MINIMUM STAGE CALCULATIONS FOR COMPLEX FRACTIONATORS

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FRACTIONATORS

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PREFACE

A method has been developed for estimating the minimum number of theoretical stages in multifeed, multiproduct distillation columns. In addition to the minimum number of stages the method predicts product compositions, product flow rates and feed and product entry or withdrawal points. The method has been programmed for the IBM 650 Computer although it is well suited to hand calculations. The method was tested by comparison with a simulation of a complex column operating at total reflux. The results of the comparison indicate that the method will give reliable estimates of the performance of a complex column at total reflux.

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CHAPTER I

INTRODUCTION

The determination of the minimum number of theoretical stages required to achieve a given separation is a useful tool in the design of multicomponent fractional distillation columns. The calculation of the minimum number of theoretical stages provides a fast method of estimating the performance of a proposed column. In a short time, several alternate designs of the column could be evaluated for feasibility before applying more rigorous design techniques such as relaxation methods or plate-to-plate calculations.

Several methods have been suggested for calculating the minimum number of theoretical stages in single feed, two-product columns. The most suitable and most widely accepted short-cut methods are those which were proposed by Fenske(3) and Winn(10).

The Fenske(3) method relates the minimum number of stages, separation and relative volatility, assuming constant relative volatility throughout the column. The Winn(10) method relates minimum number of stages, separation and two characteristic constants which are functions of the equilibrium distribution ratios (K-values) of the arbitrary key components.

A method for use on multifeed, multiproduct distillation columns has been developed and was tested in this work using an

IBM 650 Computer. A modification of the method has made possible the calculation of the feed entry point.

Although an IBM 650 was used for evaluation of the method in this work, the method is readily adapted to slide rule or desk calculator computation.

CHAPTER II

SURVEY OF LITERATURE

Several methods have been suggested for calculating the performance of a fractionator at total reflux. These may be separated into two general categories; those methods which utilize tray-by-tray calculations and those which employ semi-empirical equations.

The first of these types is by far the most difficult and time consuming. Several procedures have been employed in making the tray-by-tray calculations. Amundson and Pontinen[1] perform the tray calculations by solving the heat and material balance equations using matrix techniques. This method requires the solution and inversion of large matrices, thereby rendering the method practically useless for hand calculations. Lyster, et al[5] make tray calculations utilizing the Theile-Geddes[8] technique. Their method requires the use of a large computer, although it is well known that the Theile-Geddes[8] method is easily adapted to hand calculations.

Edmister[2] performs the tray calculations using a method based on absorbing and stripping factors.

For any of these tray-by-tray techniques an estimate of the product compositions, total stream flow rates and the number of stages would be extremely helpful.

The second of the general types, semi-empirical equations, has been well received by the Chemical Engineering profession, largely because of the ease by which calculations are made and the reduced time requirements. Since this type of calculation is the basis of this work, it will be treated in greater detail in the Theory Chapter than the first method.

CHAPTER III

THEORY

The operation of a fractionator at total reflux may best be visualized by referring to the classical McCabe-Theile[6] diagram, Figure I. At total reflux, all of the overhead product is returned to the column and no bottom product is withdrawn. This condition is of theoretical interest only because a column operating at total reflux produces no product and performs no useful function.

Another concept of total reflux is that of considering the column to be of infinite cross-section with finite feed and product streams. Under these circumstances the column is making the desired products from the given feed composition.

From a design standpoint a column operating at total reflux indicates the minimum number of stages required to make a specified separation. Since no overhead product is withdrawn from the column, or the reflux is very much larger than the distillate product, the slope of the operating line, $\frac{L}{L+D}$, is unity and coincides with the diagonal y = x line. With the slope of the operating line equal to one, the step from the operating line to the equilibrium line is a maximum, hence, the smallest number of steps for a given separation.

Referring again to Figure I, it may be seen that the number of stages at total reflux is independent of the composition at which the feed is introduced as well as the condition of the feed

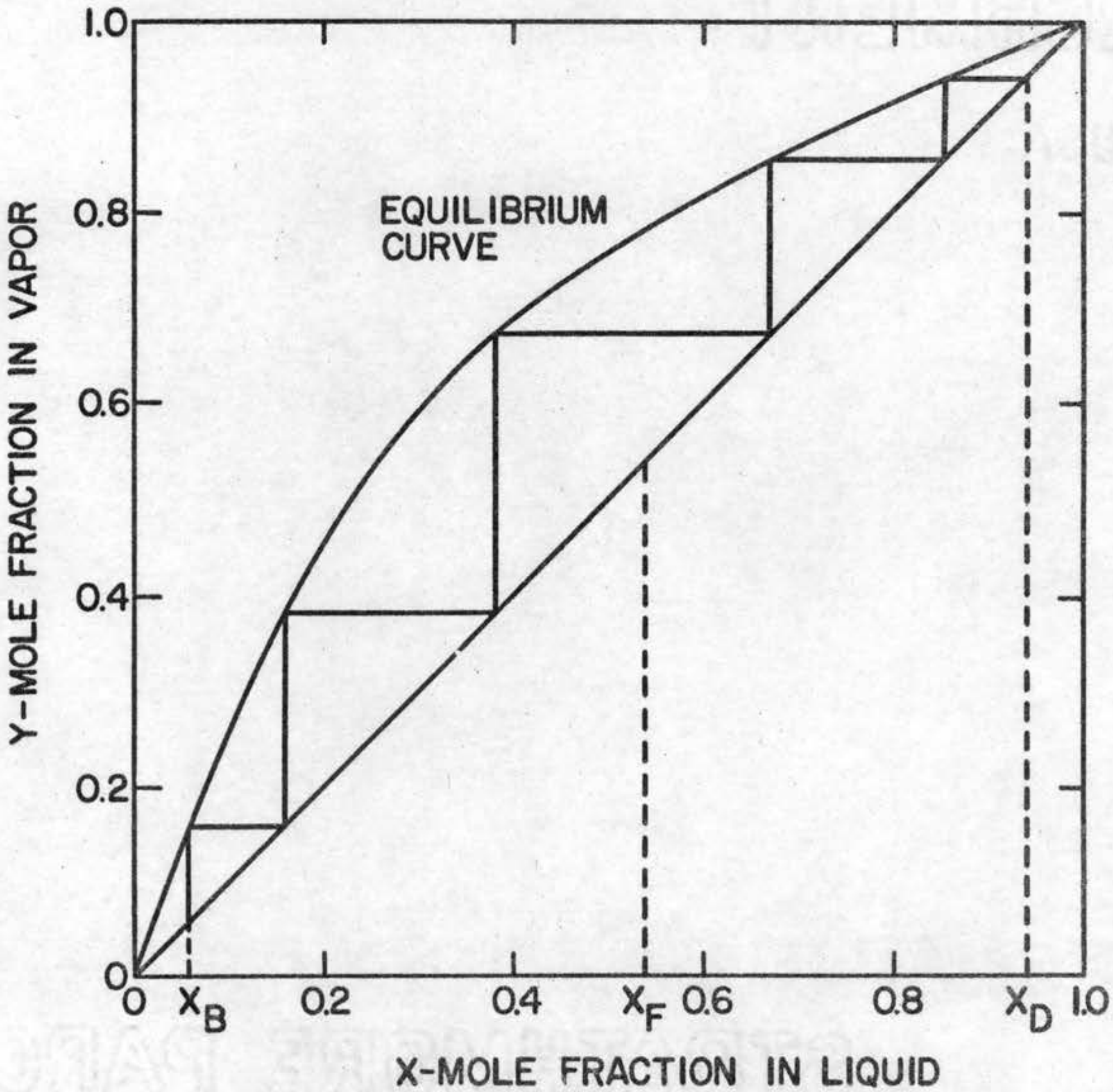

FIGURE I
McCABE–THIELE DIAGRAM

(whether it is a liquid, vapor or a mixture of liquid and vapor). Obviously, the movement of the feed entry point must be confined to any point between the distillate and bottoms product compositions.

Some authors have based their derivations of equations describing column operation at total reflux on constant molal overflow from plate-to-plate. The difference between passing streams on any plate above the feed plate is the distillate and difference below the feed plate is the bottoms product.

Or

$$V = L + D$$

$$L = V + B$$

The total reflux condition implies V and L $\gg$ D and B so that V = L. Thus, the constant molal overflow assumption is unnecessary.

Fenske[3] derived relations to calculate the minimum number of stages in single feed, two product fractionators. Constant relative volatility and constant molal overflow were the basic assumptions. The Fenske equation is derived as follows:

$$y_{LK} = K_{LK} x_{LK}$$

$$y_{HK} = K_{HK} x_{HK}$$

dividing:

$$\frac{y_{LK}}{y_{HK}} = \alpha_{LK\text{-}HK} \frac{x_{LK}}{x_{HK}} \qquad (1)$$

Equation (1) may be converted to molar ratios

$$\left(\frac{\nu_{LK}}{V}\right)\left(\frac{V}{\nu_{HK}}\right) = \alpha_{LK-HK}\left(\frac{l_{LK}}{L}\right)\left(\frac{L}{l_{HK}}\right)$$

hence:

$$\frac{\nu_{LK}}{\nu_{HK}} = \alpha_{LK-HK}\ \frac{l_{LK}}{l_{HK}} \qquad (2)$$

Material balance around the column above the feed gives

$$\nu_{nLK} = l_{(n+1)\ LK} + d_{LK} \qquad (3)$$

$$\nu_{nHK} = l_{(n+1)\ HK} + d_{HK} \qquad (4)$$

At total reflux d_{LK} and d_{HK} are very small when compared to column internal stream flows.

Dividing equation (3) by equation (4), gives:

$$\frac{\nu_{nLK}}{\nu_{nHK}} = \frac{l_{(n+1)LK}}{l_{(n+1)HK}}$$

Substituting in equation (2) gives

$$\frac{l_{(n+1)LK}}{l_{(n+1)HK}} = \alpha_{LK-HK}\ \frac{l_{nLK}}{l_{nHK}} \qquad (5)$$

Equation (5) relates the ratio of the mols of liquid of the light key and the heavy key components in the liquid on any tray to their ratio on the plate above. If these ratios were obtained from plate 1 through n the result would be

$$\left(\frac{l_{nLK}}{l_{nHK}}\right) = \alpha^{n}_{LK-HK} \left(\frac{l_{DLK}}{l_{DHK}}\right) \qquad (6)$$

Thus, the exponent of α is the number of perfect theoretical trays required to make the desired separation. Equation (6) may be rearranged to:

$$\alpha^{n}_{LK-HK} = \left(\frac{d}{b}\right)_{LK} \left(\frac{b}{d}\right)_{HK} \qquad (7)$$

Which is the usual form of Fenske's equation.

Winn's relation for calculating the minimum number of stages at total reflux is similar to Fenske's equation. Winn found that if the K-values of two components were plotted on log-log coordinates at various temperatures, an essentially straight line resulted. With this fact and the fact that a straight line on log-log coordinates is expressed analytically by

$$K = \beta\,(K')^{\theta} \qquad (8)$$

Where β and θ are constants, Winn proceeded in a manner similar to Fenske. The resulting equation is

$$\beta^{n}_{LK-HK} = \left(\frac{x_D}{x_B}\right)_{LK} \left(\frac{x_B}{x_D}\right)^{\theta}_{HK}$$

This equation may be rearranged to give

$$\beta^{n}_{LK-HK} = \left(\frac{d}{b}\right)_{LK} \left(\frac{b}{d}\right)^{\theta}_{HK} \left(\frac{B}{D}\right)^{1-\theta} \qquad (9)$$

which is similar to equation (7). β and Θ are determined by writing two equations of the form of (8), one for the temperature at the top of the column and one for the bottom of the column.

$$K_{LK} = \beta \; (K_{HK})^{\Theta} \qquad \text{at } T_D$$

$$K_{LK} = \beta \; (K_{HK})^{\Theta} \qquad \text{at } T_B$$

Solving these equations simultaneously yields Θ. β is determined by back substitution.

The Winn equation does not suffer from the assumption of constant relative volatility. Rather, it is limited only by the reliability of the K-data available, or if equation (8) does not adequately represent the K-value data.

Underwood[9], derived an expression which is similar to that of Fenske and employed the same assumptions.

The Winn equation as it was originally derived was intended for single feed, two product fractionators. If, however, one considers a complex fractionator, Figure II, as being composed of several "sections", one section between each product stream, an expression similar to the Winn equation may be written. The section concept has been used successfully by Edmister[2], in absorber calculations and in distillation calculations by absorption factor methods. In the case of an overhead product, a side product and a bottoms product, there would be two sections. The calculations are made from the distillate composition to the side draw composition, that is, calculating over section 1. If we assume equations of the type of (8) to be valid then the equation would be written

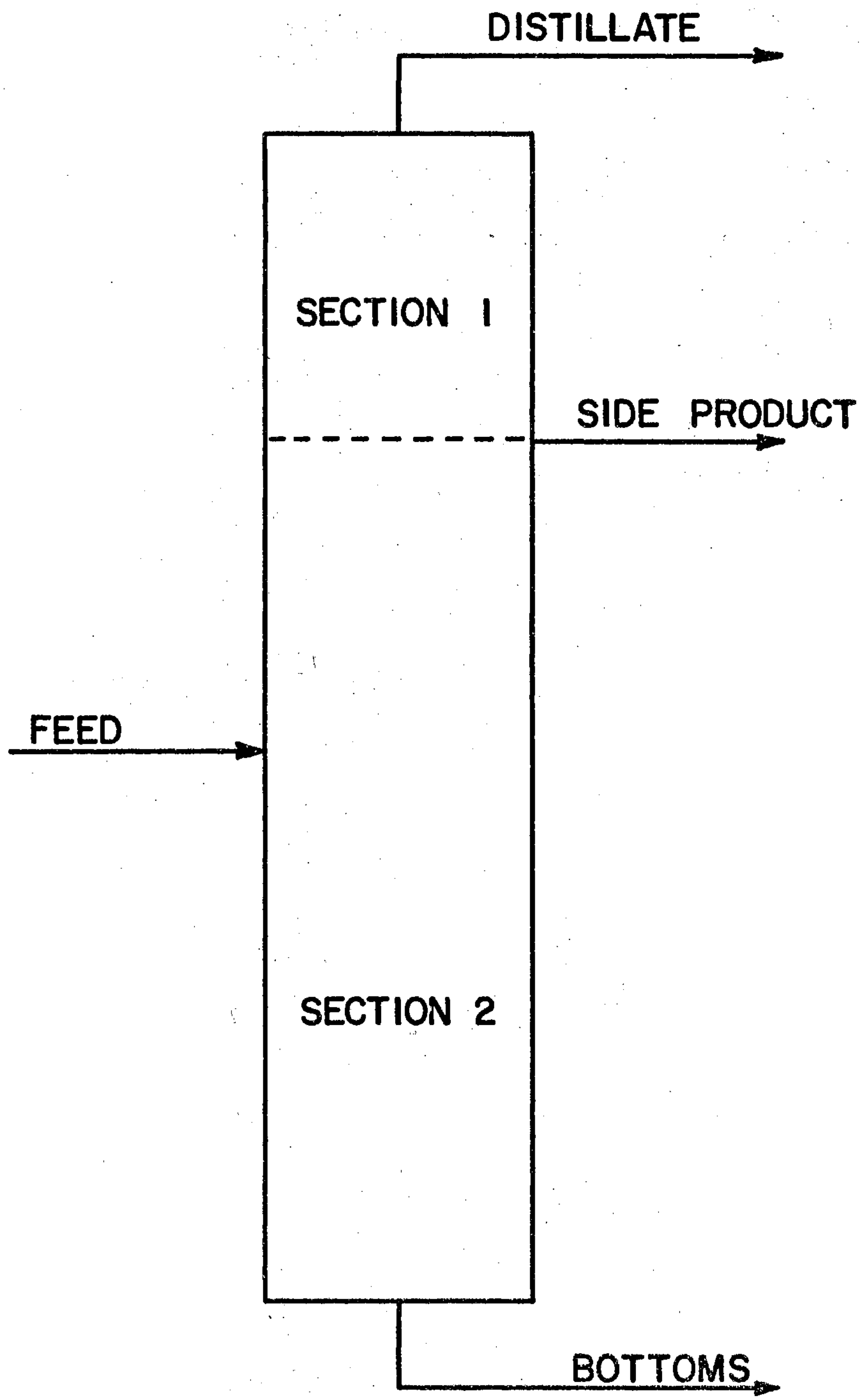

FIGURE 2
COMPLEX COLUMN

$$\beta^{S_{M_1}} = \left(\frac{d}{p}\right)_{LK} \left(\frac{p}{b}\right)_{HK}^{\theta_1} \left(\frac{P}{D}\right)^{1-\theta_1} \qquad (10)$$

for the section between the distillate and the side product and

$$\beta^{S_{M_2}} = \left(\frac{p}{b}\right)_{LK} \left(\frac{b}{p}\right)_{HK}^{\theta_2} \left(\frac{B}{P}\right)^{1-\theta_2} \qquad (11)$$

for the section between the side product and the bottoms product. These equations neglect the location of the feed plate in relation to the side product. As pointed out above, the location of the feed plate and feed condition have no effect on the total number of stages. Therefore, by analogy, the feed plate location should have no effect on the number of stages in a complex fractionator.

To extend the method to more than one side product and/or more than one feed, it is necessary only to write an additional equation of the form of (10) for each additional "section" of the column. Since the location of the feed plate has no effect on the number of stages, it follows that any number of feeds would be treated in the same way. In fact, the feeds may be summed and treated as one feed for calculation purposes. The material balance

$$d + p_1 + p_2 + \ldots + p_n + b = f_1 + f_2 + \ldots + f_n = \sum f_i = f_T \qquad (12)$$

assumes that each feed will be introduced at the proper point in the column. The actual location of the feed entries will be considered later.

The total number of plates required at total reflux is the sum of the number of stages in each section. In addition to the total number of stages, the component distributions in each stream may also be calculated. To calculate the product distributions, equation (10) may be written

$$\beta_i^{S_{M_1}} = \left(\frac{d}{p}\right)_i \left(\frac{p}{b}\right)_{HK}^{\theta_i} \left(\frac{P}{D}\right)^{1-\theta_i} \tag{13}$$

with the subscript, i, referring to any component, using the heavy key component as a base for the calculation of β_i and θ_i. A material balance around the column gives:

$$f_T = d + b + p_1 + p_2 + \dots + p_n \tag{12}$$

for each component.

Dividing both sides by p_1 (if there are no side products divide by d) gives:

$$\frac{f_T}{p_1} = 1 + \frac{d}{p_1} + \frac{b}{p_1} + \frac{p_2}{p_1} + \frac{p_3}{p_1} + \dots + \frac{p_n}{p_1} \tag{14}$$

The component distribution ratios as calculated by equation (13) will be

$$\frac{d}{p_1}, \quad \frac{p_1}{p_2}, \quad \frac{p_2}{p_3}, \quad \dots \quad \frac{p_{n-1}}{p_n}, \quad \frac{p_n}{b}$$

The ratios may be converted for use in (12) by noting that:

$$\frac{p_2}{p_1} = 1 \Big/ \frac{p_1}{p_2}, \quad \frac{p_3}{p_1} = \frac{p_2}{p_1} \cdot \frac{p_3}{p_2}$$

rearranging (13) so that

$$p_1 = \frac{f_T}{1 + \frac{d}{p_1} + \frac{p_2}{p_1} + \frac{p_3}{p_1} + \dots + \frac{p_n}{p_1} + \frac{b}{p_1}} \tag{15}$$

or

$$p_1 = \frac{f_T}{1 + \frac{d}{p_1} + \frac{p_2}{p_1} + \left(\frac{p_2}{p_1}\right)\left(\frac{p_3}{p_2}\right) + \dots + \left(\frac{p_n}{p_{n-1}}\right)\left(\frac{b}{p_n}\right)} \qquad (16)$$

and $d = \left(\frac{d}{p_1}\right) p_1, \quad p_2 = \left(\frac{p_2}{p_1}\right) p_1, \quad p_3 = \left(\frac{p_3}{p_1}\right) p_1 \qquad$ etc.

For a two product column, (15) reduces to

$$d = \frac{f_T}{1 + \frac{b}{d}}$$

To test the utility of the above equations a program for the IBM 650 Computer was written. The equations calculate the minimum number of stages for each section of the column thereby locating the position of the side product streams. Since the feed(s) are summed, it is desirable to determine the position of the feed(s) relative to the product streams.

Robinson and Gilliland(7) define an optimum intersection ratio, $\emptyset$, which relates the ratio of the compositions of the key components at the feed plate and the plate above. The ratio, $\emptyset$, is defined such that the optimum feed plate location is given by

$$\left(\frac{x_{LK}}{x_{HK}}\right)_f \leq \emptyset \leq \left(\frac{x_{LK}}{x_{HK}}\right)_{f+1} \qquad (17)$$

where f+1 is the plate above the feed plate. Since the calculations performed to find the minimum number of stages gives product distributions only, the feed plate location must be calculated on the basis of stream compositions rather than stream flow rates. If the ratio to be compared with the feed ratio occurs (n) plates from the feed plate, equation (17) must comply with this stipulation. The Fenske equation indicates a convenient relationship which may be utilized.

Rewriting the Fenske equation for the section above the feed for a simple column gives

$$\alpha_{LK-HK}^{S_{ME}} = \left(\frac{d}{f}\right)_{LK} \left(\frac{f}{d}\right)_{HK}$$

where: $\alpha^{S_{ME}}$ = minimum number of stages in the enriching section

This may be arranged so that:

$$\frac{d_{LK}}{d_{HK}} = \alpha_{LK-HK}^{S_{ME}} \frac{f_{LK}}{f_{HK}} \tag{18a}$$

or

$$\left(\frac{x_{LK}}{x_{HK}}\right)_D = \alpha_{LK-HK}^{S_{ME}} \left(\frac{x_{LK}}{x_{HK}}\right)_F \tag{18b}$$

Equation (18a) is similar to (17). Since the Winn β is similar to α, a better relation would be:

$$\left(\frac{x_{LK}}{x_{HK}}\right)_D = \beta_E^{S_{ME}} \left(\frac{x_{LK}}{x_{HK}}\right)_F^{\theta_E} \tag{19}$$

The above indicates that the feed should be introduced at a point in the column where the ratio of the key components is equal to their ratio in the feed. Equation (19) provides a method of calculating the number of stages below the top of the column that the feed should be introduced.

For a complex fractionator, the ratio of the key components in each feed may be checked against their ratio in each product stream. For example, consider a single feed, three-product column. The key component ratio in the feed must be less than the ratio in the distillate, and greater than the ratio in the side product, if the feed is to be introduced above the side product. Symbolically:

$$\left(\frac{p_{LK}}{p_{HK}}\right) < \left(\frac{f_{LK}}{f_{HK}}\right) < \left(\frac{d_{LK}}{d_{HK}}\right)$$ feed between the side product and distillate (Case 1)

$$\left(\frac{f_{LK}}{f_{HK}}\right) < \left(\frac{p_{LK}}{p_{HK}}\right)$$ feed below side product (Case 2)

Obviously, the key component ratios in the feed cannot be greater than the ratio in the distillate or less than the ratio in the bottoms. The location of the feed entry in Case 1 would be found by

$$\beta_1^{S_{FE}} = \left(\frac{d_{LK}}{d_{HK}}\right) \left(\frac{f_{HK}}{f_{LK}}\right)^{\theta_1} \left(\frac{F}{D}\right)^{1-\theta_1}$$

and in Case 2 by

$Sm_1 + S_{FP}$ where S_{FP} is computed from

$$\beta_2^{S_{FP}} = \left(\frac{p_{LK}}{p_{HK}}\right) \left(\frac{f_{LK}}{f_{HK}}\right)^{\Theta_2} \left(\frac{F}{P}\right)^{1-\Theta_2} \tag{21}$$

Similar expressions and procedures apply to more than one feed and more than one side product.

CHAPTER IV

RESULTS

To determine the effect of feed plate location on product composition at total reflux would be extremely difficult using an actual column. However, total reflux may be simulated. The simulation may be accomplished by using a digital computer for which a plate-by-plate calculation program has been written.

It was found using the above simulation, with an internal vapor rate of 10,000 mols/hr, that there was a negligible effect of feed plate location on the distillate composition. This may be seen in the following table:

TABLE I

Effect of Feed Plate Location on the Distillate Composition at Total Reflux

Feed Entry Point Plate No., Top Down	Mol Frn Light Key in Distillate	Mol Frn Heavy Key in Distillate
3	0.7559	0.2437
4	0.7552	0.2442
5	0.7552	0.2446
7	0.7554	0.2443

The total number of theoretical stages was eleven.

The results of this study indicate that the assumption that the location of the feed had little or no effect on the composition of the products is valid. Consequently, one may assume that the same negligible effect will occur if multiple feeds are summed and treated as one feed when dealing with complex fractionators.

As pointed out in the previous discussion of feed plate location, the feed should be introduced at a point in the column at which the ratio of the compositions of the key components in the feed and at the feed plate are equal.

This assumption was checked using the above simulation procedure with the same system and vapor rate. The results are listed in the following table.

TABLE II

Optimum Feed Plate Location

Feed Entry Point (Plate No., Top Down)	Feed Plate $\frac{f_{LK}}{f_{HK}}$	Distillate $\frac{d_{LK}}{d_{HK}}$	Feed $\frac{f_{LK}}{f_{HK}}$
3	1.696	3.102	1
4	1.255	3.093	1
5	0.932	3.087	1
7	0.522	3.092	1

As may be seen in Table II, the point at which the ratio of the keys in the feed are equal to the ratio at the feed plate occurs between plates 4 and 5. The feed plate location calculated from equation (19) was 4.35. By analogy, one may assume that the location of more than one feed may also be calculated from equation (19).

Tables III and IV show the comparison between two complex fractionators calculated by the method of this work and a plate-by-plate calculation procedure. In both cases the total reflux condition was simulated in the plate-by-plate calculations by using a reflux ratio of $(L_o/D) = 99.0$.

The fractionator compared in Table III is a single feed, 3-product column. The column in Table IV is almost the same as the column in Table III except the feed was altered slightly and split into two streams. The side product in both cases was withdrawn as saturated liquid. The feeds in both cases were also saturated liquids. In both examples plates are numbered from the top plate in the column to the reboiler. That is, the top plate is 1 and the reboiler is 14.

These results show that the method of this work may be used to good advantage in the preliminary design of a complex fractionator. The method of calculating the location of feed plates has been shown to be reliable. In both of the cases investigated the new method correctly indicated the trays between which the feeds should be introduced. Until now no total reflux method has been available for evaluating alternate designs of complex fractionators. The new method is fast, easy to use and well suited to hand or desk calculator computations.

TABLE III

Comparison Between Proposed Method and Plate-by-Plate

Calculation for a Complex Column

		This Work			Plate-by-Plate		
Comp.	Feed	Distillate	Side-Draw	Bottoms	Distillate	Side-Draw	Bottoms
C_2	1.38	1.12311	0.25689	0.00000	1.12309	0.25686	0.00003
C_3	4.25	0.22631	3.89744	0.12625	0.22684	3.89661	0.12655
iC_4	1.48	0.00035	0.13139	1.34826	0.00036	0.13139	1.34825
nC_4	2.10	0.00002	0.02532	2.07466	0.00002	0.02769	2.07229
iC_5	1.38	0.00000	0.00006	1.37994	0.00000	0.00016	1.37984
nC_5	0.75	0.00000	0.00001	0.74999	0.00000	0.00003	0.74997
C_6	2.25	0.00000	0.00000	2.25000	0.00000	0.00000	2.25000
Totals	13.59	1.34979	4.31111	7.92910	1.35031	4.31274	7.92693

(Cont.)

TABLE III (Cont.)

	This Work	Plate-By-Plate
T_D	518.098	518.195
T_P	591.913	591.901
T_B	756.757	756.854
Sm_1	3.90041	4-5*
Sm_2	9.53652	9-10*
Sm_T	13.43693	14+
S_{FP}	8.28286	8-9*

* Indicates Stream Withdrawn or Feed Between Trays

\+ Includes Reboiler, Excludes Total Condenser

TABLE IV

Comparison Between Proposed Method and Plate-by-Plate Calculation for a Complex Column

			This Work			Plate-By-Plate		
Comp.	Feed 1	Feed 2	Distillate	Side-Draw	Bottoms	Distillate	Side-Draw	Bottoms
C_2	0.92	0.46	1.12312	0.25688	0.0000	1.12310	0.25686	0.00004
C_3	2.95	1.30	0.22683	3.89603	0.12714	0.22683	3.89603	0.12714
iC_4	0.48	1.00	0.00034	0.12662	1.35304	0.00035	0.12663	1.35302
nC_4	1.40	0.70	0.00002	0.02405	2.07593	0.00003	0.03245	2.06752
iC_5	0.82	0.46	0.00000	0.00005	1.27995	0.00000	0.00062	1.27938
nC_5	0.50	0.25	0.00000	0.00001	0.74999	0.00000	0.00018	0.74982
C_6	1.5	0.75	0.00000	0.00000	2.25000	0.00000	0.00000	2.25000
Totals	8.57	4.92	1.35031	4.30364	7.83605	1.35031	4.31277	7.82691

(Cont.)

TABLE IV (Cont.)

	This Work	Plate-By-Plate
T_D	518.144	518.192
T_P	591.848	591.927
T_B	756.715	756.627
Sm_1	3.89782	4-5*
Sm_2	9.58008	9-10*
Sm_T	13.47790	14^+
S_{Fp_1}	6.89218	6-7*
S_{Fp_2}	9.43945	9-10*

* Indicates Stream Withdrawn or Fed Between Trays

$^+$ Includes Reboiler, Excludes Total Condenser

CHAPTER V

CONCLUSIONS

The new equation for complex fractionators will provide the design engineer with a short, reliable method of estimating the performance of complex columns operating at total reflux. The method will give estimates of the component distributions in the various product streams and the rates of those streams as well as the relative locations of the product and feed streams.

The assumption that the feed streams may be summed and treated as one feed is valid because it was shown that the location of the feed at total reflux had a negligible effect on the composition of the product streams.

The Winn method for representing equilibrium data is probably better than the assumption of constant relative volatility for a section of the column. For either case the proposed method is a preliminary estimate only. For final designs a more rigorous technique such as plate-by-plate calculation must be used.

LIST OF NOMENCLATURE

B - total mols of bottom product stream

D - total mols of distillate product stream

F - total mols of feed stream

K - equilibrium constant, $\frac{y}{x}$

L - total mols of liquid stream

N - number of actual theoretical stages

P - total mols of side stream

S - minimum number of theoretical stages

V - total mols of vapor stream

b - mols of a component in bottom product stream

d - mols of a component in distillate product stream

f - mols of a component in a feed stream

l - mols of a component in a liquid stream

p - mols of a component in a side stream

v - mols of a component in a vapor stream

x - mol fraction of a component in liquid

y - mol fraction of a component in vapor

Greek

α - relative volatility, $\frac{K_i}{K_R}$

β - ralative operability in Gilliland equation or a characteristic constant in the Winn equation

θ - a characteristic constant in the Winn equation or roots in the Underwood equation

ϕ - roots in the Underwood equation

Subscripts

B - refers to bottom plate in column or bottoms product

D - refers to distillate

E - enriching section

F - refers to feed streams or feed plate

LK - light key component

HK - heavy key component

M - minimum

T - refers to top plate in column

b - component in the bottoms product

d - component in the distillate product

f - component in the feed stream or feed plate

i - any component

m - refers to plate in stripping section

n - refers to plate in the enriching section

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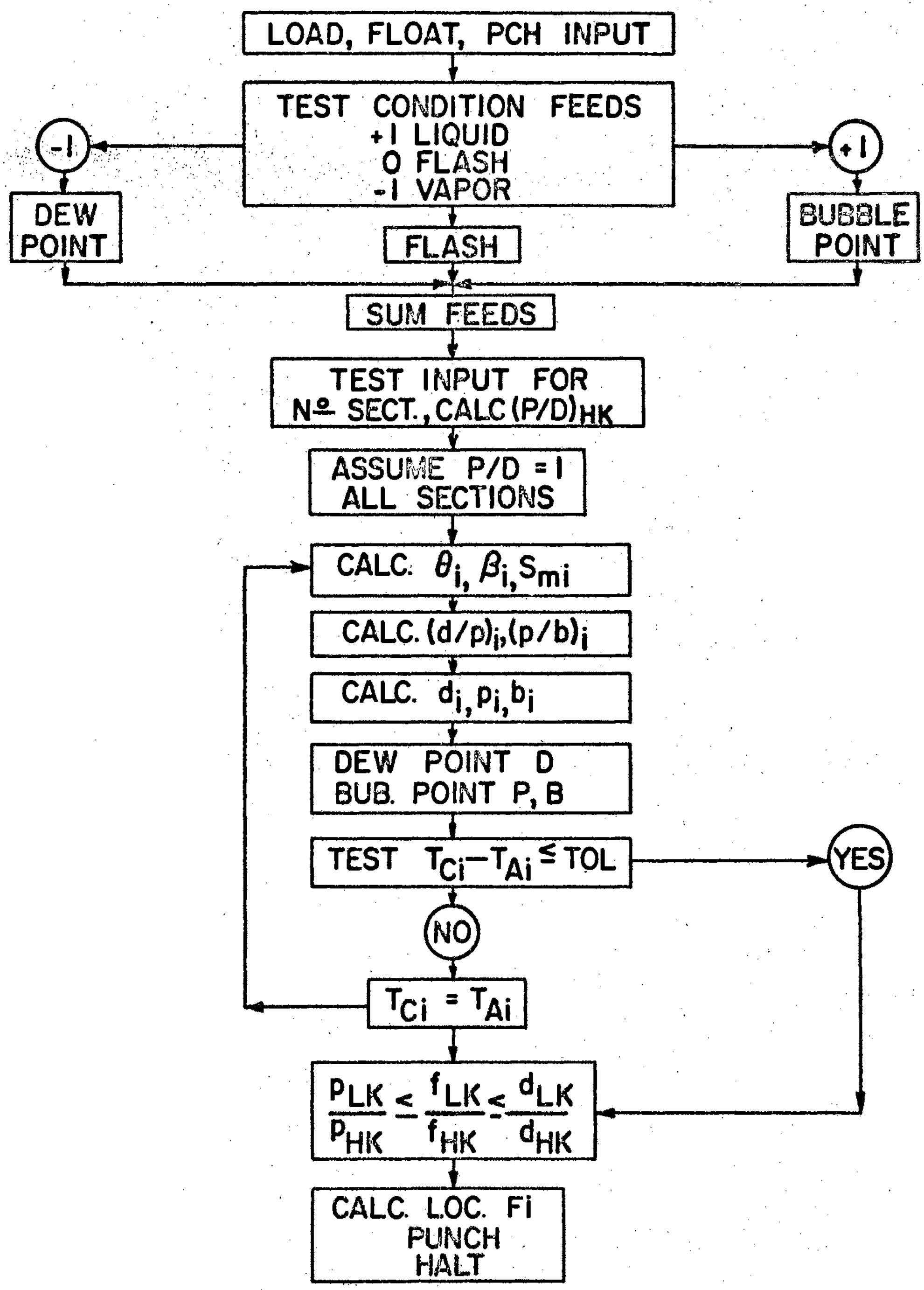
APPENDIX A

BLOCK DIAGRAM—MAIN PROGRAM



SUBROUTINES

```
        SR-1,  Punch (PCH)
        LDD    n-1
        STD    n-1
        RAL    P-Pch
        LDD    EXIT ⟶ Pch

        SR-2,  Block transfer (BT)
        SET    9040
        LDI    2000
        SET    9040
        STI    4000

        SR-3,  K-Evaluation (K-eval)
        SET
        LDI
        RAB    n-1
        STU    T
(A-1)   RAU    (d_i of K)   B
        FMP    T
        FAD    (C_i of K)   B
        FMP    T
        FAD    (b_i of K)   B
        FMP    T
```

SUBROUTINES (Cont.)

	FAD	(A_i of K) B
	NZB $\longrightarrow$	EXIT
	SXB-1	Go A-1
	SR-4,	Mol Fraction (MF)
	SET	
	LDI	
	RAB	n-1
	LDD	0
	STD	Σl_i
	STD	$\Sigma \mathcal{V}_i$
(A-1)	BMC	(-) A-2 (+) A-3
(A-2)	RAU	($\mathcal{V}_i$) B
	FAD	$\Sigma \mathcal{V}_i$
	STU	$\Sigma \mathcal{V}_i$ $\longrightarrow$ A-4
(A-3)	RAU	(l_i) B
	FAD	Σl_i
	STU	Σl_i $\longrightarrow$ (A-4)
(A-4)	NZB	$\longrightarrow$ (A-5)
	SXB-1	
(A-5)	RAB	n-1

SUBROUTINES (Cont.)

(A-6)	BMC	(-) (A-7) (+) (A-8)
(A-7)	RAU	(γ) B
	FDV	$\Sigma \gamma_i$
	STU	(y_i) B $\longrightarrow$ (A-9)
(A-8)	RAU	(1_i) B
	FDV	$\Sigma 1_i$
	STU	(x_i) B $\longrightarrow$ (A-9)
	NZB	EXIT
	SXB-1	$\longrightarrow$ (A-6)
	SR-5	Bubble Pt. - Dew Pt. (BP-DP)
	SET	
	LDI	
	LDD	EXIT
	STD	EXIT
	LDD	O
	STD	$\Sigma K_i x_i$ or $\Sigma \frac{y_i}{K_i}$
(A-10)	STU	T
	RAC	$\longrightarrow$ SR-3 (K-eval)
	RAB	n-1
(A-1)	RAU	EXIT
	BMI	(-) (A-2) (+) (A-3)

SUBROUTINES (Cont.)

(A-2)	RAU	(y_i) B
	FDV	(K_i) B
	STU	$(\frac{y_i}{K_i})$ B
	FAD	$\sum \frac{y_i}{K_i}$
	STU	$\sum \frac{y_i}{K_i} \longrightarrow$ (A-4)
(A-3)	RAU	(x_i) B
	FMP	(K_i) B
	STU	$(K_i x_i)$ B
	FAD	$\sum K_i x_i$
	STU	$\sum K_i x_i$
(A-4)	NZA	$\longrightarrow$ (A-5)
	SXA-1	$\longrightarrow$ (A-1)
(A-5)	RAU	1
	FSB	$\sum K_i x_i$ or $\sum \frac{y_i}{K_i}$
	STU	$1 - \sum K_i x_i$ or (Δ)
	RAU	Tolerance
	FSM	Δ
	BMI	(-) (A-6) (+) EXIT

SUBROUTINES (Cont.)

```
(A-6) RAU   EXIT

            (-) (A-7)
      BMI   (+) (A-8)
```

(A-7) RSU $1 - \sum \frac{y}{K} \longrightarrow$ (A-9)

(A-8) RAU $1 - \sum Kx$

(A-9) FDV 7.5

FAD 1

FMP T $\longrightarrow$ (A-10)

<u>SR-6, θ_i</u>

RAB n-1

STD EXIT

(A-1) RAU $(K_{HK})_T C$

FDV $(K_{HK})_B C$

LDD $\longrightarrow$ ln X

STU $\ln \frac{(K_{HK})_T}{(K_{HK})_B}$

RAU $(K_i)_T B$

FDV $(K_i)_B B$

LDD $\longrightarrow$ ln X

FDV $\ln \frac{(K_{HK})_T}{(K_{HK})_B}$

SUBROUTINES (Cont.)

```
        STU    (Θi) B
        NZB    ──→ EXIT
        SXB-1  ──→ (A-1)

        SR-7, βi
        RAB    n-1
        STD    EXIT
(A-1)   RAU    (K_HK) C
        LDD    ──→ ln X
        FMP    (Θi) B
        LDD    ──→ e^x
        STU    (K_HK)^Θi
        RAU    (Ki)B
        FDV    (K_HK)^Θi
        STU    ( βi) B
        NZB    EXIT
        SXB-1  ──→ (A-1)

        SR-8, Sm
        STD    EXIT
        RAU    d_LK
        FDV    p_LK
```

SUBROUTINES (Cont.)

STU	$(\frac{d}{p})_{LK}$
RAU	$(\frac{p}{d})_{HK}$ B
LDD	$\longrightarrow$ ln X
FMP	(Θ) C
LDD	$\longrightarrow$ e^x
STU	$(\frac{p}{d})_{HK}^{\Theta}$
RAU	1
FSB	(Θ) C
STU	$1-\Theta$
RAU	$\frac{P}{D}$
LDD	$\longrightarrow$ ln X
FMP	$1 - \Theta$
LDD	$\longrightarrow$ e^x
FMP	$(\frac{p}{d})_{HK}^{\Theta}$
FMP	$(\frac{d}{p})_{LK}$
LDD	$\longrightarrow$ ln X
STU	ln X
RAU	β
LDD	$\longrightarrow$ ln X
STU	ln β

SUBROUTINES (Cont.)

RAU	ln X
FDV	ln β
STU	$S_m \longrightarrow$ EXIT

<u>SR-9, $(\frac{d}{p})_i$</u>

	RAB	n-1
	STU	EXIT
(A-1)	RAU	$(\frac{p}{d})_{HK}$
	LDD	ln X
	FMP	(Θ) B
	LDD	$\longrightarrow$ e^x
	STU	$(\frac{p}{d})_{HK}^{\Theta}$
	RAU	β
	LDD	$\longrightarrow$ ln X
	FMP	S_m
	LDD	$\longrightarrow$ e^x
	STU	β^{S_m}
	RAU	1
	FSB	(Θ) B
	STU	1 - Θ
	RAU	$\frac{P}{D}$
	LDD	ln X

SUBROUTINES (Cont.)

FMP	$1 - \Theta$
LDD	$\longrightarrow e^x$
STU	$(\frac{P}{D})^{1 - \Theta}$
RAU	β^{S_m}
FDV	$(\frac{p}{d})^{\Theta}_{HK}$
FDV	$(\frac{P}{D})^{1 - \Theta}$
STU	$(\frac{d}{P})_i B$
NZB	EXIT
SXB-1	$\longrightarrow$ (A-1)

<u>SR-10, S (Feed Plate Loc.)</u>

STD	EXIT
RAU	β
LDD	$\longrightarrow \ln X$
STU	$\ln \beta$
RAU	1
FSB	Θ
STU	$1 - \Theta$
RAU	F
FDV	P
LDD	$\longrightarrow \ln X$
FMP	$1 - \Theta$

SUBROUTINES (Cont.)

LDD $\longrightarrow$ e^x

STU $(\frac{F}{P})^{1-\Theta}$

RAU 1

FDV Rf

LDD $\longrightarrow$ ln X

FMP Θ

LDD $\longrightarrow$ e^x

FMP R_p

FMP $(\frac{F}{P})^{1-\Theta}$

LDD $\longrightarrow$ ln X

FDV ln β $\longrightarrow$ EXIT

MAIN PROGRAM

```
        RAL    n
        SRT    1
        SLO    .1
        STL    (n-1)_1
        SRT    4
        STL    (n-1)_2
        RAL    (n-1)_1
        RAA    10
(A-1)   LDD
        SDA
        NZA    (A-2)
        SXA-1  (A-1)
(A-2)   RAL    No. of Sections
        SRT    1
        SLO    .1
        STL    N_s-1
        RAL    No. of Feeds
        SRT    1
        SLO    .1
        STL    N_F-1
        SET
```

MAIN PROGRAM (Cont.)

```
        LDI    Float Loop
        RAC    250
        RAA    n - 1
        SET
(A-5)   LDI    K's & F's
        RAB    (A-3) → Float
(A-3)   SET
        STI    Floated Data
        NZC    → (A-4)
        SXC-SO → (A-5)
(A-4)   RAA    No. of Key Nos (NK_i)
(A-7)   RAL    (NK_i) A
        SRT    5
        STL    (NK_i) A
        NZA    (A-6)
        SXA-1  (A-7)
(A-6)   RAA    Input
        SET
        LDI    Input Data
        RAB    → Float
        SET
        STI    Floated Input
        LDD    P-Pch
        STD    P-Pch
        RAC    → Pch
```

MAIN PROGRAM (Cont.)

	LDD	P-Pch
	STD	P-Pch
	RAC	$\longrightarrow$ Pch
	RAU	$(p_i)_{HK}$
	NZU	(A-8)
	FDV	$(d)_{HK}$
	STU	$\longrightarrow$ (A-9)
(A-8)	RAU	$(b)_{HK}$
	FDV	$(d)_{HK}$
	STU	$(\frac{b}{d})_{HK} \longrightarrow$ READ
(A-9)	RAU	$(p_2)_{HK}$
	NZU	$\longrightarrow$ (A-10)
	FDV	$(p_1)_{HK}$
	STU	$(\frac{p_2}{p_1})_{HK} \longrightarrow$ (A-11)
(A-10)	RAU	$(b)_{HK}$
	FDV	$(p_1)_{HK}$
	STU	$(\frac{b}{p_1})_{HK} \longrightarrow$ READ
(A-11)	RAU	$(p_3)_{HK}$
	NZU	$\longrightarrow$ (A-12)

MAIN PROGRAM (Cont.)

	FDV	$(p_2)_{HK}$
	STU	$(\frac{p_3}{p_2})_{HK}$ ⟶ (A-13)
(A-12)	RAU	$(b)_{HK}$
	FDV	$(p_2)_{HK}$
	STU	$(\frac{b}{p_2})_{HK}$ ⟶ READ
(A-13)	RAU	$(b)_{HK}$
	FDV	$(p_3)_{HK}$
	STU	$(\frac{b}{p_3})_{HK}$ ⟶ READ
	RAA	19
(A-14)	RAU	$(f_i)_1A$
	FAD	$(f_i)_2A$
	FAD	$(f_i)_3A$
	STU	$(\sum f_i)$ A
	NZA	⟶ (A-15)
	SXA-1	⟶ (A-14)
(A-15)	RAU	T_b
	RAC	⟶ K-Eval
	RAA	Loc K_b

MAIN PROGRAM (Cont.)

RAB	Loc_2K_b
RAC	$\longrightarrow$ BT
RAU	T_{p3}
NZU	(A-16)
RAC	$\longrightarrow$ K-Eval
RAA	Loc K_{p3}
RAB	Loc_2K_{p3}
RAC	$\longrightarrow$ BT
LDD	HK_4
RAC	HK_4
LDD	$\longrightarrow$ θ
SET	
STI	θ_4
RAA	loc K_T
RAB	Loc_2K_T
RAC	$\longrightarrow$ BT
RAU	T_{p2}
RAC	$\longrightarrow$ K-Eval
LDD	HK_3
RAC	HK_3
LDD	$\longrightarrow$ θ
SET	

MAIN PROGRAM (Cont.)

STI	θ_3
RAA	Loc K
RAB	Loc_2K
RAC	$\longrightarrow$ BT
RAU	T_{p_1}
RAC	$\longrightarrow$ K-Eval
LDD	HK_2
RAC	HK_2
LDD	$\longrightarrow \theta$
SET	
STI	θ_2
RAA	LocK
RAB	Loc_2K
RAC	$\longrightarrow$ BT
RAU	T_d
RAC	$\longrightarrow$ K-Eval
LDD	HK_1
RAC	HK_1
LDD	$\longrightarrow \theta$
SET	
STI	θ_1
RAU	T_{p_1}
RAC	$\longrightarrow$ K-Eval

MAIN PROGRAM (Cont.)

```
SET
LDI   Θ1
LDD   HK1
RAC   HK1
LDD   ⟶ β
SET
STI   β 1
RAV   Tp2
RAC   ⟶ K-Eval
SET
LDI   Θ2
LDD   HK2
RAC   HK2
LDD   ⟶ β
SET
STI   β 2
RAU   Tp3
RAC   ⟶ K-Eval
SET
LDI   Θ3
LDD   HK3
RAC   HK3
LDD   ⟶ β
```

MAIN PROGRAM (Cont.)

```
        SET
        STI      β3
        RAU   Tb
        RAC   ⟶   K-Eval
        SET
        LDI   Θ4
        LDD   HK4
        RAC   HK4
        LDD   ⟶   β
        SET
        STI   ⟶    β4
        LDD   1
        STD   P
        STD   D
        LDD   dLK
        STD   dLK
        RAU   (p1)LK
        NZU   ⟶   (A-16)
        STU   (p1)LK
(A-20)  RAA   loc Θ1
        RAB   loc2 Θ1
        RAC   ⟶   BT
```

MAIN PROGRAM (Cont.)

	RAA	loc β_1
	RAB	$loc_2 \beta_1$
	RAC	$\longrightarrow$ BT
	LDD	Section No.
	RAB	Section No.
	LDD	HK_1
	RAC	HK_1
	LDD	$\longrightarrow S_m$
	STU	Sm_1
	RAU	$(p_1)_{LK}$
	NZU	$\longrightarrow$ (A-19)
	STU	$(p_1)_{LK}$
	RAU	$(p_2)_{LK}$
	NZU	$\longrightarrow$ (A-17)
(A-21)	STU	$(p_2)_{LK}$
	RAA	loc θ_2
	RAB	$loc_2\ \theta_2$
	RAC	$\longrightarrow$ BT
	RAA	loc β_2
	RAB	$loc_2\ \beta_2$
	RAC	$\longrightarrow$ BT
	LDD	Section No.
	RAB	Section No.

MAIN PORGRAM (Cont.)

```
        LDD   HK_2
        RAC   HK_2
        LDD   ⟶ S_m
        STU   S_m2
        RAU   (p_2)_LK
        NZU   ⟶ (A-19)
        STU   (p_2)_LK
        RAU   (p_3)_LK
        NZU   ⟶ (A-18)
(A-22)  STU   (p_3)_LK
        RAA   loc θ_3
        RAB   loc_2 θ_3
        RAC   ⟶ BT
        RAA   loc β_3
        RAB   loc_2 β_3
        RAC   ⟶ BT
        LDD   Section No.
        RAB   Section No.
        LDD   HK_3
        RAC   HK_3
        LDD   ⟶ S_m
        STU   S_m3
```

MAIN PROGRAM (Cont.)

	RAU	$(p_3)_{LK}$
	NZU	$\longrightarrow$ (A-19)
	STU	$(p_3)_{LK}$
	LDD	$(b)_{LK}$
	STU	$(b)_{LK}$
	RAA	loc Θ_4
	RAB	loc_2 Θ_4
	RAC	$\longrightarrow$ BT
	RAA	loc β_4
	RAB	loc_2 β_4
	RAC	$\longrightarrow$ BT
	LDD	Section No.
	RAB	Section No.
	LDD	HK_4
	RAC	HK_4
	LDD	$\longrightarrow$ S_m
	STU	$S_{m4} \longrightarrow$ (A-2)
(A-16)	RAU	$(b)_{LK}$
	STU	$(b)_{LK} \longrightarrow$ (A-20)
(A-17)	RAU	$(b)_{LK}$
	STU	$(b)_{LK} \longrightarrow$ (A-21)

MAIN PROGRAM (Cont.)

(A-18)	RAU	$(b)_{LK}$
	STU	$(b)_{LK} \longrightarrow$ (A-22)
(A-19)	RAA	loc Θ_1
	RAB	$loc_2\ \Theta_1$
	RAC	$\longrightarrow$ BT
	RAA	loc β_1
	RAB	$loc_2\ \beta_1$
	RAC	$\longrightarrow$ BT
	LDD	Section No.
	RAC	Section No.
	LDD	S_{m1}
	STD	S_{m1}
	LDD	$\longrightarrow (\frac{d}{p})_i$
	RAA	loc $(\frac{d}{p_1})_i$
	RAB	$loc_2\ (\frac{d}{p_1})_i$
	RAC	$\longrightarrow$ BT
	RAU	S_{m2}
	NZU	$\longrightarrow$ (A-23)
(A-27)	STU	S_{m2}
	RAA	loc Θ_2

MAIN PROGRAM (Cont.)

	RAB	$loc_2\ \theta_2$
	RAC	$\longrightarrow$ BT
	RAA	$loc\ \beta_2$
	RAB	$loc_2\ \beta_2$
	RAC	$\longrightarrow$ BT
	LDD	Section No.
	RAC	Section No.
	LDD	$\longrightarrow\ (\frac{d}{p})_i$
	RAA	$loc\ (\frac{p_1}{p_2})_i$
	RAB	$loc_2\ (\frac{p_1}{p_2})_i$
	RAC	$\longrightarrow$ BT
	RAU	S_{m3}
	NZU	$\longrightarrow$ (A-24)
(A-28)	STU	S_{m3}
	RAA	$loc\ \theta_3$
	RAB	$loc_2\ \theta_3$
	RAC	$\longrightarrow$ BT
	RAA	$loc\ \beta_3$
	RAB	$loc_2\ \beta_3$
	RAC	$\longrightarrow$ BT

MAIN PROGRAM (Cont.)

	LDD	Section No.
	RAC	Section No.
	LDD	$\rightarrow (\frac{d}{p})_i$
	RAA	loc $(\frac{p_2}{p_3})_i$
	RAB	loc_2 $(\frac{p_2}{p_3})_i$
	RAC	$\rightarrow$ BT
	RAU	S_{m4}
	NZU	$\rightarrow$ (A-25)
(A-29)	STU	S_{m4}
	RAA	loc θ_4
	RAB	loc_2 θ_4
	RAC	$\rightarrow$ BT
	RAA	loc β_4
	RAB	loc_2 β_4
	RAC	$\rightarrow$ BT
	LDD	Section No.
	RAC	Section No.
	LDD	$\rightarrow (\frac{d}{p})_i$
	RAA	loc $(\frac{p_3}{b})_i$

MAIN PROGRAM (Cont.)

	RAB	$loc_2 \left(\frac{p_3}{b}\right)_i$
	RAC	$\longrightarrow$ BT $\longrightarrow$ (A-26)
(A-23)	LDD	$\frac{p_2}{p_1}$
	STD	$\longrightarrow$ (A-27)
(A-24)	LDD	$\frac{p_3}{p_2}$
	STD	$\longrightarrow$ (A-28)
(A-25)	LDD	$\frac{B}{p_3}$
	STD	$\longrightarrow$ (A-29)
	RAB	n - 1
(A-26)	RAU	1
	FAD	$\frac{d}{p_1}$
	STU	$1 + \frac{d}{p_1}$
	RAU	S_{m2}
	NZU	$\longrightarrow$ (A-30)
	RAU	1
	FDV	$\left(\frac{p_1}{p_2}\right)_i B$
	STU	$\left(\frac{p_2}{p_1}\right)_i$
	RAU	S_{m3}

MAIN PROGRAM (Cont.)

NZU	$\longrightarrow$ (A-31)
RAU	1
FDV	$(\frac{p_2}{p_3})_i B$
STU	$(\frac{p_3}{p_2})_i$
RAU	S_{m4}
NZU	$\longrightarrow$ (A-32)
RAU	$(\frac{p_2}{p_1})_i$
FMP	$(\frac{p_3}{p_2})_i$
STU	$(\frac{p_3}{p_1})_i$
FDV	$(\frac{p_3}{b})_i B$
STU	$(\frac{b}{p_1})_i$
FAD	$(\frac{p_3}{p_1})_i$
FAD	$(\frac{p_2}{p_1})_i$
FAD	$1 + \frac{d}{p_1}$
STU	Σ
RAU	(f_i) B

MAIN PROGRAM (Cont.)

	FDV	Σ
	STU	$(p_1)_i \longrightarrow$ (A-33)
(A-30)	RAU	(f_i) B
	FDV	$1 + \frac{d}{p_1}$
	STU	(b_i) B
	RSU	(b_i) B
	FAD	(f_i) B
	STU	$d_i \longrightarrow$ (A-33)
(A-31)	RAU	$1 + \frac{d}{p_1}$
	FAD	$\frac{b}{p_1}$
	STU	Σ
	RAU	(f_i) B
	FDV	Σ
	STU	$(p_1)_i$B
	RAU	$(\frac{b}{p_1})$
	FMP	$(p_1)_i$B
	STU	(b_i) B
	RAU	$(\frac{d}{p_1})_i$B
	FMP	$(p_1)_i$B

MAIN PROGRAM (Cont.)

	STU	(d_i) B $\longrightarrow$ (A-33)
(A-32)	RAU	$(\frac{p_2}{p_1})$
	FMP	$(\frac{b}{p_2})$
	STU	$(\frac{b}{p_1})$
	FAD	$(\frac{p_2}{p_1})$
	FAD	$1 + \frac{d}{p_1}$
	STU	Σ
	RAU	(f_i) B
	FDV	Σ
	STU	$(p_1)_i$B
	RAU	$(\frac{b}{p_1})$
	FMP	$(p_1)_i$B
	STU	(b_i) B
	RAU	$(\frac{p_2}{p_1})$
	FMP	$(p_1)_i$B
	STU	$(p_2)_i$B
	RAU	$(\frac{d}{p_1})$ B
	FMP	$(p_1)_i$
	STU	(d_i) B

MAIN PROGRAM (Cont.)

```
(A-33) NZB    (A-34)
       SXB-1  ⟶ (A-26)
(A-34) RAA    loc d
       RAB    loc₂ d
       RAC    ⟶ BT
       RSC    ⟶ MF
       RAU    T_d
       RSC    ⟶ DP
       LDD    T_d
       STD    T_d
       RAU    p_1
       NZU    ⟶ (A-35)
       RAA    loc p_1
       RAB    loc₂p_1
       RAC    ⟶ BT
       RAC    ⟶ MF
       RAU    T_p1
       RAC    ⟶ BP
       LDD    T_p1
       STD    T_p1
       RAU    p_2
       NZU    ⟶ (A-35)
```

MAIN PROGRAM (Cont.)

```
        RAA   loc p_2
        RAB   loc_2 p_2
        RAC   ⟶ BT
        RAC   ⟶ MF
        RAU   T_p_2
        RAC   ⟶ BP
        LDD   T_p_2
        STD   T_p_2
        RAU   p_3
        NZU   ⟶ (A-35)
        RAA   loc P_3
        RAB   loc_2 P_3
        RAC   ⟶ BT
        RAC   ⟶ MF
        RAU   T_p_3
        RAC   ⟶ BP
        LDD   T_p_3
        STD   T_p_3
(A-35)  RAA   loc b
        RAB   loc_2 b
        RAC   ⟶ BT
```

MAIN PROGRAM (Cont.)

```
        RAC   --->  MF
        RAU   T_b
        RAC   --->  BP
        LDD   T_b
        STD   T_b
        RAA   4
(A-38)  RAU   (T_d1) A
        FSB   (T_d2) A
        STU   ΔT
        RAU   tolerance
        FSM   ΔT
        BMI   --->  (A-36)
        NZA   (A-37)
        SXA-1 (A-38)
(A-37)  LDD   D
        STD   D
        LDD   p_1
        STD   p_1
        LDD   p_2
        STD   p_2
        LDD   p_3
        STD   p_3
```

MAIN PROGRAM (Cont.)

```
LDD   B
STU   B
LDD   P-Pch
STD   P-Pch
RAC   ⟶  Pch
LDD   0
STD   0
RAL   P-Pch
LDD   ⟶  Pch
LDD   T_d
STD   T_d
LDD   T_p1
STD   T_p1
LDD   T_p2
STD   T_p2
LDD   T_p3
STD   T_p3
LDD   T_b
STD   T_b
LDD   0
STD   0
```

MAIN PROGRAM (Cont.)

RAL	P-Pch
LDD	$\longrightarrow$ Pch $\longrightarrow$ load
LDD	LK_1
RAC	LK_1
LDD	HK_1
RAA	HK_1
RAU	(d_i) C
FDV	(d_i) A
STU	$(\frac{d_{LK}}{d_{HK}})$
RAU	$(f_i)_1 C$
FDV	$(f_i)_1 A$
STU	$(\frac{f_{LK}}{f_{HK}})_1$
RAU	$(f_i)_2 C$
NZU	$\longrightarrow$ (A-39)
FDV	$(f_i)_2 A$
STU	$(\frac{f_{LK}}{f_{HK}})_2$
RAU	$(f_i)_3 C$
NZU	$\longrightarrow$ (A-39)
FDV	$(f_i)_3 A$

MAIN PROGRAM (Cont.)

	STU	$\left(\frac{f_{LK}}{f_{HK}}\right)_3$
(A-39)	RAU	LK_2
	NZU	$\longrightarrow$ (A-40)
	RAC	LK_2
	LDD	HK_2
	RAA	HK_2
	RAU	$(p_i)_1C$
	FDV	$(p_i)_1A$
	STU	$\left(\frac{p_{LK}}{p_{HK}}\right)_1$
	RAU	$(f_i)_1C$
	FDV	$(f_i)_1A$
	STU	$\left(\frac{f_{LK}}{f_{HK}}\right)_i$
	RAU	$(f_i)_2C$
	NZU	$\longrightarrow$ (A-41)
	FDV	$(f_i)_2A$
	STU	$\left(\frac{f_{LK}}{f_{HK}}\right)_2$
	RAU	$(f_i)_3C$
	NZU	$\longrightarrow$ (A-41)
	FDV	$(f_i)_3A$

MAIN PROGRAM (Cont.)

	STU	$(\frac{f_{LK}}{f_{HK}})_3$
(A-41)	RAU	LK_3
	NZU	$\longrightarrow$ (A-40)
	RAC	LK_3
	LDD	HK_3
	RAA	HK_3
	RAU	$(p_i)_2C$
	FDV	$(p_i)_2A$
	STU	$(\frac{p_{LK}}{p_{HK}})_2$
	RAU	$(f_i)_1C$
	FDV	$(f_i)_1A$
	STU	$(\frac{f_{LK}}{f_{HK}})_1$
	RAU	$(f_i)_2C$
	NZU	$\longrightarrow$ (A-42)
	FDV	$(f_i)_2A$
	STU	$(\frac{f_{LK}}{f_{HK}})_2$
	RAU	$(f_i)_3C$
	NZU	$\longrightarrow$ (A-42)
	FDV	$(f_i)_3A$

MAIN PROGRAM (Cont.)

```
        STU   (f_LK/f_HK)_3
(A-42)  RAU   LK_4
        NZU   --> (A-40)
        RAC   LK_4
        LDD   HK_4
        RAA   HK_4
        RAU   (p_i)_3C
        FDV   (p_i)_3A
        STU   (p_LK/p_HK)_3
        RAU   (f_i)_1C
        FDV   (f_i)_1A
        STU   (f_LK/f_HK)_1
        RAU   (f_i)_2C
        NZU   --> (A-40)
        FDV   (f_i)_2A
        STU   (f_LK/f_HK)_2
        RAU   (f_i)_3C
        NZU   --> (A-40)
        FDV   (f_i)_3A
```

MAIN PROGRAM (Cont.)

```
        STU   (f_LK/f_HK)_3
(A-40)  RAU   (Rf_1)_2
        FSB   Rp_1
        BMI   ⟶ (A-43)
        RAU   (Rf_1)_3
        FSB   Rp_2
        BMI   ⟶ (A-44)
        RAU   (Rf_1)_4
        FSB   Rp_3
        BMI   ⟶ (A-45) or (A-46)
(A-43)  LDD   LK_1
        RAC   LK_1
        LDD   (β_1)_C
        STD   (β_1)C
        LDD   (θ_1)C
        STD   (θ_1)C
        LDD   F_1
        STD   F_1
        LDD   D
        STD   D
```

MAIN PROGRAM (Cont.)

```
        LDD  R_d
        STD  R_d
        LDD  (Rf_1)_1
        STD  (Rf_1)_1
        LDD  ——→ S
        STU  S_11 ——→ (A-47)
(A-44)  LDD  LK_2
        RAC  LK_2
        LDD  (β_2)C
        STD  (β_2)C
        LDD  (θ_2)C
        STD  (θ_2)C
        LDD  F_1
        STD  F_1
        LDD  p_1
        STD  p_1
        LDD  Rp_1
        STD  Rp_1
        LDD  (Rf_1)_2
        STD  (Rf_1)_2
```

MAIN PROGRAM (Cont.)

	LDD	$\longrightarrow$ S
	STU	$S_{21} \longrightarrow$ (A-47)
(A-45)	LDD	LK_3
	RAC	LK_3
	LDD	$(\beta_3)C$
	STD	$(\beta_3)C$
	LDD	$(\theta_3)C$
	STD	$(\theta_3)C$
	LDD	F_1
	STD	F_1
	LDD	p_2
	STD	p_2
	LDD	Rp_2
	STD	Rp_2
	LDD	$(Rf_1)_3$
	STD	$(Rf_1)_3$
	LDD	$\longrightarrow$ S
	STU	$S_{31} \longrightarrow$ (A-47)
(A-46)	LDD	LK_4
	RAC	LK_4
	LDD	$(\beta_4)C$

MAIN PROGRAM (Cont.)

	STD	$(\beta_4)C$
	LDD	$(\Theta_4)C$
	STD	$(\Theta_4)C$
	LDD	F_1
	STD	F_1
	LDD	p_3
	STD	p_3
	LDD	Rp_3
	STD	Rp_3
	LDD	$(Rf_1)_4$
	STD	$(Rf_1)_4$
	LDD	$\longrightarrow$ S
	STU	S_{41}
(A-47)	RAU	$(Rf_2)_2$
	NZU	$\longrightarrow$ (A-57)
	FSB	Rp_1
	BMI	$\longrightarrow$ (A-48)
	RAU	$(Rf_2)_3$
	FSB	Rp_2
	BMI	$\longrightarrow$ (A-49)
	RAU	$(Rf_2)_4$

MAIN PROGRAM (Cont.)

```
        FSB   Rp_3
        BMI   ⟶ (A-50) or (A-51)
(A-48)  LDD   LK_1
        RAC   LK_1
        LDD   (β_1)C
        STD   (β_1)C
        LDD   (θ_4)C
        STD   (θ_4)C
        LDD   F_2
        STD   F_2
        LDD   D
        STD   D
        LDD   R_d
        STD   R_d
        LDD   (Rf_2)_1
        STD   (Rf_2)_1
        LDD   ⟶ S
        STU   S_12 ⟶ (A-52)
(A-49)  LDD   LK_2
        RAC   LK_2
        LDD   (β_2)C
```

MAIN PROGRAM (Cont.)

	STD	$(\beta_2)C$	
	LDD	$(\theta_2)C$	
	STD	$(\theta_2)C$	
	LDD	F_2	
	STD	F_2	
	LDD	p_1	
	STD	p_1	
	LDD	Rp_1	
	STD	Rp_1	
	LDD	$(Rf_2)_2$	
	STD	$(Rf_2)_2$	
	LDD	$\longrightarrow$ S	
	STU	$S_{22} \longrightarrow$	(A-52)
(A-50)	LDD	LK_3	
	RAC	LK_3	
	LDD	$(\beta_3)C$	
	STD	$(\beta_3)C$	
	LDD	$(\theta_3)C$	
	STD	$(\theta_3)C$	
	LDD	F_2	
	STD	F_2	
	LDD	p_2	

MAIN PROGRAM (Cont.)

	STD	p_2
	LDD	Rp_2
	STD	Rp_2
	LDD	$(Rf_2)_3$
	STD	$(Rf_2)_3$
	LDD	$\longrightarrow$ S
	STU	$S_{32} \longrightarrow$ (A-52)
(A-51)	LDD	LK_4
	RAC	LK_4
	LDD	$(\beta_4)C$
	STD	$(\beta_4)C$
	LDD	$(\Theta_4)C$
	STD	$(\Theta_4)C$
	LDD	F_2
	STD	F_2
	LDD	p_3
	STD	p_3
	LDD	Rp_3
	STD	Rp_3
	LDD	$(Rf_2)_4$
	STD	$(Rf_2)_4$

MAIN PROGRAM (Cont.)

```
        LDD   ⟶ S
        STU   S_42
(A-52)  RAU   (Rf_3)_2
        NZU   (A-57)
        FSB   Rp_1
        BMI   ⟶ (A-53)
        RAU   (Rf_3)_3
        FSB   Rp_2
        BMI   ⟶ (A-54)
        RAU   (Rf_3)_4
        FSB   Rp_3
        BMI   ⟶ (A-55) or (A-56)
(A-53)  LDD   LK_1
        RAC   LK_1
        LDD   (β_1)C
        STD   (β_1)C
        LDD   (θ_1)C
        STD   (θ_1)C
        LDD   F_3
        STD   F_3
        LDD   D
```

MAIN PROGRAM (Cont.)

```
        STD   D
        LDD   R_d
        STD   R_d
        LDD   (Rf_3)_1
        STD   (Rf_3)_1
        LDD   ⟶ S
        STU   S_13 ⟶ (A-57)
(A-54)  LDD   LK_2
        RAC   LK_2
        LDD   (β_2)C
        STD   (β_2)C
        LDD   (θ_2)C
        STD   (θ_2)C
        LDD   F_3
        STD   F_3
        LDD   p_1
        STD   p_1
        LDD   Rp_1
        STD   Rp_1
        LDD   (Rf_3)_2
        STD   (Rf_2)_2
```

MAIN PROGRAM (Cont.)

	LDD	S	
	STU	S_{23}	(A-57)
(A-55)	LDD	LK_3	
	RAC	LK_3	
	LDD	$(\beta_3)C$	
	STD	$(\beta_3)C$	
	LDD	$(\theta_3)C$	
	STD	$(\theta_3)C$	
	LDD	F_3	
	STD	F_3	
	LDD	p_2	
	STD	p_2	
	LDD	Rp_2	
	STD	Rp_2	
	LDD	$(Rf_3)_3$	
	STD	$(Rf_3)_3$	
	LDD	$\longrightarrow$ S	
	STD	$S_{33} \longrightarrow$	(A-57)
(A-56)	LDD	LK_4	
	RAC	LK_4	
	LDD	$(\beta_4)C$	
	STD	$(\beta_4)C$	

MAIN PROGRAM (Cont.)

```
        LDD   (θ4)C
        STD   (θ4)C
        LDD   F3
        STD   F3
        LDD   P3
        STD   P3
        LDD   Rp3
        STD   Rp3
        LDD   (Rf3)4
        STD   (Rf3)4
        LDD   ──> S
        STU   S43
(A-57)  LDD   0
        STD   0
        RAU   P-Pch
        LDD   ──> Pch
        LDD   0
        STD   0
        RAL   P-Pch
        LDD   ──> Pch
              HALT
```

VITA

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