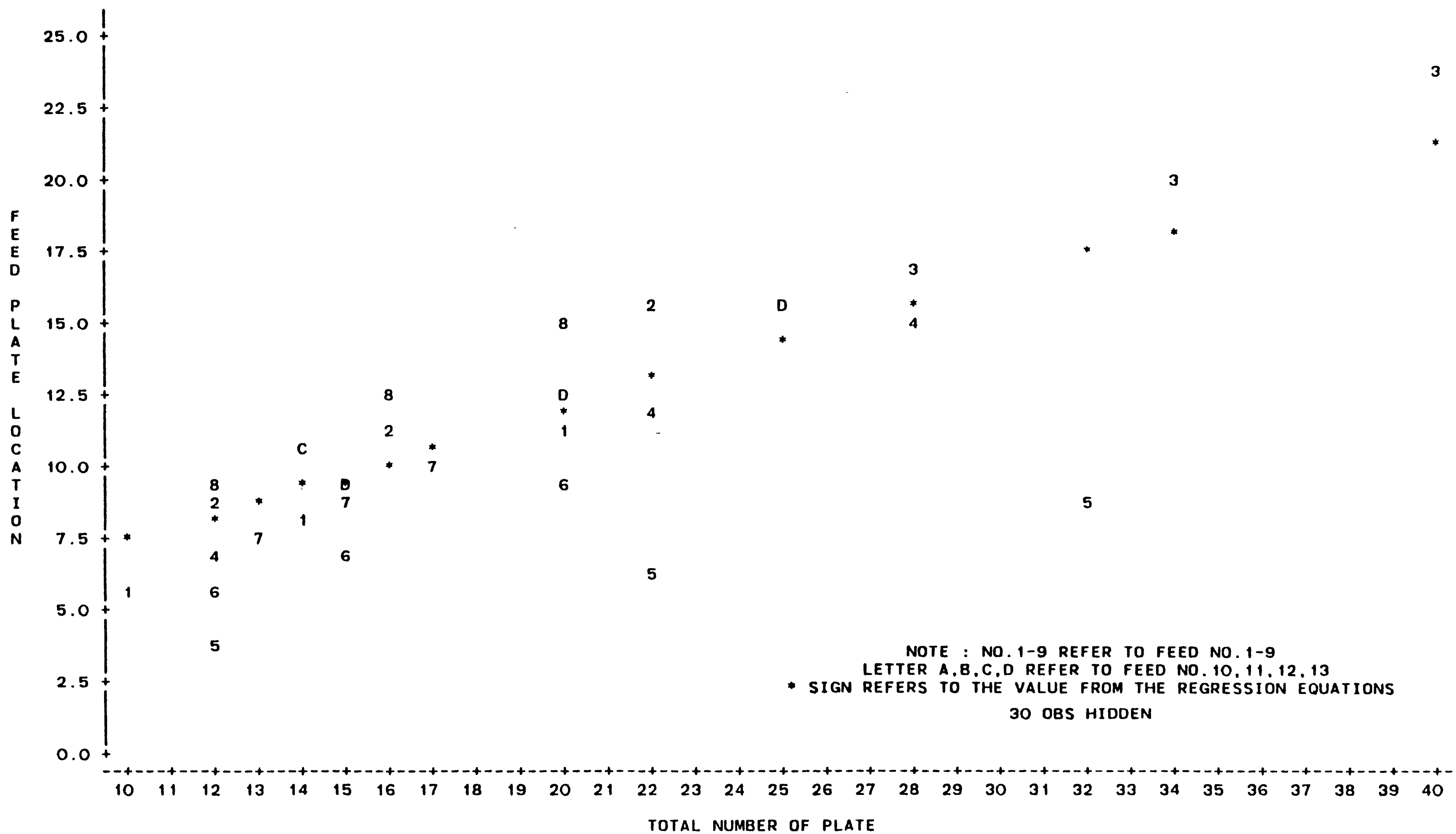
NOTE : SEE ABBREVIATION EXPLANATIONS IN APPENDIX D

Example of the Printout from the Kirkbride Correlation

FEED PLATE LOCATIONS FROM KIRKBRIDE CORRELATION

FEED NO.	TOTAL NO. OF PLATES IN COLUMN	FEED PLATE LOCATION
1	10	5 8094
	14	7.9219
	20	11.0906
2	12	8.7745
	16	11.4743
	22	15.5240
3	28	16.6528
	34	20.0982
	40	23.5436
4	12	6.7343
	22	11 9144
	28	15.0226
5	12	3.44261
	22	6.09077
	32	8.73893
6	12	5.78074
	15	7.11475
	20	9.33812
7	13	7.70001
	15	8.80001
	17	9.90001
8	12	9.3446
	16	12.2199
	20	15 0951
10	12	9.4179
	16	12.3157
	20	15.2135
11	12	9.3639
	16	12.2451
	20	15.1263
12	12	9.3947
	14	10 8400
	16	12.2853
13	15	9 6426
	20	12.6559
	25	15 6692

Example of the Printout from the Kirkbride Correlation



Example of the Printout from the Kirkbride Correlation

LINEAR REGRESSION INFORMATION FOR KIRKBRIDE CORRELATION

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: YNOSTRIP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V.
MODEL	1	357.75890954	357.75890954	47.94	0.0001	0.585053	24.4462
ERROR	34	253.73962097	7.46293003		ROOT MSE		YNOSTRIP MEAN
CORRECTED TOTAL	35	611.49853050			2 73183638		11.17488253

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
XNOPL	1	357.75890954	47.94	0.0001	1	357 75890954	47.94	0 0001

<table>
<tr><th>PARAMETER</th><th>ESTIMATE</th><th>T FOR HO:
PARAMETER=0</th><th>PR > |T|</th><th>STD ERROR OF
ESTIMATE</th></tr>
<tr><td>INTERCEPT</td><td>2.76023042</td><td>2.13</td><td>0.0408</td><td>1.29782131</td></tr>
<tr><td>XNOPL</td><td>0.45759437</td><td>6.92</td><td>0.0001</td><td>0.06609067</td></tr>
</table>

APPENDIX E

TABLE OF SLOPES AND INTERCEPTS

CORRESPONDING TO THE CONSTANTS

C1, C2, AND C3 IN MODEL 1

TABLE XLVII

SLOPES AND INTERCEPTS USED IN DETERMINING THE CONSTANTS C1, C2, AND C3 IN MODEL 1

C1	C2	C3	Slope	Intercept
0.5	0.5	0.0	0.157	5.456
0.5	1.0	0.0	0.078	7.618
0.5	1.5	0.0	0.030	9.184
1.0	0.5	0.0	0.018	6.441
1.0	1.0	0.0	-0.061	8.537
1.0	1.5	0.0	-0.111	10.267
1.5	0.5	0.0	-0.042	6.432
1.5	1.0	0.0	-0.115	8.236
1.5	1.5	0.0	-0.164	9.897
0.1	0.1	0.0	0.426	1.577
0.1	0.3	0.0	0.378	2.655
0.1	0.5	0.0	0.336	3.657
0.2	0.1	0.0	0.377	2.080
0.2	0.3	0.0	0.330	3.165
0.2	0.5	0.0	0.287	4.177
0.4	0.1	0.0	0.287	3.005
0.4	0.3	0.0	0.240	4.068
0.4	0.5	0.0	0.197	5.085
0.1	0.0	0.1	0.402	1.502
0.1	0.0	0.3	0.311	2.368
0.1	0.0	0.5	0.235	3.063
0.2	0.0	0.1	0.355	1.990
0.2	0.0	0.3	0.271	2.774
0.2	0.0	0.5	0.202	3.372
0.4	0.0	0.1	0.271	2.844
0.4	0.0	0.3	0.201	3.440
0.4	0.0	0.5	0.148	3.848

TABLE XLVII (CONTINUED)

C1	C2	C3	Slope	Intercept
0.1	0.1	0.1	0.377	2.049
0.1	0.1	0.3	0.287	2.895
0.1	0.1	0.5	0.212	3.558
0.1	0.3	0.1	0.330	3.130
0.1	0.3	0.3	0.240	3.955
0.1	0.3	0.5	0.125	4.025
0.1	0.5	0.1	0.287	4.146
0.1	0.5	0.3	0.197	4.976
0.1	0.5	0.5	0.122	5.567
0.2	0.1	0.1	0.331	2.528
0.2	0.1	0.3	0.247	3.288
0.2	0.1	0.5	0.179	3.851
0.2	0.3	0.1	0.283	3.603
0.2	0.3	0.3	0.201	4.329
0.2	0.3	0.5	0.134	4.835
0.2	0.5	0.1	0.240	4.623
0.2	0.5	0.3	0.157	5.341
0.2	0.5	0.5	0.091	5.811
0.4	0.1	0.1	0.247	3.362
0.4	0.1	0.3	0.179	3.923
0.4	0.1	0.5	0.126	4.291
0.4	0.3	0.1	0.200	4.407
0.4	0.3	0.3	0.133	4.914
0.4	0.3	0.5	0.082	5.212
0.4	0.5	0.1	0.157	5.418
0.4	0.5	0.3	0.091	5.893
0.4	0.5	0.5	0.041	5.137

APPENDIX F

MINIMIZATION OF THE ERROR SUMS TO FIND THE CONSTANTS K5 AND K6 IN MODEL 2

Estimation of the constants K5 and K6 in Model 2 is shown as the following:

Recall Model 2,

$$\log(N_r/N_s) = 0.1 \log\{(f/f')(b/d')(XLD/XHB)(100/\Delta T)^{8.2}\} + K5\ (1 - L/F)(\Delta T/100)^{K6} \quad (38)$$

The trial values of K5 were first selected as 0.1 and 0.2. The values of K6 were varied and the error sums, of each column size at L/F equal to 0.5 and 0.0, are recorded as in Table XLVIII. Effect of K6, Column size, and L/F on error sums are illustrated as Figure 47 for K5 equals to 0.1 and Figure 48 for K5 equals to 0.2.

As a result, the K5 of 0.1 and K6 of 2.1, which produce the minimum error sums, are chosen.

TABLE XLVIII

ERROR SUMS BY MODEL 2 WITH THE VARIED K5 AND K6 AT DIFFERENT COLUMN SIZES AND L/F

K5 = 0.1						
	Error Sum					
K6	L/F = 0.5			L/F = 0.0		
	Short	Medium	Tall	Short	Medium	Tall
0.0	21.39	30.98	42.73	23.38	38.47	49.68
0.1	21.26	30.80	42.51	27.97	38.00	49.10
0.4	20.77	30.14	41.69	26.50	36.29	47.08
0.6	20.34	29.57	40.98	25.27	34.83	45.55
0.8	19.80	28.85	40.10	24.08	33.30	43.72
1.0	19.12	27.95	39.98	22.73	31.68	41.76
1.2	18.27	26.83	37.59	21.01	29.65	39.21
1.6	15.84	23.62	33.62	16.30	23.81	31.91
1.8	14.31	21.38	30.84	13.39	19.92	27.43
2.0	12.40	18.50	27.42	10.44	15.50	22.82
2.1	11.27	16.94	25.63	9.82	13.66	20.44
2.2	10.02	15.14	23.66	9.65	13.11	19.01
2.3	9.34	13.16	21.49	11.22	13.59	18.52
2.4	8.93	11.54	19.13	13.38	15.82	19.52

TABLE XLVIII (CONTINUED)

K5 = 0.2						
	Error Sum					
K6	L/F = 0.5			L/F = 0.0		
	Short	Medium	Tall	Short	Medium	Tall
0.0	20.20	28.82	41.26	25.12	37.12	51.16
0.2	19.85	28.03	40.29	24.32	36.11	49.87
0.6	18.72	25.94	37.55	21.74	32.80	45.70
0.8	17.85	24.75	35.64	19.82	30.31	43.18
1.0	16.69	23.18	33.41	17.44	27.17	40.17
1.2	15.19	21.15	30.92	14.61	24.02	36.49
1.6	10.82	15.85	24.90	14.97	20.45	29.52
1.8	10.86	13.60	20.85	20.21	26.65	34.94
2.0	15.60	19.01	25.32	24.78	32.52	42.19

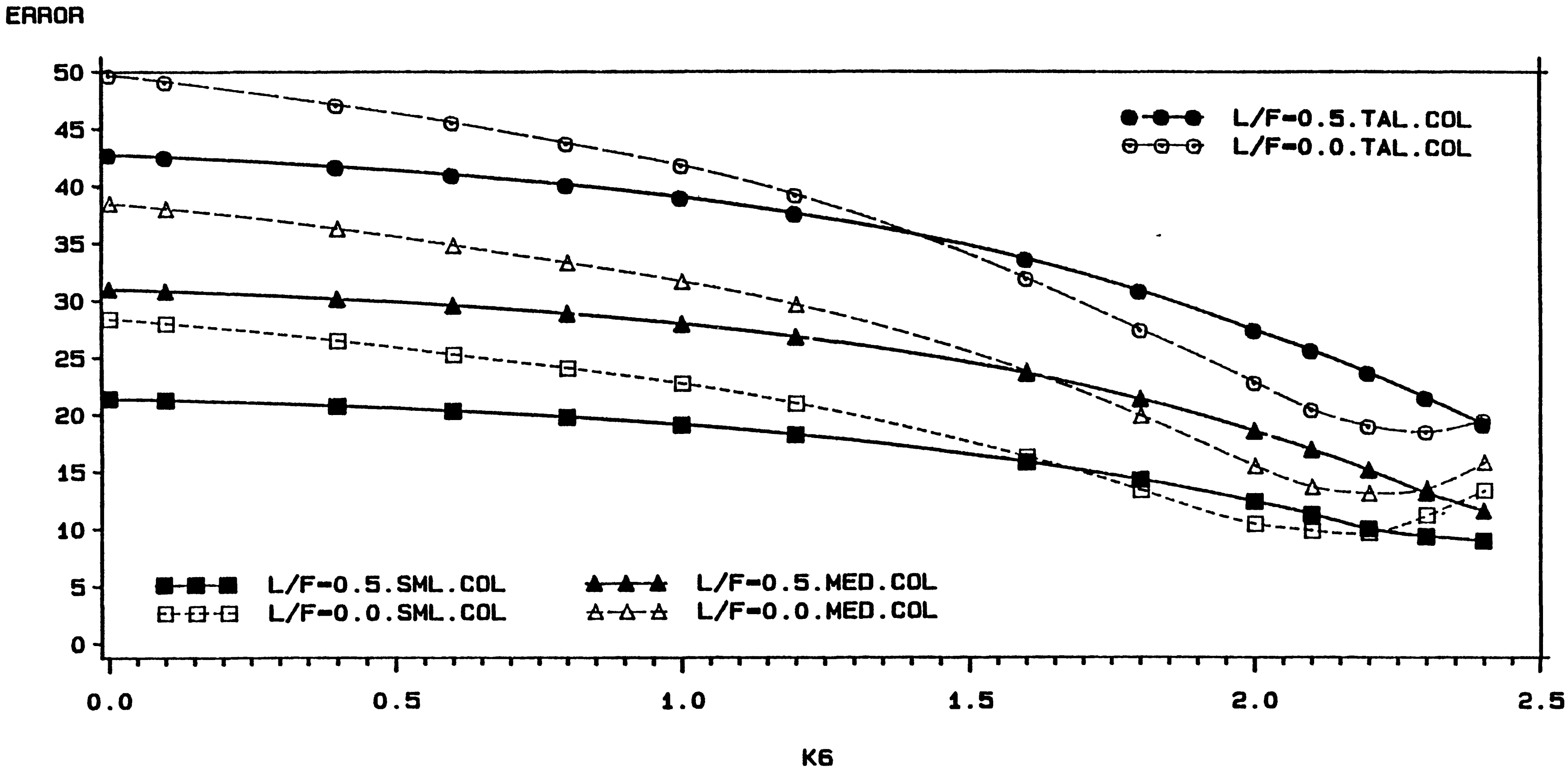


Figure 47. Effect of K6, Column Size, and L/F on Error Sums - K5 Equals to 0.1

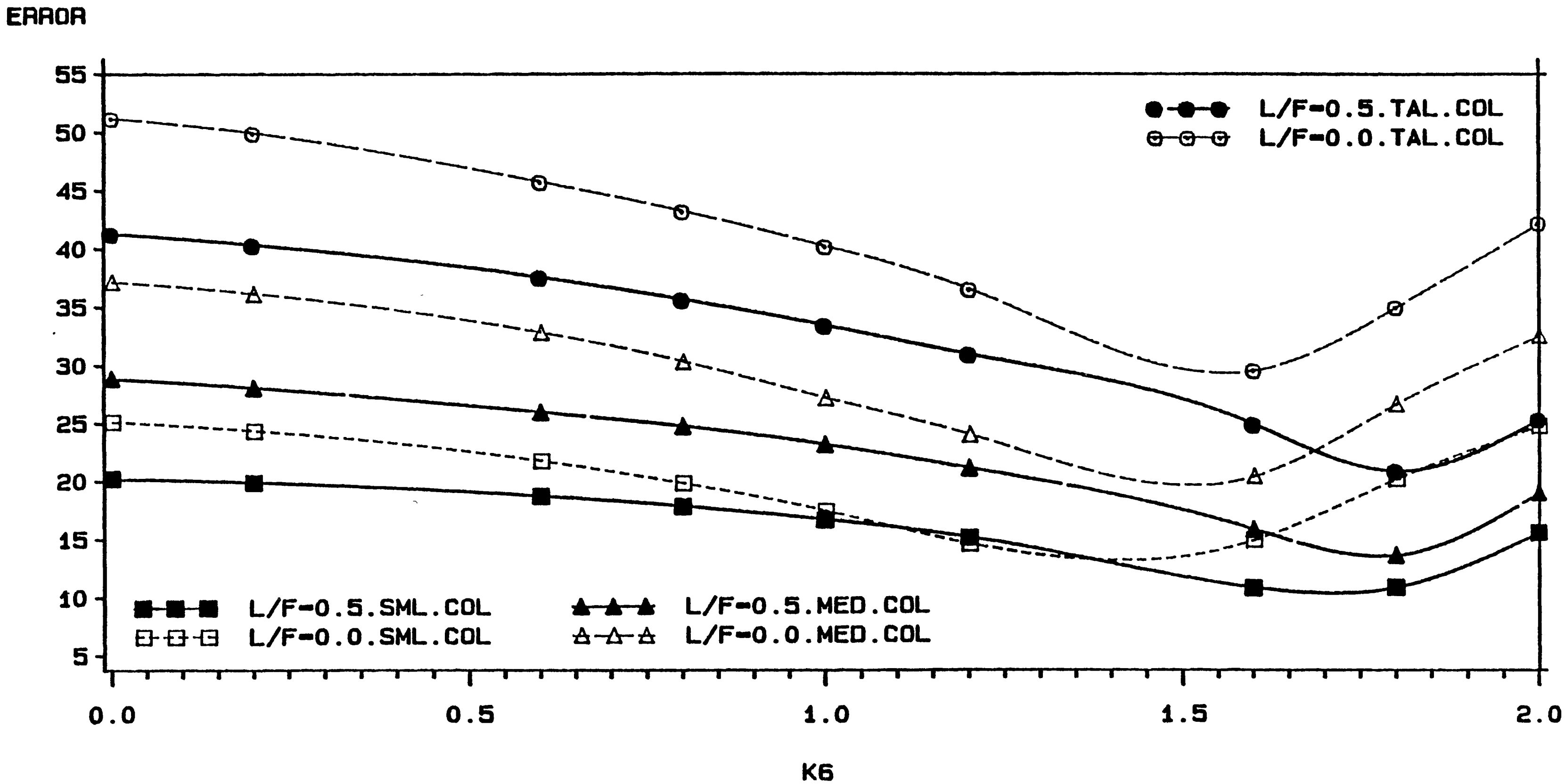


Figure 48. Effect of K6, Column Size, and L/F on Error Sums - K5 Equals to 0.2

APPENDIX G

FEED COMPOSITION, PROCESS CONDITIONS AND PREDICTIONS OF OPTIMUM FEED PLATE LOCATION USED IN TESTING THE CORRELATION

TABLE IL

COLUMN CONDITION FOR TESTING CORRELATION - TEST NO.1

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
C3H8	1.36	1.36	-
iC4H10	14.33	14.27	0.06
nC4H10	16.37	15.55	0.82
iC5H12	15.66	0.31	15.35
nC5H12	17.88	0.05	17.83
nC6H14	34.40	-	34.40
Totals	100.00	31.54	68.46
Temperature,F	92.50	48.42	155.46
Pressure,psia	25.00	25.00	30.00

Feed Condition: Saturated Liquid

TABLE L

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - TEST NO.1

Source	Feed Condition	Optimum Feed Plate Location		
		12 Pl.Col.	15 Pl.Col.	24 Pl.Col.
Kirkbride	Saturated Liquid	5.7	7.1	11.1
Akashah et al.	Saturated Liquid	6.3	7.7	11.7
Fenske	Saturated Liquid	5.7	7.0	10.9
Winn	Saturated Liquid	5.1	6.2	9.7
Model 2	Saturated Liquid	6.1	7.5	11.7
	L/F=0.75	5.9	7.2	11.3
	L/F=0.50	5.7	7.0	10.9
	L/F=0.25	5.5	6.7	10.5
	L/F=0.00	5.2	6.5	10.1
MAXISIM	Saturated Liquid	7.0	8.8	14.0
	L/F=0.75	6.6	8.4	13.7
	L/F=0.50	5.9	7.8	13.4
	L/F=0.25	5.4	7.2	13.0
	L/F=0.00	*	*	*

* Can Not Be Obtained by MAXISIM

TABLE LI

COLUMN CONDITIONS FOR TESTING CORRELATION - TEST NO.2

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
CH_4	160.00	160.00	-
C_2H_6	370.00	365.39	4.61
C_3H_8	240.00	4.61	235.39
C_4H_{10}	25.00	-	25.00
C_5H_{12}	5.00	-	5.00
Totals	800.00	530.00	270.00
Temperature,F	105.00	13.16	170.40
Pressure,psia	400.00	400.00	400.00

Feed Condition: Slightly Superheated Vapor

(T at Saturated Vapor = -68.57 °F)

TABLE LII

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - TEST NO.2

Source	Feed Condition	Optimum Feed Plate Location		
		17 Pl.Col.	26 Pl.Col.	35 Pl.Col.
Kirkbride	Saturated Liquid	8.8	13.2	17.6
Akashah et al.	Saturated Liquid	9.4	13.9	18.3
Fenske	Saturated Liquid	9.5	14.2	18.9
Winn	Saturated Liquid	8.5	12.8	17.1
Model 2	Saturated Liquid	10.6	15.9	21.1
	L/F=0.75	9.9	14.8	19.8
	L/F=0.50	9.2	13.8	18.4
	L/F=0.25	8.5	12.7	17.0
	L/F=0.00	7.8	11.7	15.6
MAXISIM	Saturated Liquid	11.2	15.6	20.0
	L/F=0.75	10.8	15.4	19.8
	L/F=0.50	10.2	15.2	20.2
	L/F=0.25	9.7	15.0	20.5
	L/F=0.00	*	*	*

* Can Not Be Obtained by MAXISIM

TABLE LIII

COLUMN CONDITIONS FOR TESTING CORRELATION -TEST NO.3

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
CH4	26.00	26.00	-
C2H6	9.00	9.00	-
C3H6	25.00	24.60	0.40
nC4H10	17.00	0.30	16.70
nC5H12	11.00	-	11.00
nC6H14	12.00	-	12.00
Totals	100.00	59.90	40.10
Temperature,F	-68.57	69.51	307.96
Pressure,psia	314.70	314.70	314.70

Feed Condition: Saturated Liquid

TABLE LIV

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - TEST NO.3

Source	Feed Condition	Optimum Feed Plate Location		
		13 Pl.Col.	19 Pl.Col.	23 Pl.Col.
Kirkbride	Saturated Liquid	6.6	9.4	11.3
Akashah et al.	Saturated Liquid	7.1	10.0	11.9
Fenske	Saturated Liquid	7.1	10.1	12.1
Winn	Saturated Liquid	6.4	9.1	10.9
Model 2	Saturated Liquid	9.2	13.1	15.7
	L/F=0.75	7.9	11.3	13.5
	L/F=0.50	6.6	9.4	11.2
	L/F=0.25	5.2	7.5	9.0
	L/F=0.00	4.1	5.8	7.0
MAXISIM	Saturated Liquid	9.9	13.5	15.8
	L/F=0.75	8.9	12.5	14.8
	L/F=0.50	7.8	11.5	14.0
	L/F=0.25	6.8	10.6	13.1
	L/F=0.00	6.0	9.7	12.2

TABLE LV

COLUMN CONDITIONS FOR TESTING CORRELATION - TEST NO.4

Component	Feed (mols/hr)	Distillate (mols/hr)	Bottom (mols/hr)
C2H6	5.00	5.00	-
C3H8	105.00	100.00	5.00
nC4H10	40.00	3.00	37.00
nC5H12	60.00	-	60.00
Totals	210.00	108.00	102.00
Temperature,F	146.17	105.13	237.08
Pressure,psia	200.00	200.00	200.00

Feed Condition: Saturated Liquid

TABLE LVI

PREDICTIONS OF OPTIMUM FEED PLATE LOCATION - TEST NO.4

Source	Feed Condition	Optimum Feed Plate Location		
		10 Pl.Col.	15 Pl.Col.	21 Pl.Col.
Kirkbride	Saturated Liquid	5.4	7.9	10.9
Akashah et al.	Saturated Liquid	5.9	8.5	11.5
Fenske	Saturated Liquid	5.9	8.6	11.9
Winn	Saturated Liquid	5.5	8.1	11.1
Model 2	Saturated Liquid	5.5	7.9	10.9
	L/F=0.75	5.2	7.5	10.3
	L/F=0.50	4.9	7.1	9.8
	L/F=0.25	4.6	6.7	9.2
	L/F=0.00	4.3	6.3	8.6
MAXISIM	Saturated Liquid	6.5	9.0	11.8
	L/F=0.75	6.0	8.4	11.2
	L/F=0.50	5.4	7.7	10.6
	L/F=0.25	4.7	7.1	10.0
	L/F=0.00	4.1	6.6	9.5

VITA

Amornvat Chenbhanich

Candidate for the Degree of

Master of Science

Thesis: OPTIMUM FEED PLATE LOCATION FOR MULTI-COMPONENT DISTILLATION SEPARATIONS

Mafor Field: Chemical Engineering

Biographical:

Personal Data: Born in Phitsanuloke, Thailand, August 9, 1959, the son of Udom and Amorn Chenbhanich.

Education: Graduated from Assumption College, Bangkok, Thailand, in May, 1978; received Bachelor of Science Degree in Chemical Technology from Chulalongkorn University, Bangkok, Thailand, in June, 1982; received Master of Gas Technology from Illinois Institute of Technology, Chicago, Illinois, in May, 1984; completed requirements for the Master of Science degree at Oklahoma State University in July, 1986.

Professional Experience: Research Assistant, Department of Chemical Engineering, Oklahoma State University, January, 1985, to July, 1986.