METHOD OF CALCULATION FOR ABSORBER-STRIPPER SYSTEMS

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PREFACE

For some time process design engineers have been faced with the tedious calculations required to predict the operation of absorber-strippers. At present, only a few methods have been developed which are fast enough for practical use by hand calculation. Some longer methods have been programed for high speed computers. The methods reported are quite limited in the type of absorption-stripping system that may be calculated.

This thesis is a report of a shortcut procedure which has been developed and programed for the IBM 650 computer. The method will predict the performance of an absorber-stripper with any normal combination of reboiler and absorption-stripping sections. The program is easily convertible for use on other digital computers.

Comparisons are made to show the results obtained in simulating actual operating columns. Much difficulty was encountered in these runs in finding consistently reliable enthalpy and equilibrium data.

I wish to thank Continental Oil Company for their permission to publish this report and for making available their computer facilities. In particular, I wish to thank Mr. D. F. Cameron, Director of the Process Center, for allowing me time to make this study; Dr. Omer Kircher for his assistance in the early development of the method; and the personnel of the computer section for much valuable assistance.

I would also like to thank Dr. Robert N. Maddox for his direction of this work and for the data he provided.

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CHAPTER I

INTRODUCTION

After several years' experience in process calculations, the author observed that a new method of calculating absorber-stripper columns was needed. This class of columns occurs frequently in petroleum refineries and natural gasoline plants. The methods used are either too long for practical hand calculation or are suitable only for special types of absorber-strippers. In some, the assumption of a denuded lean oil is required. In others, the effect of variations in temperature and light end concentration is neglected. Any generalized method would require too much time to be practical for hand calculation. Therefore a decision was made to program the method for a high speed computer. The IBM 650 computer with indexing registers and floating point devices was selected because of its availability. The resulting program can be easily converted for use on larger digital computers with the advantage that larger problems can be run.

The program evolved is a practical short cut procedure for calculating heat and material balances around any absorption-stripping column commonly encountered. It is limited in versatility only by the size of the computer available. The program has been tested on several types of columns commonly found in petroleum refineries and natural gasoline plants. It has predicted the observed operation within the accuracy of the laboratory data.

CHAPTER II

LITERATURE SURVEY

The recovery of light hydrocarbons from multicomponent gaseous mixtures by absorption with a lean oil is an important operation in petroleum refineries and natural gasoline plants. The driving force for the transfer of a light component from the gas phase to the liquid phase is proportional to the difference between the partial pressure of the component in the gas phase and the equilibrium vapor pressure of the component in solution with the lean oil. Absorption according to volatility and liquid-vapor ratios causes undesirable components to be present with the desired components. To remove the undesirable components from the rich oil, stripping sections and reboilers are frequently added to the basic absorber.

For commercial systems, the concentration of recoverable components in the feed vapor is appreciable. The absorption of these components causes a significant change in the liquid and vapor rates in the column. Considerable heat of absorption is evolved and recovered as sensible heat by the rich oil. Therefore, significant temperature variations occur in the column. Intercoolers are frequently added to maintain low column temperatures by removing the heat of absorption. Lower temperatures give higher absorption selectivity. Light lean oils are also used because of their greater absorption capacity per unit volume. The light lean oil may be partially stripped at the temperatures of the column. To prevent loss of solvent, sponge oil sections are frequently added. In these sections the tail gas and lean oil vapors are contacted with a heavier lean oil to recover the lean oil vapors.

These operating characteristics increase the complexity of commercial columns and give rise to the following requirements for a practical method of calculation. The method should:

1. Permit the calculation of complex configurations of equipment within practical time limits. This requirement calls for the use of a digital computer.
2. Be practical for computer programing.
3. Permit the calculation of systems using non-denuded lean oils.
4. Account for variations in column temperatures and rates.

Most investigators have found it convenient to assume the theoretical equilibrium stage concept even though absorption is primarily a diffusional rather than vaporizational process; i.e., over-all stage efficiencies may be used to relate theoretical stages to actual contacting stages. Ravicz(14) has developed mass transfer relationships which he combines with Murphree plate efficiencies for the non-ideal stage, to predict the products from a simple absorber. This method has been programed for a large scale digital computer (IBM 704).

Kremser(9) developed relationships to predict the efficiency of absorption, which require only the assumption of the theoretical plate concept. These equations are in terms of the absorption or stripping factor on each theoretical plate.

Souders and Brown(17) have used these equations making the assumption that an average absorption or stripping factor could be determined to represent the absorption for many plates. The factor is calculated from the wet gas and lean oil temperatures and rates.

Horton and Franklin(7) assume that an effective absorption or stripping factor for each component may be evaluated from the conditions at different points in the column. The factors for light components are evaluated near the bottom of the absorber and heavy components near the middle.

Edmister(2) has developed an effective factor which is rigorous for a two-plate column, but an approximation for columns with more plates. He assumes that the effective absorption or stripping factor is a function of the terminal absorption factors.

Other authors; Parekh(12), Hutchinson(8), Smith(16), and Ragatz(13) have used average factors differing only slightly from the factors usually employed in the Kremser-Brown method.

Sherwood(15) has formulated a method based on fundamental concepts developed by Lewis. He uses a graphical procedure, plotting the equilibrium and operating line for the key component and components adjacent to the key. A combination of graphical and analytical procedures are used for other components. Constant rates, temperatures, and pressures are assumed.

Ellis(5) has developed a graphical procedure involving plots similar to the Ponchon-Savarit diagrams used in distillation. Straight lines may be used to represent the equilibrium line. The difficulty in drawing the curved equilibrium line for Sherwood's method is eliminated. Constant rates need not be assumed.

The method of Edmister(2) has been chosen as best meeting the requirements for a practical calculation procedure. The methods of

Sherwood(15), Edmister(2), and Horton-Franklin(7) have been compared to Plate-to-Plate calculations by Edmister(3). The method of Edmister(2) gave slightly better values than the other short cut methods.

The mass transfer approach of Ravicz(14) gave errors of about the same magnitude as methods using the theoretical plate concept, probably due to inability to evaluate Murphree plate efficiencies. It would be very difficult to develop the mass transfer equations required by this method for a complex system.

The Horton-Franklin(7) method requires the estimation of vapor and liquid rates and temperatures at many places in the column. Such a procedure would be too long, even for a digital computer.

The Kremser-Brown(9, 17) approach was eliminated because of the assumption of constant rates and temperatures. This procedure does not account for the decrease in driving force caused by the presence of absorbed components in the lean oil. Ragatz(13) discusses deviations of operating columns from predicted results calculated by this method.

The graphical methods of Sherwood(15) and Ellis(5) were not suitable for computer programing.

A new method proposed by Edmister(4) had not been fully evaluated by the author at the time of this report. This method using fractions not transferred has utility in developing relationships for complex columns.

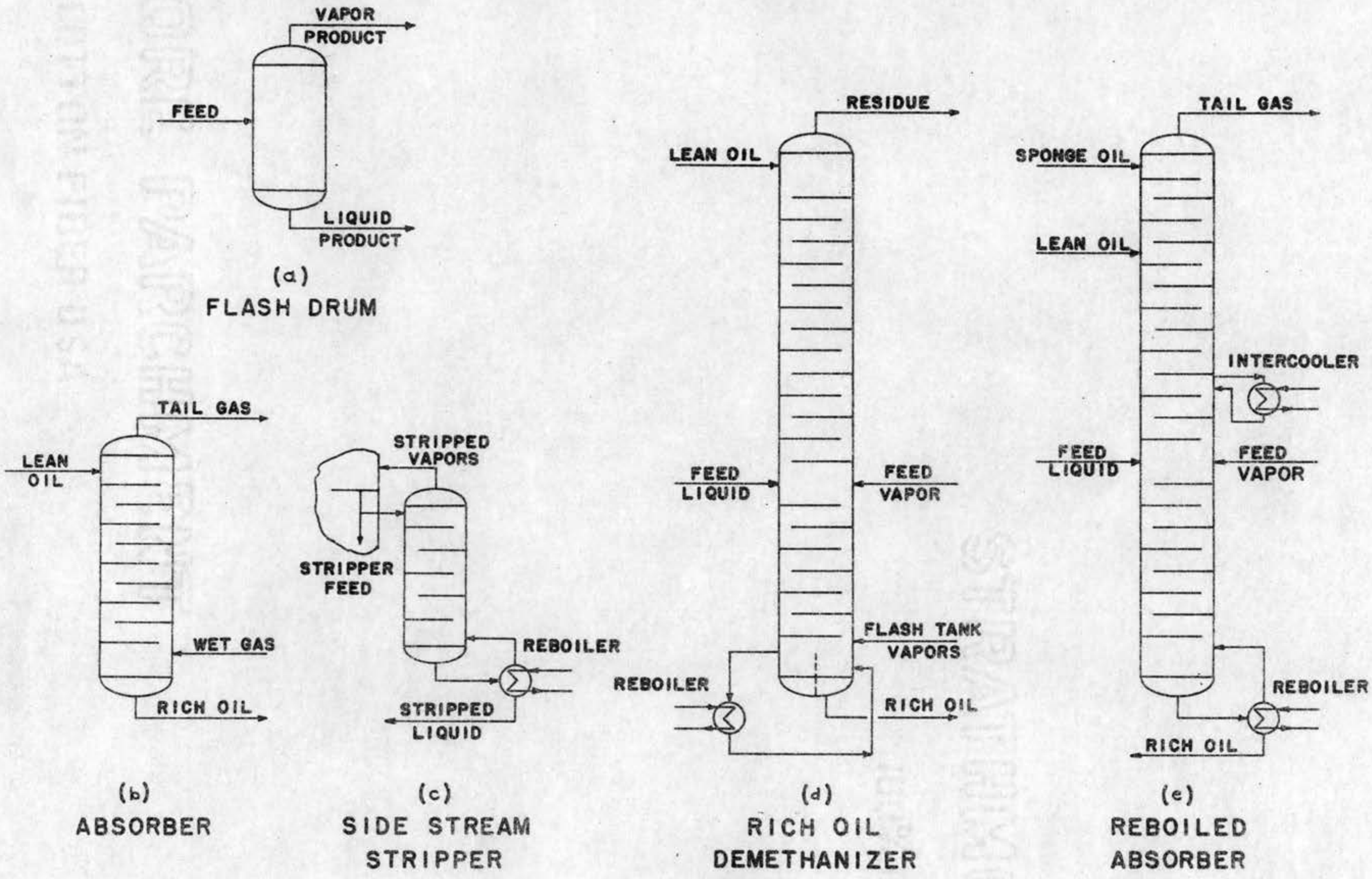
CHAPTER III

GENERATION OF THE SECTION CONCEPT

Many types of commercial columns were studied to develop a general method of calculation. Some typical types are shown in Figure 1. These include a flash drum, an absorber, a side stream stripper (with reboiler), a rich oil demethanizer, and a reboiled absorber (with sponge oil section and an intercooler). All of these pieces of equipment could be represented by Figure 2 if some of the feed streams or tray sections were missing. A further generalization can be made if the column shown in Figure 2 is considered to be made up of several sections. Each of these sections is defined by one or more streams entering or leaving the section at the top and one or more streams entering or leaving the section at the bottom. This method of breaking up a column was suggested by Edmister(4).

All the sections in the column can be represented by the section shown in Figure 3. The drawing shows an external liquid feed, a liquid feed from the section above, an external vapor feed, and a vapor feed from the section below. A liquid and a vapor stream are produced. Any given section will have a varying number of theoretical plates and some feed streams may be absent.

The method used to calculate the products will be described in Chapter IV and the logic for moving from one section to another will be described in Chapter V.



(a) FLASH DRUM

(b) ABSORBER

(c) SIDE STREAM STRIPPER

(d) RICH OIL DEMETHANIZER

(e) REBOILED ABSORBER

FIGURE 1
TYPICAL ABSORBER-STRIPPERS

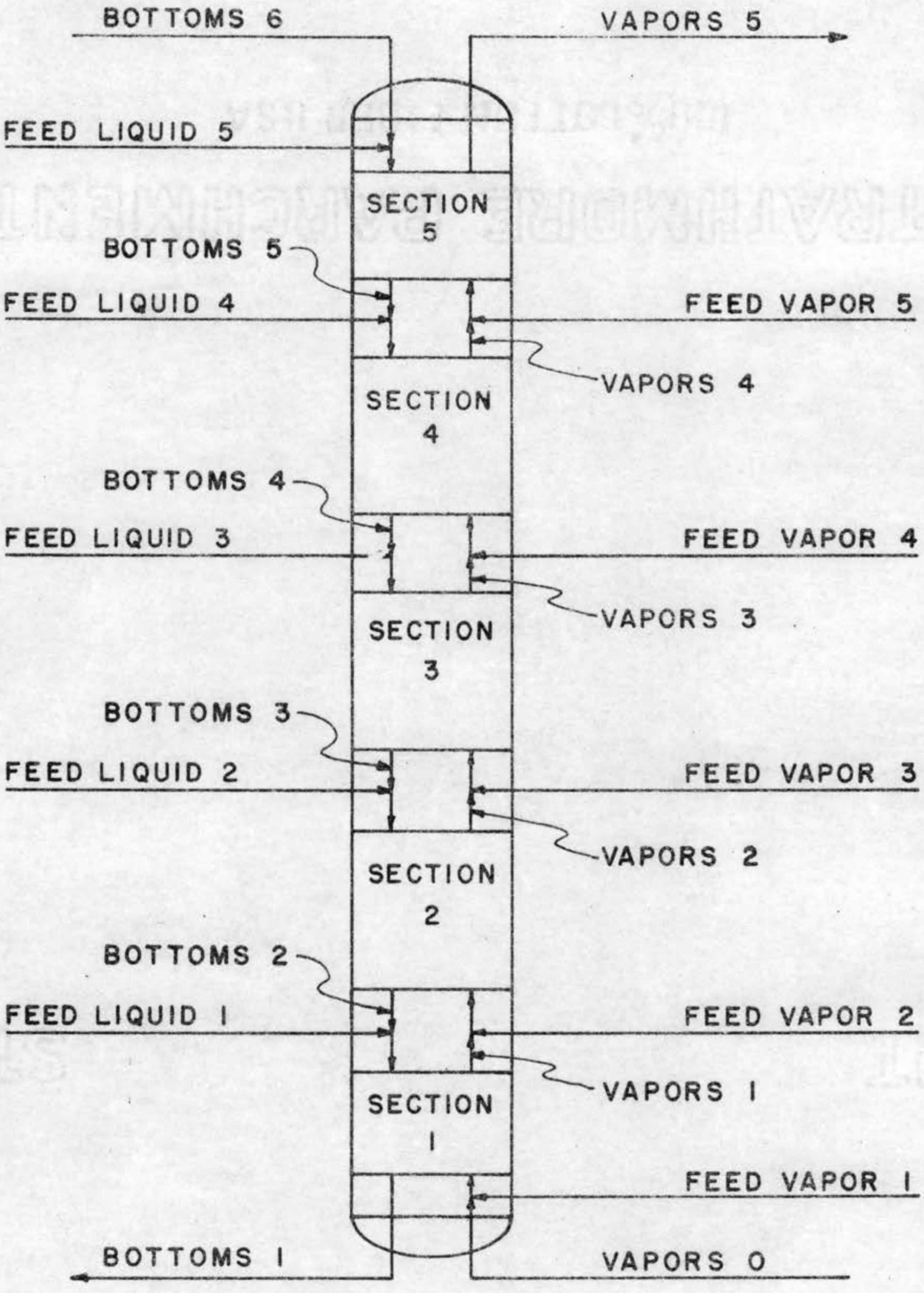


FIGURE 2

GENERAL ABSORBER-STRIPPER

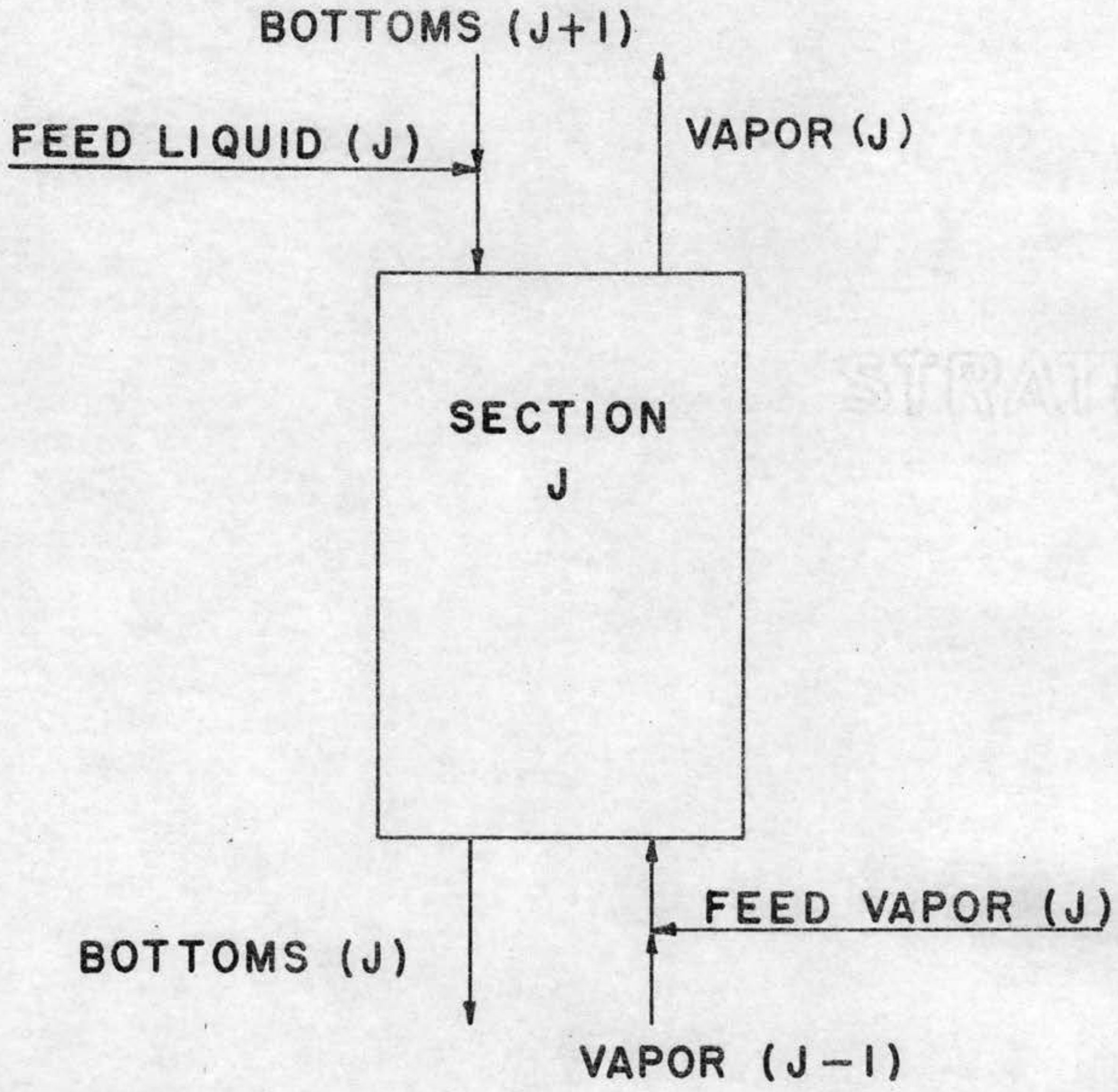


FIGURE 3

TYPICAL SECTION

CHAPTER IV

METHOD OF CALCULATION

The objective of this study was to develop a set of equations that would permit the calculation of the products from any two-phase-equilibrium stage-type of separation. The sequence selected is slanted toward the calculation of existing pieces of equipment. That is, equipment in which the feed compositions, feed rates, and number of theoretical trays in each section are known. Good assumptions can also be made of the temperatures and liquid to vapor ratios in this equipment.

New equipment can be calculated by making several trials with varying numbers of theoretical trays until the proper products are obtained.

Equations developed by Edmister(2) were used for the calculation. They are described below with the logic for their application. Edmister's equations are derived in Appendix A. A block flow diagram of the computer program for these equations is shown in Appendix B.

The calculation is made for a given component in a given section. When the calculations are begun, the following items of data are available:

1. The number of theoretical trays in the section - N.
2. An assumption of the ratio of the total liquid stream to total vapor stream at the top of the section - $(L/V)_T$.
3. An assumption of the ratio of the total liquid stream to total vapor stream at the bottom of the section - $(L/V)_B$.

4. The equilibrium constant for the component being calculated at an assumed section top temperature - K_T.
5. The equilibrium constant for the component being calculated at an assumed section bottom temperature - K_B.

The absorption factor at the top of the section (A_1) and the absorption factor at the bottom of the section (A_N) are calculated from their definitions.

$$A_1 = (L/V)_T \ / \ K_T \tag{1}$$

$$A_N = (L/V)_B \ / \ K_B \tag{2}$$

The effective absorption factor (A') may now be calculated from the terminal absorption factors.

$$A' = \frac{A_N(A_1 + 1)}{A_N + 1} \tag{3}$$

The direction of mass transfer (net stripping or net absorption) is determined by calculating the factor ($A'V-L$) from the composition of the feeds to the section.

$$V = v_F + v_{j-1} \tag{4}$$

and

$$L = l_F + l_{j+1} \tag{5}$$

where

j = the number of the section being calculated;

$j-1$ = the number of the section below the section being calculated;

$j+1$ = the number of the section above the section being calculated;

v_F = the external vapor feed to the section;

v_{j-1} = the internal vapor feed to the section from the section below;

l_F = the external liquid feed to the section, and

l_{j+1} = the internal liquid feed to the section from the section above.

If the sign of (A'V-L) is positive, net absorption occurs; if negative, net stripping occurs and stripping factors S_M and S_1 must be calculated. S_M is the stripping factor at the top of the section and S_1 is the stripping factor at the bottom of the section.

$$S_M = 1/A_1 \tag{6}$$

and

$$S_1 = 1/A_N \tag{7}$$

since by definition

$$S_M = K_T \times 1/(L/V)_T \tag{8}$$

and

$$S_1 = K_B \times 1/(L/V)_B \tag{9}$$

A different set of equations may be used for calculation of net stripping and net absorption but the equations have the same form if the proper factors (S or A) are used. For this reason the discussion will be limited to the calculation using absorption factors.

The efficiency of transfer (A_e) and fraction transferred (α) are calculated using relationships derived by Edmister(2).

$$A_e = \sqrt{A_N\ (A_1 + 1) + 0.25} - 0.5 \tag{10}$$

and

$$\alpha = (A_e^{N+1} - A_e)/(A_e^{N+1} - 1) \tag{11}$$

The validity of the effective factor is assumed in these equations and equation (10) is rigorous only for a two plate column.

The amount of the component transferred ($\triangle$) may now be calculated from the fraction transferred (α) where

$$\triangle = \alpha(A'V-L)/A' \tag{12}$$

The material balance for the section is calculated from

$$v_j = v_F + v_{j-1} - \Delta \qquad (13)$$

and

$$l_j = l_F + l_{j+1} + \Delta \qquad (14)$$

where v_j and l_j are the vapor and liquid products from the section.

The equations discussed above will be used many times in the calculation sequence so it is desirable to reduce the mathematical operations to a minimum. The use of a minimum of storage space is required by computer size limitations. To accomplish these objectives special computer techniques were used. They are described in Appendix C.

The logic for integrating the subroutine in the over-all program is described in the next section.

CHAPTER V

OVER-ALL LOGIC

The over-all calculation is considered in the following chapter. The scheme for integrating the basic subroutine is discussed. Details of the computer program including input and output data are described in Appendix C. Flow charts of the over-all program and of each section are shown in Appendix B. Appendix D has the FORTRAN program statements.

The size of the program which may be run is limited only by the size of the computer memory. A maximum of twenty different components may be present in the feeds to the column and no more than five sections may be present in the program discussed here. These restrictions will not prove a serious limitation for common types of absorber-strippers.

An additional assumption not inherent in the method is made because of computer size limitations; i.e., the L/V ratio of the streams leaving the top theoretical plate of a multiplate section is nearly the same as the ratio of the liquid to the plate and the vapor from the plate. A similar assumption is made for the bottom theoretical plate of a multiplate section. These assumptions are justified by the accuracy of the results of the program.

The unique features of this program sequence are:

1. Completion of the material balance for the first component in all sections before proceeding to the next component.
2. Elimination of the need for making initial product composition assumptions.

The first feature results in an appreciable time saving. Equilibrium constants for the very light and very heavy components have very high or very low values. Therefore, the absorption or stripping factors also have very high or very low values with the L/V ratios present in commercial equipment. At extreme values of the absorption or stripping factor, the fraction absorbed or stripped is not affected by moderate changes in the factors. So, the amount of the light components and heavy components in the tower do not change appreciably with L/V ratio. Therefore, checks are obtained immediately for these components. As the final calculation trial is approached, fewer components need to be recalculated and trials with L/V ratio as the variable become shorter.

Feature two is achieved by starting with all product rates assumed to be zero. A small penalty in computing time is paid for this convenience, but convergence is improved appreciably. Cycling and divergence are not problems.

The over-all calculation contains three important parts: (1) evaluation of equilibrium constants, (2) main calculation sequence, and (3) material and heat balances. The logic used in these parts will be explained by following a typical calculation.

Evaluation of Equilibrium Constants

The program size is first specified by determining the number of components and sections. Tower pressure is selected and temperatures are assumed for the top and bottom of each section. Data for the calculation of the equilibrium constants may be supplied in three ways:

1. By providing the N.G.S.M.A.(11) coefficients relating equilibrium constant to temperature and pressure at a calculated convergence pressure.

2. By providing the coefficients of the equation of the form selected by the N.G.S.M.A. to relate the equilibrium constant to temperature at constant pressure.
3. By supplying the equilibrium constants themselves for the top and bottom of each section.

These three options should cover most cases required to specify equilibrium constants. The form of the N.G.S.M.A. equations is discussed by Norman and Williams(11) in papers presented to the Natural Gasoline Association of America. Option one may be used when coefficients for the component at the selected convergence pressure are available. Coefficients for option two may be obtained from standard curve fitting routines if data from the N.G.S.M.A. correlations are not available. Option three is most useful when correlations are not available or when the N.G.S.M.A. equation does not represent the data accurately. Different options may be selected for different components in a given problem.

The equilibrium constants and temperatures from this part are saved for use in the main calculation sequence.

Main Calculation Sequence

Feed compositions are defined and L/V ratios are assumed by the program user at the top and bottom of each section. The number of theoretical plates in each section is specified.

Using this data and the results from the previous part, calculations are begun with the lightest component in the bottom section (section 1). The amounts of all components leaving the bottom of each section are set equal to zero. If this component is not present in the external feeds to the bottom section, the amount in the liquid leaving the bottom of the section will be zero. This will be the same as the initial amount assumed and a check is obtained. The next higher section (section 2) will now be calculated. This procedure will be followed until a section is reached in which there is some of the component in the external feeds. Then there will usually be some of this component in the liquid leaving the bottom of the section. This amount will differ from the zero quantity assumed and a check will not be obtained. The calculation will now move down one section with a liquid feed stream from the section above in addition to the external feeds. Usually, a check will not be made on this section either, so the next lower section will be calculated using the liquid from the section above as a new feed. This procedure is continued until the bottom section is reached. Special logic causes calculations to be made on this section until the amount of the component in the liquid leaving the section checks the amount calculated on the last pass within one per cent. The next higher section is now calculated using as feeds the external liquid and vapor feeds, the previously calculated liquid from the section above and the vapor from the section below. This procedure is followed, moving up a section when a check is obtained and down a section when a check is not obtained (with the exception of the bottom section) until the amount of the component in the liquid leaving the section checks the amount calculated on the last pass for every section. The second lightest component is now calculated and so on until all components have been completed.

The component quantities entering and leaving each section are summed and the calculated L/V ratios are determined. If any of the L/V ratios do not check the values assumed for the current pass within one per cent, the calculated values will be used as assumptions for the next pass. When all the L/V ratios do check, the program leaves the main calculation sequence and enters the material and heat balance section. The only values saved from the main calculation sequence are the composition of the liquid stream leaving each section, the composition of the external feeds, the L/V ratios, and the temperatures at the top and bottom of each section.

Material and Heat Balances

Complete material balances are made for each component in each section in this part of the program since vapor compositions are not retained in the previous part. Coefficients of second order polynomial equations are used to relate enthalpy of the components in the vapor and liquid to temperature. Temperatures of the external feeds are specified and heat balances are made around each section and the complete column. Reboiler and intercooler duties are also calculated.

The initial assumptions of L/V ratio and temperature are very important in the time required for the calculation. The time is almost directly dependent on the accuracy of the initial L/V ratio assumptions. Good assumptions may usually be made for existing columns by making rough heat and material balance calculations. The method of Horton and Franklin(7) may be used in these calculations. The one per cent discrepancy between calculated and assumed L/V ratios will usually insure constant stream compositions.

Temperature assumptions are checked by the heat balances for each section. If appreciable errors are observed, the entire calculation must be repeated using new temperatures. Operating data is usually available for most temperatures in existing columns. If the column terminal temperatures are not changed, a third trial will usually not be necessary.

Feed vapor and feed liquid must be supplied for each external feed. Therefore, flash calculations must be made by hand or by this program before the problem can be started.

CHAPTER VI

RESULTS AND CONCLUSIONS

The problem undertaken in this project was the development of a practical means of making a complete material and heat balance around a piece of separation equipment in which the separation could be characterized as absorption-stripping. In order for this procedure to be versatile in the type of equipment it could handle, a procedure was chosen which required many iterations. As a result, a medium-sized computer was programed to make the calculation in a reasonable amount of time. Because the computer had limited storage space, the equipment to be calculated could not be broken down into units containing only one theoretical tray. A short cut procedure was chosen which could approximate a balance around a section of equipment containing many theoretical trays. Any such procedure requires the calculation of an average or typical absorption or stripping factor over these theoretical trays. The method used to evaluate this factor was the "effective" factor method of Edmister(2).

The only assumptions required in this method are:

1. Equilibrium of the liquid and vapor leaving each theoretical stage.
2. The validity of the effective factor approximation.

Another assumption was made in the computer program itself. It was necessary to assume that the L/V ratio of streams leaving the terminal tray of a section could be approximated by the ratio of the passing liquid and vapor streams. The first assumption is frequently made in separation calculations and involves the use of over-all tray efficiencies instead of point or stage efficiencies. The second and third assumptions are justified by the ability of the procedure to predict the products from a wide range of operating equipment.

The equipment calculated included two reboiled absorbers and a rich oil demethanizer. Calculations were made on each of these columns at various operating conditions. Typical results are shown in Tables I, II, and III on the following pages. In all runs, N.G.S.M.A. "K" data(6) was used and the assumption was made that it satisfactorily represented the system.

The program is limited in versatility only by the size of the computer available. Denuded lean oils or stripping mediums need not be assumed and most commercial equipment may be calculated. The only data required are the feed compositions and temperatures and the number of theoretical trays. Initial assumptions of the column L/V ratios and temperatures must be made. Starting values of other variables are assumed by the program. The L/V ratio assumption is checked by the program. The temperature assumption must be checked outside of the program due to computer limitations. The accuracy of the initial assumptions is directly related to the time required to solve a problem.

The author originally intended to check the assumption of temperature by making heat balances around each section and revising temperatures until a balance was obtained on every section. This decision was made because of the opinion that streams were either not at their bubble and dew points or that the bubble and dew points could not be calculated accurately in absorption-stripping separations. The author discovered in making heat balances that enthalpy values varied widely for the range of temperature and pressure in these units. One set of such values is shown in Table IV. Since some doubt existed about the correct enthalpy values to use, the author decided to re-evaluate the decision not to check temperatures by calculating bubble and dew points.

A unit was selected in which most of the necessary temperatures could be measured and the others could be estimated accurately. The column was calculated using various temperatures until the products checked those measured on the operating unit. At these temperatures, section heat balances could be made and the reboiler duty checked the measured value. Dew points and bubble points were calculated for all intermediate streams. The results of these calculations are shown in Table V. The streams were found to be at their bubble and dew points and these temperatures could be easily calculated. The only restriction on the above statement being that components cannot be lumped together; i.e., the lean oil cannot be included as one component. This is particularly true in calculating the dew points. Subsequently, bubble and dew points were calculated on other units. In general, bubble points could be easily calculated since heavy components did not contribute greatly to the calculation, but dew points could be calculated only when the lean oil was broken up into as many components as possible within the limitations of the program. The temperatures of the streams leaving the reboiler could always be calculated. It would seem, therefore, that bubble point and dew point calculations may be a way to evaluate temperatures in absorption-stripping systems. Such an evaluation has not been included in this program at present.

It is the author's suggestion that this point be investigated further. Additional work to compare and evaluate the many enthalpy correlations would also be very valuable.

TABLE I

RESULTS REBOILED ABSORBER CALCULATION

Number of Sections - 5 Number of Components - 18

Overall Material Balance - Moles/Hr.

Components	Liquid Feed To Stripping Section	Vapor Feed To Lower Absorption Section	Lean Oil To Upper Absorption Section	Sponge Oil To Sponge Oil Section	Tail Gas	Rich Oil
N_2	0.4	12.3	-	-	12.7	-
H_2	0.7	39.9	-	-	40.6	-
C_1	22.6	298.9	-	-	321.5	-
$C_2^=$	3.9	18.3	-	-	21.8	0.4
C_2	40.4	131.3	-	-	143.6	28.1
$C_3^=$	24.2	29.9	-	-	11.0	43.1
C_3	111.7	120.8	-	-	29.1	203.4
$C_4^=$	31.9	11.4	6.9	-	4.0	46.2
iC_4	35.3	16.7	3.6	-	1.6	54.0
nC_4	104.3	36.8	2.2	-	1.4	141.9
$C_5^=$	14.0	1.7	47.8	-	1.2	62.3
iC_5	26.4	4.0	24.4	-	0.3	54.5
nC_5	14.5	1.7	14.9	-	0.1	31.0
C_6	12.9	1.0	8.8	-	0.0	22.7
C_7	13.8	0.4	12.5	-	0.0	26.7
C_8	3.1	-	28.7	12.7	0.3	44.2
C_9	7.4	-	47.1	33.9	0.3	88.1
C_{10}	16.0	-	196.1	165.4	0.6	376.9
Total	483.5	725.1	392.9	212.0	590.0	1,223.5

SECTION HEAT BALANCE M B.T.U./HR.

	Section 1 Reboiler	Section 2 Stripping Section	Section 3 Lower Absorption Section	Section 4 Upper Absorption Section	Section 5 Sponge Oil Section
Top L/V Ratio	1.77	4.77	1.26	1.03	0.362
Bottom L/V Ratio	1.77	2.81	1.26	1.02	0.440
Top Temperature, °F.	251	124	95	128	103
Bottom Temperature, °F.	251	188	132	132	138
Number of Theoretical Trays	1	7	1	3	2
Heat In	32,674	26,841	15,560	13,574	6,472
Heat Out	32,674	27,501	17,401	13,797	6,998
Reboiler Duty	8,909	-	-	-	-
Intercooler Duty	-	-	3,028	-	-
% Unbalance	0	2.46	11.83	1.64	8.13

Overall Heat Balance –	M B.T.U./Hr.
Heat In	24,812
Heat Out	27,348
% Unbalance	10.22

COMPARISON OF CALCULATED DATA AND LABORATORY DATA

Tail Gas Composition - Mole Per Cent

Component	Calculated Data		Laboratory Data
N_2	2.15	9.03	7.50
H_2	6.88		
C_1		54.49	50.00
C_2-	3.69	28.03	33.90
C_2	24.34		
C_3-		1.86	2.70
C_3		4.93	6.90
C_4-		.68	-
iC_4		.27	-
nC_4		.24	-
C_5-		.20	-
iC_5		.05	-
nC_5		.02	-
C_6		-	-
C_7		-	-
C_8		.05	-
C_9		.05	-
C_{10}		.10	-

	Calculated Duties	Measured Duties
Reboiler Duty	8,909	-
Intercooler Duty	3,028	2,770

TABLE II

RESULTS REBOILED ABSORBER CALCULATION

Number of Sections - 4

Overall Material Balance - Moles/Hr.

Number of Components - 11

Components	Liquid Feed To Stripping Section	Vapor Feed To Lower Absorption Section	Lean Oil To Upper Absorption Section	Tail Gas	Rich Oil
C_1	11.2	45.0	-	56.2	-
$C_2^=$	5.6	6.6	-	11.9	0.3
C_2	19.9	16.5	-	30.5	5.9
$C_3^=$	19.3	6.4	-	2.2	23.5
C_3	21.5	6.1	-	0.9	26.7
$C_4^=$	21.2	2.2	-	0.0	23.4
iC_4	3.2	0.4	-	0.0	3.6
nC_4	13.4	1.3	-	0.0	14.7
C_5	27.3	1.0	11.5	1.1	38.7
C_7	98.6	0.4	40.2	0.4	138.8
H.G.	-	-	62.7	0.4	62.3
Total	241.2	85.9	114.4	103.6	337.9

SECTION HEAT BALANCE - M B.T.U./HR.

	Section 1 Reboiler	Section 2 Stripping Section	Section 3 Lower Absorption Section	Section 4 Upper Absorption Section
Top L/V Ratio	1.87	4.92	1.07	1.10
Bottom L/V Ratio	1.87	2.85	1.05	1.07
Top Temperature	261	110	100	95
Bottom Temperature	261	183	120	110
Number of Theoretical Trays	1	6	4	4
Heat In	10,215	7,911	2,968	2,338
Heat Out	10,215	8,093	3,089	2,323
Reboiler Duty	3,005	-	-	-
Intercooler Duty	-	-	171	-
% Unbalance	0	2.30	4.08	0.64

Overall Heat Balance - M B.T.U./Hr.

Heat In	7,226
Heat Out	7,515
% Unbalance	4.0

COMPARISON OF CALCULATED DATA AND LABORATORY DATA

Tail Gas Composition - Mole Per Cent

Components	Calculated Data	Laboratory Data
C_1	54.25	54.99
$C_{\bar{2}}$	11.49	11.55
C_2	29.44	29.45
$C_{\bar{3}}$	2.12	2.74
C_3	.87	1.27
$C_{\bar{4}}$	-	-
iC_4	-	-
nC_4	-	-
C_5	1.05	-
C_7	.39	-
H.G.	.39	-

	Calculated Duties	Measured Duties
Reboiler Duty	3,005	3,119
Intercooler Duty	171	193.5

TABLE III

RESULTS RICH OIL DEMETHANIZER CALCULATION

Number of Sections - 3

Number of Components - 20

Overall Material Balance - Moles/Hr.

Components	Liquid Feed To Stripping Section	Vapor Feed To Lower Absorption Section	Lean Oil To Upper Absorption Section	Flash Vapors To Stripping Section	Tail Gas	Rich Oil
N_2	2.1	2.9	-	.6	5.6	-
C_1	129.5	40.7	1.3	25.8	132.7	64.6
C_2	68.6	4.5	.3	19.3	13.4	79.3
C_3	99.4	2.1	.2	13.0	3.5	111.2
iC_4	28.4	.3	-	1.5	.1	30.1
nC_4	108.4	.7	-	3.6	.1	112.6
iC_5	28.3	.1	-	.6	-	29.0
nC_5	31.9	.1	-	.4	-	32.4
C_6	28.0	-	.1	.2	-	28.3
C_7	9.6	-	-	.1	-	9.7
A	73.6	-	3.0	-	-	76.6
B	126.3	-	5.1	-	-	131.4
C	149.7	-	6.0	-	-	155.7
D	650.0	-	26.2	-	-	676.2
E	1,196.3	-	48.3	-	-	1,244.6
F	213.6	-	8.6	-	-	222.2
G	186.1	-	7.5	-	-	193.6
H	153.5	-	6.2	-	-	159.7
I	109.2	-	4.4	-	-	113.6
J	83.9	-	3.4	-	-	87.3
Total	3,476.4	51.4	120.6	65.1	155.4	3,558.1

SECTION HEAT BALANCE - M B.T.U./HR.

	Section 1 Reboiler	Section 2 Stripping Section	Section 3 Absorption Section
Top L/V Ratio	38.45	30.87	.78
Bottom L/V Ratio	38.45	23.07	.80
Top Temperature	284	105	100
Bottom Temperature	284	150	120
Number of Theoretical Trays	1	2	6
Heat In	138,324	96,110	34,326
Heat Out	138,324	95,848	33,700
Reboiler Duty	50,596	-	-
% Unbalance	-	.27	1.82

Overall Heat Balance - M B.T.U./Hr.

Heat In	137,052
Heat Out	148,294
% Unbalance	8.20

COMPARISON OF CALCULATED DATA AND LABORATORY DATA

Tail Gas Composition - Mole Per Cent

Components	Calculated Data	Laboratory Data
N_2	3.60	3.16
C_1	85.39	89.27
C_2	8.62	6.76
C_3	2.25	.81
iC_4	.07	-
nC_4	.07	-
iC_5	-	-
nC_5	-	-
C_6	-	-
C_7	-	-
A	-	-
B	-	-
C	-	-
D	-	-
E	-	-
F	-	-
G	-	-
H	-	-
I	-	-
J	-	-

	Calculated Duties	Measured Duties
Reboiler Duty	50,596	61,283*

* The measured reboiler duty was obtained by difference. The heat out of the column checked the measured value within 1.5 per cent.

TABLE IV

COMPARISON OF ENTHALPY VALUES FROM SEVERAL SOURCES

PRESSURE 110 P.S.I.G.

STREAM PROPERTIES				ENTHALPY B.T.U./LB.				
Phase	Molecular Weight (Normal Boiling Point)	(Specific Gravity) °A.P.I.	Temperature °F.	N.G.S.M.A.(6) from stream properties basis L at -200°F.	Maxwell(10) from stream properties basis L at -200°F.	Maxwell(10) by combining components basis L at 0°F.	Maxwell(10) by combining components basis L at -200°F.	Bauer & Middleton(1) by combining components L at 0°F.
L	(475) 195.5	43.7	100	95*	150	44.3	-	47
L	(425) 176.5	47.2	100	102*	152	44.9	-	51.5
L	(440) 181.6	46.3	120	97.5*	163	53.8	-	59.6
L	(425) 176.3	47.5	150	137*	182	69.2	-	77
L	(431) 179.2	46.8	284	217*	271	142.0	-	153
V	30.36	(.4181)	81	318	320	180	307	No
V	18.38	(.3309)	100	349	348	150	326	Values
V	20.05	(.3528)	100	346	345	152	312	For
V	19.85	(.3437)	105	348	348	161.5	330	These
V	31.44	(.4302)	284	416	418	282	401	Components

* Values obtained by data extrapolation well beyond the range of actual values. This set of data was used because it had been used to make the balances used as checks.

TABLE V

CALCULATED BUBBLE POINTS AND DEW POINTS COMPARED TO TOWER TEMPERATURE UNDER BALANCED OPERATION

Rich Oil Demethanizer

Stream	Tower Temperature	Bubble Point	Dew Point
Tower Bottoms - Rich Oil	284	283	-
Reboiler Feed	150	155	-
Absorber Rich Oil	120	120	-
Reboiled Vapors	284	-	283
Stripped Vapors	105	-	104
Tail Gas	100	-	102

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APPENDIX A

DERIVATION OF THE EQUATIONS FOR EDMISTER'S METHOD OF CALCULATING ABSORBER-STRIPPERS

In absorber-strippers, the recovery of selected components from gaseous streams is accomplished by absorption in lean solvent oils followed by stripping of the enriched solvent to recover the lean oil and the absorbed components. The mechanism for such recovery is the diffusion of components from the gas to liquid, or vice versa, by virtue of a concentration difference between the two phases.

The theoretical plate concept is used to develop the method since rigorous diffusion equations for turbulent flow (normally found in units of this type) are not suitable.

Equations will be derived for the case of absorption. Similar derivations apply to the case of stripping with only a direct substitution of proper terms being required. This fact was used in the application of the method to this program to reduce the number of equations required. Terminology will be that used in Edmister's (2) article and will be defined when used. Conversion to the author's nomenclature can be easily made from the definitions of the terms shown at the end of this section.

A typical flow diagram of an absorber is shown in figure 4 with the terminal streams identified by the proper nomenclature. A three-tray section of this absorber is shown in figure 5 indicating the nomenclature for intermediate streams. Molar vapor compositions are

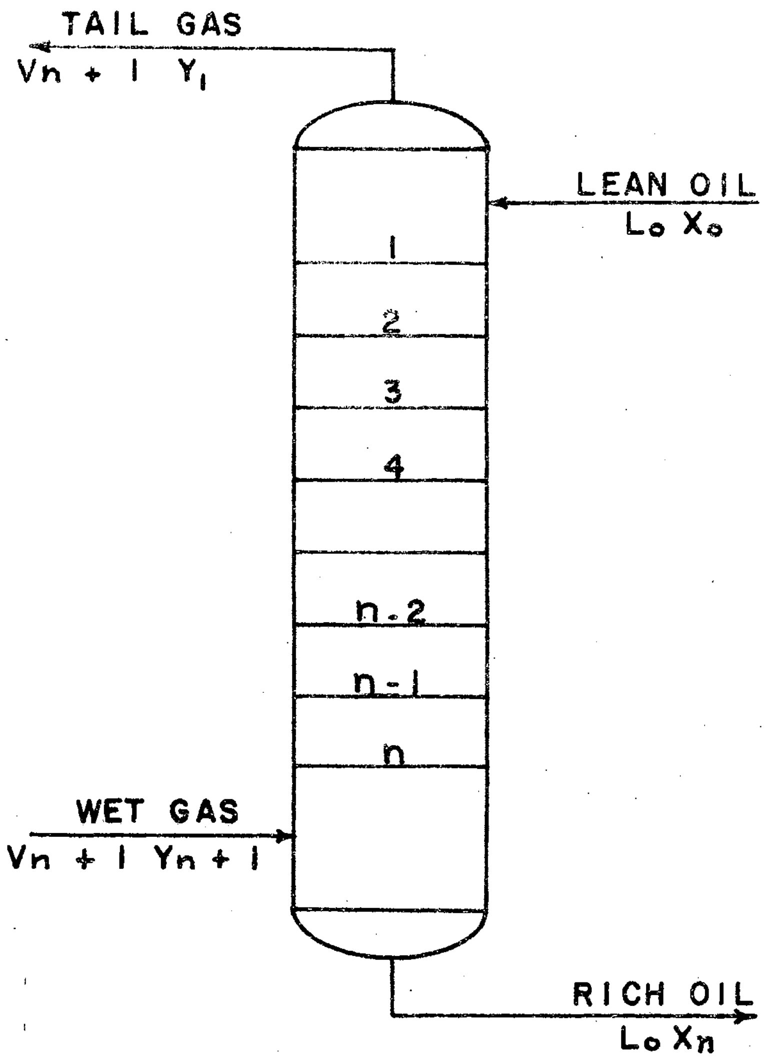


FIGURE 4

TYPICAL ABSORBER

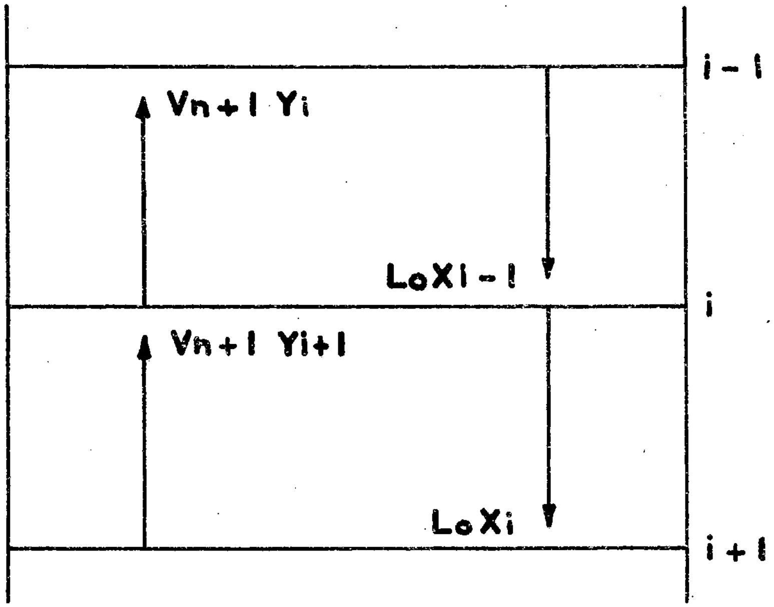


FIGURE 5

SECTION OF AN ABSORBER

referred to the wet gas and liquid compositions are referred to the lean oil.

From consideration of the three-tray section (figure 5), a material balance around tray "i" can be made for any component.

$$L_oX_{i-1} + V_{n+1}Y_{i+1} = L_oX_i + V_{n+1}Y_i \qquad (1)$$

and

$$L_o(X_i-X_{i-1}) = V_{n+1}(Y_{i+1}-Y_i)$$

where

X_i = moles of the component in the liquid from plate i per mole of lean oil

X_{i-1} = moles of the component in the liquid from plate i-1 per mole of lean oil

L_o = moles of lean oil

Y_i = moles of the component in the vapor from plate i per mole of wet gas

Y_{i+1} = moles of the component in the vapor from plate i+1 per mole of wet gas

V_{n+1} = moles of wet gas

Subscripts are not included to identify the component for these equations. A similar equation could be written for each component.

From the definition of terms

$$y_i = \frac{Y_i\ V_{n+1}}{V_i} \qquad x_i = \frac{X_i\ L_o}{L_i} \qquad (2)$$

where

y_i = the mole fraction of the component in the vapor (V_i) leaving plate i

x_i = the mole fraction of the component in the liquid (L_i) leaving plate i.

Assuming that the vapor and liquid leaving theoretical plate i are in equilibrium from the definition of a theoretical plate,

$$y_i = K_i x_i \tag{3}$$

where K is defined by the above relationship and

$$Y_i = K_i \frac{(L_o)(V_i)}{(L_i)(V_{n+1})} X_i \tag{4}$$

Similarily,

$$Y_{i-1} = K_{i-1} \frac{(L_o)(V_{i-1})}{(L_{i-1})(V_{n+1})} X_{i-1} \tag{5}$$

Solving equation 1 for Y_i

$$Y_i = Y_{i+1} - \frac{L_o}{V_{n+1}} (X_i - X_{i-1}) \tag{6}$$

Solving equations 4 and 5 for X_i and X_{i-1} and substituting for these quantities in equation 6,

$$Y_i = Y_{i+1} - \frac{L_o}{V_{n+1}} \left[\frac{(Y_i)(L_i)(V_{n+1})}{(K_i)(L_o)(V_i)} - \frac{(Y_{i-1})(L_{i-1})(V_{n+1})}{(K_{i-1})(L_o)(V_{i-1})} \right] \tag{7}$$

Eliminating L_o and V_{n+1} from the second term in equation 7 and collecting terms

$$Y_i = \frac{Y_{i+1} + \frac{L_{i-1}}{K_{i-1} V_{i-1}} Y_{i-1}}{1 + \frac{L_i}{K_i V_i}} \tag{8}$$

By definition,

$$A_i = \frac{L_i}{K_i V_i} \qquad A_{i-1} = \frac{L_{i-1}}{K_{i-1} V_{i-1}}$$

Substituting A_i and A_{i-1} in equation 8,

$$Y_i = \frac{Y_{i+1} + A_{i-1}\, Y_{i-1}}{1 + A_i} \tag{9}$$

Writing equation 9 for a single plate absorber (i = 1)

$$Y_1 = \frac{Y_2 + A_o Y_o}{1 + A_1} \tag{10}$$

where Y_1 = moles of component in the vapor leaving the top plate (plate 1) per mole of wet gas

Y_2 = moles of the component in the wet gas per mole of wet gas

Y_o = moles of the component in the gas in equilibrium with the entering lean oil per mole of wet gas

From writing equation 4 for the top of the absorber

$$Y_o = K_o \frac{L_o}{L_o} \frac{V_o}{V_{n+1}} X_o$$

and by definition,

$$A_o = L_o/K_o V_o$$

then,

$$Y_o = L_o X_o / A_o V_{n+1}$$

and

$$A_o Y_o = L_o X_o / V_{n+1} \tag{11}$$

Substituting equation 11 in equation 10

$$Y_1 = \frac{Y_2 + \dfrac{L_o X_o}{V_{n+1}}}{1 + A_1} \tag{12}$$

The equation for a two-plate absorber may be derived by writing the equation for the second plate of the absorber by analogy with equation 10

$$Y_2 = \frac{Y_3 + A_1 Y_1}{1 + A_2} \tag{13}$$

Combining equations 12 and 13, eliminating Y_1 and solving for Y_2

$$Y_2 = \frac{(A_1+1)\ Y_3 + A_1 \dfrac{L_oX_o}{V_{n+1}}}{A_1A_2 + A_2 + 1} \tag{14}$$

By a similar procedure, an equation may be written for a three-plate absorber

$$Y_3 = \frac{(A_1A_2+A_2+1)\ Y_4 + A_1A_2 \dfrac{L_oX_o}{V_{n+1}}}{A_1A_2A_3 + A_2A_3 + A_3 + 1} \tag{15}$$

From consideration of equations 12, 14, and 15, a general relation may be written

$$Y_n = \frac{(A_1A_2A_3\ldots A_{n-1}+A_2A_3\ldots A_{n-1}+\ldots+A_{n-1}+1)Y_{n+1}+(A_1A_2\ldots A_{n-1})\dfrac{L_oX_o}{V_{n+1}}}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1} \tag{16}$$

To convert this equation to an equation based on the terminal conditions of the absorber, an over-all component material balance is made on an absorber of n plates

$$L_o\ (X_n-X_o) = V_{n+1}\ (Y_{n+1}-Y_1) \tag{17}$$

But, by analogy with equation 4

$$Y_n = K_n \frac{(L_o)(V_n)}{(L_n)(V_{n+1})}\ X_n \tag{18}$$

and

$$X_n = Y_n \frac{L_n\ V_{n+1}}{K_nL_oV_n} \tag{19}$$

Substituting in equation 17 for X_n and solving for Y_n

$$Y_n = (Y_{n+1}-Y_1 + \frac{L_oX_o}{V_{n+1}})\ /\ \frac{L_n}{K_nV_n} \tag{20}$$

But, $A_n = \dfrac{L_n}{K_nV_n}$ by definition

Therefore,

$$Y_n = \frac{Y_{n+1}-Y_1 + \dfrac{L_oX_o}{V_{n+1}}}{A_n} \tag{21}$$

Setting the right sides of equations 21 and 16 equal and rearranging terms,

$$\frac{Y_{n+1}-Y_1+\dfrac{L_oX_o}{V_{n+1}}}{A_n} = \frac{(A_1A_2A_3\ldots A_{n-1}+A_2A_3\ldots A_{n-1}+\ldots+A_{n-1}+1)Y_{n+1}+(A_1A_2\ldots A_{n-1})\dfrac{L_oX_o}{V_{n+1}}}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1}$$

$$Y_{n+1}-Y_1+\frac{L_oX_o}{V_{n+1}} = \frac{(A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n)Y_{n+1}+(A_1A_2\ldots A_n)\dfrac{L_oX_o}{V_{n+1}}}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1}$$

$$Y_{n+1}-Y_1 = \left[\frac{(A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n)Y_{n+1}+(A_1A_2\ldots A_n)\dfrac{L_oX_o}{V_{n+1}}}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1} - \frac{L_oX_o}{V_{n+1}}\frac{(A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots A_n+1}\right]$$

$$Y_{n+1}-Y_1 = \frac{(A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n)Y_{n+1} - \dfrac{L_oX_o}{V_{n+1}}(A_2A_3\ldots A_n+\ldots+A_n+1)}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1}$$

$$\frac{Y_{n+1}-Y_1}{Y_{n+1}} = \frac{(A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n) - \dfrac{L_oX_o}{V_{n+1}Y_{n+1}}(A_2A_3\ldots A_n+\ldots+A_n+1)}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1} \tag{22}$$

Equation 22 is an exact expression of the efficiency of an absorber of n-plates involving only the assumption of theoretical plates. The term to the left of the equal sign is an exact expression of the absorption efficiency (E_A). The first term to the right of the equal sign gives the absorption efficiency for a denuded lean oil and the second term to the right of the equal sign is a correction for the presence of the solute in the lean oil.

Y_1 = moles of the component leaving the top plate per mole of wet gas

Y_{n+1} = moles of the component in the wet gas per mole of wet gas

V_{n+1} = moles of wet gas

L_o = moles of lean oil

X_o = moles of the component in the lean oil per mole of lean oil

$A = L/KV$ = absorption factor with subscripts referring to the theoretical plates numbered from top to bottom

Equation 22 may be used as is for the calculation of the absorber if values of A can be estimated for each plate. The Edmister modification(2) described below is accomplished by substituting a single absorption factor for the series of terms (A_1, A_2, $A_3 \ldots A_n$) in equation 22. Equation 22 may be written,

$$E_A = \frac{Y_{n+1} - Y_1}{Y_{n+1}} = \left[1 - \frac{L_oX_o}{A'V_{n+1}Y_{n+1}}\right]\left[\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right] \qquad (23)$$

if A_e and A' are defined by

$$\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1} = \frac{A_1A_2A_3 \ldots A_n + A_2A_3 \ldots A_n + \ldots + A_n}{A_1A_2A_3 \ldots A_n + A_2A_3 \ldots A_n + \ldots + A_n + 1} \qquad (24)$$

$$\frac{1}{A'}\left[\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right] = \frac{A_2A_3 \ldots A_n + A_3 \ldots A_n + \ldots + A_n + 1}{A_1A_2A_3 \ldots A_n + A_2A_3 \ldots A_n + \ldots + A_n + 1} \qquad (25)$$

Equations 24 and 25 are written from the following series sums with A' defined as a term which compensates for the difference in the numerators of equations 24 and 25.

$$S = \sum A^n + A^{n-1} + \ldots + A^2 + A$$

and

$$S(A) = A \sum A^n + A^{n-1} + \ldots + A^2 + A = \sum A^{n+1} + A^n + \ldots + A^2$$

subtracting

$$S(A-1) = A^{n+1} - A \quad \text{and } S = \frac{A^{n+1} - A}{A-1}$$

similarly

$$\frac{A^{n+1}-1}{A-1} = \sum A^n + A^{n-1} \ldots A^2 + A + 1$$

A means is now required for obtaining values of A_e and A'. Edmister$^{(2)}$ found that A_e and A' are essentially independent of n and can be expressed as functions of A_1 and A_n, terminal values of A, for most practical cases. Since A_e and A' are independent of n, equations 24 and 25 may be written for a 2-plate absorber calling the top plate 1 and the bottom plate n.

$$\frac{A_e{}^3 - A_e}{A_e{}^3 - 1} = \frac{A_1 A_n + A_n}{A_1 A_n + A_n + 1} = \frac{A_n(A_1+1)}{A_n(A_1+1)+1} \tag{26}$$

and

$$\frac{1}{A'}\left[\frac{A_e{}^3 - A_e}{A_e{}^3 - 1.}\right] = \frac{A_n + 1}{A_1 A_n + A_n + 1} = \frac{A_n + 1}{A_n(A_1+1)+1} \tag{27}$$

Equation 26 may be written as shown below by cross multiplying and collecting terms.

$$A_e{}^3 - A_e \left[A_n(A_1+1)+1\right] + A_n(A_1+1) = 0 \tag{28}$$

Equation 28 is a cubic, which may be solved by factoring, giving two positive roots and one negative root.

Discarding the positive solution $A_e = 1$, the remaining positive root from

$$A_e^2 + A_e = A_n(A_1+1) = 0 \qquad (29)$$

becomes

$$A_e = \sqrt{A_n(A_1+1)+0.25} - 0.5$$

from the solution of the binomial equation.

By combining equations 26 and 27 and solving for A'

$$A' = \frac{A_n(A_1+1)}{A_n+1} \qquad (30)$$

Equations 29 and 30 are rigorous only for a two-plate absorber. For more than two plates, the equations are only approximations. The assumptions being that the effective absorption factor is independent of the number of plates and a function of the terminal A factor.

Conversion to the author's nomenclature

1. $\alpha = \dfrac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}$ for absorbing

   $\alpha = \dfrac{S_e^{m+1} - S_e}{S_e^{m+1} - 1}$ for stripping

2. $(A'V-L) = (A'V_{n+1}Y_{n+1} - L_oX_o) = A'V_{n+1}Y_{n+1}\left[1 - \dfrac{L_oX_o}{A'V_{n+1}Y_{n+1}}\right]$

   where L_oX_o refers to the moles of liquid entering the section and $V_{n+1}Y_{n+1}$ to the moles of vapor entering the section.

3. $\Delta_A = \dfrac{\alpha\,(A'V-L)}{A'} = V_{n+1}\,Y_{n+1}\left[1 - \dfrac{L_oX_o}{A'V_{n+1}\,Y_{n+1}}\right]\left[\dfrac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right]$

4. $\Delta_S = -\alpha\,(A'V-L)$

Proof:

Δ_A is defined as the net moles transferred

therefore

$$\Delta_A = V_{n+1}\,(Y_{n+1} - Y_1)$$

similarily

$$\Delta_S = L_{m+1}\,(X_{m+1} - X_1)$$

From equations 23 and similar equations for stripping

$$E_A = \frac{Y_{n+1} - Y_1}{Y_{n+1}} = \left[1 - \frac{L_oX_o}{A'V_{n+1}Y_{n+1}}\right]\left[\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right]$$

and

$$E_S = \frac{X_{m+1} - X_1}{X_{m+1}} = \left[1 - \frac{V_oY_o}{S'L_{m+1}\,X_{m+1}}\right]\left[\frac{S_e^{m+1} - S_e}{S_e^{m+1} - 1}\right]$$

Considering the same section, $X_{m+1}\,L_{m+1}$ is the same as L_oX_o and $V_{n+1}\,Y_{n+1}$ is the same as V_oY_o. Also, $S' = 1/A'$ and $m = n$. A_1 is replaced by S_1 and A_n is replaced by S_m for stripping.

$$E_A = \frac{\Delta_A}{V_{n+1}\,Y_{n+1}} = \left[1 - \frac{L_oX_o}{A'\;V_{n+1}Y_{n+1}}\right]\left[\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right]$$

$$\Delta_A = V_{n+1}\,Y_{n+1}\left[1 - \frac{L_oX_o}{A'V_{n+1}Y_{n+1}}\right]\left[\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right]$$

$$= \frac{1}{A'}\left[A'V_{n+1}\,Y_{n+1} - L_oX_o\right]\left[\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right]$$

$$= \frac{\alpha\,(A'V-L)}{A'}$$

$$E_S = \frac{\Delta_S}{X_{m+1}L_{m+1}} = \left[1 - \frac{V_oY_o}{S'L_{m+1}X_{m+1}}\right]\left[\frac{S_e^{m+1} - S_e}{S_e^{m+1} - 1}\right]$$

$$\Delta_S = X_{m+1}L_{m+1} \left[1 - \frac{V_oY_o}{S'L_{m+1}X_{m+1}} \right] \left[\frac{S_e^{m+1} - S_e}{S_e^{m+1} - 1} \right]$$

$$= \left[X_{m+1}L_{m+1} - \frac{V_oY_o}{S'} \right] \left[\frac{S_e^{m+1} - S_e}{S_e^{m+1} - 1} \right]$$

and

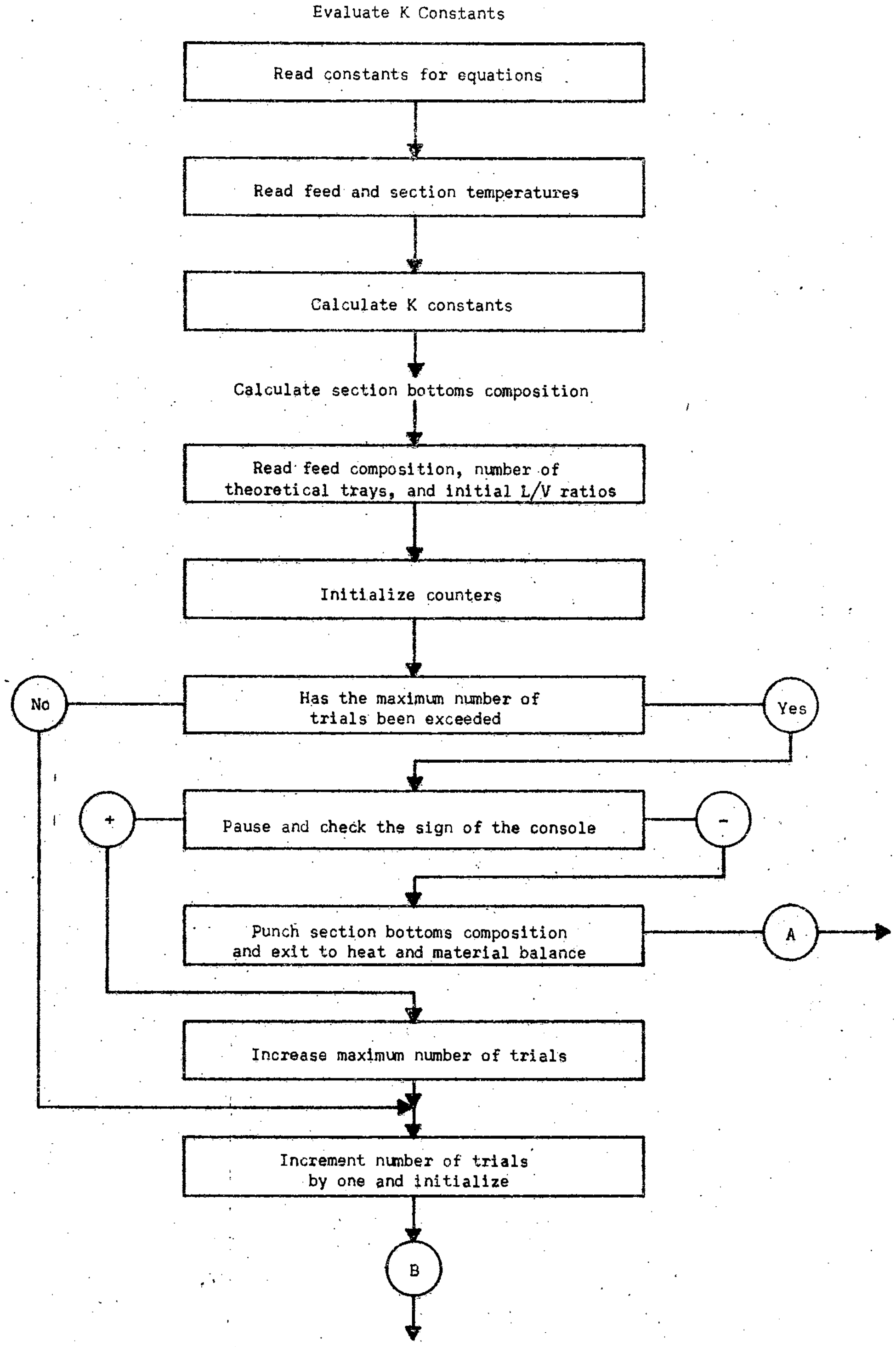
$$\Delta_S = \left[X_oL_o - A' V_{n+1}Y_{n+1} \right] \left[\frac{S_e^{m+1} - S_e}{S_e^{m+1} - 1} \right]$$

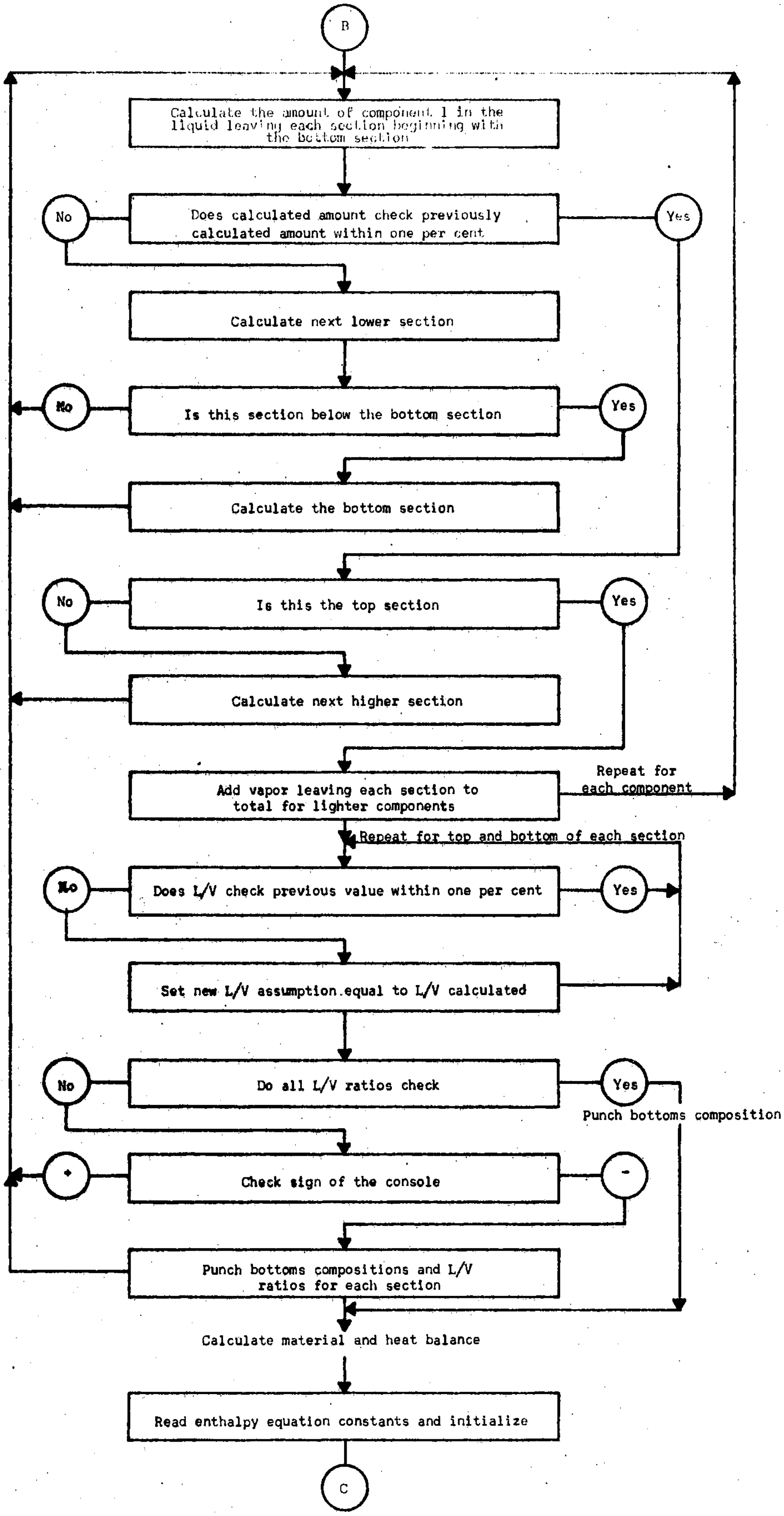
$$= - \left[A'V_{n+1}Y_{n+1} - X_oL_o \right] \left[\frac{S_e^{m+1} - S_e}{S_e^{m+1} - 1} \right]$$

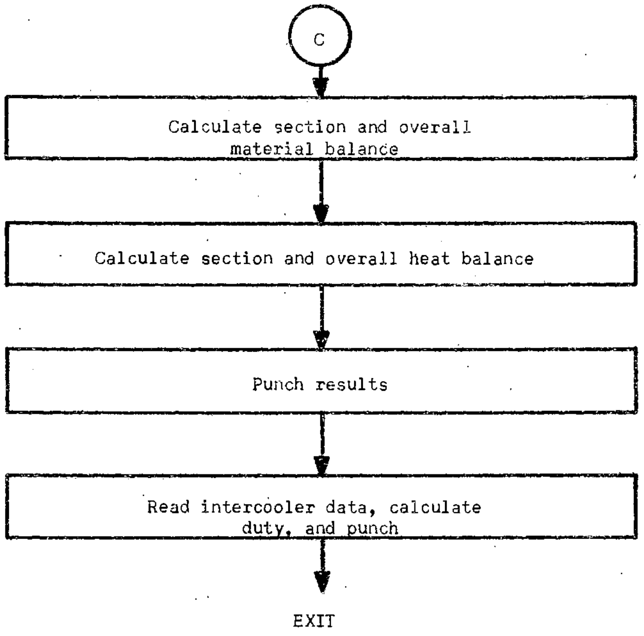
$$= - (A'V-L)\alpha$$

APPENDIX B

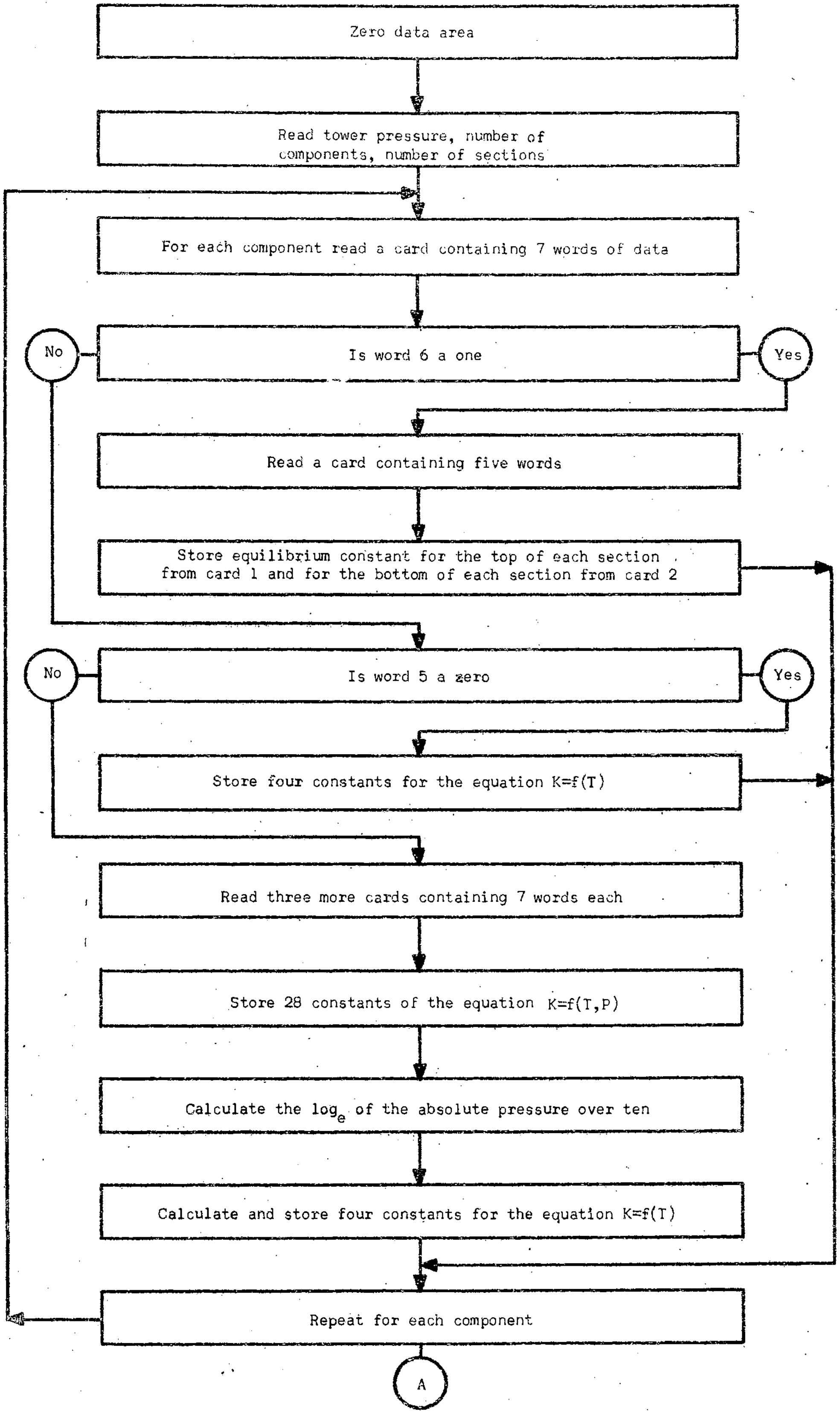
BLOCK FLOW DIAGRAMS
ABSORBER-STRIPPER PROGRAM

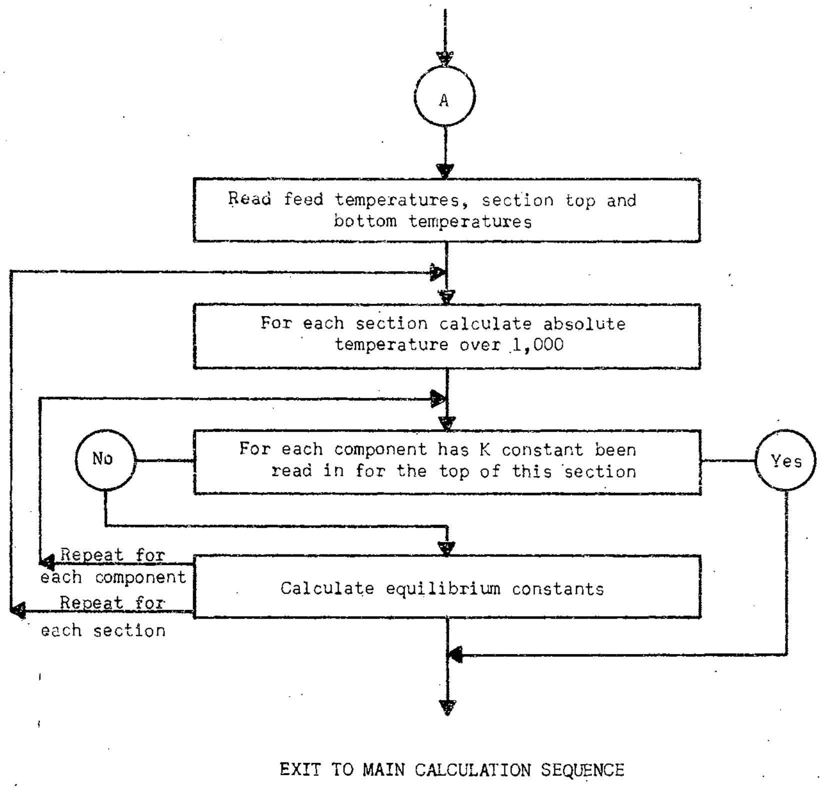


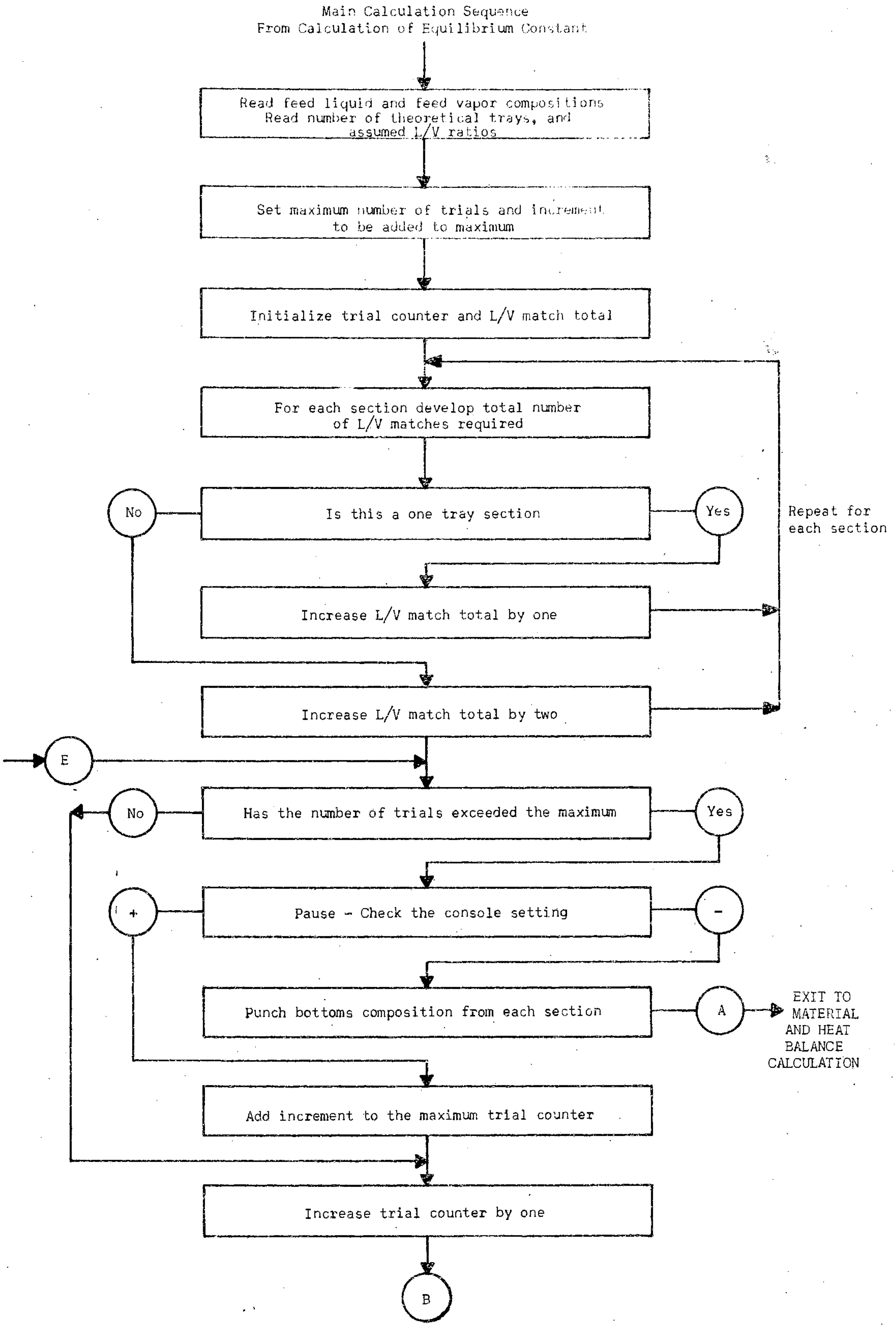

B
Calculate the amount of component 1 in the liquid leaving each section beginning with the bottom section
No
Does calculated amount check previously calculated amount within one per cent
Yes
Calculate next lower section
No
Is this section below the bottom section
Yes
Calculate the bottom section
No
Is this the top section
Yes
Calculate next higher section
Add vapor leaving each section to total for lighter components
Repeat for each component
Repeat for top and bottom of each section
No
Does L/V check previous value within one per cent
Yes
Set new L/V assumption equal to L/V calculated
No
Do all L/V ratios check
Yes
Punch bottoms composition
+
Check sign of the console
-
Punch bottoms compositions and L/V ratios for each section
Calculate material and heat balance
Read enthalpy equation constants and initialize
C

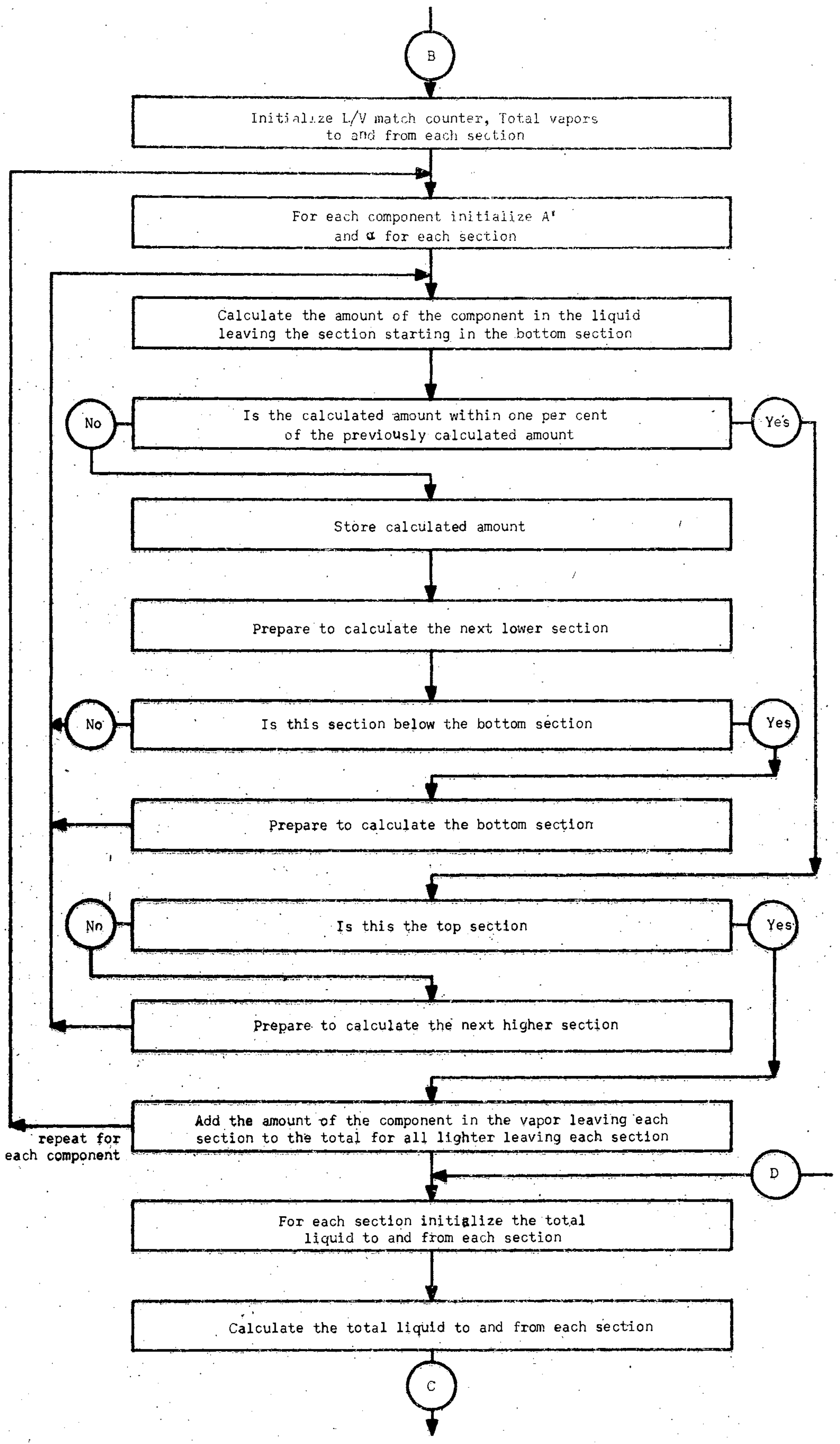

C
Calculate section and overall material balance
Calculate section and overall heat balance
Punch results
Read intercooler data, calculate duty, and punch
EXIT

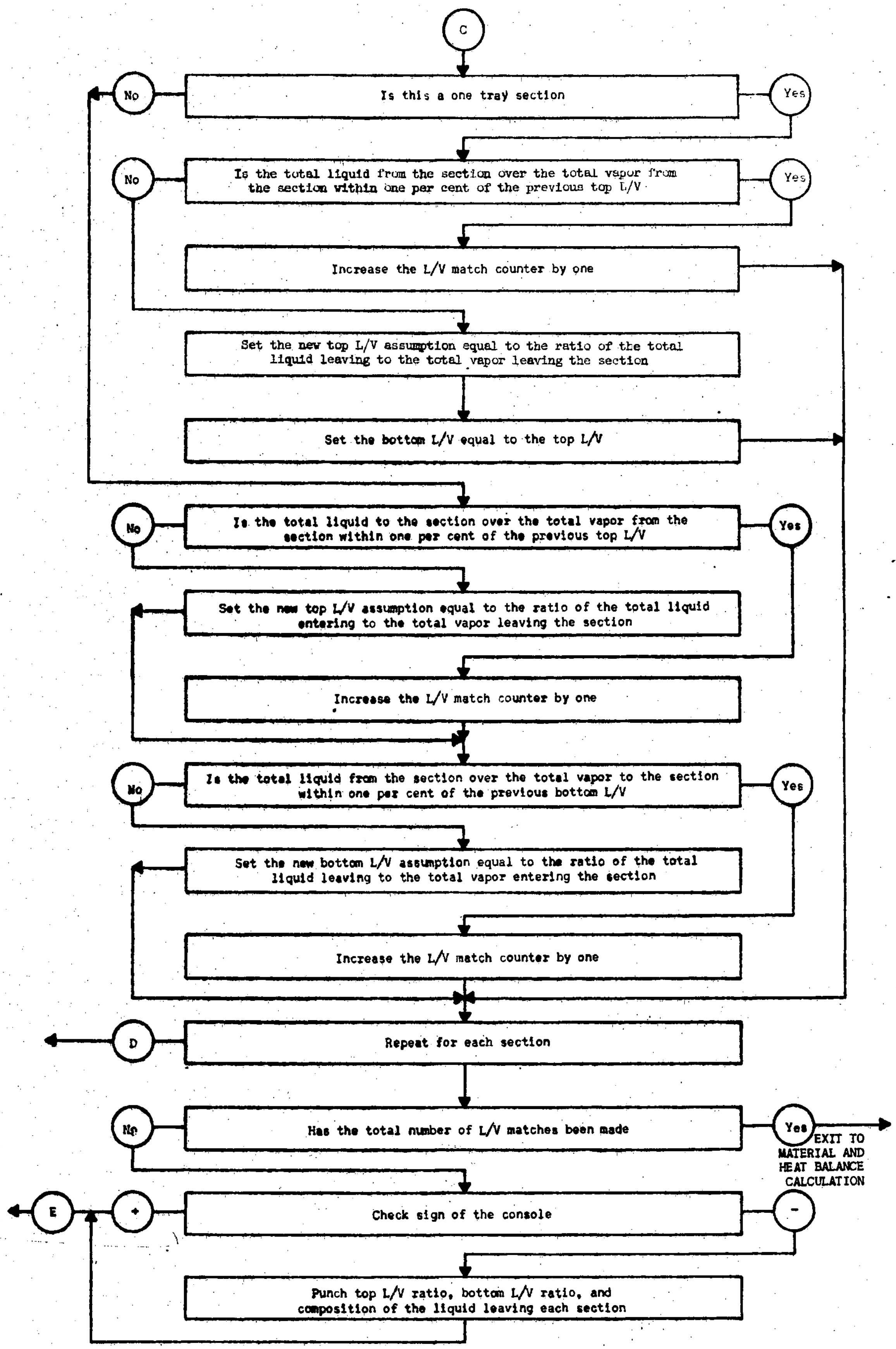
Evaluation of Equilibrium Constants




A
Read feed temperatures, section top and bottom temperatures
For each section calculate absolute temperature over 1,000
For each component has K constant been read in for the top of this section
No
Yes
Calculate equilibrium constants
Repeat for each component
Repeat for each section
EXIT TO MAIN CALCULATION SEQUENCE

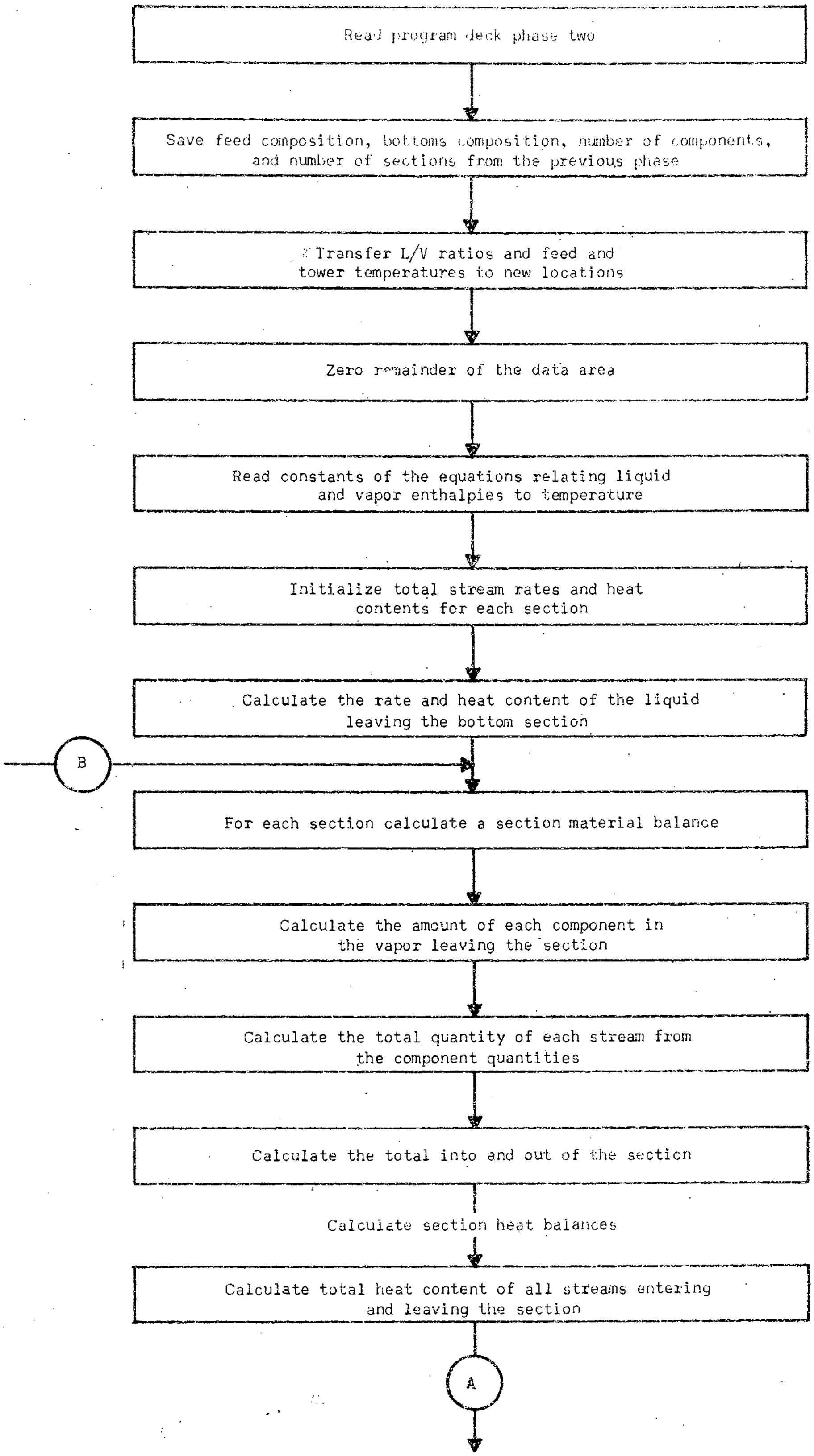

Main Calculation Sequence
From Calculation of Equilibrium Constant
Read feed liquid and feed vapor compositions
Read number of theoretical trays, and
assumed L/V ratios
Set maximum number of trials and increment
to be added to maximum
Initialize trial counter and L/V match total
For each section develop total number
of L/V matches required
No
Is this a one tray section
Yes
Repeat for
each section
Increase L/V match total by one
Increase L/V match total by two
E
No
Has the number of trials exceeded the maximum
Yes
+
Pause - Check the console setting
-
Punch bottoms composition from each section
A
EXIT TO
MATERIAL
AND HEAT
BALANCE
CALCULATION
Add increment to the maximum trial counter
Increase trial counter by one
B

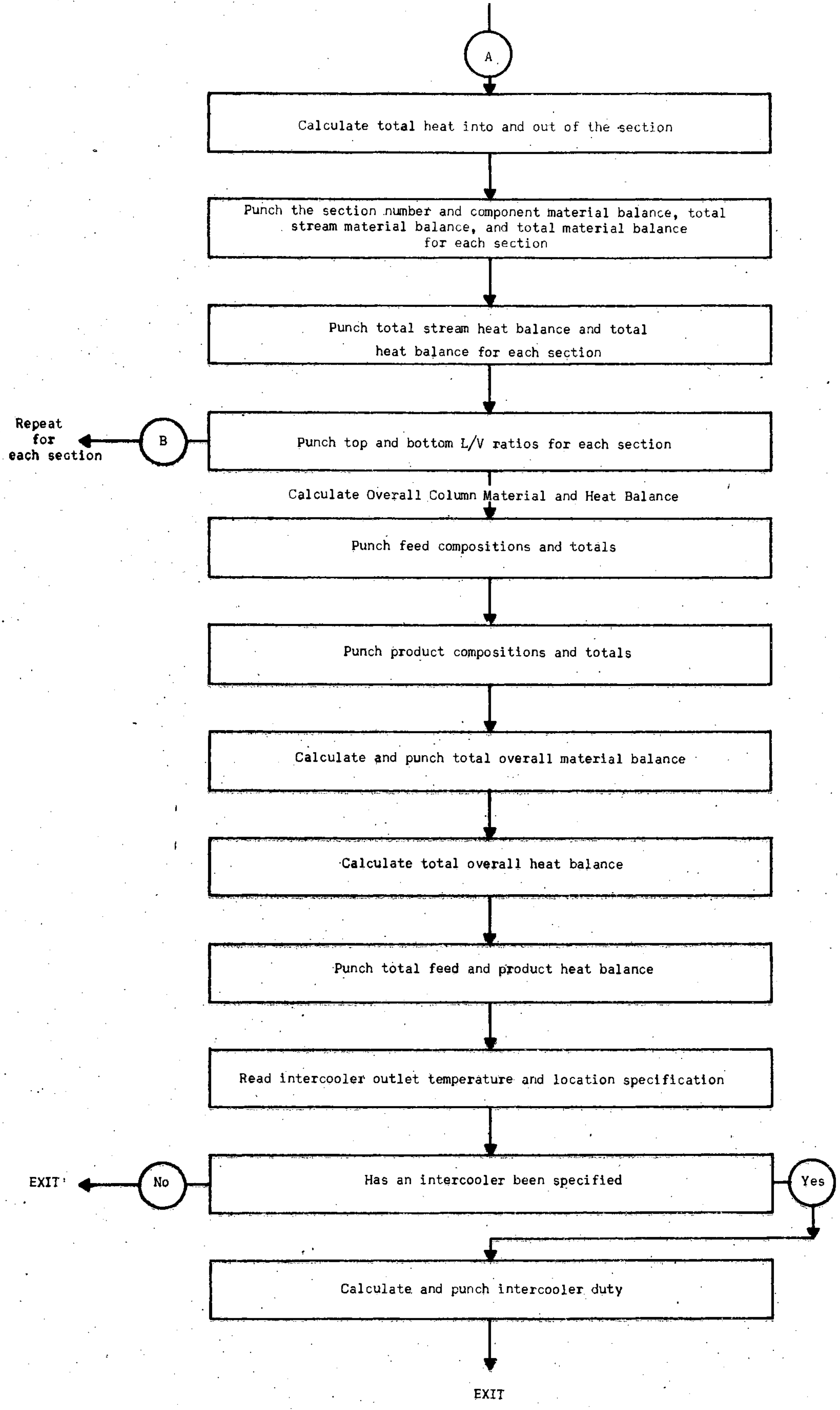

B
Initialize L/V match counter, Total vapors to and from each section
For each component initialize A' and α for each section
Calculate the amount of the component in the liquid leaving the section starting in the bottom section
No
Is the calculated amount within one per cent of the previously calculated amount
Yes
Store calculated amount
Prepare to calculate the next lower section
No
Is this section below the bottom section
Yes
Prepare to calculate the bottom section
No
Is this the top section
Yes
Prepare to calculate the next higher section
Add the amount of the component in the vapor leaving each section to the total for all lighter leaving each section
repeat for each component
D
For each section initialize the total liquid to and from each section
Calculate the total liquid to and from each section
C


C
Is this a one tray section
No
Yes
Is the total liquid from the section over the total vapor from the section within one per cent of the previous top L/V
No
Yes
Increase the L/V match counter by one
Set the new top L/V assumption equal to the ratio of the total liquid leaving to the total vapor leaving the section
Set the bottom L/V equal to the top L/V
Is the total liquid to the section over the total vapor from the section within one per cent of the previous top L/V
No
Yes
Set the new top L/V assumption equal to the ratio of the total liquid entering to the total vapor leaving the section
Increase the L/V match counter by one
Is the total liquid from the section over the total vapor to the section within one per cent of the previous bottom L/V
No
Yes
Set the new bottom L/V assumption equal to the ratio of the total liquid leaving to the total vapor entering the section
Increase the L/V match counter by one
D
Repeat for each section
No
Has the total number of L/V matches been made
Yes
EXIT TO MATERIAL AND HEAT BALANCE CALCULATION
E
+
Check sign of the console
-
Punch top L/V ratio, bottom L/V ratio, and composition of the liquid leaving each section

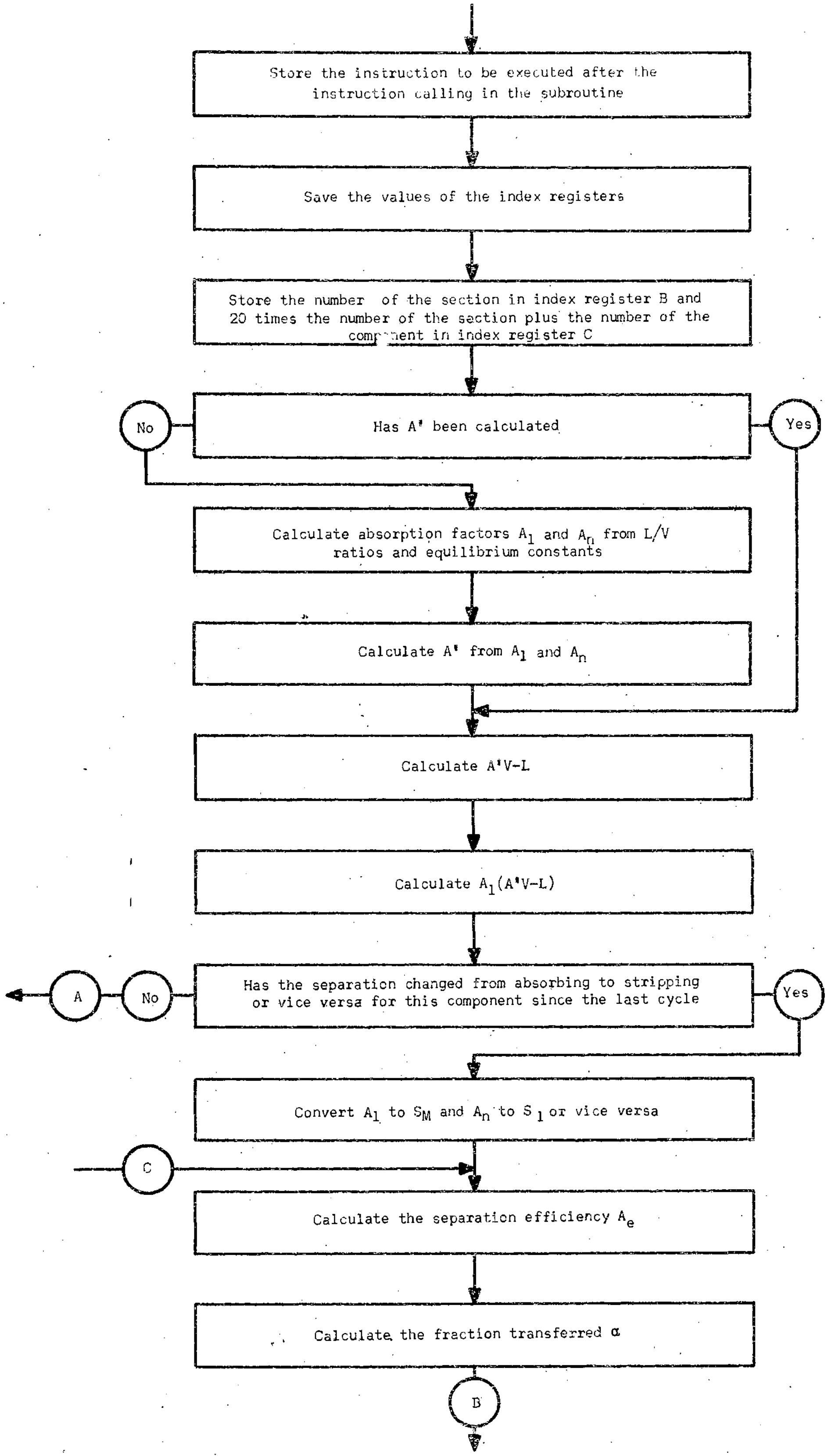
APPENDIX B

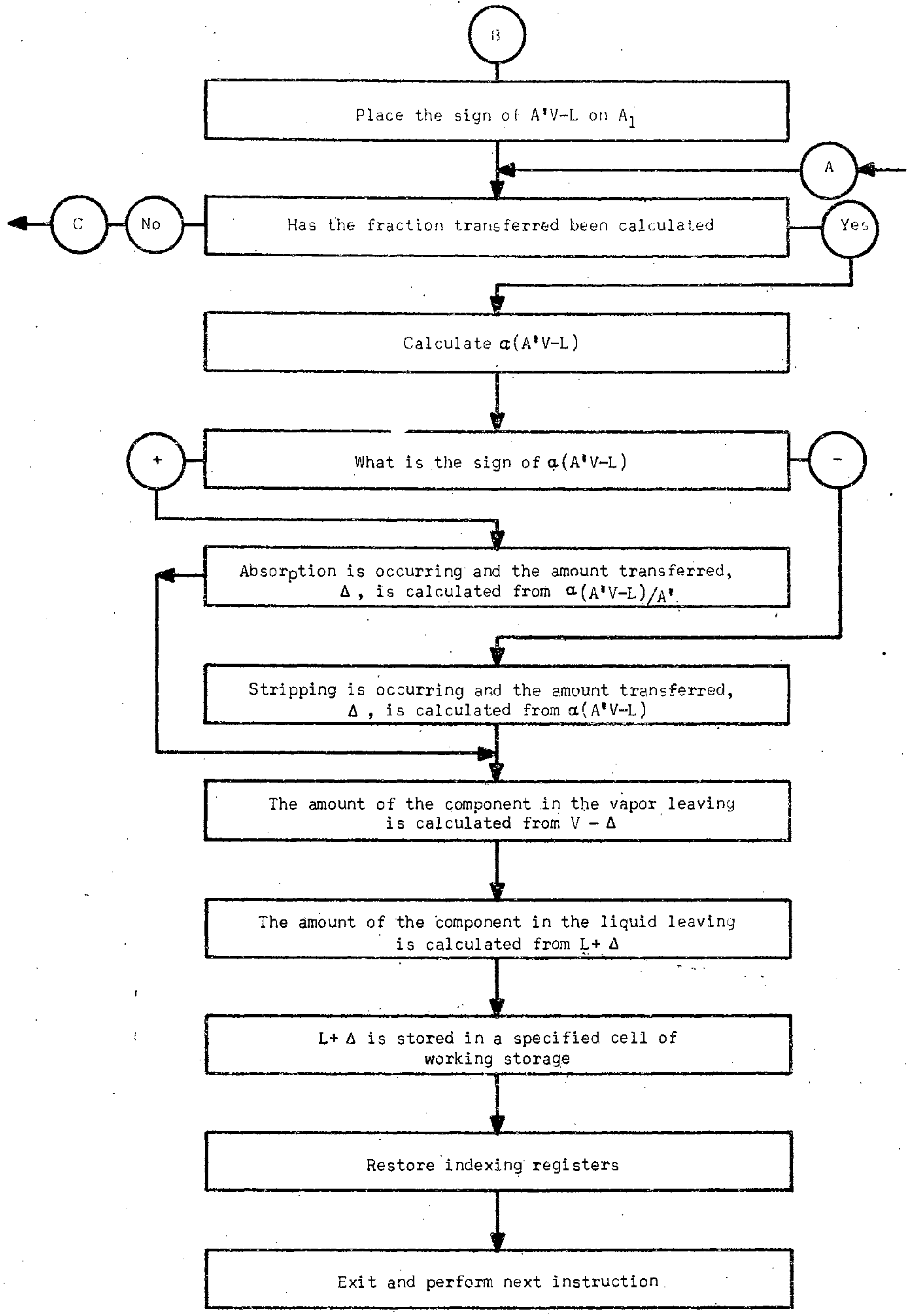
Material and Heat Balances




A
Calculate total heat into and out of the section
Punch the section number and component material balance, total stream material balance, and total material balance for each section
Punch total stream heat balance and total heat balance for each section
Repeat for each section
B
Punch top and bottom L/V ratios for each section
Calculate Overall Column Material and Heat Balance
Punch feed compositions and totals
Punch product compositions and totals
Calculate and punch total overall material balance
Calculate total overall heat balance
Punch total feed and product heat balance
Read intercooler outlet temperature and location specification
EXIT
No
Has an intercooler been specified
Yes
Calculate and punch intercooler duty
EXIT

Two Phase Separation Subroutine




B
Place the sign of $A'V-L$ on A_1
A
C
No
Has the fraction transferred been calculated
Yes
Calculate $\alpha(A'V-L)$
+
What is the sign of $\alpha(A'V-L)$
-
Absorption is occurring and the amount transferred, Δ, is calculated from $\alpha(A'V-L)/A'$
Stripping is occurring and the amount transferred, Δ, is calculated from $\alpha(A'V-L)$
The amount of the component in the vapor leaving is calculated from $V-\Delta$
The amount of the component in the liquid leaving is calculated from $L+\Delta$
$L+\Delta$ is stored in a specified cell of working storage
Restore indexing registers
Exit and perform next instruction

APPENDIX C

COMPUTER PROGRAM

The method of calculation described in the body of this report was programed for an IBM 650 digital computer. This was done to permit the selection of a calculation method which could be used on any piece of equipment without limiting assumptions. Such a method would be impractical for hand calculation on a large problem. This Appendix provides the information necessary to run a problem on the computer. Input and output formats are illustrated, and program options and computer techniques are discussed. Instructions are given for assembling the program decks and for running the problem.

Because of space limitations, a two-phase operation was required for the 650 computer. Phase one has the equilibrium constant evaluation and main calculation sequence. Phase two has the material and heat balance calculations.

Input Data

All input data is supplied in machine floating point except the number of components, the number of sections, the number of the section above an intercooler, and the number of theoretical plates in each section. All input data cards have eight ten-digit words per card and a Y punch in column 73. Input data is listed in the order in which it is assembled.

1. Data card one - Words one through three are: (1) tower pressure (p.s.i.g.), (2) number of components, and (3) number of sections.

2. Cards for evaluation of the equilibrium constant - Each component is treated separately, going from lightest to heaviest. Three types of cards may be used for any component:
   a. For option one, four cards are required for each component and each card has seven words. These cards may be purchased from the N.G.S.M.A., but they must be revised for this program. The identification word (word "one") must be shifted to word "eight" and all other words must be shifted to the left one position. One set of cards is provided at each convergence pressure for the saturated hydrocarbons from C_1 to C_{10}. The set nearest the calculated convergence pressure is ordinarily used.
   b. One card is required for option 2 containing the four coefficients (in words "one" to "four") of the N.G.S.M.A. equation(11) relating the equilibrium constant to temperature. The remaining words on the card must be filled with zeros.
   c. Two cards are required for option 3. Card one, word one, contains the equilibrium constant at the top of section one; word two at the top of section two, etc. Word six contains a floating point one. Words seven and eight are filled with zeros. Card two contains the equilibrium constants at the bottom of the sections in the same order specified for card one. Words six, seven, and eight contain zeros.
3. Temperatures - Words one through five represent sections one through five respectively. Card one contains section top

temperatures; card two section bottom temperatures; card three temperatures of the external liquid feeds to the section; and card four temperatures of the external vapor feed to the section. If the external feeds do not exist for any of these sections, zeros must be entered.

4. External liquid feed compositions - Words one through five represent external liquid feed to sections one through five respectively. Card one is for the lightest component; card two for the next lightest, etc. The amount of each component in the feed to each section must be supplied even if zero.
5. External vapor feed compositions - Same as 4.
6. Number of theoretical stages - Words one through five represent sections one through five respectively.
7. Assumed L/V ratios - Words one through five represent sections one through five respectively. Card one contains the ratios at the top of each section and card two the ratios at the bottom of each section.
8. Enthalpy equation constants - The program accepts, directly, the cards from the orthogonal polynomial curve fitting procedure used for this study. The three constants for each equation are listed one per card in word two. The zero order constant is on card one, second order constant on card two, etc. Word one must have ten punches. The liquid enthalpy constant cards for each component are stacked in order from the lightest to the heaviest component. Vapor enthalpy cards are then added in the same manner.

9. Intercooler data - One card is required. Word one is the number of the section above the intercooler and word two is the temperature of the stream leaving the intercooler.

Options

The primary program option is the choice of the way in which equilibrium constant data is supplied. The format of the input data is checked by the program to determine which branch should be taken to evaluate the equilibrium constant.

Two other options have been added to the main calculation sequence as an aid in following the progress of a calculation.

1. If the sign of the console is minus, a punchout will be obtained each time a check is made to determine whether all of the calulated L/V ratios are within one per cent of the assumed L/V ratios. The punchout contains the bottoms composition from each section and the current L/V ratios.
2. A counter is increased by one each time this check is made. A limit is set on this counter equal to ten times the number of sections. When the limit is equaled, PAUSE 1111 occurs. At this time, previous punchout should be examined to determine whether convergence can be expected in a reasonable period. The sign of the console is set positive if more trials are desired. The number of additional trials is equal to five times the number of sections. When the new limit is reached, PAUSE 1111 will occur again. If the console is set to minus, a punchout similar to that in option 1 will be obtained when the computer is restarted. The program will then transfer to the material and heat balance calculation. A restart is made after the PAUSE by pushing the program start key.

The limit has never been reached in any calculation to date.

Computer Techniques

The following techniques were used to obtain the optimum program for the calculation described in Chapter IV.

(1) The set of equations (1, 2, 3, 4, 5, 10, 11, 12, 13, and 14) using absorption factors are used for stripping as well. To keep track of the direction of mass transfer the sign of $A'V-L$ is stored on the normally positive value A_1. The product $A_1(A'V-L)$ containing the sign of $A'V-L$ from the previous calculation pass (stored on A_1) and the sign of $A'V-L$ for the current pass can be used to indicate a change of direction of mass transfer. If the sign of the product is positive, no change of direction has occurred and the absorption factors can be reused as in the previous pass. If the sign is negative a change has occurred but equations 10 and 11 can be used if the reciprocal of the current absorption factor at the top of the section is formed and stored in the space occupied by the absorption factor at the bottom of the section. A similar operation is performed using the absorption factor at the bottom of the section. The amount of the component transferred may be calculated from equation 12 if the sign of $(A'V-L)$ indicates absorption. If it indicates stripping, Δ from equation 12 must be multiplied by A' to account for the use of absorption factors instead of stripping factors.

(2) The factors A_1, A_N, and A' are recalculated only when new L/V ratios are assumed. A_e and α are calculated only if they have not been calculated previously or if a change in the direction of transfer has occurred.

The values of A_1, A_N, A', A_e, α , and v_j are saved for each section until a balance has been made for one component in all sections. The amount of the component leaving the bottom of the section (l_j) is saved for each component in each section.

At this point, consideration must be given to the use of the calculation sequence in the over-all program. For purposes of computer programing, these equations would be most efficient if written as a subroutine. The subroutine would then be called in by the logic portion of the program whenever necessary. For a subroutine, the data for and results of the routine must be in locations known to the routine. This is accomplished by assigning specified regions to the data and results in the over-all program. Absolute computer addresses are then used in the subroutine. Therefore, the locations of these regions may not be altered without changing the subroutine.

It should also be noted that special treatment must be given to the top and bottom sections if the subroutine is to be used in the same way for all sections. Storage is provided for the liquid leaving six sections instead of five to give an internal liquid feed from the section above the top section. The storage for the internal liquid feed to the top section is set to zero when the drum is cleared and remains zero. A similar problem occurs in providing a zero value internal vapor feed to the bottom section from the section below. To conserve space, the same locations were used for both of these streams by assigning the region following the liquid product region to vapor products. Since sections are numbered from the bottom up and the computer doesn't recognize a zero subscript, vapor ($j = 0$) will have the same location as liquid ($j = 6$). This order must not be disturbed.

Output

The program output includes:

1. A component material balance around each section
2. Total stream rates for each section
3. An over-all material balance for each section
4. Total stream heat contents for each section
5. An over-all heat balance for each section
6. Final L/V ratios for each section
7. A component material balance for the piece of equipment
8. Total stream rates for the piece of equipment
9. Stream heat contents for the equipment
10. An over-all heat balance for the equipment
11. Intercooler and reboiler duties

The output of the computer is collated with alphabetical identification cards to form the final report. Parts of this report are shown on the following pages for a typical section and for the complete column.

Operation

A. Deck Assembly

Data cards are assembled in the order described in this appendix. Object deck I is assembled before item one of the data and object deck II is placed between items seven and eight.

B. Console Setting

1. Storage Entry	70 1952 9999 + or -
2. Programed	STOP
3. Half Cycle	RUN
4. Control	RUN

5. Display	PROGRAM REGISTER
6. Overflow	SENSE
7. Error	STOP
C. 533 Panel	FORTRAN
D. Tabulator	
1. Board	ALPHA
2. Hammerlocks	STANDARD

E. Programed Stops

01 1111 ---- too many trials, adjust

```
ABSORBER-STRIPPER PROGRAM

STREAM QUANTITIES-MOLES/HOUR
HEAT CONTENTS-B.T.U. PER HOUR
BOTH IN MACHINE FLOATING POINT
  10.   = 1000000052
   1.   = 1000000051
    .1  = 100000005
```

```
                         WORD 1-SECTION NO.-FIXED POINT

          2

                         MATERIAL BALANCE

                         EACH LINE IS FOR ONE COMPONENT
                         COMPONENTS ARE LISTED IN ORDER
                           LIGHT TO HEAVY

                         WORD 1 LIQUID FEED
                         WORD 2 VAPOR FEED
                         WORD 3 LIQUID FROM SEC. ABOVE
                         WORD 4 VAPOR FROM SEC. BELOW
                         WORD 5 LIQUID LEAVING SECTION
                         WORD 6 VAPOR LEAVING SECTION

4000000050                          3407984050   9643763042   1000000043   7407984050
7000000050                          8229610850                             1522961151
2260000052                          3513382352   7637309848   8546000048   5773291452
3900000051                          9157413251   1728277951   2156180051   1262951152
4040000052                          1087902153   8235900052   1104696153   1210796053
2420000052                          4106239952   6893146052   1119887253   2220514052
1117000053                          1699682453   2820199253   4853739853   7831418052
3190000052                          2400824452   4505038352   9125524452   9703390051
3530000052                          2637737552   4435045752   9839130552   7636530051
1043000053                          5179724452   9557211052   2374770053   1419235052
1400000052                          5082800052   2778965252   9007205252   2545600051
2640000052                          3001811952   2068830252   7517845852   1927963051
1450000052                          1734785852   1032310452   4124122652   9297360050
1290000052                          1009534652   3759977051   2654032052   2150030050
1380000052                          1300580552   2174969051   2891911352   6166100049
3100000051                          4120391152   1699449051   4592468152   7867900049
7400000051                          8084236452   1686167051   8984944052   7909100049
1600000052                          3609596153   3603940051   3804395553   1240000050


                         TOTALS

4835000053                          1071759754   6917448153   1915285554   3317191153

                         WORD 4 TOTAL IN
                         WORD 6 TOTAL OUT

                                                 2247004554                 2247004654
```

```
                   HEAT BALANCE

                   TOTAL STREAM HEAT CONTENTS

4136366057                1020468958   1250024058   2376527658   3735541357

                   WORD 4 TOTAL HEAT IN
                   WORD 6 TOTAL HEAT OUT

                                       2684129558                2750081758

                   WORD 1 TOP L OVER V
                   WORD 2 BOTTOM L OVER V

4769000051   2814184051
```

```
      OVERALL MATERIAL BALANCE
       EACH LINE IS FOR 1 COMPONENT
       COMPONENTS LISTED IN ORDER
        LIGHT TO HEAVY

      FEED LIQUID
       WORDS 1 TO 5 REPRESENT
       SECTIONS 1 TO 5 RESPECTIVELY


4000000050
7000000050
2260000052
3900000051
4040000052
2420000052
1117000053
3190000052                 6875750051
3530000052                 3626467051
1043000053                 2168808051
1400000052                 4775699552
2640000052                 2439909052
1450000052                 1485162052
1290000052                 8840250051
1380000052                 1249422052
3100000051                 2868170052    1272000052
7400000051                 4714800052    3392000052
1600000052                 1960571053    1653600053


      TOTALS

4835000053                 3929000053    2120000053

      FEED VAPOR
       WORDS 1 TO 5 REPRESENT
       SECTIONS 1 TO 5 RESPECTIVELY

             1230000052
             3990000052
             2989000053
             1830000052
             1313000053
             2990000052
             1208000053
             1140000052
             1670000052
             3680000052
             1700000051
             4000000051
             1700000051
             1000000051
             4000000050
```

```
                    TOTALS

                           7251000053

                    PRODUCTS
                     WORD 1 RICH OIL
                     WORD 3 TAIL GAS

3562370041                 1270000052
                           4060000052
9086902047                 3214990953
4279021050                 2177209852
2811061052                 1435893952
4305726052                 1104274152
2033540653                 2914594452
4620486152                 3970895951
5404084852                 1585622451
1419048953                 1363913751
6228240052                 1174595051
5449015652                 3089339050
3091812252                 1334984050
2278034352                 4009288049-
2674414452                 4992428049-
4422523252                 2764680050
8816327352                 3047270050
3768356153                 5814900050


                    TOTALS

1223540654                 5899594053

                    WORD 1 TOTAL IN
                    WORD 3 TOTAL OUT

1813500054                 1813500054
```

```
                   OVERALL HEAT BALANCE
                    DOES NOT INCLUDE HEAT ADDED
                    IN REBOILER OR HEAT REMOVED
                    IN INTERCOOLER
                     WORD 2 TOTAL HEAT IN
                     WORD 4 HEAT OUT IN RICH OIL
                     WORD 5 HEAT OUT IN TAIL GAS
                     WORD 7 TOTAL HEAT OUT

             1519034558                2017338858   4146162857                2431955158

                   INTERCOOLER DUTY
                    MUST BE SUBTRACTED FROM THE
                    HEAT CONTENT OF THE LIQUID
                    PRODUCT FROM THE SECTION
                    ABOVE THE INTERCOOLER TO MAKE
                    A BALANCE ON THE SECTION
                    BELOW THE INTERCOOLER

3027528257
```

APPENDIX D

FORTRAN PROGRAM STATEMENTS

The following pages have the FORTRAN statements for each phase of the program and for the separation subroutine. The subroutine instructions generated by the 650 FORTRAN compiler from this list must be scrubbed to prepare the optimum program. Every effort should be made to reduce the number of instructions in the subroutine since it is executed many times during the calculation.

If instructions for phases one and two are compiled from these lists without effective scrubbing in the SOAP phase, neither will fit on the 2,000 word memory drum. Phases one and two are linked by making the following changes after assembly.

1. Change the Pause 4 in phase one to 0000008000
2. Remove the FORTRAN zeroing routine from phase two
3. Set the locations of NØC and NØS in phases one and two equal
4. Write a routine to move TØPLV(J), BTMLV(J), and TEMP(I, J) from locations 0636-0640, 0641-0645, and 0671-0690 respectively in phase one to locations 0721-0750 in phase two.
5. Write a routine to zero the remainder of the data area in phase two (Locations 0750-0812). Items 3, 4, 5 must be executed before the first read statement in phase two.

6. The FORTRAN statement list shown was compiled on a new system to be released by IBM. It was developed by Dr. John Janicek of Cities Service Research Corporation, Tulsa, Oklahoma. The input-output formats are different from normal FORTRAN, and no sequential card number is generated to be punched on output cards. Such a number must be generated by the program to permit the collating of alphabetical identifications. The new system contains an automatic scrubbing phase. A new 533 panel is also required for the new system.
7. Pause statements before each punch sequence may be changed to transfers to bypass punching used for checkout.

```
      DIMENSION EKT(20,5),EKB(20,5),
    1 FEEDL(20,5),FEEDV(20,5),BTM(20
    2 ,6),VAPOR(5),APRIM(5),FRACT(5)
    3 ,TOPLV(5),BTMLV(5),A1(5),AN(5)
      DIMENSION NOT(5),SUMTV(5),SUMB
    1 V(5),TEMP(4,5),X(4,7),B(4,7),A
    2 (20,4)
K0000 CALCULATE EQUILIBRIUM CONSTANT
      DUMMY=RCD8F(PRESS,NOC,NOS)
      DO 8 I=1,NOC
      DUMMY=RCD8F(DUMMY)
      DO 17 L=1,7
      X(1,L)=RLIST(L)
   17 CONTINUE
      IF(X(1,6)-1.0)18,19,18
   18 IF(X(1,5))1,6,1
   19 DUMMY=RCD8F(DUMMY)
      DO 20 L=1,5
      X(2,L)=RLIST(L)
      EKT(I,L)=X(1,L)
      EKB(I,L)=X(2,L)
   20 CONTINUE
      GO TO 8
    1 DO 2 K=2,4
      DUMMY=RCD8F(DUMMY)
      DO 2 L=1,7
      X(K,L)=RLIST(L)
    2 CONTINUE
```

```
      DO 3 K=1,4
      DO 3 L=1,7
      B(K,L)=X(K,L)
    3 CONTINUE
      PRESA=PRESS+14.7
      PTERM=(LOGEF(PRESA))/10.0
      DO 4 K=1,4
      A(I,K)=0.0
    4 CONTINUE
      DO 5 K=1,4
      DO 5L=1,7
       IF(L-1) 16,15,16
   15  A(I,K) = B(K,1)
       GO TO 5
   16  FLL=L-1
      A(I,K)=A(I,K)+(B(K,L)*(PTERM**
     1FLL))
    5  CONTINUE
      GO TO 8
    6 DO 7  K=1,4
      A(I,K)=X(I,K)
    7 CONTINUE
    8 CONTINUE
      DO 9 I=1,4
      DUMMY=RCD8F(DUMMY)
      DO 9 J=1,NOS
      TEMP(I,J)=RLIST(J)
    9 CONTINUE
```

```
      DO 10 J=1,NOS
      TEMAT=(TEMP(1,J)+460.0)/1000.0
      TEMAB=(TEMP(2,J)+460.0)/1000.0
      DO 10 I=1,NOC
      IF(EKT(I,J)) 21,22,21
21    GO TO 10
22    SUMAT=0.0
      SUMAB=0.0
      DO 11 K=1,4
       IF(K-1) 13,14,13
14     SUMAT = A(I,1)
       SUMAB = A(I,1)
       GO TO11
13    FLK= K-1
      SUMAT=SUMAT+(A(I,K)*(TEMAT **
     1 FLK))
      SUMAB=SUMAB+(A(I,K)*(TEMAB **
     1 FLK))
11     CONTINUE
      EKT(I,J)=(EXPEF(SUMAT/TEMAT))/
     1 PRESA
      EKB(I,J)=(EXPEF(SUMAB/TEMAB))/
     1 PRESA
10    CONTINUE
      PAUSE 1
      DO 12 I=1,NOC
      DO 23 J=1,NOS
      PLIST(J)=EKT(I,J)
```

```
   23   CONTINUE
        DUMMY=PCH8F(DUMMY)
   12   CONTINUE
        DO 24 I=1,NOC
        DO 25 J=1,NOS
        PLIST(J)=EKB(I,J)
   25   CONTINUE
        DUMMY=PCH8F(DUMMY)
   24   CONTINUE
K0000   CALCULATE BOTTOM COMPOSITIONS
        DO 26 I=1,NOC
        DUMMY=RCD8F(DUMMY)
        DO 26 J=1,NOS
        FEEDL(I,J)=RLIST(J)
   26   CONTINUE
        DO 27 I=1,NOC
        DUMMY=RCD8F(DUMMY)
        DO 27 J=1,NOS
        FEEDV(I,J)=RLIST(J)
   27   CONTINUE
        DUMMY=RCD8F(DUMMY)
        DO 28 J=1,NOS
        NOT(J)=LISTR(J)
   28   CONTINUE
        DUMMY=RCD8F(DUMMY)
        DO 29 J=1,NOS
        TOPLV(J)=RLIST(J)
   29   CONTINUE
```

```
      DUMMY=RCD8F(DUMMY)
      DO 30 J=1,NOS
      BTMLV(J)=RLIST(J)
30    CONTINUE
      MAX=10*NOS
      INDEX=0
      MORE=5*NOS
      LIMIT=0
      DO 31 J=1,NOS
      IF(NOT(J)-1)32,33,34
33    LIMIT=LIMIT+1
      GO TO 31
34    LIMIT=LIMIT+2
31    CONTINUE
35    IF(INDEX-MAX)36,37,37
37    PAUSE 1111
      IF(CONSF(1.0))38,32,39
39    MAX=MAX+MORE
36    INDEX=INDEX+1
      MATCH=0
      DO 40 J=1,NOS
      SUMTV(J)=0.0
      SUMBV(J)=0.0
40    CONTINUE
      DO 41 I=1,NOC
      DO 42 J=1,NOS
      APRIM(J)=0.0
      FRACT(J)=0.0
```

```
42   CONTINUE
     J=1
43   CALC=DISTF(I,J,NOT(J))
     IF(ABSF(CALC-BTM(I,J))-0.01*
   1 BTM(I,J))45,45,44
44   BTM(I,J)=CALC
     J=J-1
     IF(J)32,46,43
46   J=1
     GO TO 43
45   BTM(I,J)=CALC
     IF(J-NOS)47,48,32
47   J=J+1
     GO TO 43
48   DO 49 J=1,NOS
     SUMTV(J)=SUMTV(J)+VAPOR(J)
     SUMBV(J)=SUMBV(J)+VAPOR(J-1)+
   1 FEEDV(I,J)
49   CONTINUE
41   CONTINUE
     DO 50 J=1,NOS
     SUMTL=0.0
     SUMBL=0.0
     DO 51 I=1,NOC
     SUMTL=SUMTL+BTM(I,J+1)+FEEDL
   1 (I,J)
     SUMBL=SUMBL+BTM(I,J)
51   CONTINUE
```

```
     IF(NOT(J)-1)32,52,53
52   IF(ABSF(TOPLV(J)-(SUMBL/SUMTV
521  (J)))-0.01*TOPLV(J))54,54,55
54   MATCH=MATCH+1
     GO TO 50
55   TOPLV(J)=SUMBL/SUMTV(J)
     BTMLV(J)=TOPLV(J)
     GO TO 50
53   IF(ABSF(TOPLV(J)-(SUMTL/SUMTV
531  (J)))-0.01*TOPLV(J))57,57,56
56   TOPLV(J)=SUMTL/SUMTV(J)
     GO TO 58
57   MATCH=MATCH+1
58   IF(ABSF(BTMLV(J)-(SUMBL/SUMBV
581  (J)))-0.01*BTMLV(J))60,60,59
59   BTMLV(J)=SUMBL/SUMBV(J)
     GO TO 50
60   MATCH=MATCH+1
50   CONTINUE
     IF(MATCH-LIMIT)61,38,32
38   PAUSE 3
     DO 62 I=1,NOC
     DO 63 J=1,NOS
     PLIST(J)=BTM(I,J)
63   CONTINUE
     DUMMY=PCH8F(DUMMY)
62   CONTINUE
     PAUSE 4
```

```
  61  IF(CONSF(1,0))1061,32,35
1061  DO  2061 J=1,NOS
      PLIST(J)=TOPLV(J)
      DUMMY=PCH8F(DUMMY)
2061  CONTINUE
      DO 65 J=1,NOS
      PLIST(J)=BTMLV(J)
      DUMMY=PCH8F(DUMMY)
  65  CONTINUE
      DO 66 I=1,NOC
      DO  67 J=1,NOS
      PLIST(J)=BTM(I,J)
  67  CONTINUE
      DUMMY=PCH8F(DUMMY)
  66  CONTINUE
      GO TO 35
  32  STOP
      END
```

```
      DIMENSION SPACE(200),FEEDL(20,
    1 5),FEEDV(20,5),BTM(20,6),VAP(
    2 20,5),TOPLV(5),BTMLV(5),TEMP(4
    3 ,5),TLFED(5),TVFED(5),TBTMS(6)
      DIMENSION TVAP(5),CLIQH(3,20),
    1 CVAPH(3,20),HLFED(5),HVFED(5),
    2 HBTMS(6),HVAP(5)
      DO 15 I=1,NOC
      DUMMY=RCD8F(DUMMY,CLIQH(1,I))
      DUMMY=RCD8F(DUMMY,CLIQH(2,I))
      DUMMY=RCD8F(DUMMY,CLIQH(3,I))
 15   CONTINUE
      DO 19 I=1,NOC
      DUMMY=RCD8F(DUMMY,CVAPH(1,I))
      DUMMY=RCD8F(DUMMY,CVAPH(2,I))
      DUMMY=RCD8F(DUMMY,CVAPH(3,I))
 19   CONTINUE
      DO 28 J=1,NOS
      TLFED(J)=0.0
      TVFED(J)=0.0
      TBTMS(J)=0.0
      TVAP(J)=0.0
      HLFED(J)=0.0
      HVFED(J)=0.0
      HBTMS(J)=0.0
      HVAP(J)=0.0
 28    CONTINUE
       DO 3028 I=1,NOC
```

```
      TBTMS(1)=TBTMS(1)+BTM(I,1)
       HBTMS(1)=HBTMS(1)+(BTM(I,1)*
     1 (CLIQH(1,I)+(CLIQH(2,I)*TEMP(2
     2 ,1))+(CLIQH(3,I)*TEMP(2,1)*TEM
     3 P(2,1))))
 3028  CONTINUE
      NUMBR =0
      DO 51 J=1,NOS
K0000 MATERIAL BALANCE
      DO 35 I=1,NOC
      VAP(I,J)=FEEDL(I,J)+FEEDV(I,J)
     1 +BTM(I,J+1)+VAP(I,J-1)-BTM(I,J
     2 )
      TLFED(J)=TLFED(J)+FEEDL(I,J)
      TVFED(J)=TVFED(J)+FEEDV(I,J)
      TBTMS(J+1)=TBTMS(J+1)+BTM(I,J
     1  +1)
      TVAP(J) =TVAP(J)+VAP(I,J)
   35  CONTINUE
      TOTIN =TLFED(J)+TVFED(J)+TBTMS
     1 (J+1)+TVAP(J-1)
      TOTOT =TBTMS(J)+TVAP(J)
K0000 HEAT BALANCE
      DO 42 I=1,NOC
      HLFED(J)=HLFED(J)+(FEEDL(I,J)*
     1 (CLIQH(1,I)+(CLIQH(2,I)*TEMP(3
     2 ,J))+(CLIQH(3,I)*TEMP(3,J)*TEM
     3 P(3,J))))
```

```
       HVFED(J)=HVFED(J)+(FEEDV(I,J)*
     1 (CVAPH(1,I)+(CVAPH(2,I)*TEMP(4
     2 ,J))+(CVAPH(3,I)*TEMP(4,J)*TEM
     3 P(4,J))))
        HBTMS(J+1)=HBTMS(J+1)+(BTM(I,
     1 J+1)*(CLIQH(1,I)+(CLIQH(2,I)*
     2 TEMP(2,J+1))+(CLIQH(3,I)*TEMP
     3  (2,J+1)*TEMP(2,J+1))))
       HVAP(J)=HVAP(J)+(VAP(I,J)*(CVA
     1 PH(1,I)+(CVAPH(2,I)*TEMP(1,J))
     2 +(CVAPH(3,I)*TEMP(1,J)*TEMP(1,
     3 J))))
   42   CONTINUE
       HETIN=HLFED(J)+HVFED(J)+HBTMS(
     1 J+1)+HVAP(J-1)
       HETOT=HBTMS(J)+HVAP(J)
       K=J+1
       M=J-1
       DUMMY=PCH8F(J,DUMMY,DUMMY,DUMM
     1 Y,DUMMY,DUMMY,DUMMY,NUMBR)
       NUMBR =NUMBR +1
       DO 3 I=1,NOC
        IF(J-1)4045,2045,4045
 2045   X=0.0
        GO TO 46
 4045   X=VAP(I,M)
   46  DUMMY=PCH8F(FEEDL(I,J),FEEDV(I
  461  ,J),BTM(I,K),X,BTM(I,J),VAP(I,
```

```
  462 J),DUMMY,NUMBR)
      NUMBR =NUMBR +1
   3  CONTINUE
      DO 7 I=NOC,20
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
    1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR =NUMBR +1
   7  CONTINUE
       IF(J-1)5046,3046,5046
3046   Y=0.0
       GO TO 47
5046   Y=TVAP(M)
  47  DUMMY=PCH8F(TLFED(J),TVFED(J),
  471 TBTMS(K),Y,TBTMS(J),TVAP(J),DU
  472 MMY,NUMBR)
      NUMBR =NUMBR +1
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
    1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
    1 TOTIN,DUMMY,TOTOT,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
    1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
       IF(J-1)5048,3048,5048
3048   Z=0.0
       GO TO 49
```

```
 5048   Z=HVAP(M)
   49  DUMMY=PCH8F(HLFED(J),HVFED(J),
  491  HBTMS(K),Z,HBTMS(J),HVAP(J),DU
  492  MMY,NUMBR)
       NUMBR=NUMBR+1
       DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
       NUMBR=NUMBR+1
       DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1 HETIN,DUMMY,HETOT,DUMMY,NUMBR)
       NUMBR=NUMBR+1
       DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
       NUMBR=NUMBER+1
       DUMMY=PCH8F(TOPLV(J),BTMLV(J),
     1 DUMMY,DUMMY,DUMMY,DUMMY,DUMMY,
     2 NUMBR)
       NUMBR=NUMBR+1
       DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
       NUMBR=NUMBR+1
   51   CONTINUE
K0000  OVERALL MATERIAL BALANCE
       DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
       NUMBR=NUMBR+1
       NUMBR=160
       DO 53 I=1,NOC
```

```
      DO 1053 J=1,NOS
      PLIST(J)=FEEDL(I,J)
 1053 CONTINUE
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
   53 CONTINUE
      DO 9 I=NOC,20
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
    9 CONTINUE
      DO 54 J=1,NOS
      PLIST(J)=TLFED(J)
   54 CONTINUE
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      DO 56 I=1,NOC
      DO 1056 J=1,NOS
      PLIST(J)=FEEDV(I,J)
 1056 CONTINUE
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
```

```
56    CONTINUE
      DO 11 I=NOC,20
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
    1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
11    CONTINUE
      DO 57 J=1,NOS
      PLIST(J)=TVFED(J)
57    CONTINUE
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
    1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
    1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      DO 59 I=1,NOC
      DUMMY=PCH8F(BTM(1,I),DUMMY, VA
    1 P(I,NOS),DUMMY,DUMMY,DUMMY,DUM
    2 MY,NUMBR)
      NUMBR=NUMBR+1
59    CONTINUE
      DO 13 I=NOC,20
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
      DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
13    CONTINUE
      DUMMY=PCH8F(TBTMS(1),DUMMY,TVA
    1 P(NOS),DUMMY,DUMMY,DUMMY,DUMMY
```

```
     2 ,NUMBR)
      NUMBR=NUMBR+1
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      TIN=0.0
      DO 62 J=1,NOS
      TIN=TIN+TLFED(J)+TVFED(J)
62     CONTINUE
      TOUT=TBTMS(1)+TVAP(NOS)
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      DUMMY=PCH8F(TIN,DUMMY,TOUT,DUM
     1 MMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      THIN=0.0
      DO 66 J=1,NOS
      THIN=THIN+HLFED(J)+HVFED(J)
66     CONTINUE
      THOUT=HBTMS(1)+HVAP(NOS)
      DUMMY=PCH8F(DUMMY,DUMMY,DUMMY,
     1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
      NUMBR=NUMBR+1
      DUMMY=PCH8F(DUMMY,THIN,DUMMY,
     1 HBTMS(1),HVAP(NOS),DUMMY,THOUT
     2 ,NUMBR)
      NUMBR=NUMBR+1
```

```
      DUMMY=RCD8F(J,TEMPI)
      HINCL=0.0
      IF(TEMPI)71,75,71
71    DO 72 I=1,NOC
      HINCL=HINCL+(BTM(I,J)*(CLIQH(1
    1 ,I)+(CLIQH(2,I)*TEMPI)+(CLIQH(
    2 3,I)*TEMPI*TEMPI)))
72     CONTINUE
      DUTYI=HBTMS(J)-HINCL
      DUMMY=PCH8F(DUTYI,DUMMY,DUMMY,
    1 DUMMY,DUMMY,DUMMY,DUMMY,NUMBR)
75    END
```

TWO PHASE SEPARATION SUBROUTINE

```
      DISTF
      IF(APRIME(J))1,2,1
    2 A1(J)=TOPLV(J)/EKT(J)
      AN(J)=BTMLV(J)/EKB(J)
      APRIM(J)=AN(J)*((A1(J)+1.0)/(A
     1N(J)+1.0))
    1 WS1=(APRIM(J)*(FEEDV(I,J)+VAP(
   11J-1)))-(BTM(J+1,I)+FEEDL(I,J))
      WS2=WS1*A1(J)
      IF(WS2)3,4,4
    3 WS4=ABSF(A1(J))
      A1(J)=1./AN(J)
      AN(J)=1./WS4
    5 WS3=SQRTF((AN(J)*(A1(J)+1.))+.
   5125)-.5
      FRACT(J)=((WS3**(NOT(J)+1.))-W
     1S3)/((WS3**(NOT(J)+1.))-1.)
       A1(J)=ABSF(A1(J))
      IF(WS1)6,4,4
    6 A1(J)=-A1(J)
    4 IF(FRACT(J))7,5,7
    7 WS5=FRACT(J)*WS1
      IF(WS5)9,8,8
    8 WS5=WS5/APRIM(J)
    9 VAP(J)=VAP(J-1)+FEEDV(I,J)-WS5
      CALC=BTM(I,J+1)+FEEDL(I,J)+WS5
```

VITA

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Master of Science

Thesis: CALCULATION OF ABSORBER-STRIPPER SYSTEMS

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