A COMPARATIVE ANALYSIS OF MULTICOMPONENT

DISTILLATION MINIMUM REFLUX METHODS

BY

JOSEPH H. F. LOOZEN

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ABSTRACT

One of the most important factors to know in the design of distillation columns is the minimum reflux ratio. Numerous procedures have been developed for the determination of the value of the minimum reflux ratio for multi-component mixtures requiring various degrees of computational effort. Shortcut techniques are obviously advantageous with respect to computation time. After reviewing the available methods, those by Underwood, Colburn, Scheibel and Montross, Murdoch and Holland, and Shiras et al. were selected for further evaluation, mainly on the basis of practical potential.

Comparison of these procedures was accomplished by calculating the minimum reflux ratio for a large number of systems with widely varying conditions. Considerable differences were found between the results of these methods; the spread between the lowest and highest value varying from less than 10% for a 4-component system with adjacent keys to over 100% for an 8-component mixture with one split key. It was established that these deviations stem mainly from differences in the relative volatilities.

The reliability and usefulness of the methods investigated would have to be determined by comparison of the results with those from a rigorous calculation. For general application, only the techniques by Underwood

and Shiras et al. can be considered since they contain a feature for determining the product composition. Scheibel and Montross' procedure is the only one which can be used to carry out a hand calculation within a reasonable length of time.

APPROVAL OF THESIS

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JOSEPH H. F. LOOZEN

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BY

FACULTY COMMITTEE

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (CONTINUED)

CHAPTER I

INTRODUCTION

A fractionating column has two limits of operation based upon reflux ratio. The lower limit is fixed by minimum reflux; under this condition, an infinite number of theoretical equilibrium stages are required to achieve the desired separation. The upper limit is that at total reflux. It is evident that for a given product distribution a fractionating column must be operated between these two conditions with respect to reflux ratio.

The minimum reflux ratio is an important factor to know in the design of a distillation column. An operating reflux ratio which lies between 1.2 and 1.5 times the minimum reflux ratio is generally considered the most economic. This value fixes the number of plates and the heating and cooling loads necessary for a specified separation of a given feed.

A large number of investigators have developed methods for determining the minimum reflux value of multicomponent systems. Most of these methods are known as "shortcut" techniques, indicating that one or more simplifying assumptions have been made.

Shortcut methods for the approximate solution of multicomponent separation problems, in themselves a rather extensive computational effort, continue to serve useful

purposes even though computers are available to provide rigorous solutions. The available equilibrium data may not be sufficiently accurate to justify the longer rigorous methods. In design studies a large number of cases can be worked quickly by a shortcut method to get the optimum conditions, and then the exact solution can be obtained via a rigorous calculation. The computer time required for the latter is considerably longer than that for a shortcut method.

The purpose of this work was to examine the known shortcut methods and to select those which seem most valuable for practical application. These methods were then evaluated and compared by calculating the minimum reflux for a large number of hydrocarbon systems under varied conditions.

The many and complex calculations involved were carried out partly on an IBM 1130 computer and the remainder with the G. E. Mark II Time-Sharing System. The programs used have been written in Fortran IV language and are listed in the Appendix (pp. 84-101).

CHAPTER II

A COLUMN AT MINIMUM REFLUX

In a conventional distillation, one feed stream and two product streams constitute the flow of material to and from the column. For a multicomponent feed, the desired separation is usually specified in terms of two key components. One is the light key, which is the most volatile component to appear in the bottom product or bottoms, while the heavy key is the least volatile component in the top product or distillate. The separation ratio between the distillate and bottoms is specified for both keys. Usually the keys are adjacent components with respect to relative volatility. If then the separation ratio between the distillate and the bottoms is high for the light key and low for the heavy key, the distillation is called a sharp separation. All components lighter than the light key will go to the distillate, while those heavier than the heavy key end up in the bottoms. Components which appear only in one product are referred to as separated components. However, components with volatilities intermediate to those of the keys may be present. These will always be distributed between the two products and are referred to as split keys.

A distillation column operating at minimum reflux may be considered to consist of seven zones. From the

top of the column down, these zones will be referred to as distillate zone, rectifying pinch zone, rectifying zone, feedzone, stripping zone, stripping pinch zone, and bottoms zone. A schematic representation of a column operating at minimum reflux is shown in Figure 1 for a multicomponent and for a binary system.

The feed zone is very small and exists between the two plates where the feed enters the column. The feed combines with the streams entering from the adjacent sections to form the liquid and vapor streams which leave the feed zone. The zone immediately above the feed zone is the rectifying zone. All components of the feed which do not appear in the distillate are fractionated to zero in this section. The next zone upwards is the rectifying pinch zone. The temperature and composition remain constant throughout this entire section, which consists of an infinite number of plates. The top section in the distillation column is the distillate zone in which the fractionation from the pinch zone composition to that of the distillate takes place. The lower part of the distillation column consists of similar zones as just described for the upper half of the column. In the stripping zone, the light components which do not appear in the bottom product are fractionated to zero. Then follows the stripping pinch zone in which the temperature and

Binary Distillation

----distillate zone
----rectifying pinch zone
----rectifying zone
----feed zone
----stripping zone
----stripping pinch zone
----bottoms zone
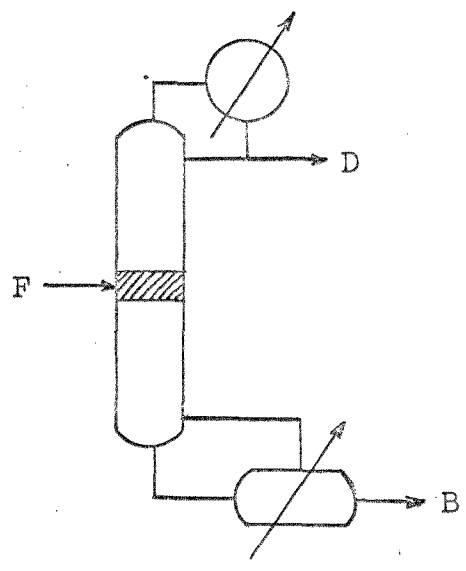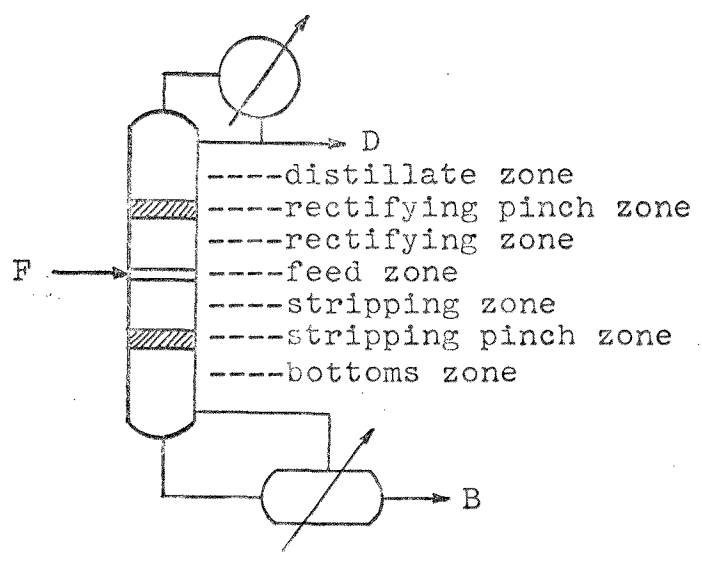
Multicomponent Distillation

FIGURE 1. A COLUMN AT MINIMUM REFLUX

composition do not change. Finally, in the bottom section of the column, fractionation to the composition of the bottom product occurs.

The above presentation is only true when the distillation yields at least one light and one heavy separated component; i. e. at least one component which appears only in the distillate, and at least one component which appears only in the bottoms. If there is no separated component in the bottom product, the stripping zone does not exist. The stripping pinch zone is then adjacent to the feed zone. This is similar for the upper half of the column if all components of the feed appear in the distillate. When all components of the feed distribute between the two products, both pinch zones merge; and the system becomes analogous to that of a binary mixture.

Figure 2 represents the McCabe-Thiele diagram for a binary mixture and for a multicomponent system in which the same two constituents are the key components. For a binary mixture, DF and BF give the minimum reflux ratio for the rectifying section and the minimum boil-up ratio for the stripping section respectively. As we move along these operating lines, the change in composition on adjacent plates becomes less and less until it becomes negligible at the feed plate. At F, the compositions are
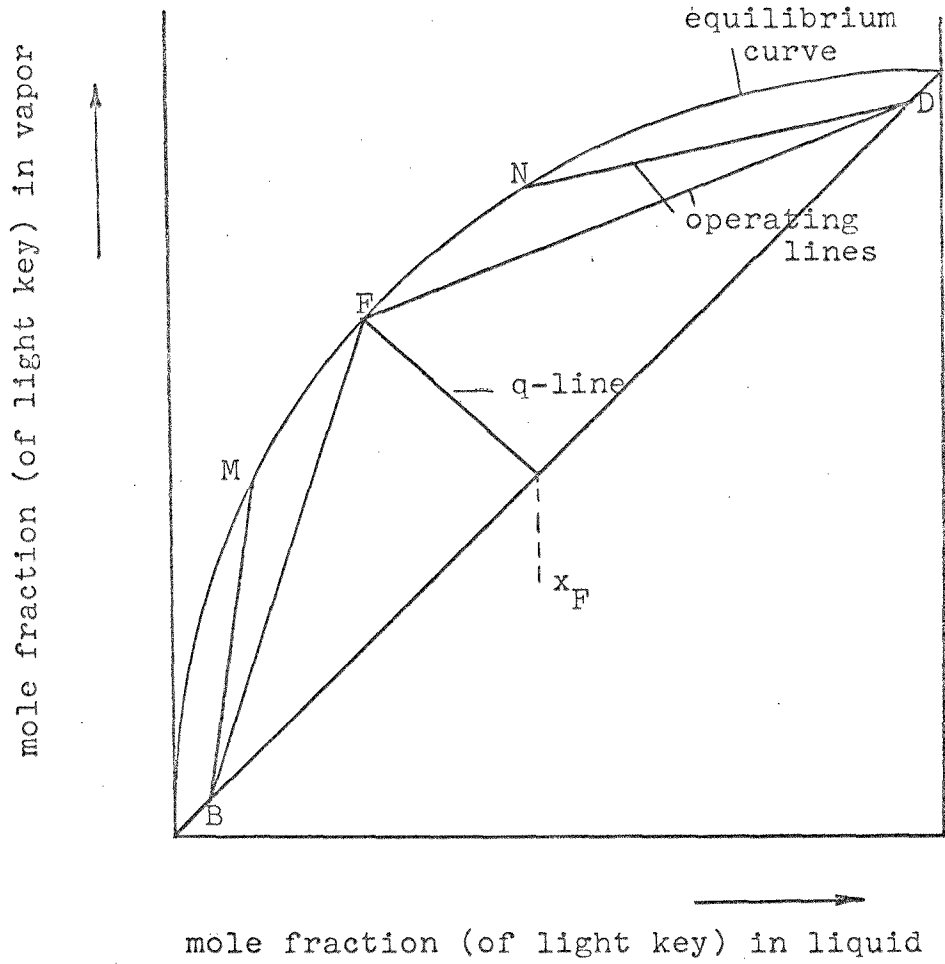
FIGURE 2. McCABE-THIELE DIAGRAM FOR A BINARY AND FOR A

MULTICOMPONENT SYSTEM

referred to as being "pinched." In a multicomponent sys-
tem, the presence of components lighter than the light
key will shift the operating line DF to some value DN;
and the components heavier than the heavy key will shift
the lower line BF to BM. The extent of these shifts de-
pends upon the required separation.

CHAPTER III

LITERATURE SURVEY

Most of the earlier work in developing methods for determining minimum reflux was directed towards empirical or shortcut techniques. The latter always included one or more assumptions which cannot really be expected to exist in a multicomponent distillation. Some of the more common assumptions are constant molal overflow and constant or linear relative volatility. Afterwards, more rigorous methods (1,2,4,7,9,13,17) have been developed, some of which still contained limiting assumptions.

In 1932, Fenske (10) and Underwood (21) independently presented procedures for determining minimum reflux assuming constant overflow and constant relative volatility. The equations include the key components only; and, as such, they should only be applied to binary mixtures or to completely distributed systems. Only for those systems is the pinch composition equal to that of the equilibrium feed.

Gilliland (11) was the first to recognize the effect of non-key components on minimum reflux. He developed two methods based on constant overflow, constant relative volatility, and known product composition which yield an upper and lower limit for the minimum reflux. Complex terms are involved in these trial and error calculations.

9

The two limits are often so far apart that the practical
value of this method is dubious.

Maxwell (14) developed a semi-empirical equation
which does not require trial and error. He determines
the minimum reflux for two arbitrary states of feed vapor-
ization and then interpolates or extrapolates for the ac-
tual feed condition. A limit is given as to the extent of
interpolation or extrapolation allowed. Several assump-
tions were made in the derivation of this method. It is
definitely the simplest one available and is recommended
if a quick answer is needed. R. C. Erbar (7) found from
a large number of problems with bubble-point liquid feed
that Maxwell's results have an average deviation of -23.1%
from those obtained by Underwood's method with a maximum
of -59.9% and a minimum of -1.1%.

Brown and Martin (5) assumed that at minimum reflux
the ratio of the key components in the liquid in the zones
of constant composition is equal to that in the liquid
feed. This can only be true in limiting cases. Calcu-
lation of the minimum reflux on this basis involves trial
and error and gives a value on the safe side.

Colburn (6) confirmed from actual data that the con-
dition which Brown and Martin (5) assumed does not exist
for most cases. He developed an empirical method which

is considered one of the most accurate and is described
in more detail in Chapter IV.

Hogan (12) derived his method from essentially the
same basic considerations as previous investigators did.
He was the first to cover distribution of more than two
components between the distillate and the bottoms.

An empirical equation for the calculation of the
minimum reflux ratio was presented by Scheibel and Mon-
tross (19). The equation yields a direct result elimina-
ting tedious trial and error procedures. This method is
described in detail in Chapter IV.

The method developed by Mayfield and May (16) is
limited to complete separations of mixtures which involve
only one component in the distillate or one component in
the bottoms.

The shortcut technique which has found the widest
acceptance was worked out by Underwood (22). Shortly
afterwards, he expanded the usefulness of this method to
determine the distillate composition (23). The method is
described in detail in Chapter IV.

Bailey and Coates (3) modified the procedure by
Scheibel and Montross (19) to apply to systems with vary-
ing volatility. This involves a lengthy correction on a

trial and error basis which offsets at least part of the
ease of calculation of the original method.

May's method (15) is based upon the resolution of the
multicomponent system into an equivalent series of binary
mixtures. Constant molal overflow and constant relative
volatility are assumed, and the method does not apply to
systems containing split keys.

Three methods for calculating minimum reflux rates
were presented by Shiras, Hanson, and Gibson (20). The
first method is limited to systems with all components of
the feed being distributed. The second method simplifies
Underwood's method (23), specifically in respect to deter-
mination of the distillate composition. This procedure is
explained in detail in Chapter IV. The third method is a
more rigorous plate to plate calculation.

Murdoch and Holland (18) developed two alternate
equations which are analytical expressions of the methods
proposed by Underwood (23) and Colburn (6). The Underwood
analogue is more useful since it can be used for split key
containing systems and will be fully explained in Chap-
ter IV.

Erbar, Joyner, and Maddox (8) pointed out that Under-
wood's (23) prediction of product composition sometimes
yields unrealistic values.

CHAPTER IV

DISCUSSION OF SELECTED SHORTCUT METHODS

As has been shown in the previous chapter, quite a large number of shortcut methods for determining minimum reflux were developed over the past forty years. All of these have been based on one or more simplifying assumptions. These assumptions may affect the value of minimum reflux differently under different conditions. The value of each method should be judged mainly on the basis of results. However, it was considered more meaningful to evaluate a small number of methods under widely varying conditions rather than to check all available methods on just a few problems. All methods have been assessed for their practical value based on range of application, reported accuracy, assumptions made, and ease of calculation. Based on these criteria, the methods by the following investigators have been selected for comparison:

Underwood

Colburn

Shiras, Hanson, and Gibson

Scheibel and Montross

Murdoch and Holland

Underwood's method (23) is generally considered the most accurate and has found the widest acceptance. It is completely rigorous for systems to which the assumptions

of constant overflow and constant relative volatility apply.
Since Colburn's procedure (16) is derived from empirical
data obtained by the laborious trial-stepwise procedure,
this method was selected because of its practical basis.
Shiras et al. (20) simplified Underwood's method by pro-
viding a means for determining in advance which components
distribute, thereby eliminating the need for solving si-
multaneous equations. The empirical equation developed by
Scheibel and Montross (19) was selected because of its ease
of calculation since it does not involve trial and error,
and Murdoch and Holland's extension of Underwood's method
seemed mainly advantageous for systems containing split-
key components (18).

Underwood's Method

Underwood assumed constant molal overflow and con-
stant relative volatility in the derivation of his rigor-
ous analytical equations. The method is exact for systems
in which above assumptions are valid and can be applied to
mixtures of any feed condition with or without split-key
components.

It is possible to predict for some systems which com-
ponents will distribute. For instance, when sharp sepa-
rations are involved, only the keys and the split-key
components will appear in both products. In many cases,
however, this prediction cannot be made with any certainty.

If there is any doubt whether or not a component will distribute, it should be considered as a distributed component and the calculation should proceed accordingly. Solution of simultaneous equations is required when components other than the keys distribute; whereby the number of unknowns, and also the number of equations, increases by one for each additional distributed component. Unrealistic values found for overhead concentrations, which either exceed the amount of the component in the feed or which are negative, have to be corrected. For systems with components of variable relative volatility, Underwood suggests to use the value at the average column temperature.

When the light key and heavy key are the only distributed components, the following stepwise method is used:

1. Determine by trial and error the value of θ, which liesbetween the α values of the key components from the equation:

$$\frac{\alpha_1 x_{1F}}{\alpha_1 - \theta} + \frac{\alpha_2 x_{2F}}{\alpha_2 - \theta} + \text{--------} \quad \frac{\alpha_n x_{nF}}{\alpha_n - \theta} = 1-q \qquad (U-1)$$

where x_{1F} = mole fraction of component 1 in the feed

α_1 = volatility of component 1 relative to that of the heavy key;

q = heat required to vaporize one mole of feed divided by the molal latent heat

of the feed. For a bubble-point feed
q = 1.0; for a dew-point feed q = 0.

2. Calculate the minimum reflux ratio $\left(\dfrac{L_o}{D}\right)_{min}$ by
substituting Θ in

$$\frac{\alpha_1 x_{1D}}{\alpha_1 - \Theta} + \frac{\alpha_2 x_{2D}}{\alpha_2 - \Theta} + ----- \frac{\alpha_n x_{nD}}{\alpha_n - \Theta} = \left(\frac{L_o}{D}\right)_{min} + 1 \qquad (U-2)$$

where x_{1D} = mole fraction of component 1 in the
distillate.

Whenever a system contains more distributed compo-
nents than the two keys, one additional Θ value has to be
determined for each additional distributed component. In
the situation where there is one split key, two values of Θ
have to be determined in a similar way as was described
before. One lies between α (light key) and α (split key),
and the other between α (split key) and α (heavy key).
The distillate will contain the components lighter than
the light key, the key components in the amount to give
the desired separation, and an unknown amount of the split
key. Multiplying the equation which contains the distil-
late fractions by the total distillate gives:

$$(L_o)_{min} + D = \frac{\alpha_1 D_1}{\alpha_1 - \Theta} + \frac{\alpha_2 D_2}{\alpha_2 - \Theta} + \frac{\alpha_{sk} D_{sk}}{\alpha_{sk} - \Theta} + ------ \frac{\alpha_n D_n}{\alpha_n - \Theta} \qquad (U-3)$$

where D_1 = number of moles of component 1 in the
distillate; sk = split key. Substitute each of the two Θ
values separately in the above equation. Subtraction of
the two resulting equations yields one equation from which

D_{sk} can be found. Then the total distillate D is known, and $(L_o)_{min}$ can be calculated from the last equation.

Colburn's Method

Colburn's empirical method involves calculation of the compositions in the rectifying and stripping pinch at a number of trial values for the reflux ratio. A certain relation between these compositions is then checked versus an empirically derived factor to determine which reflux ratio is the minimum reflux ratio. The empirical factor was derived from a large number of problems with widely different conditions, the results of which were determined by stepwise calculations. Product compositions have to be known to enable execution of the computations which involve twice the use of trial and error. It should be noted that the assumption of constant overflow was made indirectly in the development of this procedure. The applicability of this method to systems containing split keys is of questionable value.

Following is the stepwise calculational procedure:
1. Use as initial temperature for the upper pinch:

$$T_n = T_{top} + \frac{T_{bottom} - T_{top}}{3} , \qquad (C-1)$$

and for the lower pinch:

$$T_m = T_{bottom} - \frac{T_{bottom} - T_{top}}{3} , \qquad (C-2)$$

where T_{top} and T_{bottom} represent the temperatures at the two ends of the distillation column.

2. Assume a reflux ratio L_n/D for the rectifying section of the column.

3. Calculate the reflux ratio L_m/B for the stripping section from L_n/D and the given feed condition.

4. Determine the composition of the rectifying and stripping pinch using Brown and Martin's equations:

$$x_n = \frac{x_D}{K + (K-1)(L_n/D)} \qquad \text{(Rectifying Section)} \quad (C-3)$$

$$x_m = \frac{x_B}{K + (1-K)(L_m/B)} \qquad \text{(Stripping Section)} \quad (C-4)$$

where x_n = concentration of a component in the upper pinch (includes heavy key and lighter components);

x_m = concentration of a component in the lower pinch (includes light key and heavier components);

K = equilibrium ratio y^*/x of a component at the pinch temperature T_m or T_n;

x_D = concentration of a component in the distillate;

x_B = concentration of a component in the bottoms.

5. Check if the sum of the concentrations of the components in the upper pinch, $\sum x_n$, equals unity. If it does not, assume a new pinch temperature and repeat until this criteria is satisfied. Similarly, $\sum x_m$ should equal unity.

6. Evaluate Psi (1) = r_m/r_n (C-5)

   where r_m = ratio of light key to heavy key in the stripping pinch;

   r_n = ratio of light key to heavy key in the rectifying pinch.

7. Evaluate Psi (2) = $\dfrac{1}{(1-\sum C_m \alpha x_m)(1-\sum C_n x_n)}$ (C-6)

   where $\sum C_m \alpha x_m$ = Summation of values of $C_m \alpha x$ for all components heavier than the heavy key in the stripping pinch;

   $\sum C_n x_n$ = Summation of values of $C_n x$ for all components lighter than the light key in the rectifying pinch;

   C_m, C_n = correction factors, which are plotted in Colburn's article as a function of relative volatility.

8. If the two Psi-values calculated above are equal, the assumed reflux ratio is the minimum reflux ratio. If they differ by more than a few per cent, assume a new reflux ratio and repeat the calculational procedure until the two Psi-values

are within this range.

Shiras, Hanson and Gibson's Method

This method is an extension and elaboration of Underwood's method and is exact for all separations for which the assumptions of constant molal overflow and constant relative volatility are valid. A time-saving advantage is that they provide a simple means of determining the distribution of all components. Therefore, only one Θ value has to be determined; this is particularly advantageous for mixtures with more than one distributed component in addition to the key components. When the relative volatility cannot be considered constant throughout the distillation column, Shiras et al. suggest to determine this value for all components at an estimated feed plate temperature. The latter can be arrived at in two ways: one being the arithmetic mean of the top plate and reboiler temperatures weighted by the molal amounts of top and bottom product; the alternative is the temperature at which the K-values of the two key components are equally distant from unity.

The concentration in the distillate of components other than the two keys is determined for a part vapor feed from the following equation:

$$\frac{D(X_i)_D}{L_f(X_i)_f} = \frac{(\alpha_i-1)\ D(X_a)_D}{(\alpha_a-1)\ L_f(X_a)_f} + \frac{(\alpha_a-\alpha_i)\ D(X_b)_D}{(\alpha_a-1)\ L_f(X_b)_f} \qquad \text{(SHG-1)}$$

where D $\quad$ = moles of top product;

$\quad(X_i)_D$ = mole fraction of component i in distillate;

$\quad L_f$ $\quad$ = moles of liquid feed;

$\quad(X_i)_f$ = mole fraction of component i in liquid por-

$\qquad$ tion of feed;

$\quad \alpha$ $\qquad$ = volatility relative to that of the heavy

$\qquad$ key;

$\quad a$ $\qquad$ = light key component;

$\quad b$ $\qquad$ = heavy key component.

The $(X_i)_f$ values can be obtained from the flash, if any,
of the feed. If the ratio of the amount of a component in
the distillate to that of the total quantity of that com-
ponent in the feed is greater than one or negative, the
component is presumed to be non-distributing and the amount
of it in the distillate is respectively equal to that in
the feed or zero; if this ratio lies between zero and one,
the component does distribute.

If the feed is boiling-point liquid, L_f is equal to
the total feed and $(X_i)_f$ is the mole fraction of compo-
nent i in the feed.

For a dew-point feed, the equation to be used is:

$$\frac{\alpha_i D(X_i)_D}{F(X_i)_F} = \frac{\alpha_a(\alpha_i-1) \ D \ (X_a)_D}{(\alpha_a -1) \ F \ (X_a)_F} + \frac{(\alpha_a-\alpha_i) \ D \ (X_b)_D}{(\alpha_a -1) \ F \ (X_b)_F} \quad \text{(SHG-2)}$$

where F = moles of total feed;

$(X_i)_F$ = moles of component i in feed.

Having determined the distillate composition this way and the alpha values as outlined before, Underwood's "θ function" method for systems without split keys is used to calculate the minimum reflux for systems with and without split-key components.

Scheibel and Montross' Method

These investigators developed an empirical equation for the calculation of the minimum reflux ratio. It is divided into three parts:

(a) The reflux required to separate the key components, if components lighter than the light key have infinite volatility and components heavier than the heavy key have zero volatility.

(b) The reflux necessary to separate the heavier components from the light key, considering their actual volatilities.

(c) The reflux required for the separation of the lighter components from the heavy key, considering their actual volatilities.

This method was developed from a large number of problems with widely different conditions and yielded a straightforward equation which does not require trial and error.

It can be applied to systems with bubble-point liquid, part vapor, or dew-point vapor as feed. If split keys are involved, the amount of these components going overhead has to be known. The relative volatilities are determined at an estimated feed plate temperature for systems in which these quantities are temperature dependent.

Following is a step-by-step account of the minimum reflux calculation:

1. Evaluate $m = \dfrac{M_L - \sum M_D}{M_V - \sum M_A}$ (SM-1)

     where m = pseudoratio of liquid to vapor in feed;

         M_L = moles of liquid feed;

         M_V = moles of vapor feed;

         $\sum M_D$ = total moles of components heavier than heavy key in feed;

         $\sum M_A$ = total moles of components lighter than light key in feed.

2. Determine the value of x_1 between zero and unity from

$$x_1 = \frac{(\alpha_B - 1)(1+m)\dfrac{X_B}{X_B + X_C} - \alpha_B - m \pm \sqrt{Q}}{2m(\alpha_B - 1)} \qquad \text{(SM-2)}$$

     where $Q = \left\{ (\alpha_B - 1)(1+m)\dfrac{X_B}{X_B + X_C} - \alpha_B - m \right\}^2 +$

$$4m(\alpha_B - 1)(1+m)\frac{X_B}{X_B + X_C}; \qquad \text{(SM-3)}$$

x_i = mole fraction of light key at inter-
section of operating lines at minimum
reflux, based on key components only;

X_B = mole fraction of light key in feed;

X_C = mole fraction of heavy key in feed;

α_B = relative volatility of keys at feed
tray.

3. Calculate the pseudo minimum reflux ratio

$$R^1_M = \frac{x_P}{(\alpha_B-1)x_i} - \frac{(1-x_P)\alpha_B}{(1-x_i)(\alpha_B-1)} \qquad (SM-4)$$

where x_P = mole fraction of light key in distil-
late based on total keys in distillate.

4. The minimum reflux ratio R_M is then given by:

$$R_M = \frac{1}{X_B+\sum X_A}\{X_B R^1_M+(X_C+\sum X_D)\sum\frac{X_D}{\frac{\alpha_B}{\alpha_D}-1} +\sum\frac{X_A}{\alpha_A}(1+\frac{\alpha_B}{\alpha_A})\} \qquad (SM-5)$$

where X_A = total mole fraction of components
lighter than light key in feed;

X_D = total mole fraction of components
heavier than heavy key in feed.

The terms inside the brackets represent, in order,
the three fractions of the reflux necessary for the re-
quired separation as mentioned in the beginning of this
discussion.

Murdoch and Holland's Method

These investigators developed an Over-all Balance
Equation which is an extension of the Underwood method.
It is, therefore, based on the assumptions of constant
molal overflow and constant relative volatility. This
method does not require solution of simultaneous equations,
however, the procedure used for determining relative vola-
tilities is quite involved.

Murdoch and Holland use the following alpha-values
for systems with variable relative volatility:

for all components lighter than the light key $\alpha = \alpha_{PR}$,

for the keys and splitkey components $\alpha = \dfrac{\alpha_{PR} + \alpha_{PS}}{2}$,

for all components heavier than the heavy key $\alpha = \alpha_{PS}$,

where α_{PR} and α_{PS} are the relative volatilities at
the rectifying pinch and at the stripping pinch re-
spectively.

The alpha's in the pinches are determined as follows:

a. Assume a value for the minimum reflux ratio.

b. Using this value, calculate by trial and error
   the temperatures of the two pinches by pinch
   composition equations (see Colburn).

c. Evaluate the α's at these temperatures.

d. Check the calculated minimum reflux ratio versus
   the assumed value.

e. Repeat the calculation using the computed minimum
   reflux ratio if these two values differ greatly.

For systems without split keys, Underwood's "θ function" technique is applied using relative volatilities computed as outlined above. The steps involved in applying the Over-all Balance Method to systems containing split-key components are as follows:

1. Calculate, by trial and error, the θ's having values between the relative volatilities of the key components from the equation

$$\frac{\alpha_1 x_{1F}}{\alpha_1 - \theta} + \frac{\alpha_2 x_{2F}}{\alpha_2 - \theta} + ------- \frac{\alpha_n x_{nF}}{\alpha_n - \theta} = 1-q \qquad (MH-1)$$

where x_{1F} = mole fraction of component 1 in the feed;

α_1 = volatility of component 1 relative to that of the heavy key;

q = heat required to vaporize one mole of feed divided by the molal latent heat of the feed.

Two θ values are required for systems containing one split key.

2. Evaluate

$$v = \frac{\prod\limits_{i=h+1}^{\ell} \theta_i}{\prod\limits_{i=h+1}^{\ell-1} \alpha_i} \qquad (MH-2)$$

where Π = product of factors;

h = heavy key component;

ℓ = light key component;

i = component number. Components are arranged in order of increasing volatility.

3. Evaluate:

$$\sum_{j=h,\ell,L} \frac{\omega_j}{\alpha_j} Dx_{Dj} \qquad \text{(MH-3)}$$

where j = component number;

L = any component lighter than the light key;

D = moles of top product per mole of feed;

x_{Dj} = mole fraction of component j in the top product,

and
$$\omega_j = \frac{\prod_{i=h+1}^{\ell-1} \left(1-\frac{\alpha_i}{\alpha_j}\right)}{\prod_{i=h+1}^{\ell} \left(1-\frac{\Theta_i}{\alpha_j}\right)} \qquad \text{(MH-4)}$$

4. Multiply each term in item 3 by α_j giving:

$$\sum_{j=h,\ell,L} \omega_j Dx_{Dj} \qquad \text{(MH-5)}$$

5. Evaluate:
$$\rho = v\frac{\sum\limits_{j=h,\ell,L} \frac{\omega_j}{\alpha_j} Dx_{Dj}}{\sum\limits_{j=h,\ell,L} \omega_j Dx_{Dj}} \qquad \text{(MH-6)}$$

6. Calculate the minimum reflux ratio: $RMIN = \frac{\rho}{1-\rho}$

CHAPTER V

COMPUTATIONS

Selected Systems

The minimum reflux ratio was calculated for mixtures
of four to eight hydrocarbons, distilled at 400 psia. The
components involved are: CH_4, C_2H_6, C_3H_8, $i-C_4H_{10}$, $n-C_4H_{10}$,
$i-C_5H_{12}$, $n-C_5H_{12}$, and $n-C_8H_{18}$. The relative volatilities
of these compounds vary with temperature.

The following variables and combinations of these
variables were considered in setting up the 48 problems
which have been solved by each of the five methods:

1. Feed condition------dew-point vapor

   50% vapor

   bubble-point liquid

2. Feed composition----fraction of keys in the feed

   key ratio

   fraction lighter than the
   light key

   fraction heavier than the
   heavy key

3. Components----------total number

   key components

   split-key component

In problems 1-10, the feed composition is varied for
a system of four components with adjacent keys and 50%

vapor feed. Problems 11-16 involve eight components, adjacent keys, 50% vapor feed, and different feed compositions. The systems of problems 17-22 consist of eight components, including one split key, with different feed compositions and 50% vapor feed. Problems 23-28 involve six components, different feed compositions, and 50% vapor feed; although the key components are adjacent, their relative volatility is greater than in problems 1-16. Problems 29-38 and 39-48 are identical to problems 1-10 except for the feed condition, which is bubble-point liquid and dew-point vapor respectively.

All systems evaluated represent sharp separations. The separation ratio D/B, which denotes the split of a component between the top product and bottom product, is 30 for the light key and 1/30 for the heavy key in all problems.

Procedures

Since the systems to be evaluated represent sharp separations, it was reasonable to assume that the components lighter than the light key and the components heavier than the heavy key would all be separated components. The results from the method by Shiras et al. proved this to be a valid assumption. The split keys in problems 17-22 were initially assumed to distribute evenly between the

distillate and the bottom product, which deviated little
from the actual results obtained by the methods of Under-
wood and Shiras et al. The composition of the two pro-
duct streams was thus known, and the temperatures at the
top and bottom of the column were then determined by cal-
culating the dew point of the vapor with the same compo-
sition as the distillate and the bubble point of the bottom
product. In making the bubble point calculation, the mole
fraction X_i of all components in the bottom product is
known. For a bubble-point liquid, the sum of the mole
fractions in the vapor equals unity, $1 = \sum_{i=1}^{c} K_i X_i$ or in func-
tional notation, $f(T) = \sum K_i X_i - 1$. The bubble point is
then determined as the positive value of T such that $f(T) =$
0. Since each K-value increases with temperature, only one
positive value of T will satisfy that expression. The K-
values (1) are given as a polynomial of the temperature at
the specified pressure in Table 61 of the Appendix. In a
similar manner, the dew point of a vapor can be determined
from the expression $F(T) = \sum Y_i / K_i - 1$. All bubble points
and dew points were determined with an accuracy of $1^{\circ}F$
allowing $f(T)$ to deviate from zero no more than 0.007.

Underwood. A separate program was used to calculate
the relative volatilities at the average column tempera-
ture. The technique of interval halving was applied in the
trial and error procedure to determine the theta values. The

main program consists of two parts, one for systems without split-key components and the other part for systems with one split key.

Colburn. The two correction terms C_m and C_n, each of which is shown in Colburn's article in a graph as some non-linear function of a relative volatilities term, have been omitted, since according to Colburn, this can be done "without introducing appreciable error."

In determining the composition and the temperature of the pinches, it is not sufficient to find a temperature such that the sum of the mole fractions of the constituents of a particular pinch, for a given reflux and distillate composition, equals unity. It is easily overlooked that negative values can be obtained for individual mole fractions. Therefore, the second criteria is that the mole fraction of each component be positive.

Because of the sharp separations of the systems analyzed, the mole fractions of the heavy key in the distillates and those of the light key in the bottom products are rather small. Consequently, the mole fraction of the heavy key in the rectifying pinch and the mole fraction of the light key in the stripping pinch, as determined by the respective pinch equations, are very temperature sensitive. Considering only the rectifying pinch, change in

temperature of $0.1^\circ F$ may easily change the mole fraction of the heavy key in that pinch by as much as 0.2, while leaving the mole fractions of the other components essentially unaffected; the total mole fraction will then also change by 0.2. Pursuing this procedure to find the temperature which yields a total mole fraction of unity, would require temperature differences between subsequent trials of $0.01^\circ F$. This seemed unreal and unnecessary, so that the following technique was used. The temperature was determined to within $0.1^\circ F$; then the mole fraction of the heavy key was found by subtracting the sum of the mole fractions of the other components in the rectifying pinch from unity. The same procedure was used for the light key in the stripping pinch.

The minimum reflux ratio was determined, also by a trial and error procedure, to the nearest 0.01. The distribution of the split-key components, as obtained by Underwood's method, was used in the solution of problems 17-22.

Shiras et al. All systems with part vapor feed necessitated calculation of the composition of the liquid part of the feed. This was accomplished by using the equations:

$$\ell_i = f_i/(1+VK_i/L) \quad \text{and} \quad v_i = f_i - \ell_i$$

where ℓ_i = moles of liquid of component i in the feed;

f_i = total moles of component i in feed;

v_i = moles of vapor of component i in the feed;

K_i = equilibrium constant of component i;

V = total moles of vapor feed;

L = total moles of liquid feed.

If the feed contains vapor and liquid in a certain ratio V/L, a temperature is assumed and the individual ℓ_i's and v_i's are determined and summed groupwise. If $\dfrac{\sum v_i}{\sum \ell_i} = \dfrac{V}{L}$, the assumed temperature is the temperature of the feed, and the composition of the vapor and liquid are known. Another trial with a new temperature must be carried out if the above equality has not been met.

The relative volatilities at the feed-plate temperature have been determined with a separate program. The feed-plate temperature was estimated as the arithmetic mean of the top plate and reboiler temperatures, weighted by the molal amounts of distillate and bottom product. Interval halving was the convergence technique used to determine the theta value.

Scheibel and Montross. The distribution of the split key as obtained by Underwood's method for problems 17-22 was used in the final equation of the procedure by Scheibel and Montross. The fraction of the split key going overhead was added to the light key, while the remainder

became part of the heavy key.

For systems with variable relative volatilities, the investigators suggest to use the values at the feed-plate temperature; the latter is determined as the bubble point of the keys at the intersection of the feed line and equilibrium line. However, this requires the x-values of the keys at this point, which cannot be obtained without using α values. Therefore, exact execution of the procedure as proposed by Scheibel and Montross, makes it a trial and error method after all.

Murdoch and Holland. The program consists of two parts, of which that for non split-key systems is essentially a combination of Colburn's and Underwood's procedures; the other part is for mixtures containing one split key and also includes some of the techniques used by Colburn and Underwood.

The reflux ratio upon which the relative volatilities are based is within 1% of the calculated value. All theta values have been determined by interval halving.

Programs and Results

Tables 1-48 show the essential data of examples 1-48, including feed condition, feed composition, distillate composition, and the minimum reflux ratio as calculated by each of the five methods. The letters L and H desig-

nate the light and heavy key components.

The effect of the feed condition on the minimum re-
flux ratio can be seen from tables 1-10 and 29-48. For
easy comparison, the results have been grouped for each
method as shown in tables 49-53.

Table 54 illustrates the effect of the relative vola-
tilities as suggested by the different investigators when
applied to the same minimum reflux method, Scheibel's in
this case. Since Colburn in his method uses the two sets
of α values from the pinches, Murdoch and Holland's tech-
nique was applied for reducing it to one set of data.
The α values of the rectifying pinch were used for the
components lighter than the light key, those of the strip-
ping pinch for the components heavier than the heavy key;
and for the distributed components, the arithmetic aver-
age of the values in the two pinches was employed.

The relative volatilities from the different methods
which have been used in calculating the results of Table
54, are shown in tables 55-59.

The temperatures calculated for the top and bottom
of the distillation column are presented in Table 60.

Table 61 shows the equilibrium data for the hydro-
carbon compounds at 400 psia as a function of the tempera-
ture.

The computer programs for determining the minimum reflux ratio by the methods of Underwood, Colburn, Shiras et al., Scheibel and Montross, and Murdoch and Holland are given in Tables 62-66. The programs for the calculation of bubble point, dew point, and relative volatilities are shown in Tables 67-69. An explanation of the terminology used in the programs is given in Table 70. All programs were written specifically to solve the examples selected for this work, and they may require minor changes to be suitable for general application.

CHAPTER VI

CONCLUSIONS

The minimum reflux results have been given in terms of the minimum reflux ratio since this magnitude, by itself, reveals an important characteristic of any system. The initial assumption that all components lighter than the light key and heavier than the heavy key would become separated components was proven to be valid by the results of Shiras et al. This was anticipated because of the sharp separations of the systems involved.

Tables 1-10 show that the results of the five methods are within 10% of one another for 4-component systems with adjacent keys. The spread between the minimum and maximum values is larger when the system contains unequal amounts of separated light and heavy components. A similar tendency in the results is observed if the feed condition for these systems is changed. Tables 29-38 and 39-48 show this for bubble-point liquid and dew-point vapor feeds, and the remarkably identical effect of the feed condition on each of the five methods can be seen from Tables 49-53.

As is shown in Tables 11-16, the spread between the two most extreme results increased to about 30% based on the smaller value for systems containing 8 components. Again, the magnitude of this range depends on the feed

37

composition, whereby systems with unequal amounts of sep-
arated components yielded the largest difference in results.
It may be noted that the same methods gave the highest and
lowest values as in the case of the 4-component systems.
When the amount of heavy separated components exceeded
that of the light separated components, Scheibel and Mon-
tross' method yielded the lowest result; and Shiras et
al.'s procedure, the highest. The reverse was observed
when the amount of light components exceeded that of the
heavy constituents.

The data for 8-component systems containing one split
key are shown in Tables 17-22. Shiras et al.'s and Under-
wood's are the only methods which provide a means for cal-
culating the distribution of split keys. Appreciable
difference was found in the results from these two proce-
dures. Shiras' method yielded approximately the same
amount of split key in the distillate for all 6 examples,
which is surprising in view of the considerable variation
in the feed composition. These results and other data
derived from them are shown in parentheses. It is the
amount of split key in the overhead product as obtained
from Underwood's method which is included in the total
moles of distillate upon which all minimum reflux ratio's
are based. Colburn's method gave low values for the min-
imum reflux ratio for all six problems, and the trend

seen in previous results is not as prevailing in these examples. The spread between the lowest and highest values of the minimum reflux ratio ranged from 45% to 125%, a sharp increase when compared to that of the 8-component systems with adjacent keys.

When the relative volatility of adjacent keys was increased, the spread in the results ranged from 20% to 130% for the 6-component systems shown in Tables 23-28. Again, as in all previous examples, the largest difference was obtained for systems with small amounts of heavy separated components.

A remarkable parallel exists between the results given in Table 54 and those in Tables 1-49. It shows that the differences in the relative volatility data, as suggested by the respective investigators, is the main cause of the differences obtained for the value of the minimum reflux ratio.

In summary, it can be said that the spread between the results from the five methods increases when:

a. The amounts of separated light and heavy components become unequal

b. The amount of separated light components exceeds that of the separated heavy components

c. The number of components increases

d. Split keys are present

e. The relative volatility between the key components
increases.

The fact that each method uses a different basis for cal-
culating the relative volatilities accounts to a great
extent for the differences in results between the methods.

CHAPTER VII

RECOMMENDATIONS

Considerable variation was found in the results of
the minimum reflux ratio as obtained from the methods by
Underwood, Colburn, Scheibel and Montross, Murdoch and
Holland, and Shiras et al. For certain systems, the
spread was more than 100% of the lowest value. Most of
the deviations were caused by differences in the relative
volatilities as used in these particular procedures.

To ascertain which of these methods is preferable for
general application or for a particular type of system and
to determine their degree of reliability, comparison of
the results with those from a rigorous calculation is re-
quired. This would also identify which basis for the
relative volatilities best represents these properties in
systems in which they are temperature dependent.

The only methods which incorporate determination of
the product composition are those by Underwood and Shiras
et al. Colburn, and Scheibel and Montross do not offer
this feature, while Murdoch's procedure is identical to
that by Underwood. Therefore, only the first two methods
can be considered for general application. Until the
superiority of either one with respect to product predic-
tion has been established, the following combination of
these two procedures is suggested:

1. Determine which components distribute by the procedure of Shiras et al.

2. Apply Underwood's θ function technique to obtain the distillate composition and the minimum reflux. This will require solution of simultaneous equations when components other than the keys distribute. Underwood's suggestion for calculating relative volatilities in systems where they vary does not necessarily have to be followed. Data arrived at a different way should be used if they are known to be more representative of that particular system.

It is difficult to give an accurate assessment of the computer effort required for each method. The computation time involved depends on the starting values selected in trial and error procedures, convergence techniques, etc. Also, the programs used are not claimed to be optimized. A qualitative indication, shown in order of increasing effort required, is as follows: Scheibel and Montross, Underwood, Shiras et al., Murdoch and Holland, Colburn.

Scheibel and Montross' method is the only one feasible for hand calculation within a reasonable length of time and is suggested for use if a computer is not read-

ily available. Relative volatilities should be determined at the average column temperature, thereby eliminating the trial and error technique required to match these values with those at the feed plate temperature.

APPENDIX

TABLE 1. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 1
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C_3H_8	3		40.00	40.00	Underwood	2.64
$i-C_4H_{10}$	4	L	14.00	13.55	Colburn	2.69
$n-C_4H_{10}$	5	H	6.00	0.19	Shiras et al.	2.59
$i-C_5H_{12}$	6		40.00		Scheibel & Montross	2.62
					Murdoch & Holland	2.58
TOTAL			100.00	53.74		

TABLE 2. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 2
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C_3H_8	3		40.00	40.00	Underwood	3.05
$i-C_4H_{10}$	4	L	6.00	5.81	Colburn	3.42
$n-C_4H_{10}$	5	H	14.00	0.45	Shiras et al.	3.09
$i-C_5H_{12}$	6		40.00		Scheibel & Montross	3.22
					Murdoch & Holland	3.20
TOTAL			100.00	46.26		

TABLE 3. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 3
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		25.00	25.00	Underwood	4.58
i-C4H10	4	L	33.00	31.94	Colburn	4.56
n-C4H10	5	H	17.00	0.55	Shiras et al.	4.49
i-C5H12	6		25.00		Scheibel & Montross	4.48
					Murdoch & Holland	4.46
TOTAL			100.00	57.49		

TABLE 4. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 4
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		25.00	25.00	Underwood	6.19
i-C4H10	4	L	17.00	16.45	Colburn	6.58
n-C4H10	5	H	33.00	1.06	Shiras et al.	6.30
i-C5H12	6		25.00		Scheibel & Montross	6.35
					Murdoch & Holland	6.37
TOTAL			100.00	42.51		

TABLE 5. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 5
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		10.00	10.00	Underwood	6.13
i-C4H10	4	L	53.00	51.29	Colburn	6.03
n-C4H10	5	H	27.00	0.87	Shiras et al.	6.02
i-C5H12	6		10.00		Scheibel & Montross	6.00
					Murdoch & Holland	6.00
TOTAL			100.00	62.16		

TABLE 6. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 6
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		10.00	10.00	Underwood	10.25
i-C4H10	4	L	27.00	26.13	Colburn	10.56
n-C4H10	5	H	53.00	1.71	Shiras et al.	10.44
i-C5H12	6		10.00		Scheibel & Montross	10.38
					Murdoch & Holland	10.44
TOTAL			100.00	37.84		

47

TABLE 7. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 7
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		5.00	5.00	Underwood	7.48
i-C4H10	4	L	33.00	31.94	Colburn	7.39
n-C4H10	5	H	17.00	0.55	Shiras et al.	7.67
i-C5H12	6		45.00		Scheibel & Montross	7.06
					Murdoch & Holland	7.23
TOTAL			100.00	37.49		

TABLE 8. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 8
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		5.00	5.00	Underwood	13.28
i-C4H10	4	L	17.00	16.45	Colburn	13.77
n-C4H10	5	H	33.00	1.06	Shiras et al.	14.08
i-C5H12	6		45.00		Scheibel & Montross	13.00
					Murdoch & Holland	13.39
TOTAL			100.00	22.51		

TABLE 9. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 9
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		45.00	45.00	Underwood	3.24
i-C4H10	4	L	33.00	31.94	Colburn	3.26
n-C4H10	5	H	17.00	0.55	Shiras et al.	3.02
i-C5H12	6		5.00		Scheibel & Montross	3.33
					Murdoch & Holland	3.21
TOTAL			100.00	77.49		

TABLE 10. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 10
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		45.00	45.00	Underwood	3.79
i-C4H10	4	L	17.00	16.45	Colburn	4.06
n-C4H10	5	H	33.00	1.06	Shiras et al.	3.68
i-C5H12	6		5.00		Scheibel & Montross	4.16
					Murdoch & Holland	3.94
TOTAL			100.00	62.51		

TABLE 11.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 11
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		11.00	11.00	Underwood	2.98
C2H6	2		12.00	12.00	Colburn	2.95
C3H8	3		12.00	12.00	Shiras et al.	2.90
i-C4H10	4	L	20.00	19.35	Scheibel & Montross	2.94
n-C4H10	5	H	10.00	0.32	Murdoch & Holland	2.90
i-C5H12	6		12.00			
n-C5H12	7		12.00			
n-C8H18	8		11.00			
TOTAL			100.00	54.67		

TABLE 12.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 12
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		11.00	11.00	Underwood	3.51
C2H6	2		12.00	12.00	Colburn	3.91
C3H8	3		12.00	12.00	Shiras et al.	3.61
i-C4H10	4	L	10.00	9.68	Scheibel & Montross	3.68
n-C4H10	5	H	20.00	0.65	Murdoch & Holland	3.73
i-C5H12	6		12.00			
n-C5H12	7		12.00			
n-C8H18	8		11.00			
TOTAL			100.00	45.33		

TABLE 13. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 13
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		1.00	1.00	Underwood	7.41
C2H6	2		2.00	2.00	Colburn	7.42
C3H8	3		4.00	4.00	Shiras et al.	8.09
i-C4H10	4	L	20.00	19.35	Scheibel & Montross	6.90
n-C4H10	5	H	10.00	0.32	Murdoch & Holland	7.25
i-C5H12	6		30.00			
n-C5H12	7		20.00			
n-C8H18	8		13.00			
TOTAL			100.00	26.67		

TABLE 14. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 14
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		1.00	1.00	Underwood	12.33
C2H6	2		2.00	2.00	Colburn	13.16
C3H8	3		4.00	4.00	Shiras et al.	13.92
i-C4H10	4	L	10.00	9.68	Scheibel & Montross	11.85
n-C4H10	5	H	20.00	0.65	Murdoch & Holland	12.68
i-C5H12	6		30.00			
n-C5H12	7		20.00			
n-C8H18	8		13.00			
TOTAL			100.00	17.33		

TABLE 15. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 15
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		13.00	13.00	Underwood	1.80
C2H6	2		20.00	20.00	Colburn	1.81
C3H8	3		30.00	30.00	Shiras et al.	1.52
i-C4H10	4	L	20.00	19.35	Scheibel & Montross	1.93
n-C4H10	5	H	10.00	0.32	Murdoch & Holland	1.79
i-C5H12	6		4.00			
n-C5H12	7		2.00			
n-C8H18	8		1.00			
TOTAL			100.00	82.67		

TABLE 16. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 16
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		13.00	13.00	Underwood	1.80
C2H6	2		20.00	20.00	Colburn	2.02
C3H8	3		30.00	30.00	Shiras et al.	1.59
i-C4H10	4	L	10.00	9.68	Scheibel & Montross	2.13
n-C4H10	5	H	20.00	0.65	Murdoch & Holland	1.91
i-C5H12	6		4.00			
n-C5H12	7		2.00			
n-C8H18	8		1.00			
TOTAL			100.00	73.33		

TABLE 17. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 17
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		10.00	10.00	Underwood	1.19
C2H6	2		10.00	10.00	Colburn	0.82
C3H8	3		10.00	10.00	Shiras et al.	1.11 (1.11)
i-C4H10	4	L	20.00	19.35	Scheibel & Montross	1.08
n-C4H10	5		10.00	6.87(6.98)	Murdoch & Holland	1.19
i-C5H12	6	H	10.00	0.32		
n-C5H12	7		15.00			
n-C8H18	8		15.00			
TOTAL			100.00	56.54(56.65)		

TABLE 18. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 18
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		10.00	10.00	Underwood	1.46
C2H6	2		10.00	10.00	Colburn	1.15
C3H8	3		10.00	10.00	Shiras et al.	1.47 (1.46)
i-C4H10	4	L	10.00	9.68	Scheibel & Montross	1.91
n-C4H10	5		10.00	6.82(6.99)	Murdoch & Holland	1.61
i-C5H12	6	H	20.00	0.65		
n-C5H12	7		15.00			
n-C8H18	8		15.00			
TOTAL			100.00	47.15(47.32)		

TABLE 19.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 19
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		1.00	1.00	Underwood	3.24
C2H6	2		2.00	2.00	Colburn	2.63
C3H8	3		2.00	2.00	Shiras et al.	3.84 (3.77)
i-C4H10	4	L	20.00	19.35	Scheibel & Montross	2.64
n-C4H10	5		10.00	6.38(6.97)	Murdoch & Holland	3.42
i-C5H12	6	H	10.00	0.32		
n-C5H12	7		35.00			
n-C8H18	8		20.00			
TOTAL			100.00	31.05(31.64)		

TABLE 20.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 20
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		1.00	1.00	Underwood	4.90
C2H6	2		2.00	2.00	Colburn	4.13
C3H8	3		2.00	2.00	Shiras et al.	5.97 (5.80)
i-C4H10	4	L	10.00	9.68	Scheibel & Montross	5.82
n-C4H10	5		10.00	6.34(6.97)	Murdoch & Holland	5.40
i-C5H12	6	H	20.00	0.65		
n-C5H12	7		35.00			
n-C8H18	8		20.00			
TOTAL			100.00	21.67(22.30)		

TABLE 21. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 21
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
CH4	1		15.00	15.00	Underwood	0.60
C2H6	2		20.00	20.00	Colburn	0.32
C3H8	3		20.00	20.00	Shiras et al.	0.31 (0.31)
i-C4H10	4	L	20.00	19.35	Scheibel & Montross	0.67
n-C4H10	5		10.00	6.04(6.83)	Murdoch & Holland	0.56
i-C5H12	6	H	10.00	0.32		
n-C5H12	7		3.00			
n-C8H18	8		2.00			
TOTAL			100.00	80.71(81.50)		

TABLE 22. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 22
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
CH4	1		15.00	15.00	Underwood	0.65
C2H6	2		20.00	20.00	Colburn	0.42
C3H8	3		20.00	20.00	Shiras et al.	0.40 (0.39)
i-C4H10	4	L	10.00	9.68	Scheibel & Montross	0.96
n-C4H10	5		10.00	5.84(6.87)	Murdoch & Holland	0.66
i-C5H12	6	H	20.00	0.65		
n-C5H12	7		3.00			
n-C8H18	8		2.00			
TOTAL			100.00	71.17(72.20)		

TABLE 23. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 23
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
CH4	1		15.00	15.00	Underwood	0.51
C2H6	2		20.00	20.00	Colburn	0.43
C3H8	3	L	20.00	19.35	Shiras et al.	0.48
i-C4H10	4				Scheibel & Montross	0.37
n-C4H10	5				Murdoch & Holland	0.51
i-C5H12	6	H	10.00	0.32		
n-C5H12	7		20.00			
n-C8H18	8		15.00			
TOTAL			100.00	54.67		

TABLE 24, SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 24
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
CH4	1		15.00	15.00	Underwood	0.67
C2H6	2		20.00	20.00	Colburn	0.79
C3H8	3	L	10.00	9.68	Shiras et al.	0.70
i-C4H10	4				Scheibel & Montross	0.73
n-C4H10	5				Murdoch & Holland	0.78
i-C5H12	6	H	20.00	0.65		
n-C5H12	7		20.00			
n-C8H18	8		15.00			
TOTAL			100.00	45.33		

TABLE 25. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 25
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		2.00	2.00	Underwood	2.33
C2H6	2		3.00	3.00	Colburn	2.50
C3H8	3	L	20.00	19.35	Shiras et al.	2.77
i-C4H10	4				Scheibel & Montross	1.92
n-C4H10	5				Murdoch & Holland	2.70
i-C5H12	6	H	10.00	0.32		
n-C5H12	7		40.00			
n-C8H18	8		25.00			
TOTAL			100.00	24.67		

TABLE 26. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 26
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
CH4	1		2.00	2.00	Underwood	4.24
C2H6	2		3.00	3.00	Colburn	5.05
C3H8	3	L	10.00	9.68	Shiras et al.	5.18
i-C4H10	4				Scheibel & Montross	4.34
n-C4H10	5				Murdoch & Holland	5.06
i-C5H12	6	H	20.00	0.65		
n-C5H12	7		40.00			
n-C8H18	8		25.00			
TOTAL			100.00	15.33		

TABLE 27. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 27
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
CH4	1		25.00	25.00	Underwood	0.18
C2H6	2		40.00	40.00	Colburn	0.08
C3H8	3	L	20.00	19.35	Shiras et al.	0.09
i-C4H10	4				Scheibel & Montross	0.16
n-C4H10	5				Murdoch & Holland	0.10
i-C5H12	6	H	10.00	0.32		
n-C5H12	7		3.00			
n-C8H18	8		2.00			
TOTAL			100.00	84.67		

TABLE 28. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 28
FEEDCONDITION 50% VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
CH4	1		25.00	25.00	Underwood	0.19
C2H6	2		40.00	40.00	Colburn	0.09
C3H8	3	L	10.00	9.68	Shiras et al.	0.11
i-C4H10	4				Scheibel & Montross	0.21
n-C4H10	5				Murdoch & Holland	0.11
i-C5H12	6	H	20.00	0.65		
n-C5H12	7		3.00			
n-C8H18	8		2.00			
TOTAL			100.00	75.33		

TABLE 29. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 29
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
C3H8	3		40.00	40.00	Underwood	2.38
i-C4H10	4	L	14.00	13.55	Colburn	2.34
n-C4H10	5	H	6.00	0.19	Shiras et al.	2.34
i-C5H12	6		40.00		Scheibel & Montross	2.39
					Murdoch & Holland	2.29
TOTAL			100.00	53.74		

TABLE 30. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 30
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
C3H8	3		40.00	40.00	Underwood	2.45
i-C4H10	4	L	6.00	5.81	Colburn	2.71
n-C4H10	5	H	14.00	0.45	Shiras et al.	2.50
i-C5H12	6		40.00		Scheibel & Montross	2.58
					Murdoch & Holland	2.56
TOTAL			100.00	46.26		

TABLE 31.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 31
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		25.00	25.00	Underwood	4.30
i-C4H10	4	L	33.00	31.94	Colburn	4.24
n-C4H10	5	H	17.00	0.55	Shiras et al.	4.21
i-C5H12	6		25.00		Scheibel & Montross	4.18
					Murdoch & Holland	4.18
TOTAL			100.00	57.49		

TABLE 32.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 32
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		25.00	25.00	Underwood	5.48
i-C4H10	4	L	17.00	16.45	Colburn	5.82
n-C4H10	5	H	33.00	1.06	Shiras et al.	5.60
i-C5H12	6		25.00		Scheibel & Montross	5.65
					Murdoch & Holland	5.67
TOTAL			100.00	42.51		

TABLE 33. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 33
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		10.00	10.00	Underwood	5.87
i-C4H10	4	L	53.00	51.29	Colburn	5.75
n-C4H10	5	H	27.00	0.87	Shiras et al.	5.76
i-C5H12	6		10.00		Scheibel & Montross	5.74
					Murdoch & Holland	5.74
TOTAL			100.00	62.16		

TABLE 34. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 34
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		10.00	10.00	Underwood	9.43
i-C4H10	4	L	27.00	26.13	Colburn	9.69
n-C4H10	5	H	53.00	1.71	Shiras et al.	9.62
i-C5H12	6		10.00		Scheibel & Montross	9.56
					Murdoch & Holland	9.62
TOTAL			100.00	37.84		

TABLE 35.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 35
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT .	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		5.00	5.00	Underwood	6.91
i-C4H10	4	L	33.00	31.94	Colburn	6.74
n-C4H10	5	H	17.00	0.55	Shiras et al.	7.11
i-C5H12	6		45.00		Scheibel & Montross	6.60
					Murdoch & Holland	6.67
TOTAL			100.00	37.49		

TABLE 36.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 36
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		5.00	5.00	Underwood	11.72
i-C4H10	4	L	17.00	16.45	Colburn	12.16
n-C4H10	5	H	33.00	1.06	Shiras et al.	12.54
i-C5H12	6		45.00		Scheibel & Montross	11.52
					Murdoch & Holland	11.90
TOTAL			100.00	22.51		

TABLE 37.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 37
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		45.00	45.00	Underwood	3.08
i-C4H10	4	L	33.00	31.94	Colburn	3.08
n-C4H10	5	H	17.00	0.55	Shiras et al.	2.87
i-C5H12	6		5.00		Scheibel & Montross	3.13
					Murdoch & Holland	3.05
TOTAL			100.00	77.49		

TABLE 38.   SPECIFICATIONS AND SOLUTIONS OF EXAMPLES 38
FEEDCONDITION BUBBLE-POINT LIQUID

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		45.00	45.00	Underwood	3.41
i-C4H10	4	L	17.00	16.45	Colburn	3.65
n-C4H10	5	H	33.00	1.06	Shiras et al.	3.29
i-C5H12	6		5.00		Scheibel & Montross	3.69
					Murdoch & Holland	3.54
TOTAL			100.00	62.51		

TABLE 39. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 39
FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
C3H8	3		40.00	40.00	Underwood	3.05
i-C4H10	4	L	14.00	13.55	Colburn	3.21
n-C4H10	5	H	6.00	0.19	Shiras et al.	3.01
i-C5H12	6		40.00		Scheibel & Montross	3.05
					Murdoch & Holland	3.03
TOTAL			100.00	53.74		

TABLE 40. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 40
FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
C3H8	3		40.00	40.00	Underwood	3.83
i-C4H10	4	L	6.00	5.81	Colburn	4.26
n-C4H10	5	H	14.00	0.45	Shiras et al.	3.88
i-C5H12	6		40.00		Scheibel & Montross	4.04
					Murdoch & Holland	3.98
TOTAL			100.00	46.26		

64

TABLE 41. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 41
FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		25.00	25.00	Underwood	4.92
1-C4H10	4	L	33.00	31.94	Colburn	4.95
n-C4H10	5	H	17.00	.55	Shiras et al.	4.83
1-C5H12	6		25.00		Scheibel & Montross	4.84
					Murdoch & Holland	4.81
TOTAL			100.00	57.49		

TABLE 42. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 42
FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		25.00	25.00	Underwood	6.98
1-C4H10	4	L	17.00	16.45	Colburn	7.40
n-C4H10	5	H	33.00	1.06	Shiras et al.	7.10
1-C5H12	6		25.00		Scheibel & Montross	7.18
					Murdoch & Holland	7.16
TOTAL			100.00	42.51		

TABLE 43. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 43
FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		10.00	10.00	Underwood	6.43
i-C4H10	4	L	53.00	51.29	Colburn	6.36
n-C4H10	5	H	27.00	0.87	Shiras et al.	6.32
i-C5H12	6		10.00		Scheibel & Montross	6.30
					Murdoch & Holland	6.30
TOTAL			100.00	62.16		

TABLE 44. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 44
FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C3H8	3		10.00	10.00	Underwood	11.14
i-C4H10	4	L	27.00	26.13	Colburn	11.46
n-C4H10	5	H	53.00	1.71	Shiras et al.	11.33
i-C5H12	6		10.00		Scheibel & Montross	11.32
					Murdoch & Holland	11.32
TOTAL			100.00	37.84		

TABLE 45. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 45

FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C_3H_8	3		5.00	5.00	Underwood	8.16
$i-C_4H_{10}$	4	L	33.00	31.94	Colburn	8.15
$n-C_4H_{10}$	5	H	17.00	0.55	Shiras et al.	8.36
$i-C_5H_{12}$	6		45.00		Scheibel & Montross	7.67
					Murdoch & Holland	7.90
TOTAL			100.00	37.49		

TABLE 46. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 46

FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX	
					METHOD	RATIO
C_3H_8	3		5.00	5.00	Underwood	14.96
$i-C_4H_{10}$	4	L	17.00	16.45	Colburn	15.52
$n-C_4H_{10}$	5	H	33.00	1.06	Shiras et al.	15.78
$i-C_5H_{12}$	6		45.00		Scheibel & Montross	14.63
					Murdoch & Holland	15.00
TOTAL			100.00	22.51		

TABLE 47. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 47
FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
C3H8	3		45.00	45.00	Underwood	3.43
i-C4H10	4	L	33.00	31.94	Colburn	3.48
n-C4H10	5	H	17.00	0.55	Shiras et al.	3.22
i-C5H12	6		5.00		Scheibel & Montross	3.58
					Murdoch & Holland	3.42
TOTAL			100.00	77.49		

TABLE 48. SPECIFICATIONS AND SOLUTIONS OF EXAMPLE 48
FEEDCONDITION DEW-POINT VAPOR

COMPONENT	COMP NR	KEY	FEED IN MOLES	DISTILLATE IN MOLES	MINIMUM REFLUX METHOD	RATIO
C3H8	3		45.00	45.00	Underwood	4.26
i-C4H10	4	L	17.00	16.45	Colburn	4.56
n-C4H10	5	H	33.00	1.06	Shiras et al.	4.14
i-C5H12	6		5.00		Scheibel & Montross	4.69
					Murdoch & Holland	4.42
TOTAL			100.00	62.51		

TABLE 49.   VALUES OF THE MINIMUM REFLUX RATIO FOR DIFFERENT FEED CONDITIONS BY THE
            METHOD OF UNDERWOOD

		A	9.9	19.7	6.1	11.5	4.2	8.0	7.6	11.7	4.9	10.3
Bubble-Point Liq.	(29-38)		2.38	2.45	4.30	5.48	5.87	9.43	6.91	11.72	3.08	3.41
50% Vapor	(1-10)		2.64	3.05	4.58	6.19	6.13	10.25	7.48	13.28	3.24	3.80
Dew-Point Vapor	(39-48)		3.05	3.83	4.92	6.98	6.43	11.14	8.16	14.96	3.43	4.26
		B	14.8	25.6	7.4	12.8	4.9	8.7	9.1	12.6	5.9	12.1

TABLE 50.   VALUES OF THE MINIMUM REFLUX RATIO FOR DIFFERENT FEED CONDITIONS BY THE
            METHOD OF COLBURN

		A	13.0	20.7	7.0	11.6	4.6	8.3	8.8	11.8	5.5	10.1
Bubble-Point Liq.	(29-38)		2.34	2.71	4.24	5.82	5.75	9.69	6.74	12.16	3.08	3.65
50% Vapor	(1-10)		2.69	3.42	4.56	6.58	6.03	10.56	7.39	13.77	3.26	4.06
Dew-Point Vapor	(39-48)		3.21	4.26	4.95	7.40	6.36	11.46	8.15	15.52	3.48	4.56
		B	19.4	24.6	8.5	12.4	5.5	8.5	10.3	12.7	6.7	12.3

    A and B designate respectively the percentage deviation of the bubble-point
liquid and dew-point vapor results from that of the 50% vapor feed.

TABLE 51. VALUES OF THE MINIMUM REFLUX RATIO FOR DIFFERENT FEED CONDITIONS BY THE METHOD OF SHIRAS ET AL.

		A	9.7	19.1	6.2	11.1	4.3	7.8	7.3	10.9	5.0	10.6
Bubble-Point Liq.	(29-38)		2.34	2.50	4.21	5.60	5.76	9.62	7.11	12.54	2.87	3.29
50% Vapor	(1-10)		2.59	3.09	4.49	6.30	6.02	10.44	7.67	14.08	3.02	3.68
Dew-Point Vapor	(39-48)		3.01	3.88	4.83	7.10	6.32	11.33	8.36	15.78	3.22	4.14
		B	16.2	25.6	7.6	12.7	5.0	8.5	9.0	12.1	6.6	12.5

TABLE 52. VALUES OF THE MINIMUM REFLUX RATIO FOR DIFFERENT FEED CONDITIONS BY THE METHOD OF SCHEIBEL AND MONTROSS

		A	8.8	19.9	6.7	11.0	4.3	7.9	6.5	11.4	6.0	11.3
Bubble-Point Liq.	(29-38)		2.39	2.58	4.18	5.65	5.74	9.56	6.60	11.52	3.13	3.69
50% Vapor	(1-10)		2.62	3.22	4.48	6.35	6.00	10.38	7.06	13.00	3.33	4.16
Dew-Point Vapor	(39-48)		3.05	4.04	4.84	7.18	6.30	11.32	7.67	14.63	3.58	4.69
		B	16.4	25.5	8.0	13.1	5.0	9.1	8.6	12.6	7.5	12.7

A and B designate respectively the percentage deviation of the bubble-point liquid and dew-point vapor results from that of the 50% vapor feed.

TABLE 53. VALUES OF THE MINIMUM REFLUX RATIO FOR DIFFERENT FEED CONDITIONS BY THE
          METHOD OF MURDOCH AND HOLLAND

	A	11.2	20.0	6.3	11.0	4.3	7.8	7.7	11.1	5.0	10.1
Bubble-Point Liq.(29-38)		2.29	2.56	4.18	5.67	5.74	9.62	6.67	11.90	3.05	3.54
50% Vapor (1-10)		2.58	3.20	4.46	6.37	6.00	10.44	7.23	13.39	3.21	3.94
Dew-Point Vapor (39-48)		3.03	3.98	4.81	7.16	6.30	11.32	7.90	15.00	3.42	4.42
	B	17.4	24.4	7.8	12.4	5.00	8.4	9.3	12.0	6.6	12.2

    A and B designate respectively the percentage deviation of the bubble-point
liquid and dew-point vapor results from that of the 50% vapor feed.

TABLE 54. VALUES OF THE MINIMUM REFLUX RATIO BY THE METHOD OF SCHEIBEL AND MONTROSS USING RELATIVE VOLATIL-ITY DATA FROM ALL METHODS ANALYZED.

The relative volatility data used were obtained from the procedures by:

Example		Scheibel & Montross	Underwood	Colburn	Shiras et al.	Murdoch & Holland
1	(a)	2.62	2.70	2.65	2.66	2.65
2		3.22	3.11	3.21	3.15	3.22
3		4.48	4.60	4.49	4.51	4.49
4		6.35	6.21	6.38	6.32	6.38
5		6.00	6.14	6.00	6.03	6.00
6		10.38	10.24	10.43	10.43	10.43
7		7.06	7.59	7.33	7.79	7.33
8		13.00	13.30	13.37	14.12	13.38
9		3.33	3.25	3.23	3.05	3.23
10		4.16	3.89	4.03	3.77	4.03
11	(b)	2.94	3.04	2.95	2.96	2.95
12		3.68	3.51	3.70	3.60	3.70
13		6.90	7.68	7.49	8.42	7.50
14		11.85	12.38	12.65	14.02	12.71
15		1.93	1.82	1.81	1.54	1.81
16		2.13	1.86	1.97	1.64	1.96
17	(c)	1.08	1.13	1.08	1.08	1.10
18		1.91	1.69	1.81	1.76	1.84
19		2.64	2.89	3.05	3.19	3.02
20		5.82	5.68	6.21	6.43	6.19
21		0.67	0.61	0.52	0.47	0.56
22		0.96	0.73	0.60	0.60	0.75
23	(d)	0.37	0.42	0.40	0.39	0.40
24		0.73	0.59	0.68	0.63	0.68
25		1.92	1.94	2.24	2.32	2.21
26		4.34	3.97	4.70	4.92	4.71
27		0.16	0.18	0.09	0.08	0.09
28		0.21	0.17	0.09	0.09	0.10
29	(e)	2.39	2.48	2.39	2.44	2.43
30		2.58	2.50	2.56	2.55	2.61
31		4.18	4.33	4.20	4.24	4.22
32		5.65	5.50	5.62	5.62	5.68
33		5.74	5.88	5.74	5.76	5.74
34		9.56	9.42	9.56	9.61	9.61
35		6.60	7.13	6.83	7.33	6.88
36		11.52	11.89	11.89	12.71	12.04
37		3.13	3.07	3.04	2.87	3.04
38		3.69	3.44	3.57	3.33	3.58

TABLE 54 (CONTINUED)

The relative volatility data used were obtained
from the procedures by:

Example	Scheibel & Montross	Underwood	Colburn	Shiras et al.	Murdoch & Holland
39 (f)	3.05	3.09	3.10	3.06	3.06
40	4.04	3.90	4.05	3.95	4.00
41	4.84	4.94	4.86	4.86	4.84
42	7.18	7.00	7.21	7.12	7.15
43	6.30	6.44	6.33	6.33	6.30
44	11.32	11.13	11.32	11.31	11.32
45	7.67	8.16	7.94	8.36	7.89
46	14.63	14.88	15.01	15.69	14.93
47	3.58	3.49	3.49	3.28	3.48
48	4.69	4.40	4.58	4.29	4.57

(a) Examples 1-10: 4 components, adjacent keys, 50%
vapor feed

(b) Examples 11-16: 8 components, adjacent keys, 50%
vapor feed

(c) Examples 17-22: 8 components, one split key, 50%
vapor feed

(d) Examples 23-28: 6 components, adjacent keys with
higher relative volatility, 50%
vapor feed

(e) Examples 29-38: 4 components, adjacent keys, bubble-
point liquid feed

(f) Examples 39-48: 4 components, adjacent keys, dew-
point vapor feed

TABLE 55. RELATIVE VOLATILITIES BY THE METHOD OF UNDERWOOD

EXAMPLE	CH4	C2H6	C3H8	i-C4H10	n-C4H10	i-C5H12	n-C5H12	n-C8H18	TEMP. (°R)
1			1.962	1.209	1.000	0.616			724.0
2			1.999	1.215	1.000	0.605			713.5
3			1.956	1.208	1.000	0.618			726.0
4			1.992	1.214	1.000	0.607			715.5
5			1.959	1.209	1.000	0.617			725.0
6			1.980	1.212	1.000	0.610			719.0
7			1.906	1.199	1.000	0.633			731.5
8			1.928	1.203	1.000	0.626			731.5
9			2.019	1.219	1.000	0.599			708.0
10			2.049	1.224	1.000	0.591			700.0
11	11.116	3.956	1.949	1.207	1.000	0.620	0.531	0.066	728.0
12	12.653	4.244	2.023	1.219	1.000	0.598	0.505	0.057	707.0
13	9.523	3.639	1.866	1.192	1.000	0.646	0.564	0.081	755.0
14	10.243	3.785	1.904	1.199	1.000	0.634	0.548	0.074	742.0
15	13.814	4.453	2.074	1.228	1.000	0.584	0.488	0.051	693.5
16	15.243	4.702	2.135	1.238	1.000	0.568	0.470	0.046	679.0
17	15.042	5.705	2.912	1.855	1.553	1.000	0.871	0.123	752.0
18	16.333	6.012	3.018	1.897	1.580	1.000	0.864	0.115	740.5
19	12.757	5.139	2.713	1.774	1.501	1.000	0.885	0.140	776.5
20	13.049	5.213	2.739	1.785	1.508	1.000	0.883	0.138	773.0
21	20.229	6.894	3.315	2.013	1.655	1.000	0.847	0.098	712.5
22	21.059	7.074	3.374	2.036	1.669	1.000	0.844	0.096	707.5
23	20.310	6.911	3.321			1.000	0.847	0.098	712.0
24	22.118	7.301	3.448			1.000	0.841	0.092	701.5
25	16.097	5.957	2.999			1.000	0.866	0.117	742.5
26	16.333	6.012	3.018			1.000	0.864	0.115	740.5
27	27.530	8.413	3.799			1.000	0.825	0.079	676.0
28	28.795	8.663	3.876			1.000	0.822	0.077	671.0

The volatility data for examples 29-38 and 39-48 are identical to those of examples 1-10, since they are based on the same temperatures.

TABLE 56.   RELATIVE VOLATILITIES BY THE METHOD OF COLBURN

EXAMPLE	CH4	C2H6	C3H8	i-C4H10	n-C4H10	i-C5H12	n-C5H12	n-C8H18
1			2.087	1.213	1.000	0.644		
2			2.054	1.209	1.000	0.649		
3			2.027	1.213	1.000	0.621		
4			1.992	1.208	1.000	0.629		
5			1.997	1.214	1.000	0.612		
6			1.965	1.208	1.000	0.622		
7			1.984	1.207	1.000	0.633		
8			1.955	1.203	1.000	0.638		
9			2.058	1.220	1.000	0.610		
10			2.032	1.215	1.000	0.619		
11	13.760	4.444	2.073	1.213	1.000	0.638	0.554	0.076
12	12.982	4.305	2.038	1.208	1.000	0.644	0.562	0.080
13	11.848	4.096	1.985	1.200	1.000	0.657	0.578	0.088
14	11.264	3.985	1.957	1.198	1.000	0.658	0.579	0.088
15	15.675	4.776	2.153	1.227	1.000	0.612	0.522	0.063
16	15.148	4.686	2.131	1.222	1.000	0.622	0.533	0.068
17	22.507	7.384	3.475	1.880	1.568	1.000	0.902	0.168
18	19.156	6.657	3.237	1.820	1.530	1.000	0.907	0.178
19	14.518	5.578	2.869	1.739	1.478	1.000	0.910	0.186
20	13.058	5.216	2.749	1.710	1.459	1.000	0.911	0.189
21	35.279	9.896	4.245	2.103	1.709	1.000	0.872	0.124
22	31.567	9.200	4.039	2.223	1.658	1.000	0.887	0.143
23	32.560	9.388	3.321			1.000	0.898	0.160
24	22.923	7.472	2.971			1.000	0.906	0.176
25	14.730	5.630	2.615			1.000	0.913	0.194
26	12.612	5.102	2.521			1.000	0.914	0.194
27	95.158	19.300	5.275			1.000	0.822	0.076
28	85.065	17.869	4.791			1.000	0.850	0.101

TABLE 56. (CONTINUED)

EXAMPLE	CH4	C2H6	C3H8	i-C4H10	n-C4H10	i-C5H12	n-C5H12	n-C8H18
29			2.107	1.216	1.000	0.636		
30			2.084	1.212	1.000	0.644		
31			2.028	1.214	1.000	0.619		
32			2.000	1.210	1.000	0.628		
33			2.001	1.214	1.000	0.611		
34			1.968	1.209	1.000	0.621		
35			1.990	1.208	1.000	0.630		
36			1.959	1.204	1.000	0.637		
37			2.065	1.220	1.000	0.609		
38			2.043	1.216	1.000	0.618		
39			2.063	1.209	1.000	0.650		
40			2.030	1.206	1.000	0.652		
41			2.015	1.212	1.000	0.624		
42			1.984	1.207	1.000	0.631		
43			1.994	1.213	1.000	0.613		
44			1.961	1.208	1.000	0.623		
45			1.979	1.206	1.000	0.635		
46			1.951	1.202	1.000	0.640		
47			2.051	1.218	1.000	0.611		
48			2.022	1.213	1.000	0.621		

TABLE 57. RELATIVE VOLATILITIES BY THE METHOD OF SHIRAS ET AL.

EXAMPLE	CH4	C2H6	C3H8	i-C4H10	n-C4H10	i-C5H12	n-C5H12	n-C8H18	TEMP. (°R)
1			1.981	1.212	1.000	0.610			718.6
2			1.980	1.212	1.000	0.610			719.0
3			1.981	1.212	1.000	0.610			718.7
4			1.966	1.210	1.000	0.614			722.9
5			1.982	1.213	1.000	0.610			718.2
6			1.956	1.208	1.000	0.617			725.8
7			1.873	1.194	1.000	0.644			752.4
8			1.861	1.191	1.000	0.648			756.8
9			2.110	1.234	1.000	0.574			684.9
10			2.095	1.231	1.000	0.578			688.5
11	11.775	4.081	1.981	1.212	1.000	0.610	0.519	0.062	718.5
12	11.906	4.106	1.988	1.213	1.000	0.608	0.517	0.061	716.7
13	7.999	3.313	1.777	1.176	1.000	0.676	0.603	0.101	788.6
14	7.956	3.303	1.774	1.176	1.000	0.677	0.604	0.102	789.7
15	19.882	5.459	2.311	1.267	1.000	0.529	0.427	0.034	642.9
16	20.070	5.488	2.317	1.268	1.000	0.528	0.426	0.034	641.7
17	16.144	5.968	3.003	1.891	1.576	1.000	0.865	0.116	742.1
18	15.191	5.741	2.925	1.860	1.556	1.000	0.870	0.122	750.6
19	10.505	4.543	2.498	1.686	1.444	1.000	0.901	0.166	808.8
20	9.951	4.390	2.442	1.663	1.429	1.000	0.905	0.175	818.7
21	31.685	9.222	4.045	2.282	1.822	1.000	0.817	0.072	660.6
22	29.403	8.782	3.913	2.235	1.793	1.000	0.821	0.076	668.7
23	22.904	7.468	3.502			1.000	0.838	0.090	697.3
24	19.659	6.768	3.273			1.000	0.850	0.100	716.1
25	10.516	4.547	2.500			1.000	0.901	0.166	808.6
26	9.504	4.263	2.396			1.000	0.909	0.183	827.5
27	77.296	16.736	6.042			1.000	0.786	0.043	577.5
28	61.230	14.289	5.439			1.000	0.789	0.048	597.0

The volatility data for examples 29-38 and 39-48 are identical to those of examples 1-10, since they are based on the same temperatures.

TABLE 58. RELATIVE VOLATILITIES BY THE METHOD OF SCHEIBEL AND MONTROSS

EXAMPLE	CH4	C2H6	C3H8	i-C4H10	n-C4H10	i-C5H12	n-C5H12	n-C8H18
1			1.994	1.215	1.000	0.607		
2			1.953	1.208	1.000	0.619		
3			1.987	1.214	1.000	0.609		
4			1.956	1.209	1.000	0.618		
5			1.987	1.214	1.000	0.609		
6			1.956	1.209	1.000	0.618		
7			1.987	1.214	1.000	0.609		
8			1.953	1.208	1.000	0.619		
9			1.991	1.214	1.000	0.608		
10			1.956	1.209	1.000	0.618		
11	11.885	4.103	1.987	1.214	1.000	0.609	0.518	0.062
12	11.251	3.982	1.956	1.209	1.000	0.618	0.529	0.066
13	11.812	4.089	1.984	1.213	1.000	0.610	0.519	0.062
14	11.183	3.970	1.953	1.208	1.000	0.619	0.530	0.067
15	12.033	4.130	1.994	1.215	1.000	0.607	0.516	0.061
16	11.319	3.995	1.960	1.209	1.000	0.617	0.528	0.066
17	16.274	5.999	3.014	1.896	1.580	1.000	0.865	0.116
18	12.965	5.192	2.732	1.783	1.506	1.000	0.884	0.139
19	15.148	5.731	2.922	1.859	1.556	1.000	0.871	0.123
20	12.398	5.047	2.681	1.762	1.493	1.000	0.888	0.144
21	17.264	6.229	3.093	1.927	1.600	1.000	0.860	0.111
22	13.666	5.368	2.795	1.808	1.523	1.000	0.880	0.133
23	24.572	7.815	3.613			1.000	0.834	0.086
24	15.042	5.706	2.913			1.000	0.872	0.124
25	16.514	6.055	3.033			1.000	0.864	0.115
26	12.799	5.150	2.717			1.000	0.885	0.141
27	33.722	9.607	4.160			1.000	0.813	0.070
28	22.582	7.400	3.480			1.000	0.840	0.091

TABLE 58. (CONTINUED)

EXAMPLE	CH4	C2H6	C3H8	i-C4H10	n-C4H10	i-C5H12	n-C5H12	n-C8H18
29			2.001	1.216	1.000	0.605		
30			1.963	1.210	1.000	0.616		
31			1.994	1.215	1.000	0.607		
32			1.960	1.209	1.000	0.617		
33			1.991	1.214	1.000	0.608		
34			1.960	1.209	1.000	0.617		
35			1.991	1.214	1.000	0.608		
36			1.960	1.209	1.000	0.617		
37			1.994	1.215	1.000	0.607		
38			1.963	1.210	1.000	0.616		
39			1.980	1.213	1.000	0.611		
40			1.943	1.206	1.000	0.622		
41			1.984	1.213	1.000	0.610		
42			1.953	1.208	1.000	0.619		
43			1.987	1.214	1.000	0.609		
44			1.953	1.208	1.000	0.619		
45			1.980	1.213	1.000	0.611		
46			1.950	1.207	1.000	0.620		
47			1.984	1.213	1.000	0.610		
48			1.953	1.208	1.000	0.619		

TABLE 59. RELATIVE VOLATILITIES BY THE METHOD OF MURDOCH AND HOLLAND

EXAMPLE	CH4	C2H6	C3H8	i-C4H10	n-C4H10	i-C5H12	n-C5H12	n-C8H18
1			2.092	1.213	1.000	0.645		
2			2.062	1.208	1.000	0.652		
3			2.023	1.213	1.000	0.622		
4			1.994	1.208	1.000	0.631		
5			1.997	1.214	1.000	0.612		
6			1.965	1.208	1.000	0.622		
7			1.986	1.207	1.000	0.633		
8			1.956	1.203	1.000	0.639		
9			2.059	1.220	1.000	0.610		
10			2.037	1.215	1.000	0.620		
11	13.796	4.450	2.074	1.213	1.000	0.638	0.554	0.077
12	13.100	4.326	2.043	1.208	1.000	0.646	0.564	0.081
13	11.870	4.100	1.986	1.200	1.000	0.658	0.579	0.088
14	11.298	3.991	1.959	1.197	1.000	0.660	0.582	0.090
15	15.697	4.779	2.154	1.227	1.000	0.612	0.522	0.063
16	15.425	4.733	2.143	1.223	1.000	0.623	0.535	0.068
17	19.052	6.634	3.229	1.862	1.558	1.000	0.891	0.149
18	16.883	6.141	3.063	1.805	1.521	1.000	0.900	0.164
19	13.666	5.368	2.795	1.743	1.481	1.000	0.903	0.170
20	12.516	5.077	2.691	1.711	1.460	1.000	0.907	0.179
21	27.580	8.423	3.803	2.044	1.674	1.000	0.866	0.117
22	25.193	7.943	3.653	1.974	1.629	1.000	0.880	0.133
23	29.430	8.788	3.296			1.000	0.888	0.145
24	23.136	7.517	2.971			1.000	0.907	0.179
25	14.448	5.561	2.635			1.000	0.908	0.182
26	12.620	5.104	2.519			1.000	0.914	0.195
27	85.722	17.964	5.134			1.000	0.821	0.076
28	73.763	16.211	4.622			1.000	0.847	0.098

TABLE 59.   (CONTINUED)

EXAMPLE	CH4	C2H6	C3H8	i-C4H10	n-C4H10	i-C5H12	n-C5H12	n-C8H18
29			2.109	1.213	1.000	0.650		
30			2.093	1.209	1.000	0.660		
31			2.029	1.213	1.000	0.623		
32			2.002	1.208	1.000	0.634		
33			2.001	1.214	1.000	0.613		
34			1.968	1.208	1.000	0.624		
35			1.990	1.207	1.000	0.636		
36			1.960	1.2;2	1.000	0.644		
37			2.065	1.220	1.000	0.611		
38			2.048	1.215	1.000	0.622		
38			2.069	1.212	1.000	0.639		
40			2.037	1.209	1.000	0.642		
41			2.017	1.213	1.000	0.620		
42			1.986	1.209	1.000	0.627		
43			1.995	1.214	1.000	0.612		
44			1.962	1.208	1.000	0.621		
45			1.980	1.207	1.000	0.630		
46			1.952	1.203	1.000	0.635		
47			2.052	1.219	1.000	0.609		
48			2.025	1.214	1.000	0.618		

TABLE 60. TEMPERATURES AT THE TOP AND

BOTTOM OF THE DISTILLATION COLUMN

EXAMPLE	TOP, °RANKINE	BOTTOM, °RANKINE
1	652	796
2	640	787
3	677	775
4	666	765
5	697	753
6	691	747
7	698	785
8	694	775
9	666	750
10	654	746
11	626	830
12	603	811
13	683	827
14	669	815
15	616	771
16	599	759
17	646	858
18	632	849
19	697	856
20	696	850
21	625	800
22	612	803
23	555	869
24	545	858
25	612	873
26	615	866
27	534	818
28	525	817

The corresponding temperatures for examples 29-38
and 39-48 are equal to those of examples 1-10 because
of identical compositions of the products.

TABLE 61. EQUILIBRIUM DATA

p = 400 psia

Comp.	a_1 x 10	a_2 x 10^3	a_3 x 10^6	a_4 x 10^9
CH4	-3.2551482	2.3553786	-3.1371170	1.3397973
C2H6	-2.7947232	1.4124232	-1.4582948	0.50974162
C3H8	-2.7980091	1.1811943	-1.0935041	0.35180421
i-C4H10	-2.3209137	0.87122379	-0.66100972	0.1667774
n-C4H10	-2.3203344	0.83753226	-0.61774360	0.15243376
i-C5H12	-0.6981454	0.088862037	0.39689556	-0.29076073
n-C5H12	0.37103008	-0.36257004	0.99113800	-0.54441110
n-C8H18	0.905211	-0.4839184	0.819390	-0.332217

$$(K_i/T)^{1/3} = a_{1i}+a_{2i}T+a_{3i}T^2+a_{4i}T^3 \quad (T \text{ in } ^oR)$$

(Taken from Reference 1)

TABLE 62. PROGRAM FOR CALCULATING THE MINIMUM REFLUX RATIO

BY THE METHOD OF UNDERWOOD

A FORTRAN PROGRAM FOR THE IBM 1130 SYSTEM

```
       DIMENSION THETA(2),FUNC(2),FUNIC(2),FEED(8),DIST(8),
              ALFA(8)
       INDEX=1
  1    READ(2,2) LIMIT,NFC,NC,KL,KH
  2    FORMAT(5I2)
       IF(LIMIT) 3,99,3
  3    NLC=NFC+NC-1
       READ(2,5) HEAT,SDIST
  7    READ(2,5) (FEED(I),I=NFC,NLC)
       READ(2,5) (ALFA(N),N=NFC,NLC)
       READ(2,5) (DIST(M),M=NFC,NLC)
  5    FORMAT(8F10.0)
       IF(KH-KL-2) 13,12,99
 13    THIGH=ALFA(KL)
       TLOW=ALFA(KH)
       DO 40 J=1,20
       TETA=(THIGH+TLOW)*.5
       FUNCT=0.
       DO 15 I=NFC,NLC
 15    FUNCT=FUNCT+(ALFA(I)*FEED(I))/(ALFA(I)-TETA)
       FUNCT=FUNCT/100.-HEAT
       IF(FUNCT) 20,45,25
 20    TLOW=TETA
       GO TO 30
 25    THIGH=TETA
 30    IF(FUNCT**2-1.0E-6) 45,45,40
 40    CONTINUE
 45    RMIN=0.
       DO 65 I=NFC,NLC
 65    RMIN=RMIN+(DIST(I)*ALFA(I))/(ALFA(I)-TETA)
       RMIN=(RMIN/SDIST)-1.0
       WRITE(3,70) INDEX,FUNCT,TETA,RMIN
 70    FORMAT(1X,I4,8X,F8.5,5X,F8.5,2X,F7.4)
       GO TO 750
 12    KSI=KL+1
       DIST(KSI)=0.
       THIGH=ALFA(KL)
 80    TLOW=ALFA(KSI)
       DO 400 J=1,20
       THETA(KSI)=(THIGH+TLOW)*.5
       FUNCT=0.
       DO 150 I=NFC,NLC
150    FUNCT=FUNCT+(ALFA(I)*FEED(I))/(ALFA(I)-THETA(KSI))
```

TABLE 62. (CONTINUED)

```
        FUNCT=FUNCT/100.-HEAT
        IF(FUNCT) 200,450,250
200     TLOW=THETA(KSI)
        GO TO 300
250     THIGH=THETA(KSI)
300     IF(FUNCT**2-1.0E-6) 420,420,400
400     CONTINUE
420     FUN=FUNCT
        IF(KSI-KH) 430,450,450
430     KIP=KSI
        THIGH=ALFA(KIP)
        KSI=KSI+1
        GO TO 80
450     KL1=KL+1
        KL2=KL+2
        DO 550 J=KL1,KL2
        FUNC(J)=0.
        DO 550 I=NFC,NLC
        FUNC(J)=FUNC(J)+(ALFA(I)*DIST(I))/(ALFA(I)-THETA(J))
550     CONTINUE
        DO 600 J=KL1,KL2
600     FUNIC(J)=ALFA(KL1)/(ALFA(KL1)-THETA(J))
        ABEL=FUNIC(KL1)-FUNIC(KL2)
        BRAM=FUNC(KL2)-FUNC(KL1)
        DIST(KL1)=BRAM/ABEL
        SDIST=0.
        DO 650 M=NFC,NLC
650     SDIST=SDIST+DIST(M)
        FUNC(KL1)=FUNC(KL1)+FUNIC(KL1)*DIST(KL1)
        RMIN=FUNC(KL1)/SDIST-1.
        WRITE(3,700) INDEX,DIST(KL1),RMIN,THETA(KL1),THETA(KL2)
700     FORMAT(1X,I4,5X,F6.3,5X,F7.4,5X,F8.5,5X,F8.5)
750     INDEX=INDEX+1
        GO TO 1
 99     CALL EXIT
        END
```

TABLE 63. PROGRAM FOR CALCULATING THE MINIMUM REFLUX RATIO

BY THE METHOD OF COLBURN

<u>A FORTRAN PROGRAM FOR THE G.E. MARK II SYSTEM</u>

```
10         DIMENSION XDIST(8),XBOT(8),EQVN(8),EQVM(8),XN(8),
20&          XM(8),A(8,4),ALFAN(8),ALFAM(8),SUMHM(8),
25&          SUMLN(8),XNXM(8)
30         FILENAME FK
40         PRINT,"DATAFILE"
50         INPUT,FK
60         INDEX=1
70       7 READ(FK,8)L,LIMIT,NFC,NC,KL,KH
80       8 FORMAT(V)
90         NLC=NFC+NC-1
100        IF(LIMIT) 9,999,11
110      9 DO 260 I=1,8
120    260 READ(FK,8)L,(A(I,J),J=1,4)
130     11 READ(FK,8)L,TN,TM,TOTD,TOTB,FELIQ,REFLN
140        READ(FK,8)L,(XDIST(I),I=NFC,KH)
150        READ(FK,8)L,(XBOT(K),K=KL,NLC)
160    250 TOTDB=TOTD/TOTB
170        FLQTB=FELIQ/TOTB
180        JY=5
181        JYE=5
182        MIKE=10
183        IK=5
184        IKE=5
190      4 REFLM=REFLN*TOTDB+FLQTB
200        IND=1
205        ITA=1
210        INDAX=1
220        INDOX=1
230        TN1=0.
240        TN=TN-100.
250      5 XNTOT=0.
260        DO 6 I=NFC,KH
265        IF(XDIST(I)) 6,6,27
270     27 EQVN(I)=TN*(A(I,1)+A(I,2)*TN+A(I,3)*TN**2+
275&         A(I,4)*TN**3)**3
280        XN(I)=XDIST(I)/(EQVN(I)+(EQVN(I)-1.)*REFLN)
290        IF(XN(I)) 10,10,600
300    600 XNTOT=XNTOT+XN(I)
303      6 CONTINUE
305        IF(ITA-5) 270,140,150
310    270 IF(INDOX-3) 12,60,12
320     12 IF(TN1+5.-TN) 15,15,20
330     15 IF(XNTOT-1.) 20,60,10
340     10 IF(INDAX-2) 17,50,50
```

TABLE 63. (CONTINUED)

```
350    17 TN=TN+10.
360       GO TO 5
370    20 IND=IND+1
380       IF(IND-2) 30,25,30
390    25 TN1=TN
400       XNTO=XNTOT
410       TN=TN-1.
420       INDAX=2
430       GO TO 5
440    30 IF((1.-XNTOT)-(XNTOT-XNTO)) 60,60,25
450    50 TN=TN+1.
460       INDOX=3
470       GO TO 5
471    60 XNT=XNTOT
472       IF(XNTOT-1.) 120,125,130
473   120 TN=TN-0.1
474       ITA=5
475       GO TO 5
476   130 TN=TN+0.1
477       ITA=6
478       GO TO 5
479   140 IF(XNTOT-1.) 120,125,125
480   150 IF(XNTOT-1.) 125,125,130
482   125 SXN=0.
483       DO 126 I=NFC,KL
485   126 SXN=SXN+XN(I)
486       XN(KH)=1.-SXN
487       IDA=1
488       ITO=1
489       TM1=0.
500       TM=TM-100.
510    65 XMTOT=0.
520       DO 70 K=KL,NLC
525       IF(XBOT(K)) 70,70,78
530    78 EQVM(K)=TM*(A(K,1)+A(K,2)*TM+A(K,3)*TM**2+
535&      A(K,4)*TM**3)**3
540       XM(K)=XBOT(K)/(EQVM(K)+(1.-EQVM(K))*REFLM)
550       IF(XM(K)) 77,77,700
560   700 XMTOT=XMTOT+XM(K)
563    70 CONTINUE
565       IF(ITO-5) 71,160,170
570    71 IF(IDA-2) 72,100,72
580    72 IF(TM1+5.-TM) 73,73,85
590    73 IF(XMTOT-1.) 75,100,77
600    75 TM=TM+10.
610       GO TO 65
620    77 TM1=TM
630       XMTO=XMTOT
640       TM=TM-1.
650       GO TO 65
```

TABLE 63. (CONTINUED)

```
660    85 IF((XMTOT-1.)-(XMTO-XMTOT)) 90,77,77
670    90 IF(XMTO-1.) 95,100,100
680    95 TM=TM+1.
690       IDA=2
701   100 XMT=XMTOT
702       IF(XMTOT-1.) 180,200,190
703   180 TM=TM+0.1
704       ITO=5
705       GO TO 65
706   190 TM=TM-0.1
707       ITO=6
708       GO TO 65
709   160 IF(XMTOT-1.) 180,200,200
710   170 IF(XMTOT-1.) 200,200,190
712   200 SXM=0.
713       DO 108 K=KH,NLC
715   108 SXM=SXM+XM(K)
716       XM(KL)=1.-SXM
718       RMRN=(XM(KL)/XM(KH))/(XN(KL)/XN(KH))
720       TOTHM=0.
730       KH1=KH+1
740       DO 105 I=KH1,NLC
750       ALFAM(I)=EQVM(I)/EQVM(KH)
760       SUMHM(I)=ALFAM(I)*XM(I)
770   105 TOTHM=TOTHM+SUMHM(I)
780       TOTLN=0.
790       KL1=KL-1
800       DO 110 J=NFC,KL1
810       SUMLN(J)=XN(J)
820   110 TOTLN=TOTLN+SUMLN(J)
830       PSI=1./((1.-TOTHM)*(1.-TOTLN))
840       IF(RMRN-PSI) 280,350,290
845   280 IF(MIKE-10) 301,295,331
850   290 IF(MIKE-10) 301,295,331
855   295 IF(RMRN-PSI) 301,350,331
860   301 IF(RMRN-PSI) 303,350,302
870   302 IF(IK-12) 999,310,999
880   303 IF(IKE-15) 305,350,350
890   305 REFLN=REFLN+0.1
900       MIKE=5
910       IK=12
920       GO TO 4
925   310 REFLN=REFLN-0.01
930       IKE=15
935       GO TO 4
940   331 IF(RMRN-PSI) 332,350,333
945   332 IF(JY-12) 999,320,999
950   333 IF(JYE-15) 335,350,350
955   335 REFLN=REFLN-0.1
```

TABLE 63. (CONTINUED)

```
960        MIKE=15
965        JY=12
970        GO TO 4
980    320 REFLN=REFLN+0.01
990        JYE=15
1000       GO TO 4
1010   350 PRINT 115,INDEX,TN,XNTOT,TM,XMTOT,RMRN,PSI,REFLN
1020   115 FORMAT(I3,2X,7F9.4)
1030       IF(KH-KL-2) 415,400,415
1040   400 DO 410 M=KL,KH
1050   410 XNXM(M)=XN(M)/XM(M)
1060       PRINT 405,(XNXM(M),M=KL,KH)
1070   405 FORMAT(3F10.4)
1080   415 DO 420 I=NFC,KH
1090   420 ALFAN(I)=EQVN(I)/EQVN(KH)
1100       PRINT 425,(ALFAN(I),I=NFC,KH)
1110   425 FORMAT(7F10.4)
1120       DO 430 N=KL,NLC
1130   430 ALFAM(N)=EQVM(N)/EQVM(KH)
1140       PRINT 435,(ALFAM(N),N=KL,NLC)
1150   435 FORMAT(7F10.4)
1160       INDEX=INDEX+1
1170       GO TO 7
1180   999 STOP
1190       END
```

TABLE 64.   PROGRAM FOR CALCULATING THE MINIMUM REFLUX RATIO

BY THE METHOD OF SHIRAS ET AL.

A FORTRAN PROGRAM FOR THE G.E. MARK II SYSTEM

```
10          DIMENSION FEED(8),FLUID(8),VAP(8),XLIQ(8),A(8,4),
20&          EQVF(8),ALFA(8),DIST(8),EQV(8),XDIST(8),THETA(8),
25&          TERMA(8),TERMB(8),RATIO(8)
30          FILENAME FP
40          PRINT,"DATAFILE"
50          INPUT,FP
60          INDEX=1
70       7  READ(FP,8)L,LIMIT,NFC,NC,KL,KH
80       8  FORMAT(V)
90          NLC=NFC+NC-1
100         IF(LIMIT) 9,999,11
110      9  DO 12 I=1,8
120     12  READ(FP,8)L,(A(I,J),J=1,4)
130     11  READ(FP,8)L,(FEED(I),I=NFC,NLC)
140         READ(FP,8)L,(ALFA(I),I=1,8)
150         READ(FP,8)L,DIST(KL),DIST(KH),SUMVA
160         TR=715.
170         EPS=0.25
172         IF(SUMVA-50.) 244,15,144
173    144  SUMFL=0.
174         SUMVA=100.
175         GO TO 62
176    244  SUMFL=100.
177         SUMVA=0.
178         GO TO 57
180     15  SUMFL=0.
190         SUMVA=0.
200         DO 20 I=NFC,NLC
210         EQV(I)=TR*(A(I,1)+A(I,2)*TR+A(I,3)*TR**2+A(I,4)*
215&         TR**3)**3
220         FLUID(I)=FEED(I)/(1.+EQV(I))
230         VAP(I)=FEED(I)-FLUID(I)
240         SUMFL=SUMFL+FLUID(I)
250         SUMVA=SUMVA+VAP(I)
260     20  CONTINUE
270         IF(ABS(SUMFL-SUMVA)-EPS) 40,40,25
280     25  IF(SUMFL-SUMVA) 30,40,35
290     30  TR=TR-1.
300         EPS=EPS+0.025
310         GO TO 15
320     35  TR=TR+1.
330         EPS=EPS+0.025
340         GO TO 15
350     40  DO 45 K=NFC,NLC
360         XLIQ(K)=FLUID(K)/SUMFL
```

TABLE 64. (CONTINUED)

```
390    45 CONTINUE
391       GO TO 62
400    57 DO 58 I=NFC,NLC
410       FLUID(I)=FEED(I)
415    58 CONTINUE
420    62 SDIST=0.
430    65 DO 100 I=NFC,NLC
440       IF(FEED(I)) 90,90,69
445    69 IF(I-KL) 705,95,70
450    70 IF(I-KH) 705,95,705
452   705 IF(SUMVA-100.) 75,750,750
460    75 TERMA(I)=((ALFA(I)-1.)*DIST(KL))/((ALFA(KL)-1.)*
465&      FLUID(KL))
470       TERMB(I)=((ALFA(KL)-ALFA(I))*DIST(KH))/((ALFA(KL)
475&      -1.)*FLUID(KH))
480       DIST(I)=FLUID(I)*(TERMA(I)+TERMB(I))
481       GO TO 710
482   750 TERMA(I)=ALFA(KL)*(ALFA(I)-1.)*DIST(KL)/
483&      ((ALFA(KL)-1.)*FEED(KL))
485       TERMB(I)=(ALFA(KL)-ALFA(I))*DIST(KH)/((ALFA(KL)-1.)
486&      *FEED(KH))
487       DIST(I)=FEED(I)*(TERMA(I)+TERMB(I))/ALFA(I)
490   710 RATIO(I)=DIST(I)/FEED(I)
500       IF(RATIO(I)-1.) 85,80,80
510    80 DIST(I)=FEED(I)
520       GO TO 95
530    85 IF(RATIO(I)) 90,90,95
540    90 DIST(I)=0.
550    95 SDIST=SDIST+DIST(I)
560   100 CONTINUE
570       DO 105 K=NFC,NLC
580       XDIST(K)=DIST(K)/SDIST
590   105 CONTINUE
593       IF(KH-KL-2) 800,800,900
595   800 KSI=KL+1
597       GO TO 950
600   900 KSI=KH
610   950 THIGH=ALFA(KL)
620   108 TLOW=ALFA(KSI)
630       DO 130 J=1,20
640       THETA(KSI)=(THIGH+TLOW)*.5
650       FUNCT=0.
660       DO 110 I=NFC,NLC
670       FUNCT=FUNCT+(ALFA(I)*FEED(I))/(ALFA(I)-THETA(KSI))
680   110 CONTINUE
690       FUNCT=FUNCT-SUMVA
700       IF(FUNCT) 115,135,120
710   115 TLOW=THETA(KSI)
720       GO TO 125
```

TABLE 64. (CONTINUED)

```
730   120 THIGH=THETA(KSI)
740   125 IF(FUNCT/100.)**2-1.E-6) 135,135,130
750   130 CONTINUE
760   135 REFLM=0.0
770       DO 145 M=NFC,NLC
780       TERM=THETA(KSI)*XDIST(M)/(ALFA(M)-THETA(KSI))
790       REFLM=REFLM+TERM
800   145 CONTINUE
810       PRINT 48,INDEX,SUMFL,SUMVA,TR,THETA(KSI),REFLM
820    48 FORMAT(I3,2X,5F10.4)
840       PRINT 44,(DIST(M),M=NFC,NLC)
850    44 FORMAT(8F10.4)
860       INDEX=INDEX+1
870       GO TO 7
880   999 STOP
890       END
```

TABLE 65.   PROGRAM FOR CALCULATING THE MINIMUM REFLUX RATIO

BY THE METHOD OF SCHEIBEL AND MONTROSS

A FORTRAN PROGRAM FOR THE G.E. MARK II SYSTEM

```
10          DIMENSION FEED(8),DIST(8),ALFA(8)
20          FILENAME FS
30          PRINT,"DATAFILE"
40          INPUT,FS
50          INDEX=1
60        1 READ(FS,8)L,LIMIT,NFC,NC,KL,KH
70        8 FORMAT(V)
80          NLC=NFC+NC-1
90          IF(LIMIT) 9,99,3
100       3 READ(FS,8)L,XBS,XCS
110       9 READ(FS,8)L,SUMHF,SUMLF,FLMOL,FVMOL,DIST(KL),DIST(KH)
120         SMALM=(FLMOL-SUMHF)/(FVMOL-SUMLF)
130       7 READ(FS,8)L,(ALFA(N),N=NFC,NLC)
140         READ(FS,8)L,(FEED(I),I=NFC,NLC)
150         XB=FEED(KL)/100.
160         XC=FEED(KH)/100.
170         SQIRT=((((ALFA(KL)-1.)*(1.+SMALM)*XB/(XB+XC))-ALFA(KL)
180&        -SMALM)**2+(4.*SMALM*(ALFA(KL)-1.)*(1.+SMALM)*XB)/
185&        (XB+XC))**.5
190         XIN=(((ALFA(KL)-1.)*(1.+SMALM)*XB/(XB+XC))-ALFA(KL)
195&        -SMALM-SQIRT)/(2.*SMALM*(ALFA(KL)-1.))
200         IF(XIN-1.) 6,10,10
210       6 IF(XIN) 10,10,88
220      88 XI=XIN
230         GO TO 23
240      10 XIP=(((ALFA(KL)-1.)*(1.+SMALM)*XB/(XB+XC))-ALFA(KL)-
245&        SMALM+SQIRT)/(2.*SMALM*(ALFA(KL)-1.))
250         IF(XIP-1.) 15,23,23
260      15 IF(XIP) 40,18,18
270      18 XI=XIP
280      23 XP=DIST(KL)/(DIST(KL)+DIST(KH))
290         SRMIN=(XP/((ALFA(KL)-1.)*XI))-((1.-XP)*ALFA(KL))/
295&        ((1.-XI)*(ALFA(KL)-1.))
300         KH1=KH+1
310         SUMB=0.
320         DO 25 J=KH1,NLC
330      25 SUMB=SUMB+(FEED(J)/100.)/((ALFA(KL)/ALFA(J))-1.)
340         SUMT=0.
350         KL1=KL-1
360         DO 30 K=NFC,KL1
370      30 SUMT=SUMT+(.01*FEED(K)/ALFA(K))*(1.+ALFA(KL)/ALFA(K))
380         IF(KH-KL-2) 28,27,28
390      28 RMIN=(XB*SRMIN+(XC+SUMHF/100.)*SUMB+SUMT)/
395&        (XB+SUMLF/100.)
```

TABLE 65. (CONTINUED)

```
400       GO TO 29
405    27 RMIN=(XBS*SRMIN+(XCS+SUMHF/100.)*SUMB+SUMT)/
410&      (XBS+SUMLF/100.)
420    29 PRINT 35,INDEX,XI,RMIN
430    35 FORMAT(I3,2X,2F10.4)
440    40 INDEX=INDEX+1
450       GO TO 1
460    99 STOP
470       END
```

TABLE 66.   PROGRAM FOR CALCULATING THE MINIMUM REFLUX RATIO

BY THE METHOD OF MURDOCH AND HOLLAND

A FORTRAN PROGRAM FOR THE G.E. MARK II SYSTEM

```
 10          DIMENSION XDIST(8),XBOT(8),EQVN(8),EQVM(8),XN(8),
 20&         XM(8),A(8,4),ALFAN(8),ALFAM(8),ALFA(8),FEED(8),
 25&         DIST(8),TERM(8),TUM(8),THETA(8)
 30          FILENAME FC
 40          PRINT,"DATAFILE"
 50          INPUT,FC
 60          INDEX=1
 70      7   READ(FC,8)L,LIMIT,NFC,NC,KL,KH
 80      8   FORMAT(V)
 90          NLC=NFC+NC-1
100          IF(LIMIT) 9,999,11
110      9   DO 266 I=1,8
120    266   READ(FC,8)L,(A(I,J),J=1,4)
130     11   READ(FC,8)L,TN,TM,TOTD,TOTB,FELIQ,REFLN
140          READ(FC,8)L,(XDIST(I),I=NFC,KH)
150          READ(FC,8)L,(XBOT(K),K=KL,NLC)
160    250   TOTDB=TOTD/TOTB
170          FLQTB=FELIQ/TOTB
180          READ(FC,8)L,(FEED(N),N=NFC,NLC)
181          SDIST=TOTD
182          DO 2 I=NFC,KH
183      2   DIST(I)=SDIST*XDIST(I)
184          KON=1
185          HEAT=FELIQ/100.
190      4   REFLM=REFLN*TOTDB+FLQTB
200          IND=1
205          ITA=1
210          INDAX=1
220          INDOX=1
230          TN1=0.
240          TN=TN-100.
250      5   XNTOT=0.
260          DO 6 I=NFC,KH
265          IF(XDIST(I)) 6,6,27
270     27   EQVN(I)=TN*(A(I,1)+A(I,2)*TN+A(I,3)*TN**2+
275&         A(I,4)*TN**3)**3
280          XN(I)=XDIST(I)/(EQVN(I)+(EQVN(I)-1.)*REFLN)
290          IF(XN(I)) 10,10,600
300    600   XNTOT=XNTOT+XN(I)
303      6   CONTINUE
305          IF(ITA-5) 270,140,150
310    270   IF(INDOX-3) 12,60,12
320     12   IF(TN1+5.-TN) 15,15,20
```

TABLE 66. (CONTINUED)

```
330     15 IF(XNTOT-1.) 20,60,10
340     10 IF(INDAX-2) 17,50,50
350     17 TN=TN+10.
360     .  GO TO 5
370     20 IND=IND+1
380        IF(IND-2) 30,25,30
390     25 TN1=TN
400        XNTO=XNTOT
410        TN=TN-1.
420        INDAX=2
430        GO TO 5
440     30 IF((1.-XNTOT)-(XNTOT-XNTO)) 60,60,25
450     50 TN=TN+1.
460        INDOX=3
470        GO TO 5
471     60 XNT=XNTOT
472        IF(XNTOT-1.) 120,125,130
473    120 TN=TN-0.1
474        ITA=5
475        GO TO 5
476    130 TN=TN+0.1
477        ITA=6
478        GO TO 5
479    140 IF(XNTOT-1.) 120,125,125
480    150 IF(XNTOT-1.) 125,125,130
482    125 DO 126 I=NFC,KH
483    126 ALFAN(I)=EQVN(I)/EQVN(KH)
487        IDA=1
488        ITO=1
490        TM1=0.
500        TM=TM-100.
510     65 XMTOT=0.
520        DO 70 K=KL,NLC
525        IF(XBOT(K)) 70,70,78
530     78 EQVM(K)=TM*(A(K,1)+A(K,2)*TM+A(K,3)*TM**2+
535&       A(K,4)*TM**3)**3
540        XM(K)=XBOT(K)/(EQVM(K)+(1.-EQVM(K))*REFLM)
550        IF(XM(K)) 77,77,700
560    700 XMTOT=XMTOT+XM(K)
563     70 CONTINUE
565        IF(ITO-5) 71,160,170
570     71 IF(IDA-2) 72,100,72
580     72 IF(TM1+5.-TM) 73,73,85
590     73 IF(XMTOT-1.) 75,100,77
600     75 TM=TM+10.
610        GO TO 65
620     77 TM1=TM
630        XMTO=XMTOT
640        ···TM=TM-1.
```

```
650        GO TO 65
660    85  IF((XMTOT-1.)-(XMTO-XMTOT)) 90,77,77
670    90  IF(XMTO-1.) 95,100,100
680    95  TM=TM+1.
690        IDA=2
701   100  XMT=XMTOT
702        IF(XMTOT-1.) 180,200,190
703   180  TM=TM+0.1
704        ITO=5
705        GO TO 65
706   190  TM=TM-0.1
707        ITO=6
708        GO TO 65
709   160  IF(XMTOT-1.) 180,200,200
710   170  IF(XMTOT-1.) 200,200,190
712   200  DO 108 K=KL,NLC
715   108  ALFAM(K)=EQVM(K)/EQVM(KH)
720        DO 205 I=NFC,NLC
725        IF(I-KL) 210,215,215
730   215  IF(I-KH) 220,220,230
735   210  ALFA(I)=ALFAN(I)
737        GO TO 205
740   220  ALFA(I)=(ALFAN(I)+ALFAM(I))*.5
742        GO TO 205
745   230  ALFA(I)=ALFAM(I)
750   205  CONTINUE
755        IF(KH-KL-2) 235,275,235
760   235  THIGH=ALFA(KL)
765        TLOW=ALFA(KH)
770        DO 260 J=1,20
775        TETA=(THIGH+TLOW)*.5
780        FUNCT=0.
785        DO 240 I=NFC,NLC
790   240  FUNCT=FUNCT+(ALFA(I)*FEED(I))/(ALFA(I)-TETA)
800        FUNCT=FUNCT/100.-HEAT
805        IF(FUNCT) 245,265,750
810   245  TLOW=TETA
815        GO TO 255
820   750  THIGH=TETA
825   255  IF(FUNCT**2-1.0E-6) 265,265,260
830   260  CONTINUE
835   265  RMIN=0.
840        DO 720 I=NFC,NLC
845   720  RMIN=RMIN+(DIST(I)*ALFA(I))/(ALFA(I)-TETA)
850        RMIN=(RMIN/SDIST)-1.0
855        GO TO 350
860   275  KSI=KL+1
865        THIGH=ALFA(KL)
```

TABLE 66. (CONTINUED)

```
870   280 TLOW=ALFA(KSI)
875       DO 305 J=1,20
880       THETA(KSI)=(THIGH+TLOW)*.5
885       FUNCT=0.
890       DO 285 I=NFC,NLC
895   285 FUNCT=FUNCT+(ALFA(I)*FEED(I))/(ALFA(I)-THETA(KSI))
905       FUNCT=FUNCT/100.-HEAT
910       IF(FUNCT) 290,300,295
915   290 TLOW=THETA(KSI)
920       GO TO 300
925   295 THIGH=THETA(KSI)
930   300 IF(ABS(FUNCT**2)-1.0E-6) 310,310,305
935   305 CONTINUE
940   310 FUN=FUNCT
945       IF(KSI-KH) 315,320,320
950   315 KIP=KSI
955       THIGH=ALFA(KIP)
960       KSI=KSI+1
965       GO TO 280
970   320 KL1=KL+1
975       KL2=KL+2
980       V=THETA(KL1)*THETA(KL2)/ALFA(KL1)
985       STERM=0.
990       STUM=0.
995       DO 340 I=NFC,KH
1000      IF(I-KL1) 325,340,325
1005  325 TERM(I)=(ALFA(I)-ALFA(KL1))*DIST(I)/((ALFA(I)-
1007&     THETA(KL1))*(ALFA(I)-THETA(KL2)))
1010      STERM=STERM+TERM(I)
1015      TUM(I)=ALFA(I)*TERM(I)
1020  330 STUM=STUM+TUM(I)
1025  340 CONTINUE
1030      RHO=V*STERM/STUM
1035      RMIN=RHO/(1.-RHO)
1040  350 IF(ABS(RMIN-REFLN)-.01*RMIN) 365,365,355
1045  355 KON=KON+1
1050      IF(KON-10) 360,360,365
1055  360 REFLN=(REFLN+RMIN)*.5
1060      GO TO 4
1065  365 PRINT 370,INDEX,TN,TM,REFLN,RMIN,KON
1070  370 FORMAT(I3,2X,4F10.4,2X,I3)
1075      PRINT 375,(ALFA(I),I=NFC,NLC)
1080  375 FORMAT(8F8.4)
1085      INDEX=INDEX+1
1090      GO TO 7
1095  999 STOP
1100      END
```

TABLE 67. PROGRAM FOR CALCULATING THE DEW POINT OF A

MULTICOMPONENT MIXTURE

A FORTRAN PROGRAM FOR THE IBM 1130 SYSTEM

```
      DIMENSION A(8,4),Y(8),X(8),EQV(8)
      WRITE(3,63)
 63   FORMAT('1 DEW POINT CALCULATION'//' RUN NO.',5X,
           'DP(DEG.R)',5X,'SUM X'/)
      INDEX=1
 1    READ(2,2) LIMIT,NFC,NC,NLC,TR
 2    FORMAT(4I2,2X,F10.3)
      IF(LIMIT) 3,99,7
 3    READ(2,5) ((A(L,M),M=1,4),L=1,8)
 5    FORMAT(4F20.10)
 7    READ(2,10) (Y(I),I=NFC,NLC)
 10   FORMAT(8F10.5)
      EPSN=.1
      DELTA=.003
 15   XTOT=0.
 16   DO 20 I=NFC,NLC
 18   EQV(I)=TR*(A(I,1)+A(I,2)*TR+A(I,3)*TR**2+A(I,4)*TR**3)**3
      X(I)=Y(I)/EQV(I)
 20   XTOT=XTOT+X(I)
      Z=XTOT-1.
      IF(ABS(Z)-EPSN) 40,40,25
 25   IF(Z) 30,60,35
 30   TR=TR-10.
      EPSN=EPSN+.02
      GO TO 15
 35   TR=TR+10.
      EPSN=EPSN+.02
      GO TO 15
 40   IF(ABS(Z)-DELTA) 60,60,45
 45   IF(Z) 50,60,55
 50   TR=TR-1.
      DELTA=DELTA+.0002
      GO TO 15
 55   TR=TR+1.
      DELTA=DELTA+.0002
      GO TO 15
 60   WRITE(3,65) INDEX,TR,XTOT
 65   FORMAT(1X,I4,9X,F7.2,5X,F7.5)
      INDEX=INDEX+1
      GO TO 1
 99   CALL EXIT
      END
```

TABLE 68.   PROGRAM FOR CALCULATING THE BUBBLE POINT OF A

MULTICOMPONENT MIXTURE

A FORTRAN PROGRAM FOR THE IBM 1130 SYSTEM

```
      DIMENSION A(8,4),Y(8),X(8),EQV(8)
      WRITE(3,63)
  63  FORMAT('1 BUBBLE POINT CALCULATION'//' RUN NO.',
         5X,'BP(DEG.R)',5X,'SUM Y'/)
      INDEX=1
   1  READ(2,2) LIMIT,NFC,NC,NLC,TR
   2  FORMAT(4I2,2X,F10.3)
      IF(LIMIT) 3,99,7
   3  READ(2,5) ((A(L,M),M=1,4),L=1,8)
   5  FORMAT(4F20.10)
   7  READ(2,10) (X(I),I=NFC,NLC)
  10  FORMAT(8F10.5)
      EPSN=.1
      DELTA=.003
  15  YTOT=0.
  16  DO 20 I=NFC,NLC
  18  EQV(I)=TR*(A(I,1)+A(I,2)*TR+A(I,3)*TR**2+A(I,4)*TR**3)**3
      Y(I)=X(I)*EQV(I)
  20  YTOT=YTOT+Y(I)
      Z=YTOT-1.
      IF(ABS(Z)-EPSN) 40,40,25
  25  IF(Z) 30,60,35
  30  TR=TR+10.
      EPSN=EPSN+.02
      GO TO 15
  35  TR=TR-10.
      EPSN=EPSN+.02
      GO TO 15
  40  IF(ABS(Z)-DELTA) 60,60,45
  45  IF(Z) 50,60,55
  50  TR=TR+1.
      DELTA=DELTA+.0002
      GO TO 15
  55  TR=TR-1.
      DELTA=DELTA+.0002
      GO TO 15
  60  WRITE(3,65) INDEX,TR,YTOT
  65  FORMAT(1X,I4,9X,F7.2,5X,F7.5)
      INDEX=INDEX+1
      GO TO 1
  99  CALL EXIT
      END
```

TABLE 69.   PROGRAM FOR CALCULATING RELATIVE VOLATILITIES

A FORTRAN PROGRAM FOR THE IBM 1130 SYSTEM

```
      DIMENSION A(8,4),EQV(8),ALFA(8)
      WRITE(3,4)
   4  FORMAT('1 ALFA CALCULATION'//' RUN NO.',9X,'CH4',8X,
             'C2H6',7X,'C3H8',6X,'I-C4H10',5X,'N-C4H10',5X,
             'I-C5H12',5X,'N-C5H12',5X,'N-C8H18',7X,'TR'/)
      INDEX=1
   1  READ(2,2) LIMIT,KH,TR
   2  FORMAT(2I2,6X,F10.0)
      IF(LIMIT) 3,99,7
   3  READ(2,5) ((A(L,M),M=1,4),L=1,8)
   5  FORMAT(4F20.10)
   7  DO 10 I=1,8
  10  EQV(I)=TR*(A(I,1)+A(I,2)*TR+A(I,3)*TR**2+A(I,4)*TR**3)**3
      DO 15 I=1,8
  15  ALFA(I)=EQV(I)/EQV(KH)
      WRITE(3,20) INDEX,(ALFA(I),I=1,8),TR
  20  FORMAT(1X,I4,9X,F8.3,3X,F8.3,3X,F8.3,3X,F8.3,3X,F8.3,
             3X,F8.3,3X,F8.3,3X,F8.3,3X,F8.2)
      INDEX=INDEX+1
      GO TO 1
  99  CALL EXIT
      END
```

TABLE 70. PROGRAM TERMINOLOGY

A   – Represents four equilibrium constants per component

ALFA   – Volatility relative to that of the heavy key

ALFAM – Volatility relative to that of the heavy key in the stripping pinch

ALFAN – Volatility relative to that of the heavy key in the rectifying pinch

DIST   – Moles of a component in the distillate

EQV   – Equilibrium value of a component

EQVM   – Equilibrium value of a component in the stripping pinch

EQVN   – Equilibrium value of a component in the rectifying pinch

FEED   – Moles of a component in the feed

FELIQ – Total moles of liquid feed

FLMOL – Total moles of liquid feed

FLUID – Moles of a component in the liquid part of the feed

FVMOL – Total moles of vapor feed

HEAT   – Thermal condition of the feed (1-q)

KH   – Heavy key component

KL   – Light key component

NC   – Number of components

NFC   – Number of the first component

NLC   – Number of the last component

REFLM – Minimum reflux ratio (Shiras only)

REFLN – Reflux ratio

RMIN   – Minimum reflux ratio

TABLE 70. (CONTINUED)

SDIST — Total moles of distillate

SUMFL — Total moles of liquid in the feed

SUMHF — Moles of feed heavier than the heavy key

SUMLF — Moles of feed lighter than the light key

SUMVA — Total moles of vapor in the feed

TM　　— Temperature in the stripping pinch (^{O}R)

TN　　— Temperature in the rectifying pinch (^{O}R)

TOTB　— Total moles of bottoms

TOTD　— Total moles of distillate

TR　　— Temperature (^{O}R)

VAP　— Moles of a component in the vapor part of the feed

X　　— Mole fraction of a component in the liquid in equilibrium with the vapor

XBOT　— Mole fraction of a component in the bottoms

XBS　— Fraction of the feed consisting of the light key and the part of the split key going overhead

XCS　— Fraction of the feed consisting of the heavy key and the part of the split key going to the bottom product

XDIST — Mole fraction of a component in the distillate

XLIQ　— Mole fraction of a component in the liquid part of the feed

XM　　— Concentration of a component in the stripping pinch

XN　　— Concentration of a component in the rectifying pinch

Y　　— Mole fraction of a component in the vapor in equilibrium with the liquid

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