COMPUTER APPLICATION OF MULTICOMPONENT ABSORBER CALCULATIONS

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COMPUTER APPLICATION OF MULTICOMPONENT

ABSORBER CALCULATIONS

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PREFACE

A sequence of absorber calculations was adapted for use on the 650 IBM Digital Computer. The calculations evaluate the performances of non-reboiled gas absorption columns. The program developed, it is hoped, will prove to be an asset toward the understanding of absorber tower variables and solvent requirements.

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CHAPTER I

THE PROBLEM

Statement of The Problem

One well-established industrial application of mass transfer phenomena is the separation of desirable products from multicomponent systems by gas absorption. The importance of gas absorption was first realized by the chemical industries where it was utilized to obtain such products as oxides of nitrogen, chlorine, and hydrochloric acid (1). Although gas absorption has maintained an important position in the chemical field, it has obtained even greater importance in the petroleum industry. With increasing demands placed on petroleum companies for economical production of gasoline and pure petroleum products, gas absorption has become one of the primary tools of the industry.

Gas absorption equipment can be classified as two general types, multistage and continuous-contact towers. The multistage type consists of towers containing a finite number of trays (bubble-cap, sieve, or similar types). These trays promote turbulent contact of liquid and gas. The liquid and gas streams are separated during movement between trays. Packed and spray towers comprise the second type. In these towers, the gas and liquid are in continuous contact. As a result, the respective compositions of the liquid and vapor phases change throughout the towers.

Application of digital computers to engineering problems has provided the process engineer with a means that has partially removed the time element required to obtain acceptable solutions to engineering problems. Although the digital computer does not lend itself to graphical treatments, it does provide satisfactory mathematical analysis of not only straight forward solutions but also those involving trial and error.

Two accepted short-cut mathematical treatments used in gas absorption analysis are the Kremser-Brown (7) and Edmister (3) methods. Each method involves the concept of the "theoretical plate" and the assumption of equilibrium between the gas and liquid phases on each theoretical plate. The Kremser-Brown method utilizes an average absorption factor in its performance analysis. The average absorption factor is obtained by dividing the L/V ratio (total liquid to total vapor) by an equilibrium constant determined at average tower conditions. The Edmister method expresses tower performance as a function of effective absorption factors. These factors are defined as functions of conditions existing on the top and bottom theoretical plates of the tower.

The primary purpose of this investigation was to adapt the Kremser-Brown and Edmister methods for use on the 650 IBM Digital Computer. This program was to provide performance analyses of non-reboiled gas absorption towers. A secondary purpose was to evaluate the performance of the resulting program by comparison of digital computer calculations with actual industrial test run data.

Limitations of Research

The program for the computer is restricted in the following manner:

(1) The program calculates solvent oil requirements and product stream compositions of a non-reboiled straight-run absorber without intercoolers.

(2) The program capacity is a rich gas and lean solvent oil composed of a maximum of twenty different components.

(3) The lean gas temperature is fixed by the input data and the rich oil temperature calculated by heat balance.

CHAPTER II

REVIEW OF LITERATURE

A number of methods have been developed or proposed that can be used to evaluate performance of absorption towers or to design new absorption equipment. The mechanism of gas absorption has long been defined as a diffusion phenomenom dependent on such variables as temperature, pressure, concentration, physical properties of materials, and liquid-vapor quantities present. Although many years have passed since the discovery of the mechanism involved, gas absorption has not yet been completely analysed with treatments employing mathematical formulation of interphase diffusion. As a result, design and performance analysis has been achieved by methods based on the assumption of a "theoretical plate". A theoretical or ideal tray can be defined as one where the average composition of all the gas leaving the tray is in equilibrium with the average composition of all liquid leaving the tray (14). One other concept, the absorption factor, is utilized directly or indirectly in each of the treatments.

If equilibrium-solubility data are plotted in terms of mol ratios of solute to solvent of the liquid phase and the vapor phase, a curve would result representing liquid and vapor equilibrium. Each point on the curve represents the concentrations of gas and liquid phases in equilibrium at the specified temperature and pressure. A material balance made about a non-reboiled absorber similar to the one shown in Figure 1 results in the following equation:

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

where: V_{n+1} = Mols of rich gas entering the absorber

L_o = Mols of lean oil entering the absorber

X = Mols of component in liquid per mol of entering lean oil

Y = Mols of component in vapor per mol of rich gas feed.

The subscripts refer to the respective plates of the absorber. In an absorber, the plates are numbered from top to bottom of the column. The above equation is usually plotted on molal ratio coordinates. The resulting curve represents the ranges of compositions of the liquid and vapor phases during their passage through the absorber. Because the line represents the phase compositions during operation, the line is termed the "operating line". If both the equilibrium line and the "operating line" resulting from the above material balance are plotted on the same set of coordinates, lines of stair-step shape can be drawn. The steps are formed by connecting one end of the operating line with a point on the equilibrium curve by either a vertical or horizontal straight line. This point on the equilibrium line in turn is connected by either a horizontal or vertical straight line to a point on the operating line. This procedure is continued until the other end of the operating line is reached. The points obtained which lie on the operating line represent the compositions of the gas leaving a plate and the liquid going to that same plate. The equilibrium line

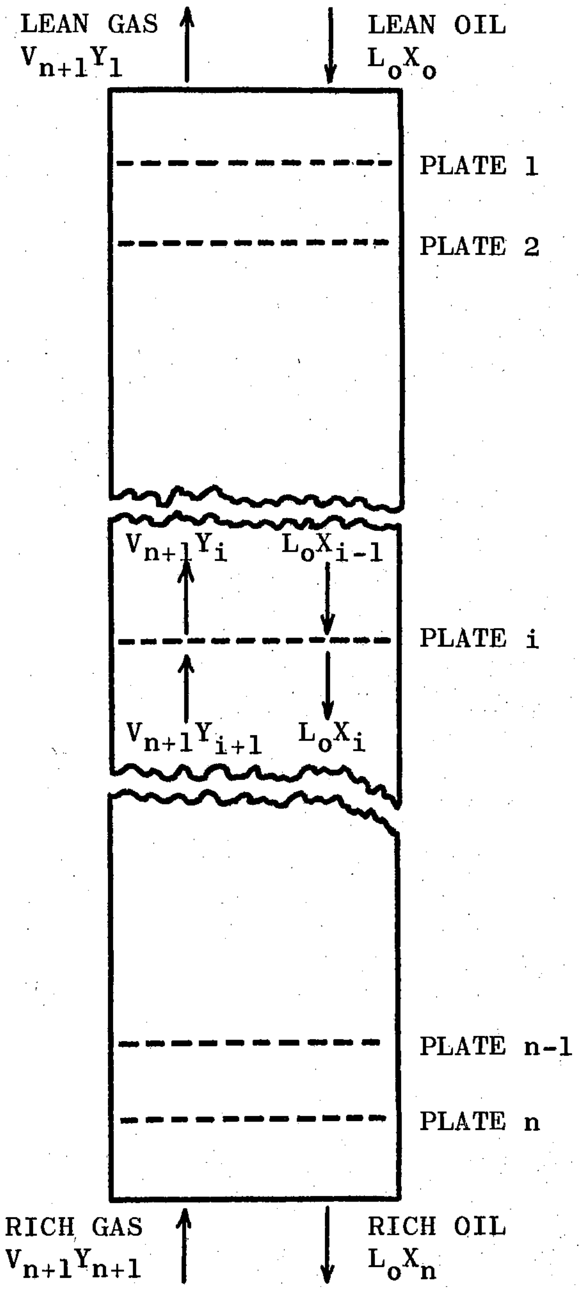

FIGURE 1

SCHEMATIC DIAGRAM OF A NON-REBOILED ABSORBER represents the compositions of the liquid and vapor leaving the same plate. The average vertical distance between the operating and equilibrium lines represents the force driving the component to the liquid phase from the vapor phase (if absorption is occurring). If stripping is occurring, the force is driving the component from the liquid phase to the vapor phase.

Multicomponent absorption requires the lines described above to be constructed for each component present in the system. However, when a "key" component recovery is designated, the recovery of each of the other components in the system is fixed. The "key" component is usually selected as the component whose equilibrium and operating lines are most nearly parallel to each other. The number of theoretical plates (number of stair-steps) required to obtain the compositions represented at the ends of the operating line is determined using a plot similar to the one described in the above discussion. The plot is made for the key component only. Location of operating lines of the other components in the system is made by trial and error. The trial and error procedure is conducted to insure the change in the solute concentration in the gas divided by the mean driving force (mean vertical distance between operating and equilibrium lines) remains the same for all components. This method, known as the Sherwood graphical method (12), although rigorous and accurate is tedious because of the exact and careful plotting of equilibrium and operating lines required. Fortunately, graphical solution for the "key" component followed by an algebraic solution for the remaining components suffices for most absorption problems.

One of the first methods for algebraic treatment of gas absorption was presented by Kremser (7). This method is based on the "theoretical plate" concept with the additional assumption being made that the pressure, liquid and vapor traffics, and temperature were constant throughout the absorber tower. Raoult's Law and Dalton's Law are also assumed to apply. A few years later, Souder and Brown (13) developed and refined the method from Kremser's theoretical formulation. Derivation of the Kremser-Brown method is presented in Appendix B. By definition of the absorption factor "A" as $\frac{Gq}{100}$ or its equivalent $\frac{L}{mV}$, Equation 8 of Appendix B may be written in the following form:

$$\frac{Y_{n+1} - Y_1}{Y_{n+1} - Y_o} = \frac{(L/mV)^{n+1} - (L/mV)}{(L/mV)^{n+1} - 1} \qquad (2)$$

The left hand side of the equation represents the amount of solute absorbed divided by the amount that would have been absorbed if the off-gas leaving were in equilibrium with the entering solvent stream. This ratio represents the efficiency of absorption for any component. Three imposed conditions of Equation 2 and their significance should be observed. If m is greater than L/V and n is large, the value to the right of the equality sign approaches L/mV. Secondly, if m is small compared with L/V and n is large, the right hand side of the equation approaches unity. When the absorption factor L/mV is unity, the value of the right hand side of Equation 2 cannot be defined. However, if the limit is taken as L/mV approaches unity, the value of the ratio is defined as $\frac{n}{n+1}$.

As a result of the assumptions of constant temperature and constant liquid and vapor traffics, the Kremser-Brown method seemed inadequate for some absorption problems encountered. In an effort to better evaluate the performance of absorption towers, Horton and Franklin (5) developed the following equation:

$$\frac{Y_{n+1} - Y_1}{Y_{n+1}} = \left[\frac{A_1A_2A_3\ldots A_n + A_2A_3\ldots A_n + \ldots + A_n}{A_1A_2A_3\ldots A_n + A_2A_3\ldots A_n + \ldots + A_n + 1}\right] - \left[\frac{L_o}{V_{n+1}}\;\frac{X_o}{Y_{n+1}}\right]\left[\frac{A_2A_3\ldots A_n + A_3\ldots A_n + \ldots + A_n + 1}{A_1A_2A_3\ldots A_n + A_2A_3\ldots A_n + \ldots + A_n + 1}\right] \quad (3)$$

The second term to the right of the equality sign is a correction for the presence of solute in the solvent. The equation is based on the assumption of liquid and vapor equilibrium and the "theoretical plate" concept. In Appendix B, Equation 3 is shown to be analogous to the Kremser-Brown equation.

Horton and Franklin present two methods for calculating the performance of an absorber. The first method involves determination of the absorption factors for each component on each plate and substitution into Equation 3. An effective absorption factor is calculated in the second method and substituted into Equation 8 of Appendix B. This method requires calculation of the L/V ratio and temperature for the point in the tower representing the effective absorption factor of the component in question. Horton and Franklin present a chart relating the values of the absorption (or stripping) factors to the locations of the effective absorption factors in the column. The positions of the effective factors are determined from the chart. The liquid quantities, vapor quantities, and temperatures are calculated at the positions in the column determined from the chart. The following equations are used to estimate the required quantities and temperatures.

$$\left(\frac{V_1}{V_{n+1}}\right)^{1/n} = \frac{V_i}{V_{i+1}} \tag{4}$$

$$\frac{T_n - T_i}{T_n - T_o} = \frac{V_{n+1} - V_{i+1}}{V_{n+1} - V_1} \tag{5}$$

The above equations assume constant percent absorption per plate and plate temperature changes proportional to gas contraction or expansion. In the second method, the term "effective absorption factor" is introduced. At some position in the column the absorption factor of the component becomes critical or controlling. In the general area in which the absorption factor is critical, the last increment of absorption of that component occurs. The critical value of the absorption factor is termed the effective absorption factor. Horton and Franklin observed that the effective absorption factor for a light hydrocarbon corresponds to a position near the bottom of the absorber and the position of the factor for the heavy component is near the middle of the tower. One disadvantage presented by estimation of the positions of the effective absorption factor by the Horton and Franklin chart is that the factor is not expressed as a continuous function of position in the tower. The continuous function deficiency of the Horton and Franklin method is eliminated with a different approach to the problem presented by Edmister (3).

Edmister utilizes the concept of an effective absorption factor but not in the manner presented by Horton and Franklin. Two additional terms, A_e and A', are defined by the following equations.

$$\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1} = \frac{A_1A_2A_3\ldots A_n + A_2A_3\ldots A_n + \ldots + A_n}{A_1A_2A_3\ldots A_n + A_2A_3\ldots A_n + \ldots + A_n + 1} \tag{6}$$

$$\frac{1}{A'}\left[\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right] = \frac{A_2A_3\ldots A_n + A_3\ldots A_n + \ldots + A_n + 1}{A_1A_2A_3\ldots A_n + A_2A_3\ldots A_n + \ldots + A_n + 1} \tag{7}$$

Analysis of test data and plate to plate calculations indicates A_e and A' are essentially independent of the number of plates in the tower. Equations 6 and 7 are written for a two plate absorber and the terms A_e and A' evaluated as:

$$A_e = \sqrt{A_n(A_1 + 1) + 0.25} - 0.5 \tag{8}$$

$$A' = \frac{A_n(A_1 + 1)}{A_n + 1} \tag{9}$$

The calculation procedure is a trial and error type of solution. Quantities absorbed are first assumed to obtain a stream material balance. Using stream quantities from the material balance, the rich oil temperature is calculated from a heat balance if an off-gas stream temperature is assumed. Ratios of liquid to vapor and temperatures for the top and bottom plates can be estimated from Equations 4 and 5. The effective absorption factors are then evaluated from the absorption factors found for the top and bottom plates. The absorption efficiencies are calculated and a material balance made after substitution into Equation 13 of Appendix B. If the solvent oil contains a large percentage of light components, stripping may occur. If stripping occurs, stripping factors as well as absorption factors are calculated. Detailed derivations of the Kremser-Brown and Edmister methods are presented in Appendix B.

The methods outlined above are generally calculated with the additional assumption of adiabatic tower performance and no heat of absorption occurring. However, Hull and Raymond (6) developed a calculation procedure including heat balance corrections for heat of absorption and ambient heat losses.

Heat of absorption values were calculated by use of Equation 10 and are presented in graphical form as a function of pressure and the component involved.

$$\triangle H = \frac{R}{M} \quad \frac{T_1 T_2}{T_2 - T_1} \quad \ln \frac{K_2}{K_1} \qquad (10)$$

In order to establish tower temperatures by heat balance, one of the product stream temperatures must be estimated or evaluated. Hull and Raymond developed a correlation from test data which relates $\triangle T$ (the off-gas temperature minus the lean oil temperature) with the heat evolved in the "top section of the absorber" per unit weight lean oil. The top section is defined as the average of the top three plates or the first theoretical plate. The method can be used only if the lean oil is the main quantity involved in the heat balance. The effective absorption factor for each component is graphically correlated as a function of the difference between the bottom tower and average tower temperatures. The term A_c (equal to $\frac{A_n(A_1+1)}{A_n+1}$) is presented as a function of the difference between the bottom and top temperatures of the tower. The average tower temperature is estimated from a graphical correlation of average tower temperature and lean oil to rich gas ratio. The L/V ratios at the top and bottom of the tower are established by trial and error estimation of the shrinkage occurring in the tower. Upon evaluation of the absorption factors, the remaining calculations are similar to those of the Edmister or Franklin methods.

In the Edmister method presented above, a wide range of values for absorption and stripping factors is encountered. A need for expressing absorber performance as a function of variables whose numerical values would always be of a limited range is evident. As a result, Edmister (2) presented a method of analysis which utilizes two new absorption factors ϕ_A and ψ_A (for stripping ϕ_S and ψ_S). The new absorption factors are defined as:

$$\phi_A = \frac{1}{\Sigma_A + 1} \qquad (11)$$

$$\psi_A = \left[1 - \frac{\pi}{\Sigma_A + 1}\right] \qquad (12)$$

Where: $\pi = A_1 A_2 A_3 \ldots A_n$

$\Sigma_A = A_1 A_2 A_3 \ldots A_n + A_2 A_3 \ldots A_n + \ldots + A_n.$

By examining Equations 11 and 12, one observes that the numerical values for ϕ_A and ψ_A will always be between zero and unity. The new absorption factors provide a means of analysis for any component regardless of the value of A (or S). The significance of the terms ϕ_A and ψ_S should be observed. The term ϕ_A is the fraction of any rich gas component not recovered in an absorber. Similarly, ψ_A is the fraction of any component in the lean oil lost to the off-gas.

CHAPTER III

DESCRIPTION OF PROGRAM AND EVALUATION PROCEDURE

Of the methods discussed in the previous chapter, adaptation of the Kremser-Brown and Edmister methods to the digital computer seemed most promising. These two methods are mathematical treatments and do not require graphical correlations or tables that cannot be expressed as continuous mathematical functions. The following is a discussion of the 650 IBM computer program and the data requirements for its application.

Before a program can be obtained, definition of the problems to be encountered is necessary. The maximum number of components in the rich gas and lean oil solvent is fixed at twenty for each stream. The typical problem will require calculation of the total and individual component quantities of the lean gas stream and the rich oil product stream, the rich oil temperature, and the lean oil requirement for a specified percentage recovery of a "key" component. Compositions of the rich gas and solvent oil will constitute known data of the problem. Also, the number of theoretical plates and the tower pressure will be known.

In addition to the above input data concerning the tower, the feed, and the solvent oil; equilibrium "K" values and vapor and liquid enthalpy data for all components in the system are required. The equilibrium values are obtained with a program calculation method developed by Norman and Williams (9). The Norman and Williams program makes least squares fits to power series of NGAA equilibrium data. The "K" values obtained are fitted to an equation of the form $K = a + bT + cT^2$ expressing K as a function of temperature by use of a program developed by Pulley (11). Pulley's program makes a curve fit using the Cholesky least squares method for n data points. The liquid and vapor enthalpies are curve fitted by a 3-data point high speed curve fit (4). An "n" data point curve fit for enthalpy is not necessary because of the continuously smooth curve that is obtained by plotting enthalpy data as a function of temperature.

The program consists of a Kremser-Brown calculation on the specified tower followed by an Edmister calculation which uses the Kremser-Brown results as a first approximation of the product stream quantities and tower temperatures. The sequence of calculations followed by the absorber program is outlined in block form in Appendix C and briefly described in the following discussion.

The input data requirements of the program provide variance of the lean gas temperature by specification of the quantity $\triangle T$. The term $\triangle T$ is the difference between the lean gas and lean oil temperatures. After a complete punch out of all input data read into the computer, the Kremser-Brown section of the program calculates the lean gas temperature by addition of $\triangle T$ to the lean oil temperature. The rich oil temperature is assumed to be that of the rich gas as a first approximation. The average tower temperature is calculated as the arithmetic average of the rich oil and lean oil temperatures.

Specification of the recovery for the key component fixes the recovery of all components in the system. For the key component, the absorption factor "A" must be a quantity which when substituted into Equation 8 of Appendix B will make the value of the term on the right of the equality sign that of the key component recovery. The approximate lean oil rate required to give the value of the key absorption factor desired is evaluated from the equation $A_k = \frac{L}{K_k V}$. The "A" factors of all remaining components are then calculated from the expression $A_i = \frac{A_k K_k}{K_i}$.

The Y_o term of Equation 8 of Appendix B represents the quantity of the component in the vapor that would exist if the vapor were in equilibrium with the entering lean oil. These terms are evaluated from Equation 4 with the assumption that V_i equals V_{n+1} and the substitution of K values for m values. The absorption of each component is then calculated by substitution of the above values into Equation 8. The total absorption is tested to determine if the value is within a specified tolerance of the total absorption of the last trial. If the total is not within tolerance, the lean gas quantity of the previous trial is substituted for V in the expression $A_k = \frac{L}{K_k V}$. When the total absorption test is satisfied and the tower material balance completed, a heat balance is performed to evaluated the rich oil product stream temperature. The heat balance is a trial and error type solution because a rich oil temperature must first be assumed before the enthalpy of the rich oil stream can be evaluated. If an incorrect temperature is assumed, the program applies a correction to obtain the temperature for the next trial. The heat balance error divided by the total heat input is calculated. This quantity is divided by an arbitrary constant (four) and is multiplied by the old temperature assumed. This correction term is then added to the previously assumed temperature to obtain the temperature assumed for the next trial. The rich oil temperature obtained from the heat balance of a specified tolerance is tested to determine if it is within an allowable mismatch of the rich oil temperature assumed at the beginning of the Kremser-Brown calculations. If the heat balance temperature is not within a specified mismatch of the assumed temperature, the Kremser-Brown calculations are begun again. The heat balance rich oil temperature is the temperature assumed for the next trial. When the mismatch between the rich oil temperature assumed and that calculated is within tolerance, the results of the Kremser-Brown are punched. The Edmister section of the program is then read into the computer.

The Edmister section of the program calculates stream totals from the stream component quantities obtained in the Kremser-Brown section. The assumption is made that the absorption occurring on each plate is the same. The absorption quantity for each plate is determined as the assumed total absorption divided by the number of theoretical plates in the absorber. The L/V ratios required in the evaluation of the absorption factors of the top and bottom plates are obtained by the following procedure. The liquid leaving the top plate is assumed to be the total lean oil quantity plus the absorption for one plate and the vapor leaving the bottom plate is assumed to be the total rich gas quantity minus the absorption for one plate. The top plate liquid divided by the total off-gas quantity and the total rich oil quantity divided by the bottom plate vapor give the required L/V ratios. These ratios are divided by component K values to provide the absorption factors. The top and bottom plate stripping factors are obtained by taking the reciprocals of the absorption factors for those plates. The reason stripping factors are calculated is that if the lean oil stream contains an appreciable percentage of light components the quantities of the components stripped must be determined. By substitution of the required absorption and stripping factors into Equations 11, 12, 11', and 12' of Appendix B, the effective factors and the terms A' and S' are evaluated.

The algebraic signs of the quantities in the first bracket to the right of the equality signs of Equations 13 and 13' indicate which transfer mechanism (absorption or stripping) is controlling. Negative signs indicate the other transfer mechanism prevails. In the program, the sign of the quantity $\left[1 - \frac{L_0X_0}{A'V_{n+1}Y_{n+1}}\right]$ is tested to determine if absorption of that component is occurring. If the sign is negative, Equation 13' is evaluated to obtain the quantity of the component stripped. A positive sign causes the quantity absorbed to be calculated by Equation 13. The net absorption is determined as the difference between the total quantity absorbed and the total quantity stripped.

A material balance about the tower provides the stream quantities and compositions used in the Edmister heat balance. The rich oil temperature is obtained by an over-all heat balance. This temperature is tested to determine if the mismatch between the calculated value and the assumed value is within a specified tolerance. The assumed rich oil temperature for the first trial in the Edmister calculations is the final rich oil temperature calculated in the

Kremser-Brown section of the program. If the mismatch is not within tolerance, the calculated value is used as the assumed rich oil temperature of the next trial and the Edmister calculations are begun again. When a rich oil temperature within tolerance is obtained, the calculated absorption efficiency for the key component is compared with the specified value. If the calculated absorption efficiency is not within a given tolerance, the lean oil rate is corrected by multiplying the old lean oil rate by the ratio $\frac{E_a}{E_c}$ to obtain the lean oil rate for the next trial. When the desired absorption efficiency is obtained (through multiple machine iteration), the results of the Edmister calculations are punched.

Evaluations of the quantities $\frac{A^{n+1} - A}{A^{n+1} - 1}$ and $\frac{S^{n+1} - S}{S^{n+1} - 1}$, K equilibrium values, and enthalpies are achieved with subroutines. The K equilibrium and enthalpy values are evaluated by equations of the form $y = a + bT + cT^2$. The coefficients used are obtained from curve fits described at the beginning of this chapter. The effective factor subroutine makes a test which limits the values of A's and S's that can be used. If the factor value is greater than 100, the quantity $\frac{A^{n+1} - A}{A^{n+1} - 1}$ or $\frac{S^{n+1} - S}{S^{n+1} - 1}$ is assumed equal to 1 thus eliminating possible generation of a number too large for the subroutine to evaluate. If the factor value is less than 100, the factor is raised to the required power using the expression $X^n = e^{n \ln X}$. This requires subroutines which first evaluate the natural logarithm of a number and then raise the result to a power of e. The required calculations have been adapted for computer application by Pulley (10).

The performance of the program was evaluated, with the exception of Problem One, by comparison of computer results with actual test run data provided by NGAA (15). Computer results for Problem One were not compared with test run data but with hand calculations which evaluated the lean gas temperature as the dew point temperature of the off-gas stream and the rich oil temperature as the bubble point temperature of the rich oil stream. The rich gas and lean oil stream compositions of the problems used are indicated in Appendix A. The system pressures of the twenty problems used to evaluate the performance of the program ranged from 64.7 to 1815 psia.

In addition to the evaluation made of the program as described above, the effect of changing the lean gas temperature was studied. In this study, incremental values for $\triangle T$ of plus and minus 5, 10 and 15 degrees were run for each of four problems.

The equilibrium K values used by Norman and Williams (9) were obtained from NGAA (17). The "K" values published by NGAA were developed by Fluor Corporation and presented as functions of convergence pressure, temperature, and system pressure. The convergence pressure method was used to correlate the effect of composition on K values. Estimation of system convergence pressures was made with the aid of convergence pressure envelope charts relating convergence pressures with system temperatures. The vapor and liquid enthalpies used were obtained from NGSMA (16). The charts were developed by M. W. Kellogg Company and presented as functions of temperature, pressure, and molecular weight.

CHAPTER IV

RESULTS

A sequence of absorber calculations was adapted to the 650 IBM computer. The data presented on the following pages were obtained during a performance test of the calculation sequence.

Tabular form is used in the presentation of the following information:

1. Experimental and computer calculated rates of the lean solvent and product streams.
2. Material balances.
3. Rich Oil temperatures.
4. Absorption and stripping factors.
5. Effect of lean gas temperature on the rich oil temperature, total absorption, and solvent oil requirement.

In all tables presented, digits to the right of the decimal point are carried for consistency not to indicate degree of accuracy or precision of the number.

The effect of the number of theoretical plates on rich oil temperature, solvent requirements, and top and bottom plate L/V ratios are presented in graphical form.

TABLE I

KREMSER-BROWN CALCULATED STREAM RATES AND EXPERIMENTAL TEST RUN RATES (15)

Problem Number	Lean Gas Rate Mols/100 Mols Rich Gas Calculated	Experimental	Lean Oil Rate Mols/100 Mols Rich Gas Calculated	Experimental	Rich Oil Rate Mols/100 Mols Rich Gas Calculated	Experimental
1	50.76145	65.578	67.99035	66.667	117.22892	101.088
2	90.92196	90.1587	67.77350	91.1811	76.85154	101.0223
3	71.57727	73.4214	89.59562	82.2657	118.01835	108.8442
4	92.71822	91.2693	15.11946	18.1593	22.40124	26.8900
5	86.17574	86.3098	18.23245	10.8951	32.05671	24.5852
6	83.66077	77.1916	20.46198	10.63146	36.80122	22.8083
7	22.27936	26.1609	126.20231	299.2556	203.92296	373.0947
8	78.92591	78.1458	26.55263	22.5075	47.62673	44.3616
9	81.43847	87.6559	25.29116	176.0599	43.85270	188.4040
10	87.49512	87.9141	19.11845	14.7978	31.62333	26.8836

TABLE I (Continued)

Problem Number	Lean Gas Rate Mols/100 Mols Rich Gas Calculated	Experimental	Lean Oil Rate Mols/100 Mols Rich Gas Calculated	Experimental	Rich Oil Rate Mols/100 Mols Rich Gas Calculated	Experimental
11	67.73932	73.0590	111.30942	126.1373	143.57011	153.0783
12	91.80026	91.5996	15.76065	11.3306	23.96039	19.7310
13	90.23139	90.7589	18.07077	11.6313	27.83938	20.8724
14	27.12420	30.3872	56.06253	41.9015	128.93833	111.5142
15	59.49623	68.2204	50.67830	45.8187	91.18207	77.5983
16	89.44989	88.5904	19.83366	18.5493	30.38377	29.9589
17	88.11484	88.5892	17.57845	15.6362	29.46360	27.0471
18	85.38579	84.8707	25.84908	21.1188	40.46329	36.2481
19	87.31247	86.3491	17.12290	11.3159	29.81043	24.9668
20	83.99234	87.1827	22.36844	11.1992	38.37610	24.0165

TABLE II

EDMISTER CALCULATED STREAM RATES AND EXPERIMENTAL TEST RUN RATES

Problem	Lean Gas Rate		Lean Oil Rate		Rich Oil Rate	
	Mols/100 Mols Rich Gas		Mols/100 Mols Rich Gas		Mols/100 Mols Rich Gas	
Number	Calculated	Experimental	Calculated	Experimental	Calculated	Experimental
1	70.93108	65.578	85.57967	66.667	114.64859	101.088
2	90.77441	90.1587	68.02102	91.1811	77.24661	101.0223
3	71.67658	73.4214	89.13029	82.2657	117.45372	108.8442
4	92.48855	91.2693	10.96961	18.1593	18.48107	26.8900
5	85.06710	86.3098	8.54755	10.8951	23.48045	24.5852
6	82.02264	77.1916	9.63648	10.6315	27.61384	22.8083
7	24.20502	26.1609	209.99720	299.2556	285.79219	373.0947
8	77.76742	78.1458	21.06523	22.5075	43.29780	44.3616
9	80.31624	87.6559	16.54016	176.0599	36.22392	188.4040
10	86.70278	87.9141	11.48392	14.7978	24.78116	26.8836

TABLE II (Continued)

Number	Lean Gas Rate Mols/100 Mols Rich Gas Calculated	 Experimental	Lean Oil Rate Mols/100 Mols Rich Gas Calculated	 Experimental	Rich Oil Rate Mols/100 Mols Rich Gas Calculated	 Experimental
11	67.69623	73.0590	119.43498	126.1373	151.73875	153.0783
12	91.02193	91.5996	10.79769	11.3306	19.77576	19.7310
13	89.60734	90.7589	11.70992	11.6313	22.10258	20.8724
14	27.75929	30.3872	63.05072	41.9015	135.29144	111.5142
15	59.06838	68.2204	46.90107	45.8187	87.83269	77.5983
16	89.02945	88.5904	14.84201	18.5493	25.81256	29.9589
17	87.47947	88.5892	10.50414	15.6362	23.02468	27.0471
18	84.54455	84.8707	17.60983	21.1188	33.06528	36.2481
19	86.40486	86.3491	9.02017	11.3159	22.61532	24.9668
20	83.49272	87.1827	9.21735	11.1992	25.72464	24.0165

TABLE III

EXPERIMENTAL RICH OIL TEMPERATURES AND RICH OIL TEMPERATURES CALCULATED BY HEAT BALANCE

Problem Number	Pressure Psia	Rich Oil Temperature Degrees Rankine		
		Kremser-Brown Calculation	Edmister Calculation	Experimental Data
1	64.7	627.416	586.487	554
2	75	513.272	513.141	520
3	195	541.540	541.540	537
4	410	539.014	539.571	550
5	1565	525.707	518.277	547
6	1575	510.873	507.670	544
7	94.7	559.830	551.769	550
8	545	555.233	561.358	562
9	80.7	535.384	542.477	520
10	720	540.181	539.213	562
11	60.7	540.475	539.430	538
12	865	516.265	514.266	527
13	975	550.596	549.545	556
14	208.7	574.435	571.198	534.5
15	266	577.428	578.666	571
16	427	554.382	556.521	565
17	695	558.378	558.907	571
18	950	546.167	543.693	564
19	1464	543.588	540.236	574
20	1815	553.614	545.720	550

TABLE IV

VARIATION OF LEAN OIL RATE AND TOTAL ABSORPTION WITH ΔT

PROBLEM ONE

EDMISTER CALCULATION

PRESSURE 64.7 PSIA THEORETICAL PLATES FOUR

(T_{LG}) Lean Gas Temp. °R	(T_{LO}) Lean Oil Temp. °R	(T_{RO}) Rich Oil Temp. °R	(ΔT) Difference (T_{LG}-T_{LO})	Lean Oil Rate Mols	Absorption Mols
535.00	550	599.39	-15	83.72728	31.20708
540.00	550	597.19	-10	84.56820	30.87138
545.00	550	594.97	- 5	83.51885	30.98310
550.00	550	592.63	+ 0	85.03355	30.26471
555.00	550	590.11	+ 5	86.25086	29.55407
560.00	550	587.53	+10	86.58934	28.99790
565.00	550	585.51	+15	85.41863	29.35230

TABLE V

VARIATION OF LEAN OIL RATE AND TOTAL ABSORPTION WITH ΔT

PROBLEM FOUR

EDMISTER CALCULATION

PRESSURE 410 PSIA THEORETICAL PLATES NINE

(T_{LG}) Lean Gas Temp. °R	(T_{LO}) Lean Oil Temp. °R	(T_{RO}) Rich Oil Temp. °R	(ΔT) Difference (T_{LG}-T_{LO})	Lean Oil Rate Mols	Absorption Mols
517.50	533	553.52	-15.5	11.65712	7.64707
522.50	533	551.11	-10.5	11.42600	7.68806
527.50	533	548.69	- 5.5	11.65201	7.53772
533.00	533	545.82	+ 0.0	11.26801	7.60253
538.50	533	543.02	+ 5.5	10.93418	7.65779
543.50	533	540.13	+10.5	11.02377	7.47255
548.50	533	537.353	+15.5	10.61021	7.52413

TABLE VI

VARIATION OF LEAN OIL RATE AND TOTAL ABSORPTION WITH $\triangle T$

PROBLEM FIVE

EDMISTER CALCULATION

PRESSURE 1565 PSIA THEORETICAL PLATES SIX

(T_{LG}) Lean Gas Temp. °R	(T_{LO}) Lean Oil Temp. °R	(T_{RO}) Rich Oil Temp. °R	($\triangle T$) Difference (T_{LG}-T_{LO})	Lean Oil Rate Mols	Absorption Mols
517	532	540.57	-15	10.02563	14.95677
522	532	537.27	-10	9.89399	14.93642
527	532	534.27	- 5	9.49716	15.15418
532	532	531.08	0	9.44799	15.03087
537	532	527.86	+ 5	9.27407	15.03844
542	532	523.98	+10	8.60823	15.35168
547	532	520.49	+15	8.69742	15.00425

TABLE VII

VARIATION OF LEAN OIL RATE AND TOTAL ABSORPTION WITH $\triangle T$

PROBLEM SEVENTEEN

EDMISTER CALCULATION

PRESSURE 695 PSIA THEORETICAL PLATES NINE

(T_{LG}) Lean Gas Temp. °R	(T_{LO}) Lean Oil Temp. °R	(T_{RO}) Rich Oil Temp. °R	($\triangle T$) Difference (T_{LG}-T_{LO})	Lean Oil Rate Mols	Absorption Mols
539	554	574.26	-15	10.40333	11.51515
544	554	571.78	-10	10.41944	11.43860
549	554	569.18	- 5	10.80865	11.12062
554	554	566.46	+ 0	10.19859	11.38937
559	554	564.05	+ 5	9.96760	11.43324
564	554	561.23	+10	9.89088	11.34932
569	554	558.31	+15	9.50050	11.44340

TABLE VIII

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM ONE

PRESSURE 64.7 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency
Components	Mols	Mol Fractions	Mols	Mol Fractions	Factors
C_1	8.03963	.15838	0.29370	.00251	.03581
C_2	21.24683	.41856	3.75317	.03202	.15223
C_3	18.80398	.37044	14.52936	.12394	.43995
nC_4	2.63065	.05182	30.86815	.26332	.89646
nC_5	0.04036	.00079	50.78695	.43323	.99526
C_6			12.74819	.10875	.99990
C_7			4.24940	.03625	1.00000
Totals	50.76145	1.00000	117.22892	1.00000	

TABLE IX

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM TWO

PRESSURE 75 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	84.77541	.93240	2.14459	.02791	.02494
C_2	3.63546	.03998	0.69454	.00904	.16189
C_3	2.39332	.02632	2.92668	.03808	.55285
iC_4	0.05783	.00064	0.54217	.00705	.90465
nC_4	0.05663	.00062	1.41337	.01839	.96193
iC_5	0.00330	.00004	1.35670	.01765	.99760
C_{14}			67.77350	.88188	1.00000
Totals	90.92196	1.00000	76.85154	1.00000	

TABLE X

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM THREE

PRESSURE 195 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	65.10274	.90954	6.27726	.05319	.08794
C_2	6.15594	.08600	6.21406	.05265	.50235
C_3	0.31707	.00443	9.41293	.07976	.96741
iC_4	0.00101	.00001	1.28899	.01092	.99922
nC_4	0.00050	.00001	3.18950	.02703	.99984
iC_5			0.72000	.00610	1.00000
nC_5			1.32000	.01118	1.00000
C_{12}			89.59562	.75917	1.00000
Totals	71.57727	1.00000	118.01835	1.00000	

TABLE XI

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM FOUR

PRESSURE 410 PSIA

Components	Lean Gas Mols	Lean Gas Mol Fractions	Rich Oil Mols	Rich Oil Mol Fractions	Absorption Efficiency Factors
C_1	83.70510	.90279	1.87990	.08392	.02220
C_2	6.53774	.07051	0.91026	.04063	.12338
C_3	2.32511	.02508	1.48889	.06646	.39295
iC_4	0.09789	.00106	0.52611	.02349	.84449
nC_4	0.05232	.00056	1.40868	.06288	.96452
iC_5	0.00006	.00000	1.06794	.04767	.99994
C_{12}			15.11946	.67494	1.00000
Totals	92.71822	1.00000	22.40124	1.00000	

TABLE XII

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM FIVE

PRESSURE 1565 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	78.99507	.91667	6.88493	.21477	.08103
C_2	5.89270	.06838	2.55730	.07977	.30509
C_3	1.22730	.01424	2.40270	.07495	.66450
iC_4	0.04047	.00047	0.50953	.01589	.92725
nC_4	0.01987	.00023	0.80013	.02496	.97608
iC_5	0.00018	.00000	0.18982	.00592	.99907
nC_5	0.00015	.00000	0.47985	.01497	.99970
C_{11}			18.23245	.56876	1.00000
Totals	86.17574	1.00000	32.05671	1.00000	

TABLE XIII

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM SIX

PRESSURE 1575 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	77.11005	.92170	8.37996	.22771	.09909
C_2	5.35284	.06398	3.21716	.08742	.37819
C_3	1.09276	.01306	2.76724	.07519	.71934
iC_4	0.05955	.00071	0.55045	.01496	.90350
nC_4	0.03914	.00047	0.73086	.01986	.94982
iC_5	0.00644	.00008	0.69356	.01885	.99094
C_{11}			20.46198	.55601	1.00000
Totals	83.66077	1.00000	36.80122	1.00000	

TABLE XIV

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM SEVEN

PRESSURE 94.7 PSIA

Components	Lean Gas Mols	Lean Gas Mol Fractions	Rich Oil Mols	Rich Oil Mol Fractions	Absorption Efficiency Factors
C_1	17.39947	.78097	4.06053	.01991	.19637
C_2	4.64876	.20866	22.49124	.11029	.83510
C_3	0.23099	.01037	50.06901	.24553	.99561
iC_4	0.00011	.00001	0.54989	.00270	.99980
nC_4	0.00002	.00000	0.39998	.00196	.99994
iC_5			0.15000	.00074	1.00000
C_{14}			126.20231	.61887	1.00000
Totals	22.27936	1.00000	203.92296	1.00000	

TABLE XV

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM EIGHT

PRESSURE 545 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	73.24895	.92807	4.49105	.09430	.05847
C_2	4.81801	.06104	2.16199	.04539	.31245
C_3	0.85640	.01085	5.61360	.11787	.86908
iC_4	0.00209	.00003	1.57791	.03313	.99870
nC_4	0.00046	.00001	3.26954	.06865	.99986
iC_5			1.33000	.02793	1.00000
nC_5			0.96000	.02016	1.00000
C_6			1.67000	.03506	1.00000
C_{13}			26.55263	.55752	1.00000
Totals	78.92591	1.00000	47.62673	1.00000	

TABLE XVI

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM NINE

PRESSURE 80.7 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	76.02629	.93354	6.17371	.14078	.07597
C_2	4.31113	.05294	2.58887	.05904	.37810
C_3	1.07176	.01316	5.53824	.12629	.83951
iC_4	0.01589	.00020	0.79411	.01811	.98061
nC_4	0.01282	.00016	1.89718	.04326	.99337
iC_5	0.00058	.00001	1.56942	.03579	.99964
C_{14}			25.29116	.57673	1.00000
Totals	81.43847	1.00000	43.85270	1.00000	

TABLE XVII

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM TEN

PRESSURE 720 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency
Components	Mols	Mol Fractions	Mols	Mol Fractions	Factors
C_1	77.02897	.88038	3.76644	.11910	.04662
C_2	7.71001	.08812	2.27511	.07194	.22785
C_3	2.68607	.03070	4.35349	.13767	.61843
iC_4	0.04323	.00049	0.57353	.01814	.92991
nC_4	0.02662	.00030	1.08993	.03447	.97616
iC_5	0.00014	.00000	0.15937	.00504	.99911
nC_5	0.00008	.00000	0.28703	.00908	.99969
C_{13}			19.11845	.60457	1.00000
Totals	87.49512	1.00000	31.62333	1.00000	

TABLE XVIII

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM ELEVEN

PRESSURE 60.7 PSIA

Components	Lean Gas Mols	Lean Gas Mol Fractions	Rich Oil Mols	Rich Oil Mol Fractions	Absorption Efficiency Factors
C_1	50.96987	.75244	2.04013	.01421	.03904
C_2	11.35853	.16768	3.45147	.02404	.23572
C_3	5.24058	.07736	13.18942	.09187	.71867
iC_4	0.09412	.00139	2.78588	.01940	.96779
nC_4	0.07533	.00111	7.21467	.05025	.98982
iC_5	0.00088	.00001	3.57912	.02493	.99976
C_{14}			111.30942	.77530	1.00000
Totals	67.73932	1.00000	143.57011	1.00000	

TABLE XIX

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM TWELVE

PRESSURE 865 PSIA

Components	Lean Gas Mols	Lean Gas Mol Fractions	Rich Oil Mols	Rich Oil Mol Fractions	Absorption Efficiency Factors
C_1	86.67038	.94412	4.06962	.16985	.04532
C_2	4.44632	.04843	1.31368	.05483	.22999
C_3	0.68268	.00744	1.35732	.05665	.66778
iC_4	0.00082	.00001	0.23918	.00998	.99662
nC_4	0.00005	.00000	0.52995	.02212	.99991
iC_5			0.26000	.01085	1.00000
nC_5			0.15000	.00626	1.00000
C_6			0.28000	.01169	1.00000
C_{12}			15.76065	.65778	1.00000
Totals	91.80026	1.00000	23.96039	1.00000	

TABLE XX

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM THIRTEEN

PRESSURE 975 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	84.55677	.93711	4.62323	.16607	.05239
C_2	4.41467	.04893	1.26533	.04545	.22470
C_3	1.16101	.01287	1.47899	.05313	.56296
iC_4	0.06691	.00074	0.55309	.01987	.89319
nC_4	0.03136	.00035	0.79864	.02869	.96265
iC_5	0.00039	.00000	0.31961	.01148	.99881
nC_5	0.00028	.00000	0.72972	.02621	.99962
C_{14}			18.07077	.64911	1.00000
Totals	90.23139	1.00000	27.83938	1.00000	

TABLE XXI

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM FOURTEEN

PRESSURE 208.7 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	8.78672	.32394	1.46500	.01136	.14765
C_2	16.99026	.62639	32.32968	.25074	.66406
C_3	1.33085	.04906	32.62165	.25300	.96222
iC_4	0.00938	.00035	2.13232	.01654	.99579
nC_4	0.00689	.00025	3.62689	.02813	.99818
iC_5	0.00011	.00000	0.70025	.00543	.99984
C_{12}			56.06252	.43480	1.00000
Totals	27.12421	1.00000	128.93831		

TABLE XXII

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM FIFTEEN

PRESSURE 266 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	44.94589	.75544	3.46411	.03799	.07269
C_2	12.81061	.21532	7.27939	.07983	.36626
C_3	1.73807	.02921	20.22193	.22178	.92208
iC_4	0.00123	.00002	2.22877	.02444	.99946
nC_4	0.00043	.00001	6.03957	.06624	.99993
iC_5			0.69000	.00757	1.00000
nC_5			0.58000	.00636	1.00000
C_{12}			50.67830	.55579	1.00000
Totals	59.49623	1.00000	91.18207	1.00000	

TABLE XXIII

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM SIXTEEN

PRESSURE 427 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	78.90203	.88208	2.41797	.07958	.03006
C_2	7.35708	.08225	1.35292	.04453	.15681
C_3	3.07047	.03433	2.72953	.08984	.47339
iC_4	0.08360	.00093	0.82640	.02720	.90901
nC_4	0.03660	.00041	1.76340	.05804	.97987
iC_5	0.00012	.00000	1.45988	.04805	.99992
C_{14}			19.83366	.65277	1.00000
Totals	89.44989	1.00000	30.38377	1.00000	

TABLE XXIV

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM SEVENTEEN

PRESSURE 695 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency
Components	Mols	Mol Fractions	Mols	Mol Fractions	Factors
C_1	76.50167	.86820	3.11661	.10578	.03962
C_2	8.77644	.09960	1.94221	.06592	.18307
C_3	2.71910	.03086	2.65894	.09024	.49753
iC_4	0.07582	.00086	0.71669	.02432	.90538
nC_4	0.04178	.00047	2.01213	.06829	.97988
iC_5	0.00003	.00000	0.40833	.01386	.99993
nC_5	0.00001	.00000	1.03025	.03497	.99999
C_{13}			17.57845	.59662	1.00000
Totals	88.11485	1.00000	29.46361		

TABLE XXV

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM EIGHTEEN

PRESSURE 950 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	81.01406	.94880	6.78594	.16771	.07813
C_2	3.87786	.04542	1.98214	.04899	.34089
C_3	0.48782	.00571	2.25218	.05566	.82366
iC_4	0.00526	.00006	0.87474	.02162	.99409
nC_4	0.00078	.00001	0.87922	.02173	.99913
iC_5			0.47000	.01162	1.00000
nC_5			1.37000	.03386	1.00000
C_{13}			25.84908	.63883	1.00000
Totals	85.38579	1.00000	40.46329	1.00000	

TABLE XXVI

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM NINETEEN

PRESSURE 1464 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency
Components	Mols	Mol Fractions	Mols	Mol Fractions	Factors
C_1	79.92337	.91537	5.87663	.19713	.06923
C_2	5.56983	.06379	1.91017	.06408	.25756
C_3	1.71338	.01962	2.30662	.07738	.57659
iC_4	0.06852	.00078	0.57148	.01917	.89408
nC_4	0.03695	.00042	1.16305	.03901	.96959
iC_5	0.00042	.00000	0.85958	.02884	.99952
C_{14}			17.12290	.57439	1.00000
Totals	87.31247	1.00000	29.81043	1.00000	

TABLE XXVII

KREMSER-BROWN MATERIAL BALANCE AND ABSORPTION EFFICIENCY FACTORS

PROBLEM TWENTY

PRESSURE 1815 PSIA

	Lean Gas		Rich Oil		Absorption Efficiency Factors
Components	Mols	Mol Fractions	Mols	Mol Fractions	
C_1	76.56826	.91161	8.82174	.22988	.10443
C_2	4.24197	.05050	1.90803	.04972	.31281
C_3	2.66746	.03176	3.05254	.07954	.53664
iC_4	0.20221	.00241	0.46779	.01219	.70074
nC_4	0.20326	.00242	0.65674	.01711	.76584
iC_5	0.03100	.00037	0.24900	.00649	.89050
nC_5	0.07817	.00093	0.85183	.02220	.91690
C_{14}			22.36844	.58287	1.00000
Totals	83.99234	1.00000	38.37610	1.00000	

TABLE XXVIII

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM ONE

PRESSURE 64.7 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	8.05587	.11357	0.27747	.00242	.03330	
C_2	21.36965	.30127	3.63036	.03167	.14521	
C_3	18.66995	.26321	14.66338	.12790	.43990	
nC_4	12.67279	.17866	23.02467	.20083	.66383	
nC_5	8.98392	.12666	52.83670	.46086		.05434
C_6	1.06148	.01497	14.98470	.13070		.06615
C_7	0.11742	.00166	5.23132	.04563		.02195
Totals	70.93108	1.00000	114.64861	1.00000		

TABLE XXIX

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM TWO

PRESSURE 75 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	84.63639	.93238	2.28362	.02956	.02627	
C_2	3.61391	.03981	0.71609	.00927	.16538	
C_3	2.37751	.02619	2.94249	.03809	.55310	
iC_4	0.05943	.00065	0.54057	.00700	.90095	
nC_4	0.05924	.00065	1.41076	.01826	.95970	
iC_5	0.00367	.00004	1.35633	.01756	.99730	
C_{14}	0.02427	.00027	67.99675	.88026		.00036
Totals	90.77441	1.00000	77.24661	1.00000		

TABLE XXX

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM THREE

PRESSURE 195 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	65.17666	.90932	6.20334	.05282	.08691	
C_2	6.17629	.08617	6.19371	.05273	.50070	
C_3	0.29976	.00418	9.43024	.08029	.96919	
iC_4	0.00089	.00001	1.28911	.01098	.99931	
nC_4	0.00043	.00001	3.18957	.02716	.99986	
iC_5	0.00000	.00000	0.72000	.00613	1.00000	
nC_5	0.00000	.00000	1.32000	.01124	1.00000	
C_{12}	0.02254	.00031	89.10775	.75866		.00025
Totals	71.67658	1.00000	117.45372	1.00000		

TABLE XXXI

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM FOUR

PRESSURE 410 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	83.47049	.90250	2.11451	.11441	.02471	
C_2	6.47064	.06996	0.97736	.05288	.13123	
C_3	2.31583	.02504	1.49817	.08107	.39281	
iC_4	0.11641	.00126	0.50759	.02747	.81344	
nC_4	0.07947	.00086	1.38153	.07475	.94560	
iC_5	0.00018	.00000	1.06782	.05778	.99983	
C_{12}	0.03553	.00038	10.93409	.59164		.00324
Totals	92.48855	1.00000	18.48107	1.00000		

TABLE XXXII

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM FIVE

PRESSURE 1565 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	78.02706	.91724	7.85294	.33445	.09144	
C_2	5.69729	.06697	2.75271	.11723	.32576	
C_3	1.21539	.01429	2.41461	.10283	.66518	
iC_4	0.04824	.00057	0.50176	.02137	.91229	
nC_4	0.02735	.00032	0.79265	.03376	.96665	
iC_5	0.00036	.00000	0.18964	.00808	.99812	
nC_5	0.00033	.00000	0.47967	.02043	.99932	
C_{11}	0.05108	.00060	8.49646	.36185		.00598
Totals	85.06710	1.00000	23.48045	1.00000		

TABLE XXXIII

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM SIX

PRESSURE 1575 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	75.67415	.92260	9.81585	.35547	.11482	
C_2	5.10904	.06229	3.46096	.12533	.40385	
C_3	1.08296	.01320	2.77704	.10057	.71944	
iC_4	0.06634	.00081	0.54366	.01969	.89125	
nC_4	0.04752	.00058	0.72248	.02616	.93828	
iC_5	0.00937	.00011	0.69063	.02501	.98662	
C_{11}	0.03326	.00041	9.60322	.34777		.00345
Totals	82.02264	1.00000	27.61384			

TABLE XXXIV

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM SEVEN

PRESSURE 94.7 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	18.43323	.76155	3.02677	.01059	.14104	
C_2	5.54713	.22917	21.59287	.07555	.79561	
C_3	0.21994	.00909	50.08006	.17523	.99563	
iC_4	0.00009	.00000	0.54991	.00192	.99983	
nC_4	0.00002	.00000	0.39998	.00140	.99995	
iC_5	0.00000	.00000	0.15000	.00052	1.00000	
C_{14}	0.00460	.00019	209.99260	.73477		.00002
Totals	24.20502	1.00000	285.79219	1.00000		

TABLE XXXV

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM EIGHT

PRESSURE 545 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	72.25806	.92916	5.48194	.12661	.07052	
C_2	4.65452	.05985	2.32548	.05371	.33316	
C_3	0.84725	.01089	5.62275	.12986	.86905	
iC_4	0.00243	.00003	1.57757	.03644	.99846	
nC_4	0.00059	.00001	3.26941	.07551	.99982	
iC_5	0.00000	.00000	1.33000	.03072	1.00000	
nC_5	0.00000	.00000	0.96000	.02217	1.00000	
C_6	0.00000	.00000	1.67000	.03857	1.00000	
C_{13}	0.00457	.00006	21.06066	.48641		.00022
Totals	77.76742	1.00000	43.29780	1.00000		

TABLE XXXVI

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM NINE

PRESSURE 80.7 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	75.05021	.93443	7.14979	.19738	.08698	
C_2	4.17309	.05196	2.72691	.07528	.39520	
C_3	1.05947	.01319	5.55053	.15323	.83972	
iC_4	0.01663	.00021	0.79337	.02190	.97947	
nC_4	0.01386	.00017	1.89614	.05234	.99274	
iC_5	0.00065	.00001	1.56935	.04332	.99958	
C_{14}	0.00232	.00003	16.53784	.45654		.00014
Totals	80.31624	1.00000	36.22392	1.00000		

TABLE XXXVII

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM TEN

PRESSURE 720 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	76.41397	.88133	4.38143	.17681	.05423	
C_2	7.50091	.08651	2.48420	.10025	.24879	
C_3	2.67344	.03090	4.36047	.17596	.61943	
iC_4	0.05408	.00062	0.56268	.02271	.91231	
nC_4	0.03922	.00045	1.07733	.04347	.96487	
iC_5	0.00031	.00000	0.15920	.00642	.99804	
nC_5	0.00021	.00000	0.28690	.01158	.99925	
C_{13}	0.01497	.00017	11.46895	.46281		.00130
Totals	86.69711	1.00000	24.78116	1.00000		

TABLE XXXVIII

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM ELEVEN

PRESSURE 60.7 PSIA

Components	Lean Gas		Rich Oil		Efficiency Factors	
	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	50.95308	.75267	2.05692	.01356	.03880	
C_2	11.37343	.16801	3.43657	.02265	.23204	
C_3	5.18849	.07664	13.24151	.08727	.71848	
iC_4	0.09096	.00134	2.78904	.01838	.96842	
nC_4	0.07108	.00105	7.21892	.04757	.99025	
iC_5	0.00083	.00001	3.57917	.02359	.99977	
C_{14}	0.01836	.00027	119.41662	.78699		.00015
Totals	67.69623	1.00000	151.73875	1.00000		

TABLE XXXIX

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM TWELVE

PRESSURE 865 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	86.00002	.94483	4.73998	.23969	.05224	
C_2	4.31873	.04745	1.44127	.07288	.25022	
C_3	0.67638	.00743	1.36362	.06895	.66844	
iC_4	0.00165	.00002	0.23835	.01205	.99312	
nC_4	0.00015	.00000	0.52985	.02679	.99972	
iC_5	0.00000	.00000	0.26000	.01315	1.00000	
nC_5	0.00000	.00000	0.15000	.00759	1.00000	
C_6	0.00000	.00000	0.28000	.01416	1.00000	
C_{12}	0.02500	.00027	10.77269	.54474		.00232
Totals	91.02193	1.00000	19.77576	1.00000		

TABLE XL

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM THIRTEEN

PRESSURE 975 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	83.99677	.93739	5.18323	.23451	.05812	
C_2	4.32931	.04831	1.35069	.06111	.23780	
C_3	1.15481	.01289	1.48519	.06720	.56257	
iC_4	0.07726	.00086	0.54274	.02456	.87539	
nC_4	0.04122	.00046	0.78878	.03569	.95033	
iC_5	0.00070	.00001	0.31930	.01445	.99781	
nC_5	0.00056	.00001	0.72944	.03300	.99924	
C_{14}	0.00670	.00007	11.70321	.52950		.00057
Totals	89.60734	1.00000	22.10258	1.00000		

TABLE XLI

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM FOURTEEN

PRESSURE 208.7 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	8.91796	.32126	1.33377	.00986	.13010	
C_2	17.53677	.63174	31.78316	.23492	.64443	
C_3	1.28006	.04611	32.67243	.24150	.96230	
iC_4	0.00868	.00031	2.13302	.01577	.99595	
nC_4	0.00633	.00023	3.62745	.02681	.99826	
iC_5	0.00010	.00000	0.70026	.00518	.99985	
C_{12}	0.00937	.00034	63.04135	.46597		.00015
Totals	27.75927	1.00000	135.29144	1.00000		

TABLE XLII

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM FIFTEEN

PRESSURE 266 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	44.70374	.75681	3.70626	.04220	.07656	
C_2	12.63594	.21392	7.45406	.08487	.37103	
C_3	1.69471	.02869	20.26529	.23073	.92283	
iC_4	0.00120	.00002	2.22880	.02538	.99946	
nC_4	0.00042	.00001	6.03958	.06876	.99993	
iC_5	0.00000	.00000	0.69000	.00786	1.00000	
nC_5	0.00000	.00000	0.58000	.00660	1.00000	
C_{12}	0.03236	.00055	46.86871	.53361		.00069
Totals	59.06838	1.00000	87.83269	1.00000		

TABLE XLIII

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM SIXTEEN

PRESSURE 427 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	78.56075	.88241	2.75925	.10690	.03393	
C_2	7.25922	.08154	1.45078	.05620	.16657	
C_3	3.05440	.03431	2.74560	.10637	.47338	
iC_4	0.09851	.00111	0.81149	.03144	.89175	
nC_4	0.05075	.00057	1.74925	.06777	.97181	
iC_5	0.00024	.00000	1.45976	.05655	.99984	
C_{14}	0.00560	.00006	14.83641	.57477		.00038
Totals	89.02945	1.00000	25.81256	1.00000		

TABLE XLIV

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM SEVENTEEN

PRESSURE 695 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	75.99224	.86869	3.62604	.15748	.04554	
C_2	8.60082	.09832	2.11783	.09198	.19758	
C_3	2.70018	.03087	2.67786	.11630	.49792	
iC_4	0.09769	.00112	0.69482	.03018	.87673	
nC_4	0.07137	.00082	1.98254	.08611	.96525	
iC_5	0.00010	.00000	0.40826	.01773	.99975	
nC_5	0.00006	.00000	1.03020	.04474	.99995	
C_{13}	0.01703	.00019	10.48712	.45547		.00162
Totals	87.47949	1.00000	23.02467	1.00000		

TABLE XLV

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM EIGHTEEN

PRESSURE 950 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	80.27741	.94953	7.52259	.22751	.08568	
C_2	3.76235	.04450	2.09765	.06344	.35796	
C_3	0.48277	.00571	2.25723	.06827	.82381	
iC_4	0.00650	.00008	0.87350	.02642	.99261	
nC_4	0.00107	.00001	0.87893	.02658	.99878	
iC_5	0.00000	.00000	0.47000	.01421	.99999	
nC_5	0.00000	.00000	1.37000	.04143	1.00000	
C_{13}	0.01444	.00017	17.59539	.53214		.00082
Totals	84.54455	1.00000	33.06528	1.00000		

TABLE XLVI

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM NINETEEN

PRESSURE 1464 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	79.12557	.91575	6.67443	.29513	.07779	
C_2	5.43230	.06287	2.04770	.09054	.27376	
C_3	1.70336	.01971	2.31664	.10244	.57628	
iC_4	0.08220	.00095	0.55780	.02466	.87156	
nC_4	0.05393	.00062	1.14607	.05068	.95506	
iC_5	0.00099	.00001	0.85901	.03798	.99884	
C_{14}	0.00649	.00008	9.01368	.39857		.00072
Totals	86.40486	1.00000	22.61532	1.00000		

TABLE XLVII

EDMISTER MATERIAL BALANCE AND ABSORPTION - STRIPPING EFFICIENCY FACTORS

PROBLEM TWENTY

PRESSURE 1815 PSIA

	Lean Gas		Rich Oil		Efficiency Factors	
Components	Mols	Mol Fractions	Mols	Mol Fractions	Absorption	Stripping
C_1	76.11659	.91166	9.27341	.36049	.10860	
C_2	4.18668	.05014	1.96332	.07632	.31924	
C_3	2.65139	.03176	3.06861	.11929	.53647	
iC_4	0.20437	.00245	0.46563	.01810	.69497	
nC_4	0.20735	.00248	0.65265	.02537	.75890	
iC_5	0.03281	.00039	0.24719	.00961	.88281	
nC_5	0.08381	.00100	0.84619	.03289	.90989	
C_{14}	0.00972	.00012	9.20763	.35793		.00105
Totals	83.49272	1.00000	25.72464			

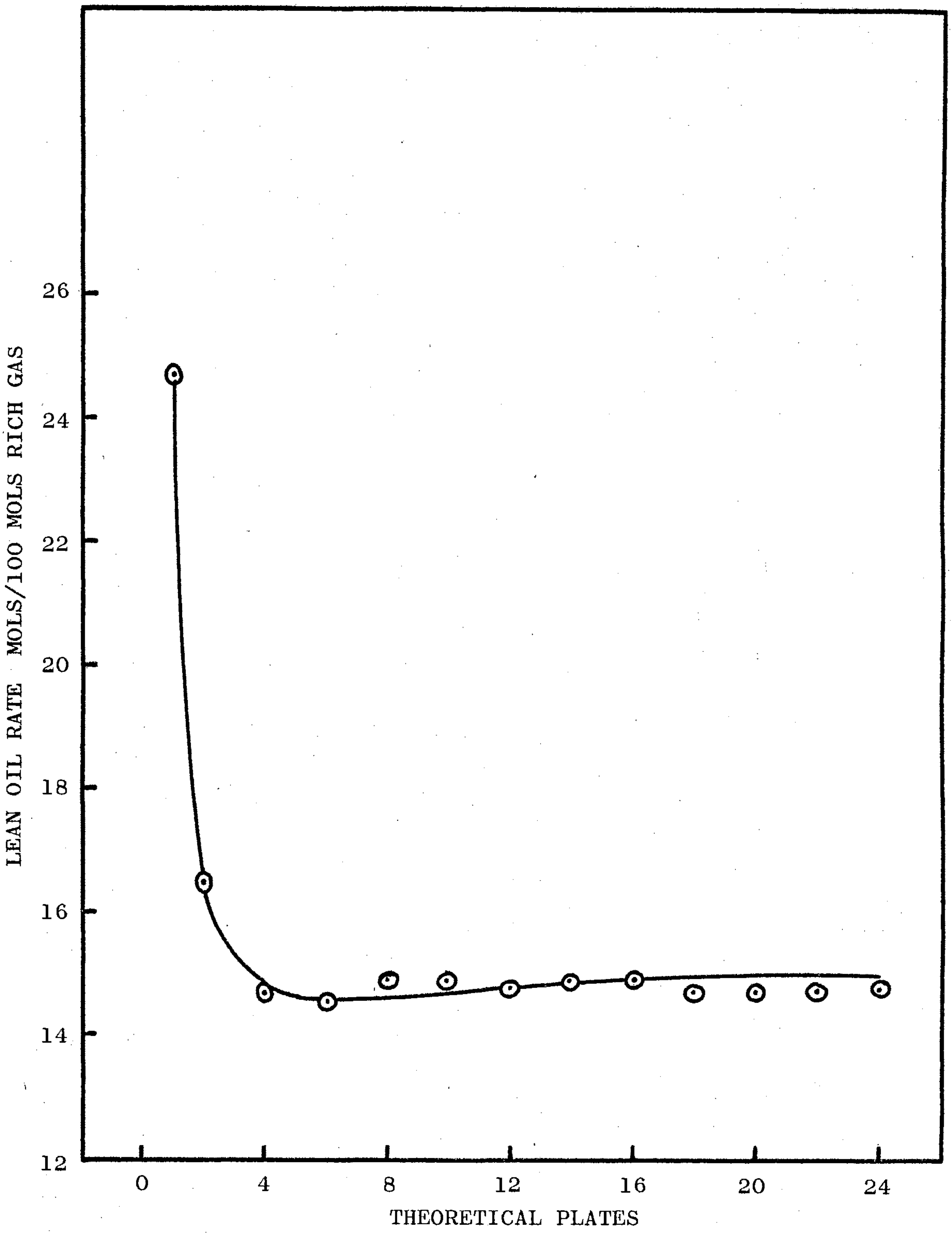

FIGURE 2

PLATE - LEAN OIL RATE DIAGRAM

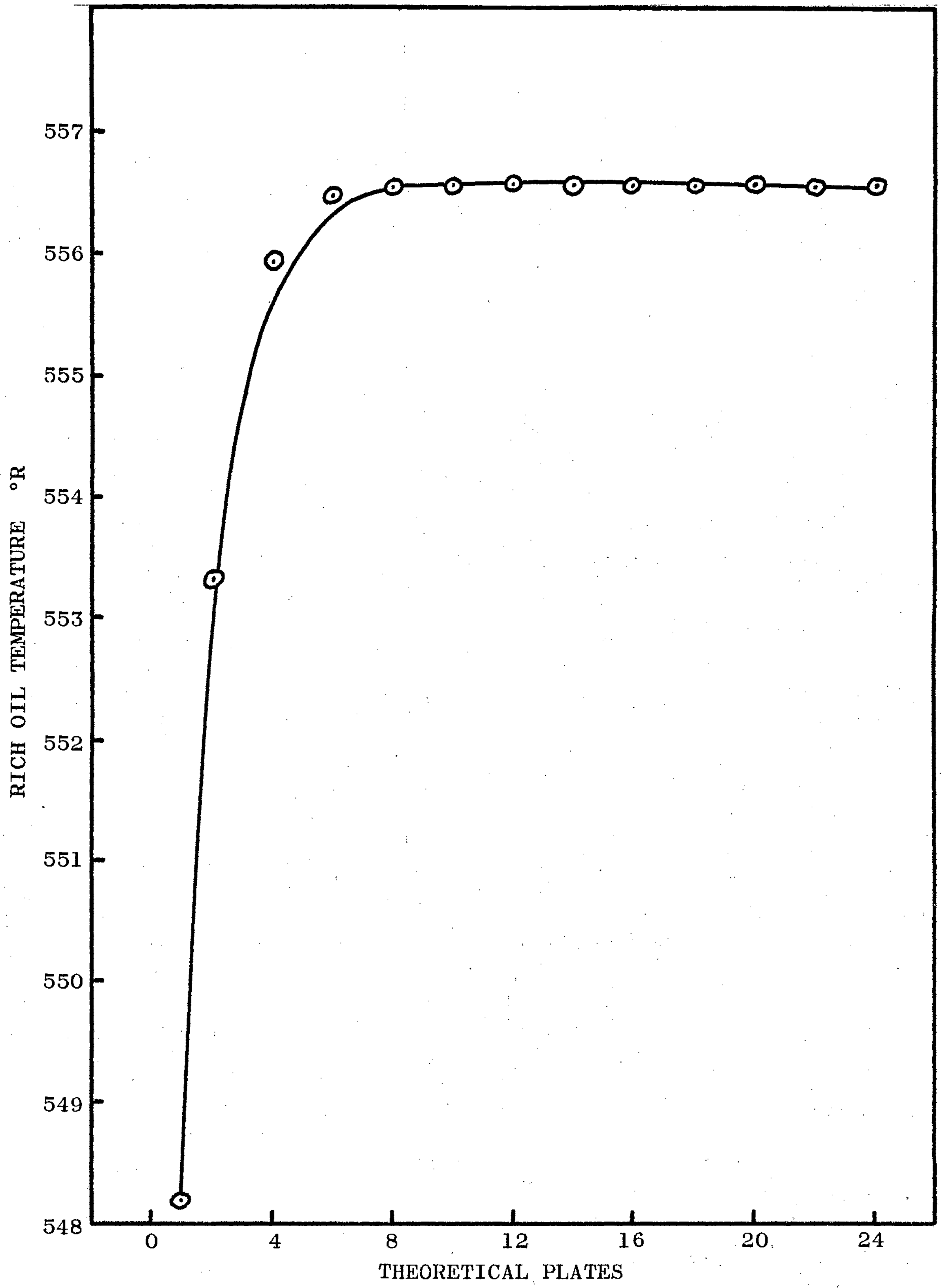

FIGURE 3

PLATE - RICH OIL TEMPERATURE DIAGRAM

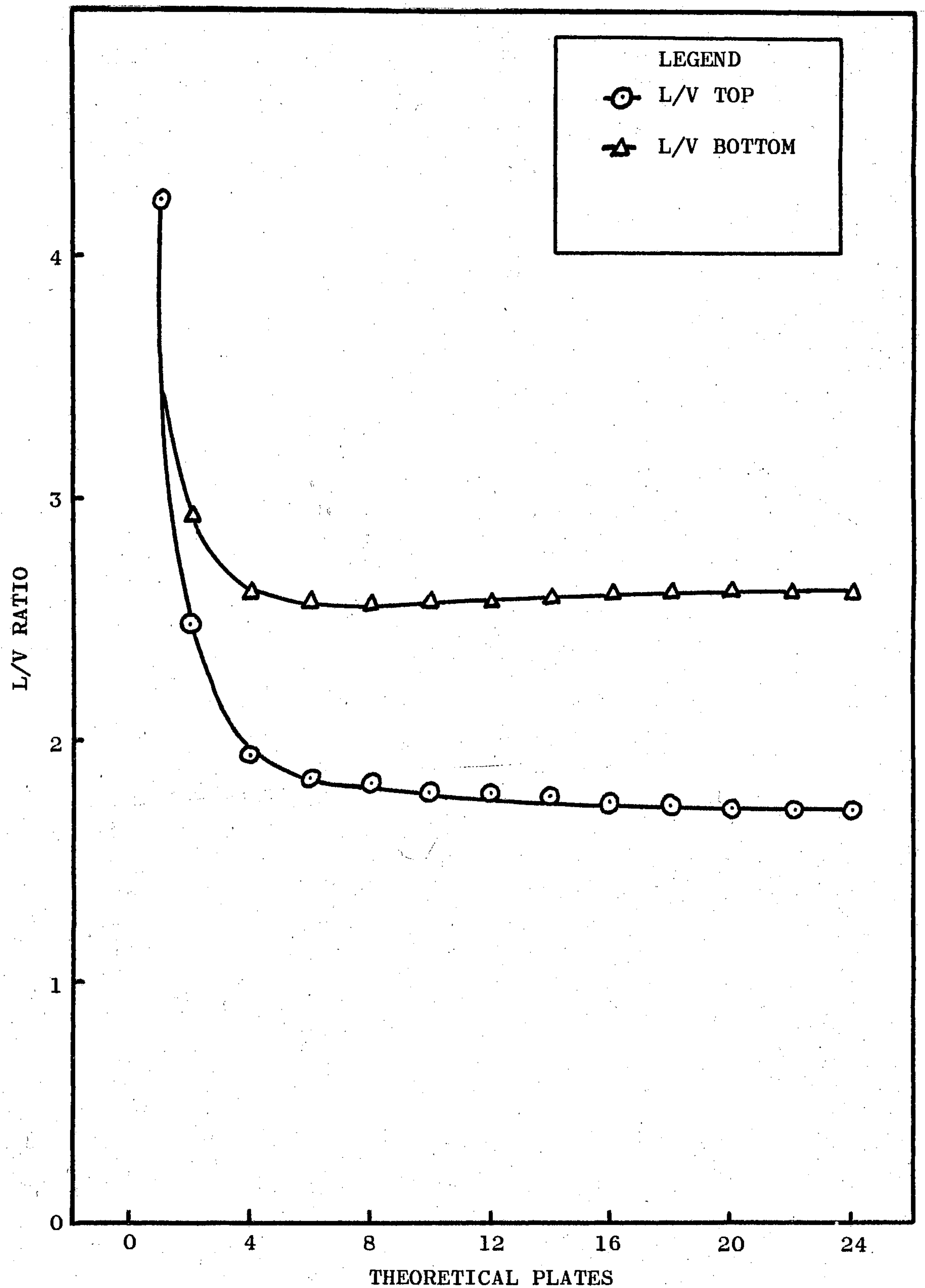

FIGURE 4

PLATE - L/V RATIO DIAGRAM

CHAPTER V

DISCUSSION OF RESULTS

The program for the computer performs the required calculations on a non-reboiled absorber. The rich gas feed and lean oil solvent compositions are each limited to not more than twenty individual components. Absorption problems generally encountered do not possess feed product streams containing more than ten components; therefore, a program limited to twenty components for the stream compositions should prove adequate.

The number of plates of each problem used to evaluate the performance of the developed program are reported by NGAA (15) as actual plates. The problem of reducing the number of actual plates to an equivalent number of theoretical plates is immediately evident. No information regarding over-all plate efficiencies of the absorber towers on which test runs were performed is available. The over-all plate efficiencies of low pressure hydrocarbon absorbers have been reported to range between 20 and 45 percent and high pressure towers (100 to 500 psia) between 45 and 60 percent (8). With these efficiencies as guides, the problems obtained from NGAA were run on the computer with the theoretical plate number being varied until the lean gas composition closely matched that of experimental data. The properties of the lean solvent oils usually given are normal boiling points and molecular weights but may or may not include information regarding the composition of the oil in terms of individual components. Problem data from NGAA provide only molecular weights of the solvent oils. The assumption was made that the solvent oil would behave as the pure hydrocarbon having the molecular weight nearest that of the solvent oil. Estimation of K equilibrium data and enthalpies was then made for the lean oil as if it were a pure hydrocarbon stream.

The criterion for considering performance of the program good is that the calculated lean oil requirements, temperatures, and product compositions be similar to those obtained during actual test runs.

The lean gas, lean oil, and rich oil rates calculated by the program are presented in Tables I and II. Also presented are test run data listed as "experimental" with the exception of Problem One. The experimental data for Problem One was obtained by hand calculations using dew point and bubble point calculations to estimate the lean gas and rich oil temperatures. Comparison of the results obtained by the Kremser-Brown method and those obtained by the Edmister method with actual experimental data indicate the Edmister results are consistently closer than the Kremser-Brown to experimental values. This is to be expected because the Kremser-Brown calculations are based on the arithmetic average of the temperatures and pressures existing at the top and bottom of the absorber. Also, the Kremser-Brown performs calculations as if no absorption had occurred. No provision is made in the Kremser-Brown portion of the program for possible stripping of light components from the lean oil during its passage through the tower. If an essentially denuded oil is used as the solvent to the tower, the above assumption of no stripping would have no great consequence on the Kremser-Brown results. The Kremser-Brown lean oil rates, without exception, compare unfavorably with actual test run data. The Edmister stream rates approximate actual test run results with a much greater degree of accuracy than do the rates obtained from the Kremser-Brown calculations.

Although the approximation of actual test run data by the Edmister method is better than by the Kremser-Brown, the results obtained for Problems 7 and 9 do not compare with any degree of accuracy to the experimental results. Possible error could have resulted from poor determination of the number of theoretical plates to be used in the problems. The experimental lean oil to rich gas ratios of these problems are 1.75 for Problem 9 and 2.98 for Problem 7. These ratios are much larger than those of the other problems used in this study. This fact indicates the lean oil to rich oil ratios used during the test runs of Problems 7 and 9 could have been in excess of those necessary.

As shown in Table III, the rich oil temperatures calculated by heat balance agree well with actual data for low pressure absorber systems but for high pressure absorber systems the deviation from actual data becomes quite evident. This deviation was probably a result of error in vapor and liquid enthalpies used for the high pressure range. The curves of the enthalpy charts used (16) were extrapolated to obtain the required liquid and vapor enthalpies for high pressures. Error in estimating enthalpies from extrapolated curves was probable.

The deviations from actual test run data indicated in Tables I, II, and III might be partially attributed to the following factor. The K equilibrium data used in the curve fitting routines were obtained from NGAA charts for a range of temperatures from 0°F to 200°F. This range was in excess of that needed to calculate equilibrium data for the tower temperatures encountered in this study. The temperature range in experimental data was from 50°F to 120°F. An excessive range for K data is expected to introduce error in the determination of product stream compositions, temperatures, and lean oil requirements. A least squares curve fit of data obtained over an excessive temperature range results in local deviations from actual equilibrium data.

Figures 2 and 3 relate the effect of the number of theoretical plates on the rich oil temperature and lean oil rate of Problem 16. The temperature of the rich oil increased sharply with an initial increase of theoretical plates but remained almost constant with a number of theoretical plates in excess of eight. Similarly, after a sharp initial decrease in lean oil requirements, an almost constant quantity of lean oil was calculated if more than eight theoretical plates were used. Figure 4 indicates the effect of theoretical plates on L/V ratios. The L/V ratios first decreased in value with an increase of theoretical plates. Upon further increases of theoretical plates, the L/V ratios approached constant values. Similar behavior for other problems was observed during the performance study.

The above observations can be explained by examination of Equations 8 and 13 in Appendix B. Each of these equations contain a quantity similar to the term

$$\frac{A^{n+1} - A}{A^{n+1} - 1} .$$

This term may be expressed as

$$\frac{\left(\frac{L}{KV}\right)^{n+1} - \frac{L}{KV}}{\left(\frac{L}{KV}\right)^{n+1} - 1} .$$

In Equations 8 and 13, the required value of A, for a specified absorption efficiency, decreases with an increase in the number of theoretical plates. Using the equivalent for the absorption factor L/KV, one observes that the value of L/V (K equilibrium value is essentially constant) must decrease if the specified value of the left hand side of Equations 8 and 13 is to be maintained. If V (the gas stream) is considered essentially constant throughout the absorber, the decrease of the L/V ratio results from a decrease of the lean oil rate. An increase of plates is, therefore, expected to decrease the lean oil rate requirement. The rich oil temperature of the absorber is calculated by a heat balance around the tower. If the liquid quantity passing through the absorber is reduced, the heat balance around the tower is maintained by increasing the temperature of the liquid leaving the tower. With the total absorption remaining essentially the same, the reduction of lean oil rate provides less oil to take up the heat of absorption.

Estimation of the temperatures of the lean gas stream and the rich oil stream were first attempted by dew point and bubble point calculations on the product streams. The method was unsuccessful for feed streams containing a large percentage of light hydrocarbons. The temperatures calculated by this method often differed as much as one hundred degrees from actual test run data. Consequently, dew point and bubble point estimation of the product stream temperatures was abandoned. The method used is the calculation of the rich oil temperature from an over-all heat balance with the lean gas temperature being specified in the input data.

During the performance study of the calculation sequence, the lean gas temperature in each of the twenty problems was set to the exact value of the lean gas temperature obtained during an actual test run. In actual use of the program, such specification of the lean gas temperature will not be possible. Past engineering experience or available information regarding the absorber to be evaluated will be necessary before a lean gas temperature can be fixed. The average temperature difference between the lean gas and lean oil temperatures for problems provided by NGAA was about nine degrees Fahrenheit. This value or some similar value may be used as a guide for fixing the lean gas temperature.

The effect of the lean gas temperature on total absorption and lean oil rate requirement are presented in Tables IV, V, VI, and VII. The lean gas temperature was varied by five degree increments above and below the lean oil temperatures in each of the four problems used for this investigation. The temperature of the rich oil stream decreased as the temperature of the lean gas increased. The reason for such behavior was that the rich oil temperature was determined by an over-all heat balance about the tower assumed to be adiabatic and in which no heat of solution occurred.

Also observed was an increase of the lean oil rate requirement with the increase of the lean gas temperature. If the number of plates is fixed, the lean oil rate increases. This increase results from the fact that K equilibrium values increase with temperature. If the absorption is to remain the same, the absorption factor must maintain a constant value. The factor remains constant because the L term in the quantity L/KV increases to compensate for the increasing K value. The gas quantity is not greatly affected by the small temperature change. The lean oil requirement and the total net absorption was not changed by any great percentage through a range of thirty degrees. The effect of an increase in the lean gas temperature, although small, was to increase the lean oil rate and decrease the total net mols absorbed. The conclusion made was that the results of tower calculations are not appreciably changed if the lean gas temperature is estimated with only a fair degree of accuracy.

Problems with lean gas temperatures less than the lean oil temperatures required a longer running time on the computer. The excessive time was caused by cycling that occurred in the Edmister method during the evaluation of a lean oil rate giving the correct absorption efficiency for the key component of the rich gas. The average time requirement of problems of this type for program loading, calculations, and punch out was between twenty-five and thirty minutes. The time requirement was shortened if the tolerance specified for the absorption efficiency was increased. Time requirement observed for the problems with a lean gas temperature greater than the lean oil temperature was under fifteen minutes.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to adapt a sequence of absorber calculations to the IBM 650 Digital Computer. The calculation sequence was to make a mathematic performance analysis on a straight-run non-reboiled absorber. The sequence utilizes the Kremser-Brown method to obtain a first approximation of tower performance. The Edmister absorber calculations are then performed with first assumptions based on the Kremser-Brown results.

Analysis of the results in Tables I, II, and III indicates the Kremser-Brown calculations do not compare favorably with actual test run data. The Edmister results agree reasonably well with available absorber performance data.

Product stream temperatures of absorbers using gas feeds having a large percentage methane or light hydrocarbon content could not be accurately estimated by dew point and bubble point calculations. Specification of the lean gas temperature in the input data and the calculation of the rich oil temperature by heat balance were adequate for most problems encountered.

The effect of increasing the value of the estimated lean gas temperature was small. The general trend caused by the increase was an increase of lean oil required, a decrease of total absorption, and a lower rich oil temperature.

An increased number of theoretical plates caused a sharp initial increase of the rich oil temperature followed by insignificant changes with continued plate increases. An initial decrease of lean oil rate requirement followed by only slight variation was observed with theoretical plate increases.

The program can provide extensive evaluation of absorber performance for different tower conditions by elimination of a large portion of the time element normally involved in multi-trial solutions.

Recommendations for future investigation are:

(1) Computer application to stripper calculations with an eventual goal of developing one program or two related programs capable of performing calculations for both strippers and absorbers.

(2) Application of the program to a study of over-all plate efficiencies on absorbers for which test run data are available.

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APPENDIX A

RICH GAS FEED AND LEAN OIL COMPOSITIONS FOR PROBLEMS USED IN PROGRAM EVALUATION

TABLE XLVIII

RICH GAS FEED AND LEAN OIL COMPOSITIONS

Problem Number	One		Two		Three		Four		Five	
Components	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn
C_1	8.33		86.92		71.38		85.585		85.88	
C_2	25.00		4.33		12.37		7.448		8.45	
C_3	33.33		5.32		9.73		3.814		3.63	
iC_4	-		0.60		1.29		0.624		0.55	
nC_4	25.00	0.1250	1.47		3.19		1.461		0.82	
iC_5	-	-	1.36		0.72		1.068		0.19	
nC_5	8.33	0.6250			1.32				0.48	
C_6		0.1875								
C_7		0.0625								
C_{11}										1.00
C_{12}						1.00		1.000		
C_{13}										
C_{14}				1.00						
Totals	100.00	1.0000	100.00	1.00	100.00	1.00	100.000	1.000	100.00	1.00

TABLE XLVIII (Continued)

Problem Number	Six		Seven		Eight		Nine		Ten	
Components	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn
C_1	85.49		21.46		77.74		82.20		80.80	
C_2	8.57		27.14		6.98		6.90		9.98	
C_3	3.86		50.30		6.47		6.61		7.04	
iC_4	0.61		0.55		1.58		0.81		0.62	
nC_4	0.77		0.40		3.27		1.91		1.12	
iC_5	0.70		0.15		1.33		1.57		0.16	
nC_5					0.96				0.29	
C_6					1.67					
C_7										
C_{11}		1.00								
C_{12}										
C_{13}						1.00				1.00
C_{14}				1.00				1.00		
Totals	100.00	1.00	100.00	1.00	100.00	1.00	100.00	1.00	100.00	1.00

TABLE XLVIII (Continued)

Problem Number	Eleven		Twelve		Thirteen		Fourteen		Fifteen	
Components	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn
C_1	53.01		90.74		89.18		10.25		48.41	
C_2	14.81		5.76		5.68		49.32		20.09	
C_3	18.43		2.04		2.64		33.95		21.96	
iC_4	2.88		0.24		0.62		2.14		2.23	
nC_4	7.29		0.53		0.83		3.63		6.04	
iC_5	3.58		0.26		0.32		0.70		0.69	
nC_5			0.15		0.73				0.58	
C_6			0.28							
C_7										
C_{11}										
C_{12}				1.00				1.00		1.00
C_{13}										
C_{14}		1.00				1.00				
Totals	100.00	1.00	100.00	1.00	100.00	1.00	100.00	1.00	100.00	1.00

TABLE XLVIII (Continued)

Problem Number	Sixteen		Seventeen		Eighteen		Nineteen		Twenty	
Components	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn	Rich Gas Mols	Lean Oil Mol Frn
C_1	81.32		79.618		87.80		85.80		85.39	
C_2	8.71		10.719		5.86		7.48		6.15	
C_3	5.80		5.378		2.74		4.02		5.72	
iC_4	0.91		0.792		0.88		0.64		0.67	
nC_4	1.80		2.054		0.88		1.20		0.86	
iC_5	1.46		0.408		0.47		0.86		0.28	
nC_5			1.030		1.37				0.93	
C_6										
C_7										
C_{11}										
C_{12}										
C_{13}				1.000		1.00				
C_{14}		1.00						1.00		1.00
Totals	100.00	1.00	100.000	1.000	100.00	1.00	100.00	1.00	100.00	1.00

APPENDIX B

DEVELOPMENT OF ABSORBER EQUATIONS

APPENDIX B

DEVELOPMENT OF ABSORBER EQUATIONS

Kremser-Brown Equations

Assumptions:

(1) Raoult's Law applies

(2) Theoretical plate concept applies.

(3) An average absorption factor may be used.

(4) The gas and oil stream quantities remain constant throughout the absorber or stripper column.

(5) Equilibrium between vapor and liquid exists on each theoretical plate.

Derivation: From the ideal gas law, the partial pressure p' of a solute gas equals the product of its vapor pressure P at the same temperature and its mol fraction in the solution x (Raoult's Law).

$$p' = Px$$

Because the partial pressure equals the total pressure multiplied by the mol fraction in the gas (Dalton's Law), Raoult's Law may be written:

$$\pi y = Px = p' \qquad (1)$$

A material balance around a column similar to the one shown in Figure 1 provides the following equation.

$$V_{n+1}(Y_{n+1} - Y_1) = L_o(X_n - X_o) \qquad (2)$$

The following equation is obtained by a material balance around Plate i.

$$V_{n+1}(Y_{i+1} - Y_i) = L_o(X_i - X_{i-1}) \tag{3}$$

From Equation 1, the following expression is obtained.

$$\frac{y}{x} = \frac{\pi}{P} = m$$

By definition of mol fraction of a component in a stream, the following equations are obtained.

$$y_i = \frac{Y_i V_{n+1}}{V_i} ; \quad x_i = \frac{X_i L_o}{L_i}$$

By substitution into Equation 1, the following is obtained.

$$Y_i = \left[m \frac{L_o}{L_i} \quad \frac{V_i}{V_{n+1}} \right] X_i \tag{4}$$

Substitution for X_i and X_{i-1} in Equation 3 is made by use of Equation 4.

$$Y_{i+1} - Y_i = \frac{Y_i L_i}{m_i V_i} - \frac{Y_{i-1} L_{i-1}}{m_{i-1} V_{i-1}}$$

By defining A_i as $\frac{L_i}{m_i V_i}$ and A_{i-1} as $\frac{L_{i-1}}{m_{i-1} V_{i-1}}$, the above equation becomes

$$Y_i = \frac{Y_{i+1} + A_{i-1} Y_{i-1}}{A_i + 1} \tag{5}$$

Equation 5 may be written for a one plate absorber and a two plate absorber.

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

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

By substituting for Y_1 in the last equation and rearranging, one obtains the expression:

$$Y_2 = \frac{(A_1 + 1)Y_3 + A_1 A_o Y_o}{A_1 A_2 + A_2 + 1} \,.$$

Similarly, for three plates

$$Y_3 = \frac{(A_1 A_2 + A_2 + 1)Y_4 + A_1 A_2 A_o Y_o}{A_1 A_2 A_3 + A_2 A_3 + A_3 + 1}$$

By analogy, the general equation for n plates can be written.

$$Y_n = \frac{(A_1 A_2 A_3 \ldots A_{n-1} + A_2 A_3 \ldots A_{n-1} + \ldots + A_{n-1} + 1) Y_{n+1} + A_1 A_2 \ldots A_{n-1} A_o Y_o}{A_1 A_2 A_3 \ldots A_n + A_2 A_3 \ldots A_n + \ldots + A_n + 1} \qquad (6)$$

By use of Equation 4 to substitute for X_n and rearrangement, Equation 2 becomes

$$V_{n+1}(Y_{n+1} - Y_1) = L_o \left[\left(\frac{L_n V_{n+1}}{L_o m V_n} Y_n \right) - X_o \right]$$

By definition of A_i as $\frac{L_i}{m_i V_i}$, the above equation becomes

$$Y_{n+1} - Y_1 = A_n Y_n - \frac{L_o X_o}{V_{n+1}}$$

or

$$Y_n = \frac{1}{A_n} \left[Y_{n+1} - Y_1 + \frac{L_o X_o}{V_{n+1}} \right]$$

By substitution for Y_n and replacement of $A_o Y_o$ with its equivalent from Equation 4, Equation 6 becomes

$$\frac{Y_{n+1} - Y_1}{Y_{n+1}} = \frac{A_1 A_2 A_3 \ldots A_n + A_2 A_3 \ldots A_n + \ldots + A_n}{A_1 A_2 A_3 \ldots A_n + A_2 A_3 \ldots A_n + \ldots + A_n + 1} -$$

$$\frac{L_o X_o}{V_{n+1} Y_{n+1}} \left[1 - \frac{A_1 A_2 \ldots A_n}{A_1 A_2 A_3 \ldots A_n + A_2 A_3 \ldots A_n + \ldots + A_n + 1} \right]$$

or

$$\frac{Y_{n+1} - Y_1}{Y_{n+1}} = \frac{A_1A_2A_3 \ldots A_n + A_2A_3 \ldots A_n + \ldots + A_n}{A_1A_2A_3 \ldots A_n + A_2A_3 \ldots A_n + \ldots + A_n + 1} - \frac{L_oX_o}{V_{n+1}Y_{n+1}} \left[\frac{A_2A_3 \ldots A_n + \ldots + A_n + 1}{A_1A_2A_3 \ldots A_n + A_2A_3 \ldots A_n + \ldots + A_n + 1} \right] \qquad (7)$$

With the use of the following expressions for the sums of geometric progressions

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

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

and an average absorption factor A, Equation 7 can be written as

$$\frac{Y_{n+1} - Y_1}{Y_{n+1}} = \frac{A^{n+1} - A}{A^{n+1} - 1} - \frac{Y_o}{Y_{n+1}} \left[\frac{A^{n+1} - A}{A^{n+1} - 1} \right]$$

or

$$\frac{Y_{n+1} - Y_1}{Y_{n+1} - Y_o} = \frac{A^{n+1} - A}{A^{n+1} - 1} \qquad (8)$$

Equation 8 is the form usually referred to as the Kremser-Brown equation.

Souder and Brown replaced the assumption that Raoult's Law applied with the assumption of equilibrium between the gas and liquid leaving each theoretical plate in the tower. Equation 1 can now be written as

$$y = Kx$$

and Equation 4 becomes

$$Y_1 = \left[K_i \frac{L_o}{L_i} \frac{V_i}{V_{n+1}} \right] X_i .$$

Edmister Equations

Derivation: The Edmister derivation is very similar to the derivation shown for the Kremser-Brown method until Equation 7 is obtained.

Edmister (2) defined the terms A_e and A' by the following relations:

$$\frac{A_e^{n+1}-A_e}{A_e^{n+1}-1} = \frac{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1} \tag{9}$$

$$\frac{1}{A'}\left[\frac{A_e^{n+1}-A_e}{A_e^{n+1}-1}\right] = \frac{A_2A_3\ldots A_n+A_3\ldots A_n+\ldots+A_n+1}{A_1A_2A_3\ldots A_n+A_2A_3\ldots A_n+\ldots+A_n+1} \tag{10}$$

Edmister reported that a study of plate to plate results and test run data indicated the terms A_e and A' essentially independent of the number of theoretical plates. Therefore, the terms A_e and A' could be expressed as functions of the top and bottom plate absorption factors. By writing the above equations for a two plate absorber, the following expressions are obtained.

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

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

$$\frac{1}{A'} = \left[\frac{A_n+1}{A_n(A_1+1)+1}\right]\frac{A_n(A_1+1)+1}{A_n(A_1+1)}$$

$$A' = \frac{A_n(A_1+1)}{A_n+1} \tag{11}$$

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

$$A_e^3 A_n A_1 + A_e^3 A_n + A_e^3 - A_e A_n A_1 - A_e A_n - A_e = A_e^3 A_n A_1 + A_e^3 A_n - A_n A_1 - A_n$$

$$A_e^3 - A_e A_n A_1 - A_e A_n - A_e + A_n A_1 + A_n = 0$$

$$\left[A_e - 1\right]\left[A_e^2 + A_e - A_n (A_1 + 1)\right] = 0$$

One root of this equation is $A_e = 1$ but has no significance. The remaining are one negative and one positive root.

$$A_e = \frac{-1 \pm \sqrt{1 + 4A_n(A_1 + 1)}}{2}$$

By definition, A equals L/KV. The terms L, K, and V are positive values. The result is that the quantity L/KV or A is positive. This fact allows the negative root to be disregarded. From the previous equation, the positive roots of A are represented by the following equation.

$$A_e = \sqrt{A_n(A_1 + 1) + .25} - .5 \qquad (12)$$

By use of Equations 11 and 12, Equation 7 can be written as

$$E_a = \frac{Y_{n+1} - Y_1}{Y_{n+1}} = \left[1 - \frac{L_o X_o}{A' V_{n+1} Y_{n+1}}\right]\left[\frac{A_e^{n+1} - A_e}{A_e^{n+1} - 1}\right] \qquad (13)$$

The stripping factor is defined as $S = \frac{KV}{L}$ or the reciprocal of the absorption factor. By steps analogous to those presented above, expressions for stripping calculations of the Kremser-Brown and Edmister methods can be obtained. These equations will not be derived but are presented below.

$$\frac{X_{m+1} - X_1}{X_{m+1}} = \frac{S_1 S_2 S_3 \ldots S_m + S_2 S_3 \ldots S_m + \ldots + S_m}{S_1 S_2 S_3 \ldots S_m + S_2 S_3 \ldots S_m + \ldots + S_m + 1}$$

$$- \frac{V_o Y_o}{L_{m+1} X_{m+1}} \left[\frac{S_2 S_3 \ldots S_m + S_3 \ldots S_m + \ldots + S_m + 1}{S_1 S_2 S_3 \ldots S_m + S_2 S_3 \ldots S_m + \ldots + S_m + 1} \right] \qquad (7')$$

$$\frac{X_{m+1} - X_1}{X_{m+1} - X} = \frac{S^{m+1} - S}{S^{m+1} - 1} \qquad (8')$$

$$S' = \frac{S_m (S_1 + 1)}{S_m + 1} \qquad (11')$$

$$S_e = \sqrt{S_m (S_1 + 1) + .25} - .5 \qquad (12')$$

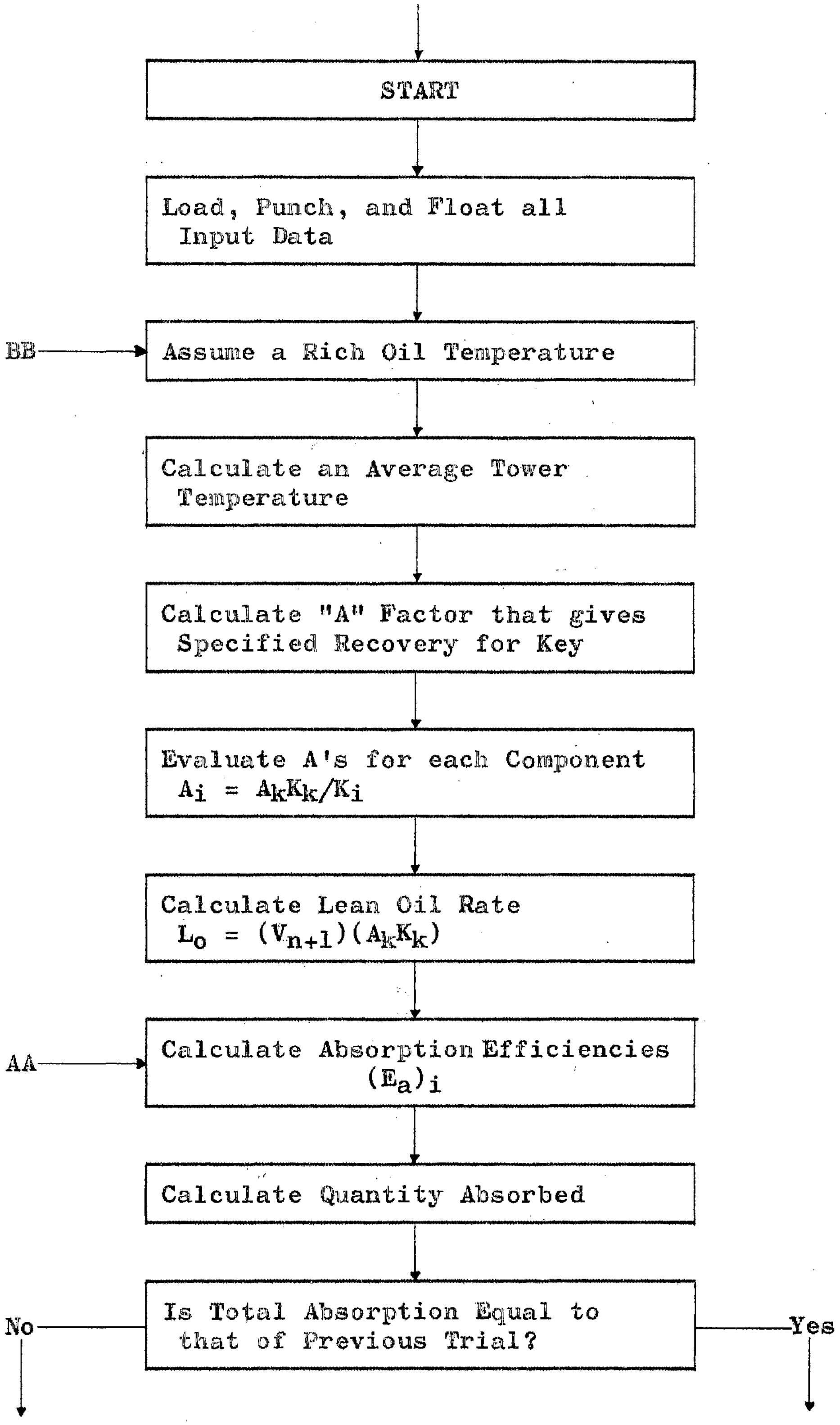
$$E_s = \frac{X_{m+1} - X_1}{X_{m+1}} = \left[1 - \frac{V_o Y_o}{S' L_{m+1} X_{m+1}} \right] \left[\frac{S_e^{m+1} - S_e}{S_e^{m+1} - 1} \right] \qquad (13')$$

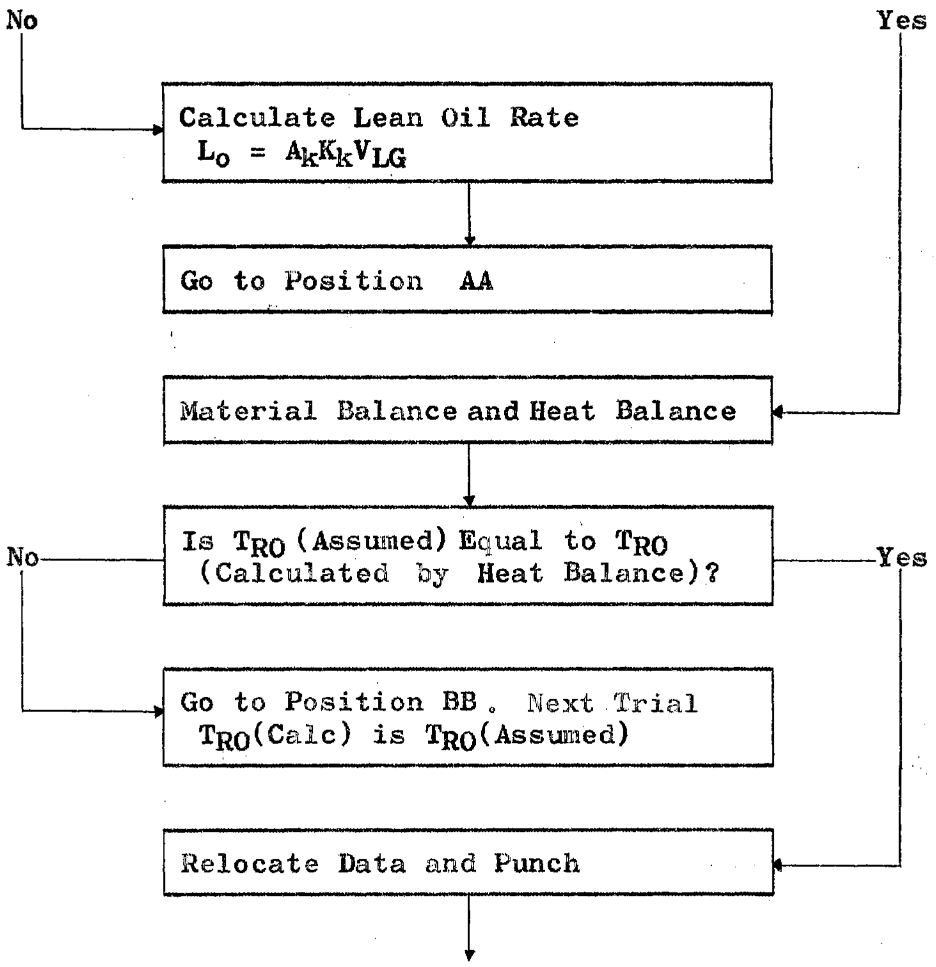
APPENDIX C

BLOCK DIAGRAM OF ABSORBER PROGRAM

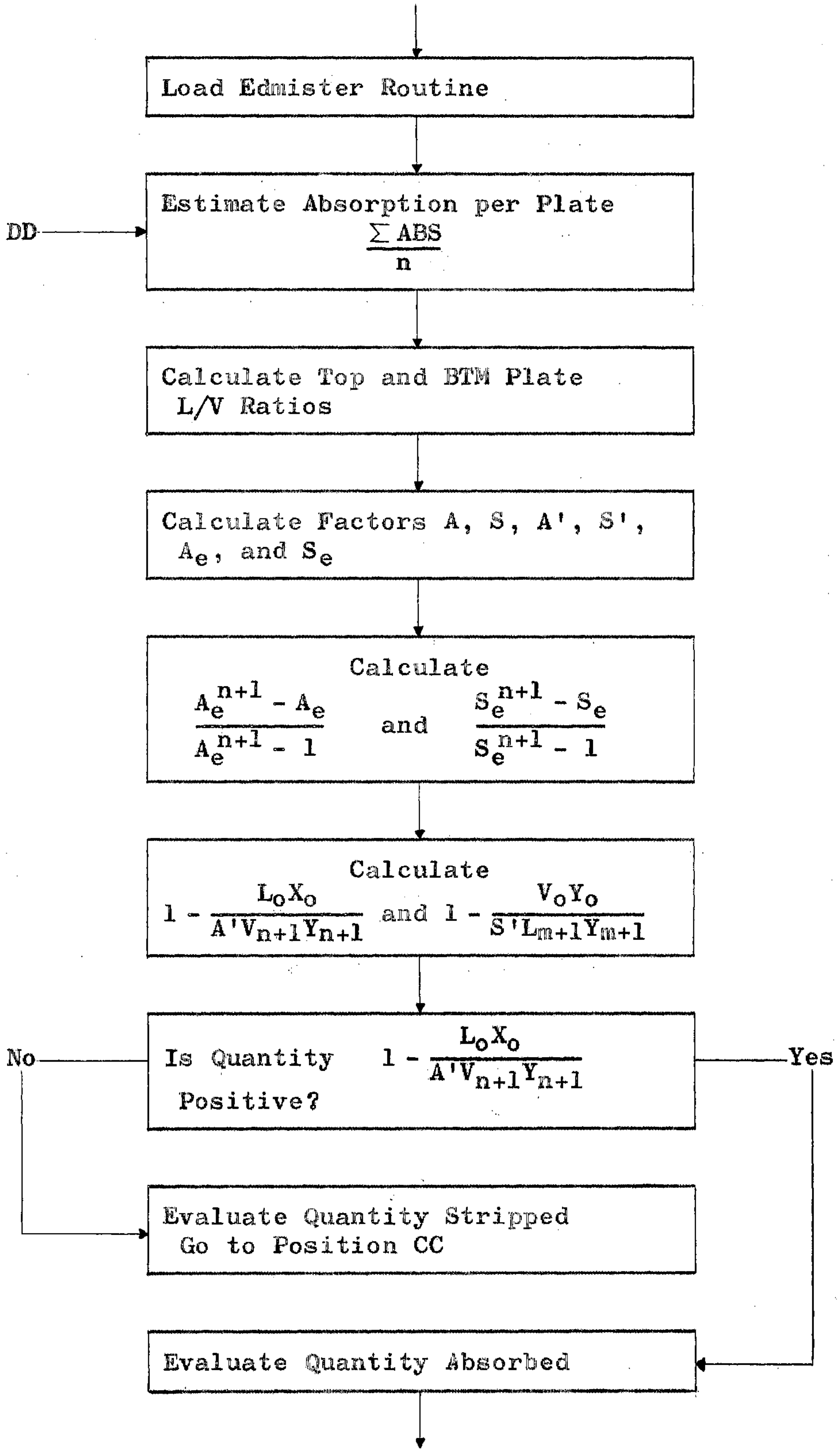
BLOCK DIAGRAM OF ABSORBER CALCULATION

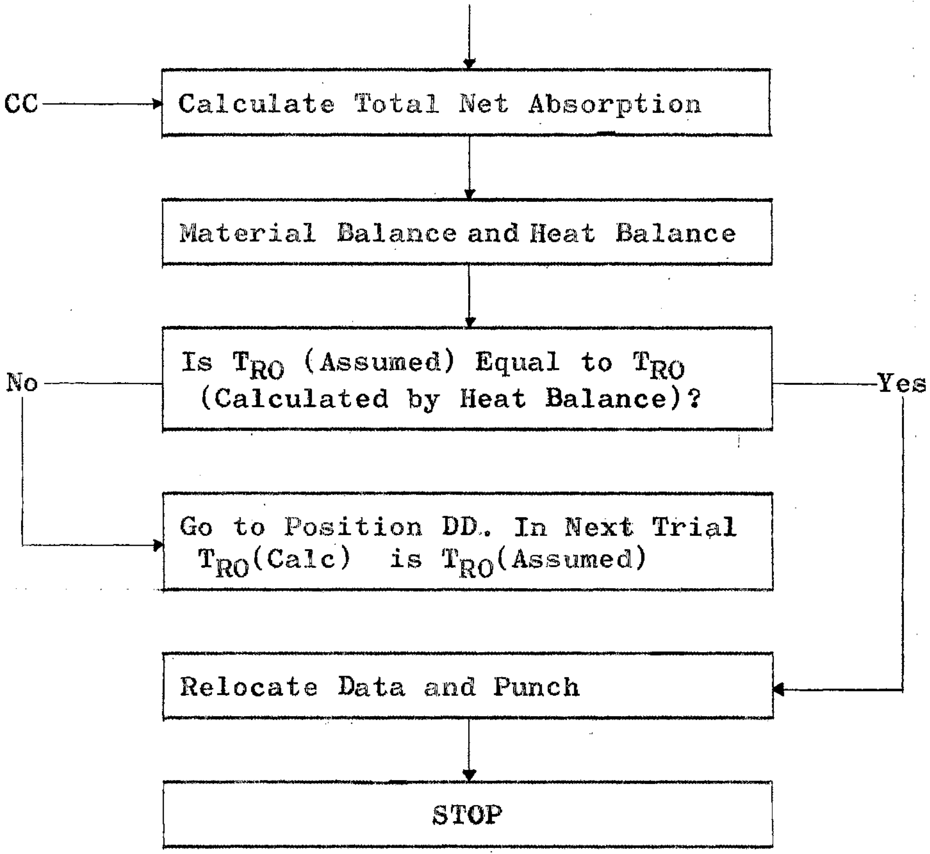
KREMSER-BROWN SECTION




No
Yes
Calculate Lean Oil Rate
$L_o = A_k K_k V_{LG}$
Go to Position AA
Material Balance and Heat Balance
Is T_{RO} (Assumed) Equal to T_{RO} (Calculated by Heat Balance)?
No
Yes
Go to Position BB. Next Trial T_{RO}(Calc) is T_{RO}(Assumed)
Relocate Data and Punch

EDMISTER SECTION





CC
Calculate Total Net Absorption
Material Balance and Heat Balance
Is T_{RO} (Assumed) Equal to T_{RO} (Calculated by Heat Balance)?
No
Yes
Go to Position DD. In Next Trial T_{RO}(Calc) is T_{RO}(Assumed)
Relocate Data and Punch
STOP

NOMENCLATURE

NOMENCLATURE

L = Mols of liquid

V = Mols of vapor

Y = Mols of a component in the vapor phase per mol of vapor entering the absorber or stripper

X = Mols of a component in the liquid phase per mol of liquid entering the absorber or stripper

G = Oil to gas ratio, gal. per 1000 standard cubic feet

K = Equilibrium constant

q = Equilibrium constant

m = Equilibrium constant

T = Temperature

A_e = Effective absorption factor

A' = Effective absorption factor

$\triangle H$ = Heat of absorption

R = Gas constant

M = Molecular weight

$A_c = \frac{A_n(A_1 + 1)}{A_n + 1}$, absorption factor

A = Absorption factor, $\frac{L}{KV}$

E_a = Absorption efficiency

E_s = Stripping efficiency

p' = Partial pressure of solute

P = Vapor pressure of component

x = Mol fraction of a component in liquid

y = Mol fraction of a component in gas

π = Total pressure

$\sum ABS$ = Total mols absorbed

S_e = Effective stripping factor

S' = Effective stripping factor

S = Stripping factor, $\frac{KV}{L}$

$\pi_A = A_1 A_2 A_3 \ldots A_n$

$\pi_S = S_1 S_2 S_3 \ldots S_n$

$\phi_A = \frac{1}{\Sigma_A + 1}$

$\phi_S = \frac{1}{\Sigma_S + 1}$

$\psi_A = \left[1 - \frac{\pi_A}{\Sigma_A + 1}\right]$

$\psi_S = \left[1 - \frac{\pi_S}{\Sigma_S + 1}\right]$

$\Sigma_A = A_1 A_2 A_3 \ldots A_n + A_2 A_3 \ldots A_n + \ldots + A_n$

$\Sigma_S = S_1 S_2 S_3 \ldots S_n + S_2 S_3 \ldots S_n + \ldots + S_n$

Subscripts

1, 2, 3 ... n = Plate numbers - top to bottom for absorbers

1, 2, 3 ... m = Plate numbers - bottom to top for strippers

o = Reference to solvent oil in absorbers. Reference to stripping medium in strippers. Also, indicates top tower conditions for an absorber or bottom tower conditions for a stripper.

n+1 = Refers to wet gas or rich gas entering an absorber; refers to the rich oil entering a stripper

i = Any random plate

k = Reference to "key" component or specified component

LG = Reference to lean gas

LO = Reference to lean oil

RO = Reference to rich oil

VITA

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Master of Science

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Professional experience: Employed by Magnolia Petroleum Company, Technical Service Department of the refinery in Beaumont, Texas during the Summers of 1957 and 1958.