ABSTRACT

LINDE "DOUBLE COLUMN" SIMULATION

by John A. Bazan

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The purpose of this thesis is to develop a Fortran Computer Program to simulate the operation of a Linde "Double Column" for the separation of air into oxygen and nitrogen. The model outputs the number of contact stages required, the reflux ratio, the heat loads (condenser and reboiler, and the five profiles of temperature, pressure, vapor flow rate, liquid flow rate, and light component composition. From this data, the proposed design can be evaluated, and the effect of varying operating conditions explored.

APPROVAL OF THESIS

COMPUTER SIMULATION OF A LINDE "DOUBLE COLUMN"

by

John A. Bazan

FOR

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CHAPTER I

THEORY BEHIND THE "DOUBLE COLUMN"

Air separation is an important commercial enterprise in today's world. From production as a laboratory curiosity in the late nineteenth century, the production of oxygen and nitrogen rose in 1966 to 256 and 91 billion standard cubic feet respectively.[1] Predominant among separation techniques employed is fractional distillation utilizing the Linde "Double Column" first developed by Carl Linde in 1910. Actually consisting of a distillation column surmounted by a dual feed reboiled absorber, the "Double Column" when combined with a Joule-Thompson cycle is essential for the high purity separation of air's bulk constituents; oxygen, nitrogen and argon. Therefore, the purpose of this thesis project is to present a mathematical model to simulate the operation of the "Double Column" for design purposes. To understand how the model works, however, it is necessary to describe the evolution of the "Double Column" design. For clarity, air will be treated as a binary mixture of oxygen and nitrogen in this discussion.

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1. Simpson, C.H., Chemicals from the Atmosphere, New York: Doubleday, Inc., 1969, p.136.

The first major use for pure oxygen occurred in 1895 when Henri Louis Le Chatelier demonstrated the oxyacteylene flame's cutting and welding abilities. The steel industry, which remains today the largest user of oxygen, began with the introduction of this essential tool. As the demand increased for larger and larger amounts of oxygen, a commercially feasible means of supply had to be developed. To this end, Carl Linde began operation of his simpliest cycle for air separation in 1902.[2] This simple cycle, illustrated in Figure 1, consists of a heat exchanger, a stripping column and an expansion valve. Clean,dry, carbon dioxide free air is compressed to between 30 and 200 atmospheres, and introduced into the heat exchanger at point B', where it is cooled by the returning cold products at A and D. After passing through the sump coil at E, the compressed air is expanded isenthalpically in the expansion valve, V, to atmospheric pressure. The resulting stream , mostly liquid, enters the top of the stripper at point L. As the liquid descends it becomes oxygen enriched until it is finally evaporated by thermal contact with the compressed air in the coil, E. At steady state, pure oxygen is withdrawn at A and impure nitrogen, containing approximately seven to ten percent oxygen, is withdrawn at D. If both products are

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[2] Ruhemann,M., The Separation of Gases, Second Edition, London: Oxford University Press, 1952,p.141.

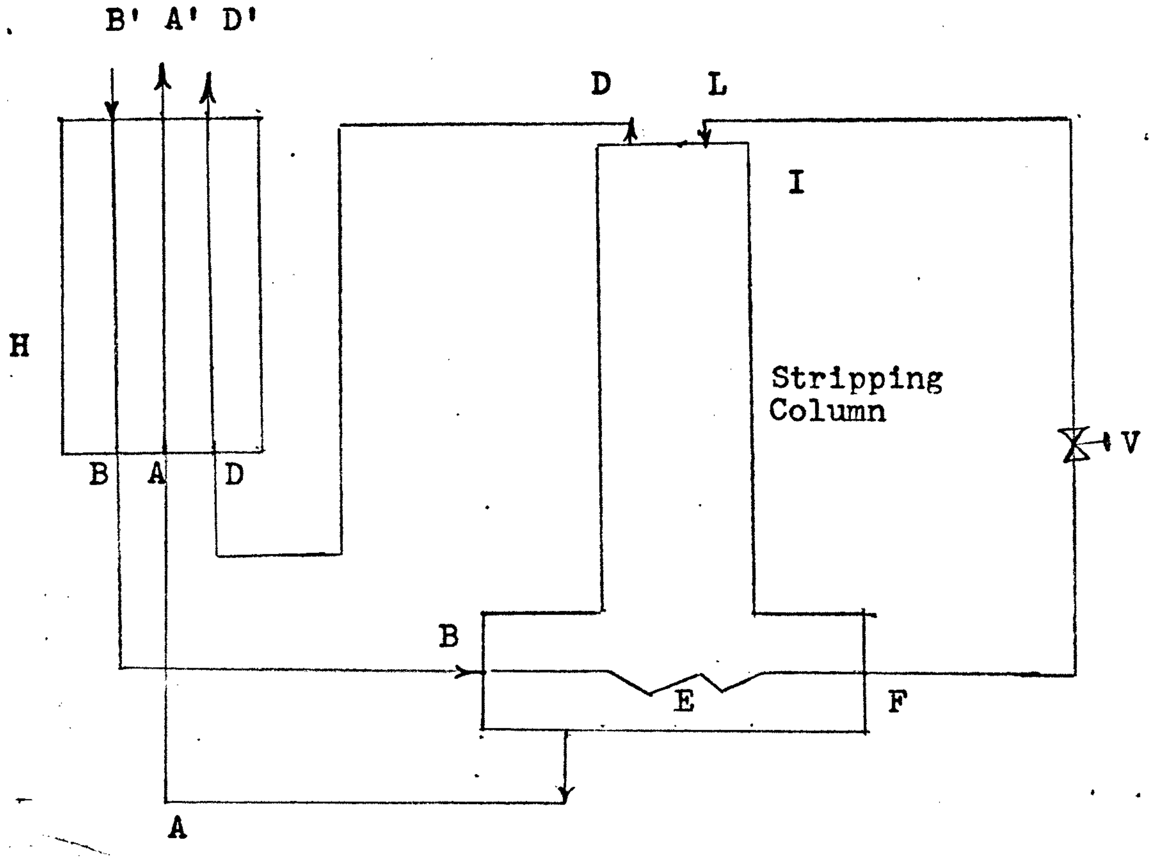

FIGURE 1

H = The heat exchanger

V = The expansion valve

B',B = Inlet feed air

A',A = Oxygen product

D',D = Nitrogen product

E = Evaporator

to be gaseous, both product streams return through the heat exchanger precooling the incoming air. If, however, a liquid oxygen product is desired, only the nitrogen is used to cool the feed air. To compensate for the loss of the refrigeration provided by the returning liquid oxygen stream, the entering air must now be compressed to a higher pressure since the incoming air must be cooled to the same temperature as when both returning products are used for cooling. It is essential that the entering air be dry and free of carbon dioxide because at the extremely low temperatures used, the water and carbon dioxide will freeze on the cold surfaces in the plant, "seriously impairing the efficiency or in extreme case causing blockages."[3] Removal of carbon dioxide is usually achieved by scrubbing with an 8 percent caustic soda solution. Water vapor is removed at each compression stage in catchpots and removed by adsorption on specially prepared alumina.[4] In the latest air separation plants, two exchangers are used whereby the two stream flow paths can be interchanged by means of "reversing valves" thus permitting the solid deposits of carbon dioxide and water to be purged with the exhaust stream as it is heated via indirect heat transfer with the incoming feed.

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[3] Din, F. and A. H. Cockett, Low Temperature Techniques New York: Interscience Publishers, Inc., 1960, p.161.

[4] Ibid.

The simple Linde cycle is inefficient because it has two essential disadvantages. First, while 99+ percent oxygen can be produced, only 90 to 93 percent nitrogen can be obtained. Since nitrogen had no commercial value in 1902, this particular problem was of little consequence. Today, however, large quantities of nitrogen are used for "blanketing" purposes, i.e. use as an inert atmosphere, in the electronics and other industries. Nitrogen is also used extensively in the production of ammonia and fertilizers and for its cryogenic characteristics.[5] However, in 1902 the loss of almost twenty percent of the valuable oxygen with the nitrogen prompted an improvement in design.

To recover the oxygen, the rising nitrogen vapors should be contacted with a liquid stream which is richer in nitrogen. To this end, the basic stripping column of Figure 1 must be extended above point I, and a rectifying section complete with its associated reflux generating equipment added. Theoretically, the tower which is now symmetrical and complete should negate both drawbacks of the stripping section of Figure 1. Unfortunately, the inhibiting factor in the design is the low temperature that would be necessary in the condenser. Fractional distillation above room temperature utilizes cooling water as the heat sink to provide the reflux stream;

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[5] Simpson, C.H., Chemicals from the Atmosphere, New York: Doubleday, Inc., 1969, p. 139.

but in air separation a heat sink colder than ambient-pressure boiling nitrogen would be needed, colder than -320°F. (140°R.)! The only convenient refrigerating fluids available are air and its products oxygen and nitrogen. Liquid nitrogen boiling at a reduced pressure could be used, but the nitrogen reaches the condenser as a vapor and would first have to be condensed. The only refrigerant available is the liquid oxygen boiling in the reboiler. The boiling point of oxygen is 162°R., and nitrogen 139°R. Therefore, the vapor pressure of the oxygen would have to be reduced to approximately 90 mm. of mercury (1.741 psia) to lower its temperature to 133°R. The oxygen at this temperature could easily condense the nitrogen boiling at 139°R. Since such a low pressure is difficult to maintain, the alternative is to raise the reflux temperature by increasing the column pressure to 5 atmospheres. The boiling point of nitrogen is now 169°R., above the 162°R. of oxygen at one atmosphere. The column,as shown in Figure 2, utilizes the oxygen at A" to condense the nitrogen in the condenser at D.

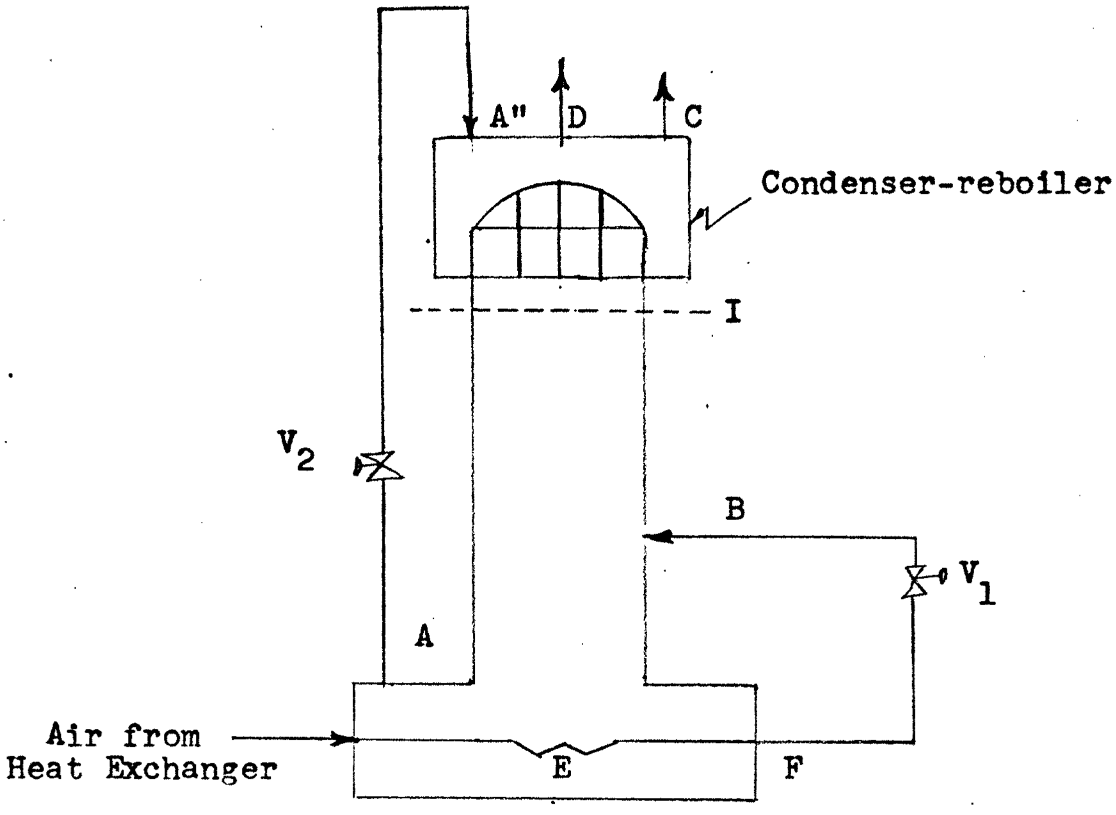

FIGURE 2

B= Air at 5 atmospheres

D= Nitrogen at 5 atmospheres

I= Point where rectifying section was added.

A= Oxygen at 5 atmospheres

A"= Oxygen at 1 atmosphere

C= Bottoms product

Though the problem of condensing the nitrogen has been solved, a column as described in Figure 2 will not produce simultaneously both products in the pure state. Assuming complete separation of the air into oxygen and nitrogen,[6] and assuming a bubble point feed, an enthalpy concentration diagram gives the amount of heat which must be withdrawn from the condenser per mole of nitrogen product as 873 g-calories per g-mole of N_2 produced. Since the product is pure nitrogen, one mole of entering air produces 0.79 moles of nitrogen product and the condenser duty is therefore 79 per cent of 873, or 690 g-calories. To absorb this heat there exists the latent heat of oxygen at one atmosphere, $\lambda = 1632$ g-calories per g-mole of oxygen. Since every mole of entering air produces 0.21 moles of oxygen, the refrigerating capacity is therefore twenty-one percent of the latent heat or 343 g-calories. From this heat balance it can be shown[7] that the maximum oxygen purity obtainable, assuming a 100 percent nitrogen product, with a column as in Figure 2 is 60 percent oxygen.

To obtain both pure products simultaneously, the impure oxygen at A must be further purified before entering the

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[6] Ruhemann, M., <u>The Separation of Gases</u>, Second Edition, London: Oxford University Press, 1952, p. 156.

[7] <u>Ibid</u>., p. 157.

condenser. Referring to Figure 3, a set of plates between the condenser-reboiler and A" will purify the impure oxygen stream. Pure nitrogen and oxygen of 99+ percent purity may be simultaneously withdrawn at D and C respectively, however, valuable oxygen, at least the equilibrium vapor at point A", will be lost at E. Again a refrigerant is needed to provide a nitrogen rich stream to absorb the oxygen in the vapor at E. If the column is extended at point E, and liquid nitrogen withdrawn at D is expanded to one atmosphere pressure in a valve, and reintroduced at the top of the column extension, it will absorb the oxygen from stream E which is recovered as part of stream C.

The final result (Figure 4) is the Linde "Double Column" as evolved by Carl Linde in 1910. The column consists of a distillation column operating at 5 atmospheres pressure surmounted by a dual feed reboiled absorber operating at one atmosphere. The final cycle is as described by Ruhemann:[8]

> "Compressed air, precooled in a heat exchanger enters the evaporator coil at P, is expanded to 5 atm. pressure in the valve V and delivered to the middle of the lower column at B. Here it is separated into pure liquid nitrogen and a liquid containing about 38 per cent of oxygen. The latter is withdrawn from the lower column at A,

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[8] Ruhemann, M., <u>The Separation of Gases</u>, Second Edition, London: Oxford University Press, 1952, p.158.

expanded to essentially atmospheric pressure in the valve V_O , and admitted in the middle of the upper column at (A"). The liquid nitrogen collects in the trough below the condenser, whence it is removed at E, expanded to atmospheric pressure in the valve V_N, and admitted at the top of the upper column at E'. Finally gaseous oxygen is withdrawn immediately above the condenser at C and gaseous nitrogen at D. "

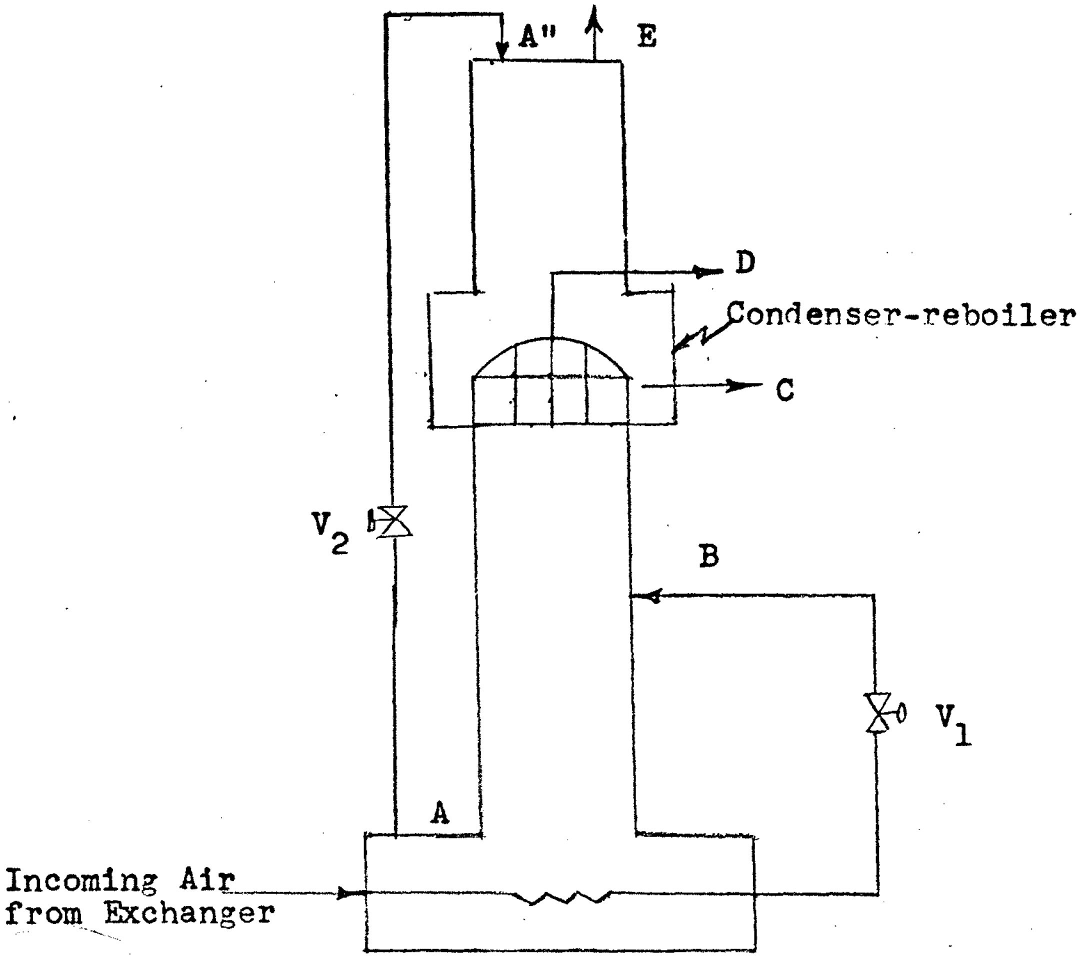

FIGURE 3

B = Air at 5 atmospheres

A"= Oxygen at 1 atmosphere

D= Nitrogen product from lower column

C= Oxygen product

E= Nitrogen product

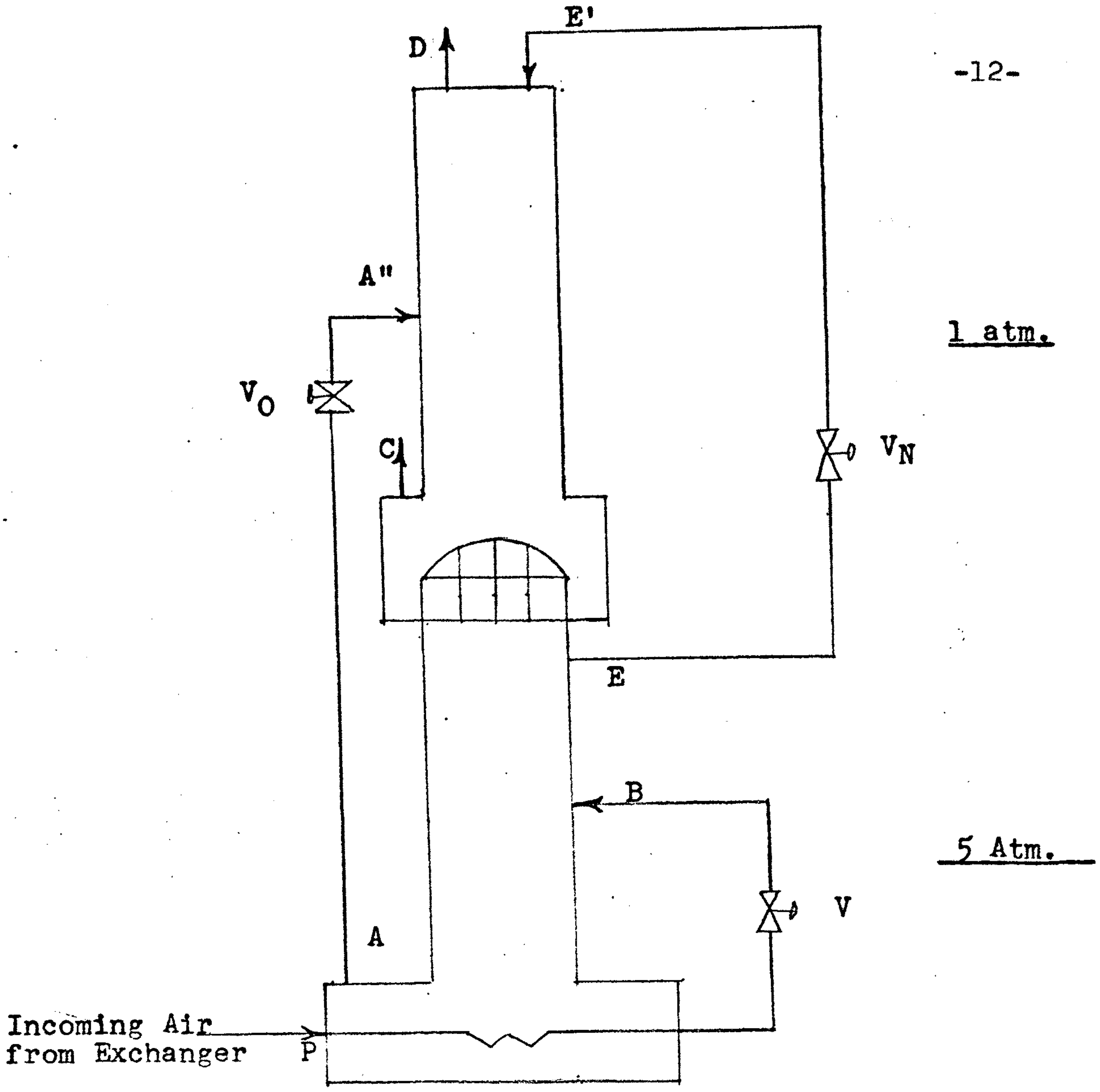

FIGURE 4

A" = Impure oxygen at 1 atmosphere

B = Air at 5 atmospheres

C= Pure Oxygen product at 1 atmosphere

D= Pure Nitrogen product at 1 atmosphere

E= liquid nitrogen stream at 5 atmospheres

E'= absorber "lean oil feed" stream at 1 atmosphere

CHAPTER II

APPROACH AND METHODS USED IN DEVELOPING THE MODEL

The purpose of the model is to provide design information; such as, the number of theoretical plates, temperatures, stream rates and compositional profiles for the Linde "Double Column." Since more than 99 percent of the air consists of oxygen and nitrogen, it is considered to be a binary mixture of these compounds in the model. In reality, the approximately 1 percent argon in the air does not allow absolutely pure products to be produced, but for 99 percent pure oxygen and nitrogen the assumption of a binary is adequate. If all the argon is collected with the oxygen, the latter cannot exceed 95 percent in purity; if it is extracted with the nitrogen and the oxygen is pure, the purity of the nitrogen cannot exceed 98.7 percent. Distributed argon will allow approximately 99 percent pure oxygen and nitrogen to be produced. Future work could incorporate the effect of argon into the model and allow for a more accurate design. Further, assumption of a binary mixture allows use of the Sorel[1] method of calculation which is a rigorous plate to plate method utilizing

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[1] Sorel, M., "La Rectification de l'alcool," Paris, 1893.

alternating material and enthalpy balances, coupled with the equilibrium vapor-liquid relationships. The method has been extended by Lewis and Matheson to multicomponent systems and a simplified version has been used in a graphical representation by McCabe and Thiele.

The model itself consists of three sections: (1) input and preliminary calculations, (2) iterative calculations in each column, and (3) output.

Input and Preliminary Calculations

Input to the model comprises three categories: (1) system options, (2) tower parameters, and (3) basic data.

1. System options. The system options are a set of three codes which specify the distillate and feed thermal conditions, and the tower configuration used. All thermal conditions from a subcooled liquid to a superheated vapor are allowed in the feed. Only a superheated vapor distillate, which is physically impossible, is prohibited as a distillate thermal condition. Three tower configurations are possible within the framework of the model: a single tower, a double distillation tower with either product stream of the first tower becoming a feed stream to the second tower, and the Linde "Double Column."

2. Tower parameters. Twelve tower parameters are required to define the problem for each tower:

A. Feed rate, lb-moles/hour.

B. Feed composition, mole fraction light component.

C. Reflux factor, R(actual)/R(min), dimensionless.

D. Pressure drops across condenser, each plate and the reboiler, psi.

E. Equilibrium data reference pressure, psia.

F. Tolerances on bubble-dew point component summations and overall tolerance on composition, lb-moles.

G. Initial temperature and pressure estimates at top and bottom of column, ^{o}F. and psia.

H. Minimum product purities distillate and bottoms, mole fraction light component.

<u>Note</u>: If the thermal conditions of the feed and distillate are other than saturated liquid or vapor, the appropriate feed and/or condenser temperatures must be given as input. If a partial condenser is used, the fraction vapor distillate must be input to the model. A complete input form appears in Appendix A.

3. <u>Basic data</u>. The final block of input data consists of the vapor-liquid equilibrium data and the enthalpy data. The equilibrium constant for each component is computed

from the equation:

$$\ln(KP) = A + B/T$$

where, K= equilibrium constant, dimensionless.

P= stage pressure, psia.

T= temperature, ^{o}R.

A & B = correlation constants defined by:

$$B = \ln(K_1/K_2)*(T_1T_2/(T_2-T_1))$$

and $$A = \ln(K_1P_{ref})-B/T_1$$

where the subscripts (1) and (2) refer to two different temperatures and P_{ref} is the equilibrium reference pressure.

This correlation pressure corrects the equilibrium constant to the pressure at each plate in the column.

Enthalpy values are calculated from the linear equations:

$$h = a_h + b_h T$$

and

$$H = A_H + B_H T$$

where, h,H = liquid and vapor component enthalpies, Btu/lb-mole.

T= temperature, ^{o}R.

a_h, b_h, A_H, B_H = correlation constants.

For each component two vapor-liquid equilibrium values and four enthalpy points (two liquid, two vapor) are required as input. Enthalpy values are combined using Kay's rule to obtain the mixture values:

$$h_{avg} = \sum x_i h_i$$

or,

$$H_{avg} = \sum y_i H_i$$

where, h_{avg}, H_{avg} = average enthalpy (liquid or vapor), Btu/lb-mole.

h_i, H_i = component liquid or vapor enthalpies, Btu/lb-mole.

x_i,y_i = light component mole fraction (liquid and vapor).

Preliminary Calculations.

Before the iterative procedure can be implemented, three preliminary calculations are made; namely, (1) feed condition evaluation, (2) minimum reflux determination, and (3) condenser duty evaluation.

1. Feed condition evaluation. Based on the feed code entered, the feed temperature is determined by a bubble or dew point calculation. If a flashed, subcooled, or superheated feed is specified, the feed temperature must be supplied. At this temperature and the average tower pressure, the feed vapor and liquid compositions, and the fraction

vaporized are determined as follows:

$x = (1-K_2)/(K_1-K_2)$

$y = K_1 x$

Fraction vapor = $(z-x)/(y-x)$

where, K_1 and K_2 are the equilibrium constants of components (1) and (2) at the feed temperature and pressure.

z = the bulk feed composition for the light component.

Using the feed compositions, temperature, and the fraction vapor, the feed enthalpy is computed.

2. Minimum reflux determination. The minimum reflux ratio is determined by linear interpolation between the minimum reflux based upon a dew and bubble point feed condition using the fraction feed vaporized as the correlating factor. Utilizing a concept from the McCabe-Thiele graphical method for binary systems, the operating line slope is related to the reflux ratio by:[2]

$$\text{Slope} = (x_D-y)/(x_D-x_F) = R/(R+1) \qquad (1)$$

where, x_D = distillate composition of light component.

y = point where operating line intersects feed locus line.

x_F = feed composition of light component.

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[2] Smith, Buford D., Design of Equilibrium Stage Processes, New York: McGraw-Hill Book Co., 1963, p. 130.

If the point of intersection of the operating line and the feed locus line, y, is taken at the intersection of the operating line and the equilibrium curve, the minimum reflux ratio can be evaluated by an equation similar to (1):

$$\text{Slope(min)} = R_{min} / R_{min} + 1.$$

For a bubble point feed, the slope is given by:

$$\text{Slope}_L = (x_D - Kx_F) / (x_D - x_F) = (R_{min}/(R_{min}+1.))_L$$

where, K= the equilibrium constant at the feed temperature and pressure .

For a dew point feed, the slope is given by:

$$\text{Slope}_V = (x_D - x_F)/(x_D - (x_F/K)) = (R_{min}/(R_{min}+1.))_V$$

From the above equations, the minimum reflux ratios for a bubble and dew point feed are evaluated, and the composite minimum reflux obtained from the equation:

$$R_{min} = f \cdot R_{minV} + (1.-f) \cdot R_{minL}$$

where, f = fraction feed vaporized

R_{minV}, R_{minL} = the vapor and liquid minimum refluxes respectively.

Finally, the operating reflux ratio is calculated as the product of the reflux factor and the minimum reflux ratio.

3. Condenser duty evaluation. The distillate drum pressure equals the column top pressure minus the condenser pressure drop. The distillate rate is fixed for

the column by the equation:

$$D = F * (x_F - x_B)/(z_D - x_B)$$

where, F= feed rate, lb-moles/hr.

x_F= feed composition, light component

x_B= bottoms composition, light component

z_D= distillate composition, light component

Based on the distillate code chosen, the condenser temperature is obtained by a bubble or dew point calculation. For a subcooled distillate, this temperature must be supplied. For a partial condenser, the liquid-vapor split must be specified so that the flash temperature can be calculated. With the temperature and pressure specified, equations similar to those used in the feed evaluation section are used to evaluate the vapor and liquid compositions of the distillate, and the fraction distillate vaporized. Referring to Figure 5, the following procedure is followed:

A. The composition of the vapor and liquid from plate 1 are determined:

$$y_1 = (D_V y_D + D_L x_D + L_0 x_D)/ V_1$$

where, $L_0 = RD$

$V_1 = L_0 + D$

T_1 = dew point temperature of V_1

$x_1 = y_1 / K_1$

B. The distillate enthalpy is evaluated:

$$DH = D_L h_{D_L} + D_V H_{D_V}$$

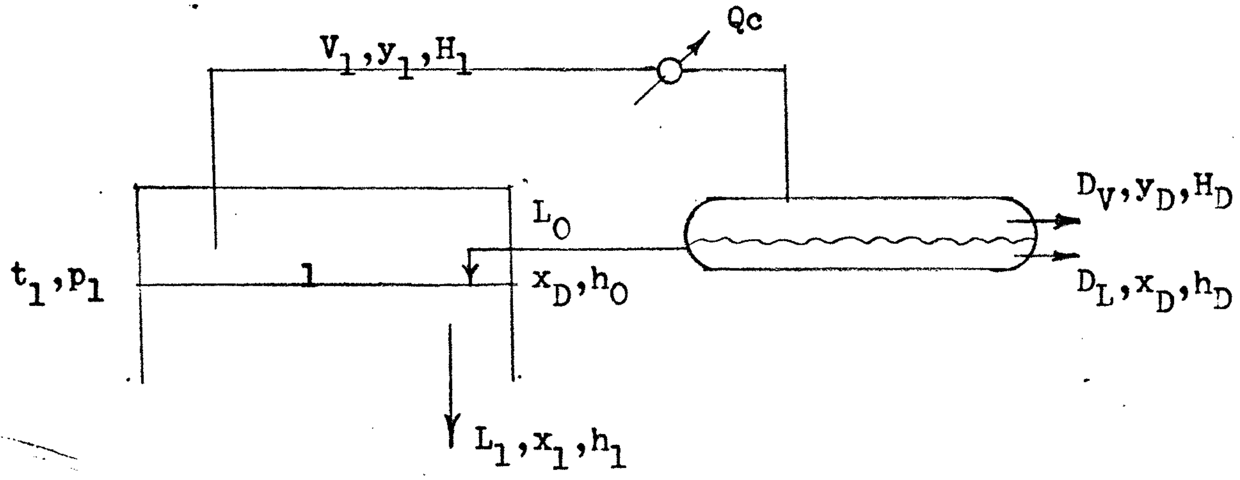


FIGURE 5

and by a heat balance, the condenser duty is:

$$Qc=L_0h_0 +DH - V_1H_1$$

Iterative Calculations

The iterative calculations for each column are divided into three sections; the rectifying section, the feed zone and the stripping section.

1. High pressure tower-rectifying section. Calculations for the high pressure tower begin at the condenser and proceed toward the reboiler. Referring to Figure 6, the following procedure is followed:

A. The composition of x_1 is determined by equilibrium; $x_1 = y_1/K_1$

B. The composition of y_2 is assumed.

C. A dew point calculation determines t_2.

D. L_1 and V_2 are calculated by material balance (envelope).

$$L_1=(D_Lx_D-D_Ly_2+D_Vy_D-D_Vy_2)/(y_2-x_1)$$

$$V_2=(D_Lx_D-D_Lx_1+D_Vy_D-D_Vx_1)/(y_2-x_1)$$

an energy balance determines the criteria for convergence:

E. $Eqn=V_2H_2 - L_1h_1 +Qc$

F. The value of Eqn is compared with the distillate enthalpy, and steps A to E repeated until converged.

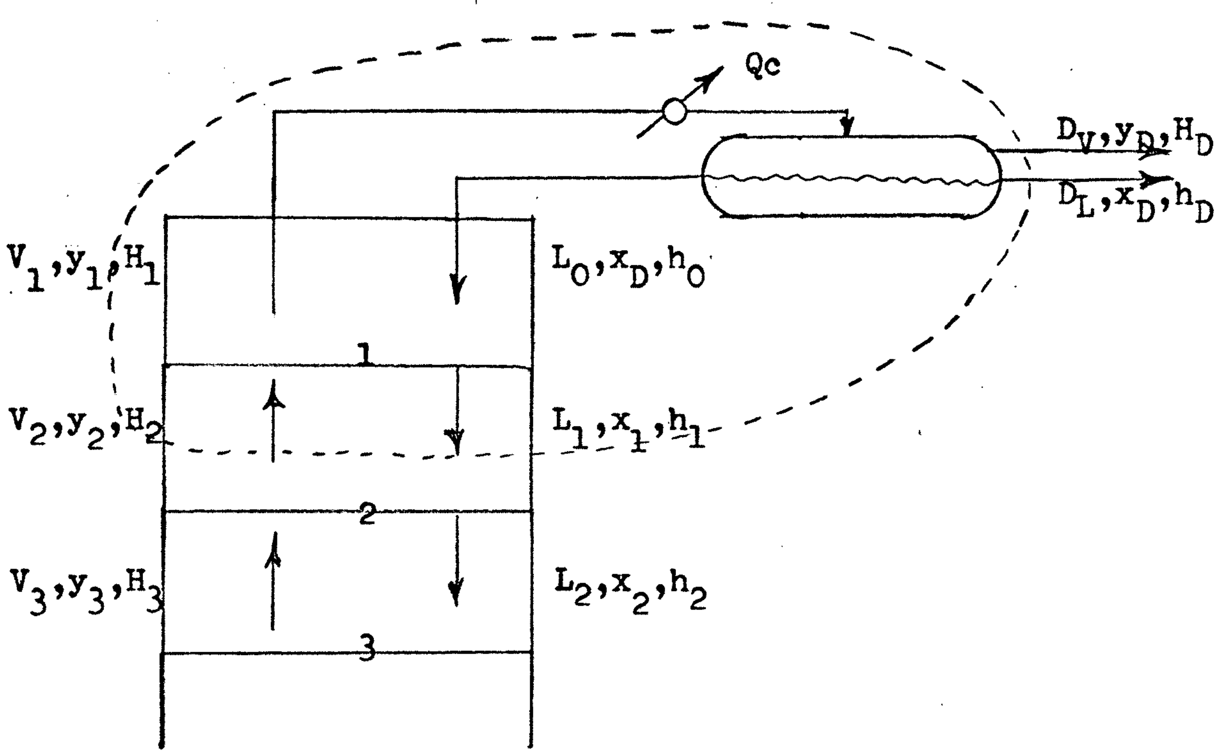

Qc
D_V, y_D, H_D
D_L, x_D, h_D
V_1, y_1, H_1
L_0, x_D, h_0
1
V_2, y_2, H_2
L_1, x_1, h_1
2
V_3, y_3, H_3
L_2, x_2, h_2
3

FIGURE 6

2. <u>High pressure tower-feed zone</u>. The feed zone refers to that area of the tower where the computed compositions of the vapor and liquid approximate those obtained from the feed flash calculation. The calculations in this region differ from those in the rectifying section in that the material and enthalpy balances are performed between stages and not around the condenser. At the feed zone, the following procedure is followed (Figure 7):

A. The composition of x_f is calculated by equilibrium; $x_f = y_f/K_f$

B. The composition of y_{f+1} is assumed.

C. A dew point calculation determines t_{f+1} .

D. V_{f+1} is determined by a material balance around stages f-1 and f (envelope I).

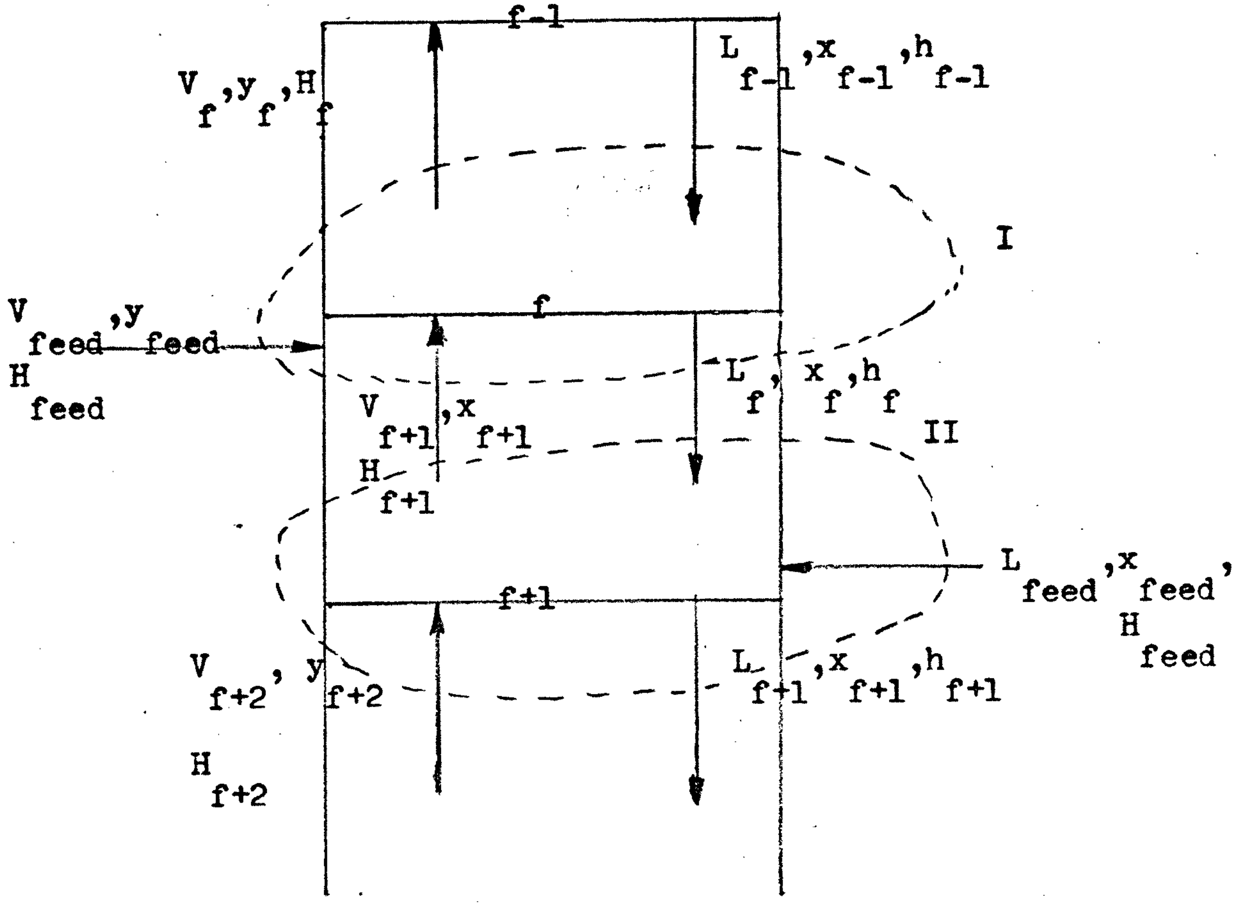
$$Eqn_1=V_{f+1}=(V_f y_f-V_{feed}y_{feed}-L_{f-1}x_{f-1}+(V_{feed}+L_{f-1}-V_f)x_f)/(y_{f+1}-x_f)$$

E. V_{f+1} is also determined by an enthalpy balance around stages f-1 and f(envelope I).

$$Eqn_2=V_{f+1}=(V_f H_f-V_{feed}H_{feed}-L_{f-1}h_{f-1}+(L_{f-1}+V_{feed}-V_f)h_f)/(H_{f+1}-h_f)$$

F. The values of Eqn_1 and Eqn_2 are compared until converged .

Steps A to F are repeated for stages f and f+1 (envelope II), with the liquid feed being added to the system.



f-1
V_f, y_f, H_f
$L_{f-1}, x_{f-1}, h_{f-1}$
I
f
V_{feed}, y_{feed}
H_{feed}
L_f, x_f, h_f
V_{f+1}, x_{f+1}
H_{f+1}
II
$L_{feed}, x_{feed},$
H_{feed}
f+1
V_{f+2}, y_{f+2}
H_{f+2}
$L_{f+1}, x_{f+1}, h_{f+1}$

FIGURE 7

3. <u>High pressure tower-stripping section</u>. The stripping section calculations correspond to those used in the rectifying section, with only a modification in the material and enthalpy balances to reflect the addition of the feed stream to the tower. Referring to Figure 8, the procedure is as follows:

A. The composition of x_{f+3} is determined by equilibrium; $x_{f+3} = y_{f+3}/K_{f+3}$

B. The value of y_{f+4} is assumed.

C. A dew point calculation fixes t_{f+4} .

D. L_{f+3} and V_{f+4} are computed from a material balance around the condenser (envelope):

$$L_{f+3}=(D_Lx_D-D_Ly_{f+4}+D_Vy_D-D_Vy_{f+4}+Fy_{f+4}-Fz_F)/(y_{f+4}-x_{f+3})$$

$$V_{f+4}=(D_Lx_D-D_Lx_{f+3}+D_Vy_D-D_Vx_{f+3}+Fx_{f+3}-Fz_F)/(y_{f+4}-x_{f+3})$$

an energy balance determines the criteria for convergence:

E. $$Eqn = V_{f+4}H_{f+4}-L_{f+3}h_{f+3}+Qc+H_{Feed_{TOT}}$$

The value of Eqn is compared with the distillate enthalpy , and steps A to E repeated until converged.

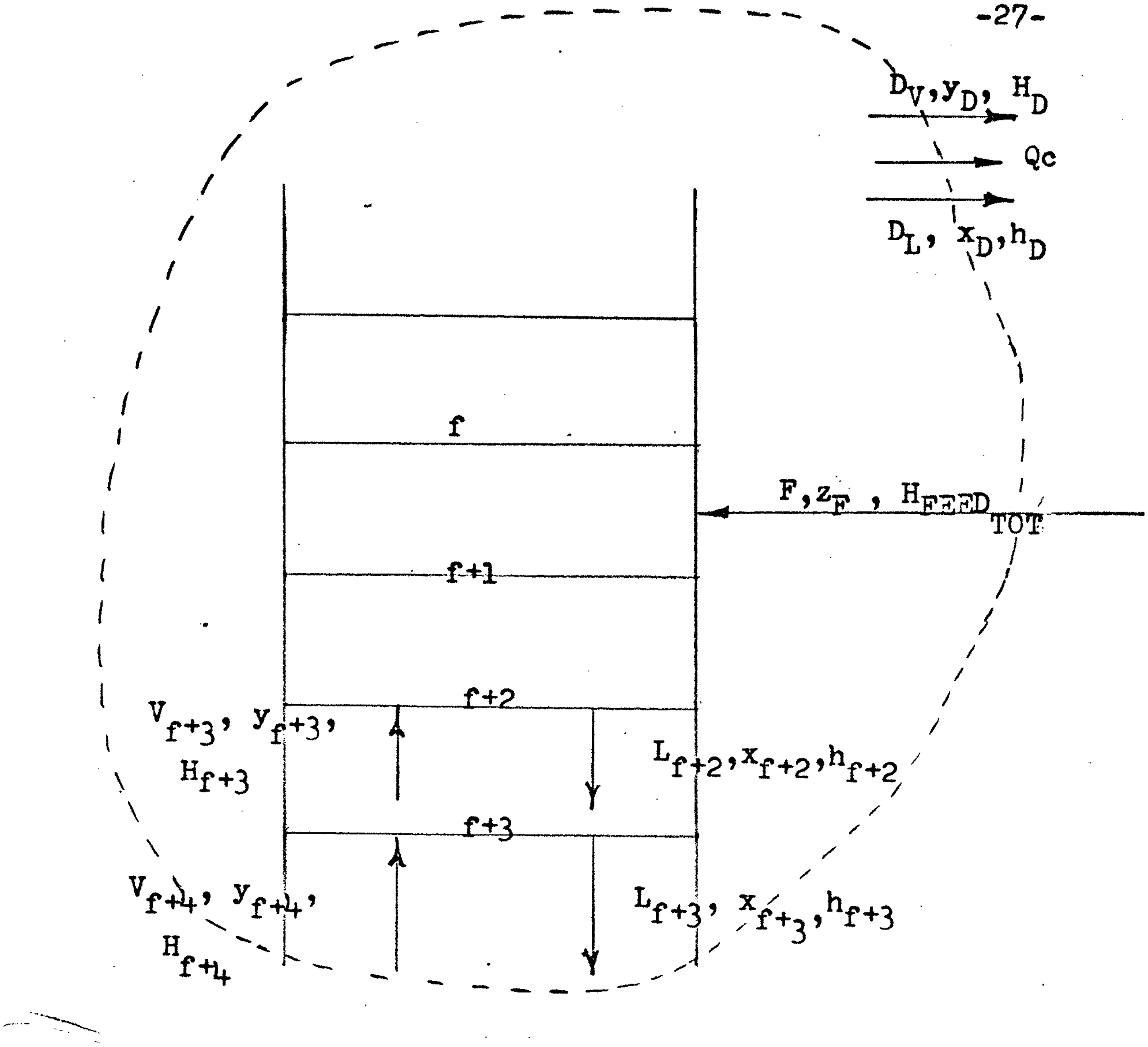

D_V, y_D, H_D
Q_c
D_L, x_D, h_D
f
$F, z_F, H_{FEED_{TOT}}$
f+1
f+2
$V_{f+3}, y_{f+3}, H_{f+3}$
$L_{f+2}, x_{f+2}, h_{f+2}$
f+3
$V_{f+4}, y_{f+4}, H_{f+4}$
$L_{f+3}, x_{f+3}, h_{f+3}$

FIGURE 8

Iterative Calculations- Overall Program Logic

The overall program logic consists of three separate calculational blocks: (1) the high pressure tower, (2) the two isenthalpic valves between columns, and (3) the second distillation tower or the absorber section. Each column computational block is further subdivided into two separate routines; an initialization routine, and a convergence routine.

1(a) . High pressure column-initialization routine. Calculation begins at the condenser and proceeds downward by repetitive application of the rectifying section procedure previously outlined. Computations continue until the computed liquid composition equals or becomes less than the feed liquid composition. The calculations now shift to the reboiler, and a procedure similar to that used in the rectifying section is employed except that the material and enthalpy balances are performed around the bottoms product stream and calculations are made from the reboiler upward. Referring to Figure 9, the procedure is :

A. The composition of y_2 is calculated by equilibrium; $y_2 = K_2 x_2$

B. The composition of x_3 is assumed.

C. A bubble point calculation determines the temperature t_3 .

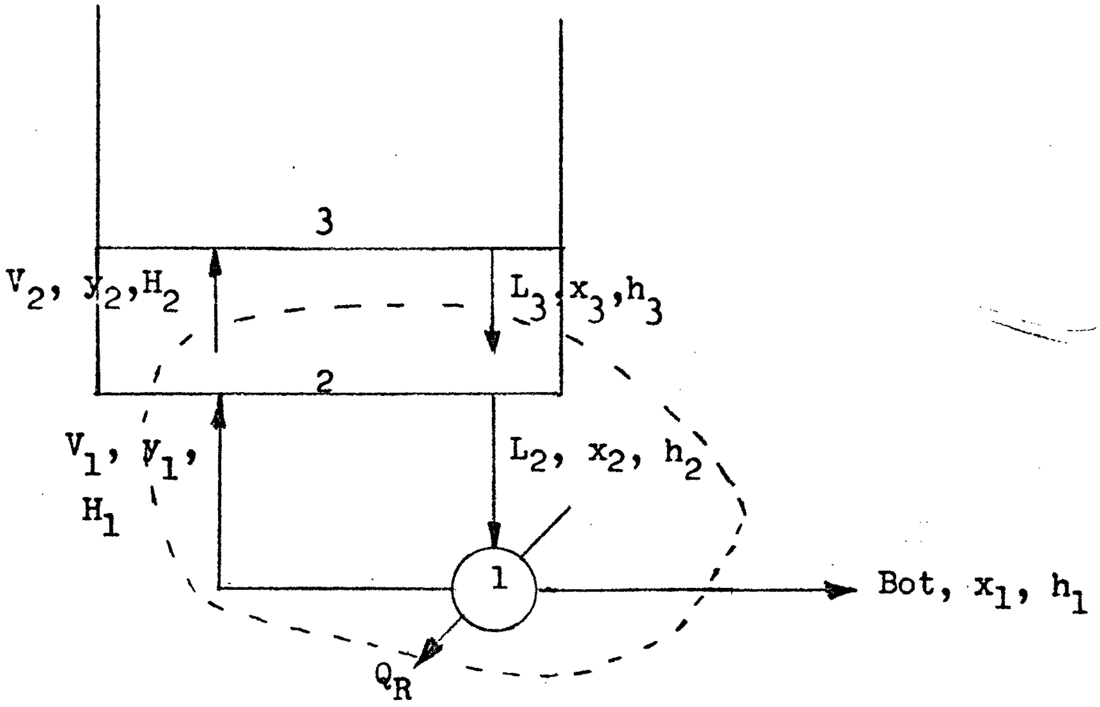


FIGURE 9

D. L_3 and V_2 are determined by material balance (envelope) :

$$L_3 = Bot \cdot (x_1-y_2)/(x_3-y_2)$$
$$V_2 = Bot \cdot (x_1-x_3)/(x_3-y_2)$$

an energy balance determines the criteria for convergence:

E. $$Eqn = L_3h_3-V_2H_2 +Q_R$$

The value of Eqn is compared with the bottoms enthalpy, and steps A to E repeated until converged.

Calculation in the stripping section continues until the computed vapor composition exceeds the feed vapor composition. At the conclusion of the first pass, the number of stages and the feed stage location are fixed.

1(b) . High pressure column-convergence routine. After pressure corrections have been made to reflect the true number of stages in the column, the calculations are repeated starting at the condenser. As before, the rectifying region series of calculations is repeated until the feed zone is reached. Computations now proceed through the feed stage using the feed zone procedure, and then continue with the stripping section procedure described for Figure 8. The reflux ratio is now adjusted and the entire calculational block repeated until the desired bottoms composition is attained.

2. Isenthalpic valves. If only a single tower is to be solved, the calculations cease. However, if a second tower exists, the product streams from the high pressure tower must be reduced to approximately atmospheric pressure. Equilibrium and enthalpy data at the lower pressure are input, and depending upon the tower configuration either one or both valves are simulated. The valve simulation is a trial and error procedure wherein the constant enthalpy across the valve is the criteria for convergence. The procedure used is as follows:

A. A temperature is assumed between the bubble and dew points at the lower pressure.

B. A feed flash at this temperature yields the liquid and vapor compositions.

C. The combined enthalpy of the product liquid and vapor streams is calculated.

D. The composite enthalpy computed above is compared with the enthalpy of the stream before the valve.

E. Steps A to D are repeated until convergence is achieved.

If a double distillation tower configuration is used, only the bottoms or distillate product is pressure reduced. If the Linde "Double Column" is used, both product streams undergo pressure reduction.

3. Second distillation tower or absorber. If the second tower is a distillation column, the pressure reduced product stream (bottoms or distillate) becomes the feed stream to this low pressure column. The calculational scheme is exactly the same as in the high pressure column, and after the second column bottoms composition is converged calculations cease. If,however, the second tower is an absorber, the calculations are somewhat more involved. As in the high pressure tower, the computational block is subdivided into an initialization routine and a convergence routine.

3(a) . Absorber-initialization routine. Since a condenser does not exist in the reboiled absorber, calculations cannot begin at the condenser. Because the heat to the reboiler is supplied by the condenser of column one, it is logical to begin the calculations at this point. Pursuant to the fact that the vapor products are required, the reboiler is assumed to be a total reboiler, and the appropriate adjustment to the enthalpy balance for the reboiler calculation is made. Proceeding up the absorber, calculations similar to those described for the "stripping section," Figure 9, are performed. Calculations proceed until the computed vapor composition becomes equal to or less than the feed vapor composition.

Proceeding through the feed stage, a computational approach that is similar to the feed zone calculation of the high pressure tower is utilized except that calculations are from the bottom up and the liquid composition rather than the vapor composition is unknown.

After the feed zone, calculations follow the procedure of the high pressure stripping section with a shift to bottom up and unknown liquid composition as in the feed zone calculations above. Calculations continue until the computed liquid composition equals or exceeds the value of the "lean oil" feed composition determined by the valve calculation.

3(b) . Absorber-convergence routine. Even though the liquid composition computed now equals or exceeds the required value, the computed rate of flow of the "lean oil" feed stream will,in general,not match the required value. Two adjustments must be made for the absorber to be independently balanced. First, the variations in the pressure of the feed stage must be dampened out, and second, the computed "lean oil" feed rate must be adjusted to the value obtained from the valve calculation.

To achieve the first objective, the initialization procedure for the absorber is repeated until there is no variation in the feed stage location. Unfortunately the second problem is more involved. Since there is no condenser, the reflux ratio does not exist, and another means of adjusting the "lean oil" flow rate must be devised. To meet the "lean oil" requirement, the reboiler duty of the absorber is adjusted until the required rate is obtained. The absorber is now independently but unfortunately also arbitrarily converged.

Iterative Calculations-Overall Convergence

The arbitrary value of the reboiler duty as set in the previous section is now practically approached by adjusting the number of contact stages in the high pressure tower by means of the bottoms composition. The bottoms composition is adjusted, and the entire calculational loop is repeated until no further adjustment of the absorber reboiler duty is required. An elaboration of the problems encountered in this type of convergence will be made in the next chapter.

Output

The computer output generated incorporates all the information necessary to design the Linde "Double Column." Output is generated as each tower is independently converged, and intermediate trials indicate only the convergence trend. The tower parameters and calculated constants are printed and act as a check on the input data. The initialization routine, which determines the number of stages required, is printed in entirety. The first convergence routine pass is also printed in entirety so that the method of calculation can be illustrated. Subsequent passes are suppressed, and only the direction of convergence is indicated. The final converged trial is printed in its entirety, including the five profiles of temperature, pressure, vapor flow rate, liquid flow rate and light component composition. Lastly, an enthalpy balance is presented incorporating all tower input and output streams. A sample of the output is presented with the examples of Chapter IV.

CHAPTER III

CONVERGENCE PROBLEM

As indicated in the previous chapter, the problem of convergence in a Linde "Double Column " involves ramifications which are nonexistent in an ordinary dual column fractional distillation complex. Whereas in a distillation plant operating above the ambient temperature, the reflux ratio, and hence the condenser and reboiler heat loads can be varied within wide limits, the lack of a condenser on the absorber negates the use of a simple "key" to control convergence. Unlike the ambient temperature columns, the heat loads of the high pressure column's condenser and the absorber's reboiler are interdependent and the entire high pressure tower must be adjusted to achieve convergence. The method used to adjust the high pressure column's condenser duty is to adjust the bottoms composition. Initially this procedure has the effect of changing the number of contact stages and therefore increasing or decreasing the condenser duty. A fine adjustment is achieved as the number of stages remains constant and only the bottoms enthalpy varies.

Unlike the reflux ratio which can vary from minimum to infinity, the variation of the high pressure column bottoms composition, x_{B1} , is set between narrow theoretical and even tighter practical limits. Figure 10 illustrates the "Double Column" construction on an enthalpy concentration diagram.[1] Line Z'AR' represents the "lean oil" feed in the absorber, and at a value of x_{B_1} approximately equal to 0.67, it coincides with the "tie line" through A, i.e. the minimum reflux ratio the absorber would theoretically have. Similarly, line RBZ corresponds to the reflux ratio in the high pressure column, and at a value of x_{B_1} equal to approximately 0.57, the line coincides with the "tie line" through B, i.e. the minimum reflux ratio for the high pressure column. The theoretical limits for the light key bottoms composition are therefore 0.57 and 0.67. As Ruhemann states: " Practically x_A (x_{B_1}) can vary between 60 and 64 per cent."[2] This is a small margin indeed and indicates just how sensitive the convergence problem can be.

During development of the model, another convergence problem emerged. Unlike the first convergence problem which is a physical limitation of the system, this problem results from the method of calculation used. The Sorel method was originally developed by Sorel in 1896, before the age of computers. Utilizing graphs of the equilibrium and enthalpy

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[1] Ruhemann, M., <u>The Separation of Gases</u>, Second Edition, London: Oxford University Press, 1952, p. 159.

[2] <u>Ibid</u>., p. 160.

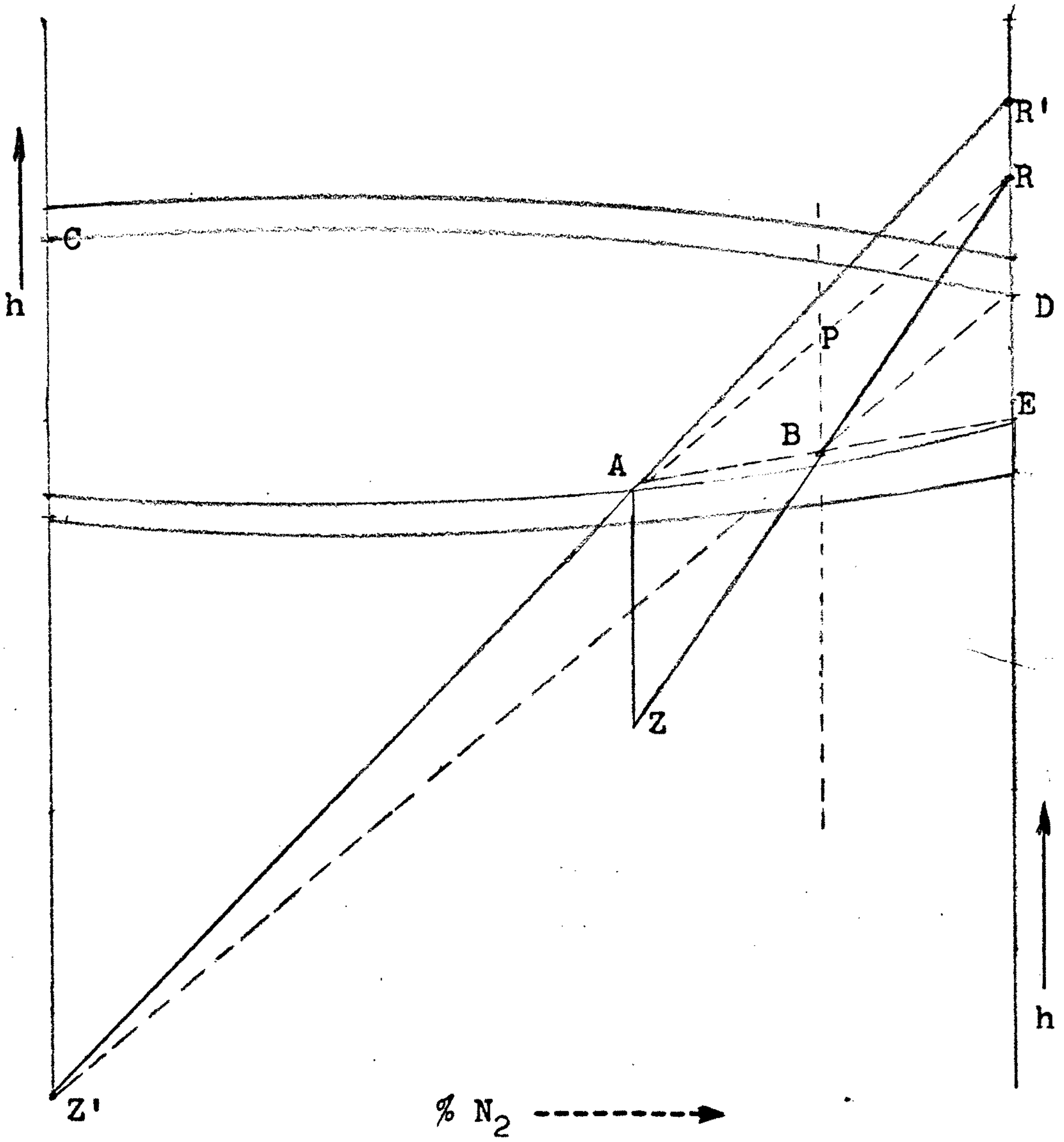

FIGURE 10

functions, and designed for hand calculation, the tolerances for convergence were extremely loose. The feed stage calculation, especially, was solved by the addition of the feed stream between two stages with no attempt made to add the feed liquid to one plate and the feed vapor to another stage. When the former method was applied to a computer with a tolerance on composition of 10^{-4} or tighter, the discrepancy caused the enthalpy balance to fail to converge and a zone of constant composition appeared. No solution to the problem was possible since the "pinch point" could not be passed. Subsequently, the feed zone equations were rewritten to incorporate the effect of separate addition of the feed liquid and feed vapor plus a much more restrictive tolerance on the appropriate equilibrium calculations. The result of these modifications to the computational algorithm resulted in a converged solution to the set of material-equilibrium-enthalpy equations.

CHAPTER IV

EXAMPLE PROBLEMS

This chapter contains three example problems chosen to illustrate the model's ability to solve problems of varying complexity.

Example No. 1 : The design of a Linde "Double Column" for the separation of air into oxygen and nitrogen.

Example No. 2 : The design of a single fractional distillation column separating benzene and toluene.

Example No. 3 : The design of a dual fractional distillation complex for the separation of benzene and toluene.

A. Example No. 1 - Linde "Double Column."

The purpose of this example is to solve the problem for which the model was developed, the design of a Linde "Double Column." The necessary input data are:

1 (A) Select system options

(a) Tower type code = 4
Linde "Double Column."

(b) Feed thermal code = 3
A bubble point feed is the most advantageous condition.[1]

(c) Distillate thermal code = 3
A bubble point distillate will be the best "lean oil" feed to the absorber.

2 (A) Set tower parameters

(a) Feed rate = 100 lb-moles/hour
A convenient number was chosen to simplify the calculational check. The feed rate should not exceed 100,000 lb-moles/hour so as to avoid an output format error.

(b) Feed composition light key = 0.79
Air is considered as a binary containing 79 percent nitrogen.

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[1] Ruhemann, M., The Separation of Gases, Second Edition, London: Oxford University Press, 1952, p. 156.

(c) Reflux factor = 1.1

Air plants normally operate close to minimum reflux.

(d) Pressure drops--stage=0.1 psi., condenser= 0.3 psi., reboiler= 0.1 psi.

Pressure drops per stage range from 0.07 to 0.15 psi.[2] Condenser and reboiler pressure drops are generally higher due to the increased piping associated with these sections.

(e) Equilibrium reference pressure= 73.5 psia.

The suggested pressure for the distillation tower is 5 atmospheres absolute.

(f) Tolerances = 10^{-6} and 10^{-4}

The tolerance on the bubble or dew points (component summations) = 10^{-6} ; i.e. $\sum Kx$ or $\sum y/K = 1.0 \pm 10^{-6}$. The overall tolerance , 10^{-4}, is on the bottoms composition of the light component (x_{B1}).

(g) Initial temperature and pressure estimates:

	TOP	BOTTOM
T, ^oF.	-280.3	-274.0
P, psia	73.8	78.8

---

[2] Peters,M.S. and K.D. Timmerhaus, Plant Design and Economics for Chemical Engineers, Second Edition, New York: Mc Graw-Hill Book Co.,1968, p. 622.

The initial temperature estimates are used only for initialization and need not be very accurate. The pressure estimates are used in the determination of the number of stages, and therefore can have an effect on the tower convergence.

(h) Product purities, light component:

overhead= 0.98 : bottoms= 0.60

The bottoms composition is within the practical limits discussed in chapter III.

3 (A) Basic data

(a) Enthalpy data

Liquid and vapor enthalpy values for both components at -289°F. and -266.1°F. were estimated from an "Esso Blue Book" graph supplied by Dr. Edward C. Roche, Jr., and input in the order: (1) temperature(°F.), (2) liquid enthalpies (Btu/lb-mole), and (3) vapor enthalpies(Btu/lb-mole).

(b) Equilibrium data

Vapor-liquid equilibrium data for each component[3] were entered at temperatures of -289°F. and -266.1°F. The values were

---

[3] Van Winkle, M., Distillation, New York: Mc Graw-Hill Book Company, 1967, p.284.

input in the following order:
(1) temperature (°F.), (2) light component equilibrium constant, and
(3) heavy component equilibrium constant.

2 (B) Absorber tower parameters

(d) Pressure drops--stage=0.1 psi., condenser=0.3 psi., reboiler=0.1 psi. The same values as were used in the high pressure column.

(e) Equilibrium reference pressure=14.7 psia.

(f) Tolerances = 10^{-6} and 10^{-4}
The same values as were used in the high pressure column.

(g) Initial temperature and pressure estimates:

	TOP	BOTTOM
T, °F.	-310.9	-307.7
P, psia.	15.0	20.0

(h) Product purities, light component:
overhead= 0.99 : bottoms= 0.01

3 (B) Absorber basic data

(a) Enthalpy data
As in the high pressure column, enthalpy data at -319.7°F. and -300.0°F. were supplied to the model from the "Esso Blue Book" graph previously mentioned.

(b) Equilibrium data

As before, vapor-liquid equilibrium data[4] for each component were supplied to the model at -319.7°F. and -300.0°F.

The above data were inserted into the model and the results are that the high pressure tower requires 7 stages plus a reboiler and a condenser, the bottoms composition of the light key is 0.61, and the reflux ratio is 0.98649. The condenser and reboiler duties are 203,940 and 204,195 Btu/hour, respectively. The absorber requires 13 stages plus a total reboiler (see attached printout). The high pressure column was checked using DISTL, a rigorous distillation program developed by Dr. Edward C. Roche, Jr. The solution checks favorably within the tolerance limits. A check on the absorber using ABSR , a rigorous absorber program developed by Mr. Robert Lukach and Dr. Edward C. Roche, Jr. also gave favorable results.

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[4] Van Winkle, M., Distillation, New York: McGraw-Hill Book Company, 1967, p. 284.

```
                        _COLUMN_NUMBER___1-----PROBLEM NUMBER   [illegible]

  -------------TOTAL_CONDENSER===ALL_LIQUID_DISTILLATE-----------------------------

                    INPUT DATA USED IN CALCULATIONS
  ---------------------------------------------------------------------------------

     FEED RATE   XF(1)     XB(1)     DIST.RATE   DIST.SPLIT  ZD(1)
     MOLS/HOUR                       MOLS/HOUR

     100.00000  .790000   .600000    49.99995     0.00000   .980000

     PRESSURE DROP/STAGE=0.1000     CONDENSER PRESSURE DROP=0.3000     REBOILER PRESSURE DROP=0.1000

  ----------------------------------*****CONSTANTS*****-----TOWER_NUMBER_1-------
     EQUILIBRIUM               PRESSURE              ENTHALPY-LIQUID       ENTHALPY-VAPOR

  A1      11.41600             73.50000              -743.70459            4259.03900

  B1   -1206.56730             73.50000                17.13020               0.00000

  A2      10.15647             73.50000              -213.52954            4339.14060

  B2   -1151.48900             73.50000                13.97386               4.19216
  ---------------------------------------------------------------------------------
```

```
          BUBBLE POINT FEED

          THE FRACTION FEED VAPORIZED= 0.0001

           XFEED=  0.78999     YFEED=  0.90614     HFEED= 0.22290438E 06     TFEED=-286.24707


  MINIMUM REFLUX =     0.63588         REFLUX RATIO=     0.69947

          THE FRACTION DISTILLATE VAPORIZED= 0.0007
-----------------------------------------------------------------------------

                TEMPERATURES---DEGREES FAHRENHEIT

      TOP          BOTTOM       FEED        CONDENSER

    -280.30005  -274.00000  -286.24707  -290.21606

             PRESSURES---PSIA

    PTOP=    73.80000    PBOTTOM=    78.80000
-----------------------------------------------------------------------------
```

```
     FIRST PASS---DETERMINATION OF NUMBER OF STAGES

              RECTIFYING SECTION
    STAGE     TEMPERATURE     LIQUID RATE     VAPOR RATE          PRESSURE
              DEGREES F       MOLES/HR.       MOLES/HR.            PSIA


    COND.      -290.21606        49.99995         0.00000        73.50000
      1        -289.67944        34.83177        84.97330        73.80000
      2        -289.21021        34.46559        84.83192        73.89999
      3        -288.76343        34.31805        84.46524        73.99998
      4        -288.35132        34.11691        84.31810        74.09998
      5        -287.98462        33.95007        84.11673        74.19997
      6        -287.66724        33.87671        83.94994        74.29996
      7        -287.39648        33.61829        83.87653        74.39995
      8        -287.17651        33.56702        83.61823        74.49994
      9        -286.99365        33.39804        83.56694        74.59993
     10        -286.84790        33.47160        83.39790        74.69992

THE NET VAPOR ENTERING THE RECTIFYING SECTION IS   83.47151


     STAGE     X(1)            Y(1)

      1        0.9505086       0.9799908
      2        0.9219195       0.9678856
      3        0.8954541       0.9562954
      4        0.8717471       0.9455838
      5        0.8513058       0.9360884
      6        0.8341948       0.9279497
      7        0.8201004       0.9211059
      8        0.8091582       0.9157078
      9        0.8004780       0.9113712
     10        0.7940014       0.9081022

     THE NUMBER OF STAGES IN THE RECTIFYING SECTION    ARE 10
```

```
                STRIPPING SECTION

      STAGE     TEMPERATURE      LIQUID RATE      VAPOR RATE          PRESSURE
                DEGREES F        MOLES/HR.        MOLES/HR.             PSIA

        11      -285.48438       134.21709          84.33714          78.59998
        12      -285.30298       133.99014          84.21704          78.69998
        13      -284.82056       133.04175          83.99010          78.79999
   REB. 14      -281.67847        50.00005          83.04169          78.89999

   THE NET LIQUID ENTERING THE STRIPPING SECTION IS  134.33719

        STAGE     X(1)             Y(1)

        11       0.7892518        0.9058817
        12       0.7809044        0.9016114
        13       0.7560924        0.8885984
   REB. 14       0.6000000        0.8500769

        THE NUMBER OF STAGES IN THE STRIPPING SECTION      ARE  4


        THE TOTAL NUMBER OF STAGES IN TOWER ARE   14


        PASS NUMBER  1 IS COMPLETE
```

```
                REVISED VALUES BASED ON TRUE PRESSURE PROFILE

               BUBBLE POINT FEED
               THE FRACTION FEED VAPORIZED= 0.0001
                XFEED=  0.78999     YFEED=  0.90603     HFEED= 0.22172456E 06     TFEED=-286.96240

   MINIMUM REFLUX =      0.63745          REFLUX RATIO=      0.70120
               THE FRACTION DISTILLATE VAPORIZED= 0.0007
  --------------------------------------------------------------------------


                        TEMPERATURES---DEGREES FAHRENHEIT
          TOP         BOTTOM       FEED        CONDENSER
       -289.67944  -284.82056  -286.96240  -290.21606
                   PRESSURES---PSIA
     PTOP=    73.80000     PBOTTOM=    75.00000

  --------------------------------------------------------------------------
```

```
                         PASS NUMBER    2

          THE VALUE OF THE REFLUX RATIO=    0.70120

     STAGE      TEMPERATURE       LIQUID RATE      VAPOR RATE            PRESSURE
                DEGREES F         MOLES/HR.        MOLES/HR.              PSIA


     COND.       -290.21606        85.05971          0.00000           73.50000
        1        -289.67944        34.90472         85.05971           73.80000
        2        -289.20972        34.52682         84.90474           73.89999
        3        -288.76196        34.39322         84.52681           73.99998
        4        -288.34839        34.19337         84.39325           74.09998
        5        -287.97998        34.02261         84.19322           74.19997
        6        -287.66113        33.94830         84.02267           74.29996
        7        -287.38867        33.69162         83.94812           74.39995
        8        -287.16724        33.64117         83.69150           74.49994
        9        -286.98315        33.47137         83.64120           74.59993
       10        -286.83618        33.54501         83.47134           74.69992
       11        -286.70947        33.48264         83.54491           74.79991
       12        -286.60547       133.55978         83.47589           74.89990
       13        -286.26709       133.10303         83.55968           74.99989
  REB. 14        -285.32739        50.00005         83.10312           75.09988

     STAGE      X(1)              Y(1)

        1       0.9505087         0.9799909
        2       0.9218869         0.9678707
        3       0.8953639         0.9562570
        4       0.8715686         0.9455024
        5       0.8510251         0.9359576
        6       0.8338265         0.9277697
        7       0.8196422         0.9208828
        8       0.8086179         0.9154395
        9       0.7998692         0.9110632
       10       0.7933309         0.9077635
       11       0.7879876         0.9050432
       12       0.7839639         0.9029832
       13       0.7667707         0.8940374
  REB. 14       0.7173544         0.8671048
```

```
PASS   REFLUX RATIO   BOTTOMS COMP.

   3        0.63108       0.8147993
   4        0.77132       0.4868704
   5        0.71207       0.6760574
   6        0.73879       0.5804196
   7        0.72937       0.6110585
   8        0.73343       0.5988229
   9        0.73222       0.6027896
  10        0.73294       0.6000825
```

```
     FINAL CONVERGENCE ACHIEVED ON BOTTOMS          COMPOSITION ---TOWER NUMBER 1

            THE FEED IS INTRODUCED BETWEEN STAGES     11     AND     12

          RLOW=  0.63108      R=  0.73294      RHIGH=  0.77132

   STAGE     TEMPERATURE      PRESSURE      LIQUID RATE     VAPOR RATE      X(COMP.1)       Y(COMP.1)
             DEGREES F         PSIA         MOLES/HR.        MOLES/HR.

   COND.      -290.21606      73.50000       49.99995        0.00000         0.97999         0.99205
     1        -289.67944      73.80000       36.44078       86.64709         0.95051         0.97999
     2        -289.19873      73.89999       36.22591       86.44073         0.92117         0.96756
     3        -288.72729      73.99998       35.78514       86.22601         0.89318         0.95528
     4        -288.28735      74.09998       35.61053       85.78525         0.86781         0.94378
     5        -287.88794      74.19997       35.36249       85.61038         0.84546         0.93333
     6        -287.53906      74.29996       35.25792       85.36230         0.82656         0.92426
     7        -287.23877      74.39995       35.04657       85.25792         0.81085         0.91654
     8        -286.99023      74.49994       35.15302       85.04649         0.79835         0.91029
     9        -286.77539      74.59993       35.06006       85.15292         0.78793         0.90500
    10        -286.59912      74.69992       34.90157       85.06000         0.77981         0.90083
    11        -286.45898      74.79991       34.81210       84.90155         0.77378         0.89770
    12        -286.34521      74.89990      134.46739       84.80545         0.76927         0.89535
    13        -285.43994      74.99989      132.94766       84.46738         0.72155         0.86946
 REB. 14      -282.98364      75.09988       50.00005       82.94757         0.60008         0.79482

                            ENTHALPY BALANCE (BTU/HR.)
   FEED ENTHALPY= 0.22172456E 06             REBOILER DUTY= 0.18321863E 06

                     TOTAL ENTHALPY IN = 0.40494319E 06

 DISTILLATE ENTHALPY = 0.10823056E 06  BOTTOMS ENTHALPY = 0.11386025E 06  CONDENSER DUTY =-0.18285238E 06

                     TOTAL ENTHALPY OUT = 0.40494319E 06

                        TOWER NUMBER 1 IS COMPLETE
```

```
                                   _COLUMN_NUMBER___2-----PROBLEM NUMBER   [illegible]

                              AIR PLANT---D(1)=REFLUX(2)

  ----------------------------------*****CONSTANTS*****_____TOWER_NUMBER_2_______
      EQUILIBRIUM                PRESSURE                 ENTHALPY-LIQUID      ENTHALPY-VAPOR
  A1       12.24675             14.70000            -3444.33690          2182.85660
  B1    -1330.35910             14.70000               34.13612            12.80102
  A2       10.54674             14.70000            -3149.98040          2393.01070
  B2    -1279.70550             14.70000               32.48738            16.24368
  -----------------------------------------------------------------------------------
```

```
                    INPUT DATA USED IN CALCULATIONS
--------------------------------------------------------------------------------

     FEED RATE   XF(1)    XB(1)    DIST.RATE   DIST.SPLIT  ZD(1)
     MOLS/HOUR                     MOLS/HOUR

      50.00003 .600082  .010000    30.10622     0.00000  .990000

    PRESSURE DROP/STAGE=0.1000     CONDENSER PRESSURE DROP=0.3000     REBOILER PRESSURE DROP=0.1000

              FLASHED FEED

              THE FRACTION FEED VAPORIZED= 0.2438

               XFEED=  0.53082     YFEED=  0.81494     HFEED= 0.11378713E 06     TFEED=-311.45361
```

```
                    AIR PLANT---SECOND COLUMN---ABSORBER SECTION

   STAGE     TEMPERATURE      PRESSURE     LIQUID RATE     VAPOR RATE     X(COMP,1)      Y(COMP,1)
             DEGREES F         PSIA        MOLES/HR.        MOLES/HR.

    REB.     -290.58301      20.09999       20.45335        44.77570       0.01000        0.01000
     2       -291.19800      20.00000       65.22905        44.16626       0.01000        0.03935
     3       -292.57813      19.89999       64.61961        43.36884       0.03006        0.11139
     4       -295.40796      19.79999       63.82219        42.54596       0.07889        0.25632
     5       -299.82837      19.69998       62.99931        42.25026       0.17635        0.46070
     6       -304.44556      19.59998       62.70361        42.97437       0.31369        0.64370
     7       -307.70435      19.49997       63.42772        43.57489       0.43936        0.75466
     8       -309.43457      19.39996       64.02824        43.16164       0.51679        0.80702
     9       -310.72705      19.29996       25.80382        55.62257       0.57999        0.84336
    10       -312.13257      19.19995       26.07591        55.94418       0.65617        0.88120
    11       -313.50903      19.09995       26.39746        56.47319       0.73864        0.91631
    12       -314.68335      18.99994       26.92656        56.94569       0.81509        0.94455
    13       -315.56641      18.89993       27.39900        57.39355       0.87552        0.96443
    14       -316.17676      18.79993       27.84702        57.47720       0.91760        0.97720
    15       -316.57935      18.69992       27.93033        57.58319       0.94403        0.98483
    16       -316.84912      18.59991       28.03665        57.65257       0.95981        0.98922
  TOP 17     -317.03809      18.49991       28.10562        57.82990       0.96890        0.99173
```

```
            REVISED VALUES BASED ON TRUE PRESSURE PROFILE


                           TRIAL NUMBER 2
                  THE FEED IS INTRODUCED BETWEEN STAGES      8     AND      9


                   INPUT DATA USED IN CALCULATIONS
   ------------------------------------------------------------------------------


      FEED RATE   XF(1)     XB(1)     DIST.RATE   DIST.SPLIT  ZD(1)
      MOLS/HOUR                       MOLS/HOUR

       50.00002  .600082   .010000    30.10620     0.00000   .990000

            FLASHED FEED

            THE FRACTION FEED VAPORIZED= 0.2258

             XFEED=  0.53631      YFEED=  0.81880      HFEED= 0.11379119E 06      TFEED=-309.81860
```

```
                         AIR PLANT---SECOND COLUMN---ABSORBER SECTION

   STAGE      TEMPERATURE         PRESSURE       LIQUID RATE       VAPOR RATE       X(COMP.1)        Y(COMP.1)
              DEGREES F            PSIA          MOLES/HR.          MOLES/HR.


    REB.       -290.58301         20.09999         20.45212         44.77692         0.01000          0.01000
      2        -291.19800         20.00000         65.22903         44.16626         0.01000          0.03935
      3        -292.57813         19.89999         64.61838         43.36945         0.03006          0.11139
      4        -295.40796         19.79999         63.82159         42.54588         0.07890          0.25632
      5        -299.82886         19.69998         62.99802         42.25092         0.17636          0.46071
      6        -304.44604         19.59998         62.70303         42.97536         0.31370          0.64372
      7        -307.70483         19.49997         63.42747         43.57590         0.43938          0.75468
      8        -309.43506         19.39996         64.02802         43.95508         0.51681          0.80703
      9        -310.73633         19.29996         25.69504         55.61357         0.58051          0.84364
     10        -312.14209         19.19995         26.06569         55.94432         0.65674          0.88145
     11        -313.51758         19.09995         26.39638         56.46870         0.73922          0.91655
     12        -314.69067         18.99994         26.92081         56.94894         0.81561          0.94472
     13        -315.57129         18.89993         27.40129         57.39001         0.87592          0.96457
     14        -316.18066         18.79993         27.84200         57.47438         0.91792          0.97730
     15        -316.58228         18.69992         27.92639         57.58716         0.94427          0.98489
     16        -316.85107         18.59991         28.03926         57.65076         0.95999          0.98928
     17        -317.04004         18.49991         28.10318         57.84618         0.96905          0.99175
 TOP 18        -317.18359         18.39990         28.29810         57.69617         0.97425          0.99316

                PRESSURE VARIATIONS HAVE BEEN DAMPED
```

```
TRIAL     OVERHEAD FEED     OVERHEAD FEED     CONDENSER DUTY(1)     REBOILER DUTY(2)
            REQUIRED           ACTUAL

  2        35.8200070       28.1484060           0.1828524E 06        0.1828524E 06
  3        35.8200070       40.1277160           0.1828524E 06        0.2136609E 06
  4        35.8200070       35.1592100           0.1828524E 06        0.2007569E 06
  5        35.8200070       36.8414610           0.1828524E 06        0.2051918E 06
  6        35.8200070       36.1804650           0.1828524E 06        0.2030937E 06
```

```
              THE SECOND TOWER IS INDEPENDENTLY CLOSED

             THE FEED IS INTRODUCED BETWEEN STAGES       8      AND       9

   STAGE     TEMPERATURE        PRESSURE      LIQUID RATE     VAPOR RATE      X(COMP.1)       Y(COMP.1)
             DEGREES F           PSIA         MOLES/HR.        MOLES/HR.

    REB.     -290.58301        20.09999       20.45212        51.99762        0.01000         0.01000
      2      -291.19800        20.00000       72.44974        51.42238        0.01000         0.03935
      3      -292.63477        19.89999       71.87450        50.43419        0.03100         0.11455
      4      -295.68652        19.79999       70.88632        49.31038        0.08439         0.27043
      5      -300.49683        19.69998       69.76250        49.42889        0.19408         0.48969
      6      -305.41821        19.59998       69.88101        50.32549        0.34930         0.67923
      7      -308.71362        19.49997       70.77760        51.23323        0.48585         0.78727
      8      -310.37329        19.39996       71.68533        45.03790        0.56551         0.83549
      9      -311.73584        19.29996       26.77785        56.81207        0.63753         0.87249
     10      -313.22046        19.19995       27.26418        64.09064        0.72506         0.91090
     11      -314.76733        19.09995       34.54268        64.64423        0.82740         0.94876
     12      -315.77393        18.99994       35.09659        65.08287        0.89845         0.97151
     13      -316.37500        18.89993       35.53482        65.50285        0.94074         0.98390
     14      -316.72949        18.79993       35.95555        65.51746        0.96368         0.99029
     15      -316.94751        18.69992       35.96947        65.42711        0.97532         0.99346
     16      -317.09619        18.59991       35.87918        65.48859        0.98107         0.99501
     17      -317.21143        18.49991       35.94066        65.57368        0.98391         0.99578
 TOP 18      -317.31104        18.39990       36.02478        65.72682        0.98533         0.99614
 ---------------------------ENTHALPY BALANCE (BTU/HR.)-----------------------

 FEED ENTHALPY= 0.11386025E 06     REBOILER DUTY= 0.20309369E 06     REFLUX ENTHALPY= 0.51528977E 05

                   TOTAL ENTHALPY IN = 0.36848288E 06

   BOTTOMS ENTHALPY 0.10506306E 06          TOP PRODUCT ENTHALPY 0.26370438E 06

                   TOTAL ENTHALPY OUT = 0.36876744E 06
 ----------------------------------------------------------------------------

                      TOWER NUMBER TWO IS COMPLETE
```

```
------------------------------------COLUMN_NUMBER___1=====PROBLEM_NUMBER___1-----

     FEED RATE   XF(1)     XB(1)     DIST.RATE   DIST.SPLIT  ZD(1)
     MOLS/HOUR                       MOLS/HOUR

     100.00000  .790000   .600000     49.99995     0.00000   .980000

    PRESSURE DROP/STAGE=0.1000      CONDENSER PRESSURE DROP=0.3000      REBOILER PRESSURE DROP=0.1000

              BUBBLE POINT FEED

              THE FRACTION FEED VAPORIZED= 0.0001

               XFEED=  0.78999      YFEED=  0.90604      HFEED= 0.22186631E 06      TFEED=-286.87842


  MINIMUM REFLUX =      0.63727          REFLUX RATIO=      0.92451

              THE FRACTION DISTILLATE VAPORIZED= 0.0007
 -------------------------------------------------------------------------------

                       TEMPERATURES---DEGREES FAHRENHEIT

         TOP         BOTTOM        FEED        CONDENSER

     -289.67944  -284.82056  -286.87842  -290.21606

                   PRESSURES---PSIA

    PTOP=    73.80000     PBOTTOM=    75.00000

 -------------------------------------------------------------------------------
```

```
     FIRST PASS---DETERMINATION OF NUMBER OF STAGES

              RECTIFYING SECTION

    STAGE     TEMPERATURE     LIQUID RATE     VAPOR RATE          PRESSURE
              DEGREES F       MOLES/HR.       MOLES/HR.            PSIA

    COND.      -290.21606       49.99995          0.00000         73.50000
      1        -289.67944       46.03233         96.22549         73.80000
      2        -289.13745       45.50606         96.03291         73.89999
      3        -288.54321       45.20465         95.50630         73.99998
      4        -287.91992       44.75742         95.20457         74.09998
      5        -287.30127       44.41364         94.75739         74.19997

THE NET VAPOR ENTERING THE RECTIFYING SECTION IS   94.41357

     STAGE     X(1)            Y(1)

      1        0.9505087       0.9799909
      2        0.9172261       0.9658588
      3        0.8816244       0.9500852
      4        0.8453791       0.9332849
      5        0.8105946       0.9164088

     THE NUMBER OF STAGES IN THE RECTIFYING SECTION     ARE   5
```

```
                STRIPPING SECTION

      STAGE     TEMPERATURE      LIQUID RATE     VAPOR RATE           PRESSURE
                DEGREES F        MOLES/HR.       MOLES/HR.             PSIA


        6       -286.55273        144.08479        94.50697         74.89998
        7       -285.69678        142.24242        94.08473         74.99998
   REB.  8      -282.98193         50.00005        92.24237         75.09999

   THE NET LIQUID ENTERING THE STRIPPING SECTION IS  144.50702


       STAGE     X(1)            Y(1)

        6        0.7809684       0.9014373
        7        0.7353791       0.8771416
   REB.  8       0.6000000       0.8087614

       THE NUMBER OF STAGES IN THE STRIPPING SECTION      ARE  3



       THE TOTAL NUMBER OF STAGES IN TOWER ARE    8



       PASS NUMBER  1 IS COMPLETE
```

```
                REVISED VALUES BASED ON TRUE PRESSURE PROFILE

               BUBBLE POINT FEED
               THE FRACTION FEED VAPORIZED= 0.0000
                XFEED=  0.79000    YFEED=  0.90603    HFEED= 0.22166063E 06     TFEED=-286.99609


   MINIMUM REFLUX =      0.63752          REFLUX RATIO=      0.92487
               THE FRACTION DISTILLATE VAPORIZED= 0.0007
 ---------------------------------------------------------------------------


                         TEMPERATURES---DEGREES FAHRENHEIT
          TOP          BOTTOM       FEED         CONDENSER
      -289.67944  -285.69678  -286.99609  -290.21606
                   PRESSURES---PSIA
      PTOP=    73.80000     PBOTTOM=    74.39999
 ---------------------------------------------------------------------------
```

```
                              PASS NUMBER    2

            THE VALUE OF THE REFLUX RATIO=    0.92487

      STAGE       TEMPERATURE        LIQUID RATE        VAPOR RATE            PRESSURE
                  DEGREES F          MOLES/HR.          MOLES/HR.              PSIA


      COND.       -290.21606           96.24353            0.00000          73.50000
        1         -289.67944           46.04573           96.24353          73.80000
        2         -289.13745           45.52342           96.04535          73.89999
        3         -288.54297           45.21733           95.52313          73.99998
        4         -287.91943           44.77368           95.21741          74.09998
        5         -287.30054           44.42981           94.77353          74.19997
        6         -286.71509           44.08714           94.42984          74.29996
        7         -286.18823          142.92807           94.08455          74.39995
  REB.  8         -284.39893           50.00005           92.92810          74.49994

       STAGE       X(1)              Y(1)

        1          0.9505087         0.9799910
        2          0.9172242         0.9658567
        3          0.8816087         0.9500784
        4          0.8453494         0.9332706
        5          0.8105475         0.9163826
        6          0.7787657         0.9002667
        7          0.7511740         0.8857007
  REB.  8          0.6587275         0.8325084

 ----PASS NUMBER  2 IS COMPLETE-------------------------------------------------
```

```
PASS   REFLUX RATIO   BOTTOMS COMP.

   3        0.83239       0.7420707
   4        1.01736       0.5885121
   5        0.96420       0.6281107
   6        0.99636       0.6051644
   7        1.00486       0.5989576
   8        1.00202       0.6006418
   9        1.00327       0.5998993
  10        1.00287       0.6001325
  11        1.00309       0.6000246
```

```
          FINAL CONVERGENCE ACHIEVED ON BOTTOMS             COMPOSITION ---TOWER NUMBER 1

                   THE FEED IS INTRODUCED BETWEEN STAGES      6      AND      7

               RLOW=  0.83239     R=  1.00309     RHIGH=  1.01736

      STAGE     TEMPERATURE      PRESSURE      LIQUID RATE     VAPOR RATE     X(COMP.1)     Y(COMP.1)
                DEGREES F        PSIA          MOLES/HR.        MOLES/HR.


      COND.      -290.21606      73.50000       49.99995        0.00000       0.97999       0.99205
        1        -289.67944      73.80000       49.78699      100.15421       0.95051       0.97999
        2        -289.11694      73.89999       49.42500       99.78674       0.91590       0.96528
        3        -288.47412      73.99998       48.93660       99.42522       0.87732       0.94813
        4        -287.77783      74.09998       48.53621       98.93628       0.83683       0.92921
        5        -287.06323      74.19997       47.82237       98.53607       0.79676       0.90947
        6        -286.38135      74.29996       47.40067       97.82228       0.76000       0.89042
        7        -285.76050      74.39995      145.56458       97.39795       0.72784       0.87293
   REB.  8       -283.19263      74.49994       50.00005       95.56448       0.60002       0.79471

                            ENTHALPY BALANCE (BTU/HR.)
      FEED ENTHALPY= 0.22166063E 06          REBOILER DUTY= 0.21162094E 06

                       TOTAL ENTHALPY IN = 0.43328156E 06

   DISTILLATE ENTHALPY = 0.10823056E 06  BOTTOMS ENTHALPY = 0.11369438E 06  CONDENSER DUTY =-0.21135663E 06

                       TOTAL ENTHALPY OUT = 0.43328156E 06

                            TOWER NUMBER 1 IS COMPLETE
```

```
                         COLUMN NUMBER   2-----PROBLEM NUMBER

              INPUT DATA USED IN CALCULATIONS
   -----------------------------------------------------------------------

      FEED RATE   XF(1)    XB(1)    DIST.RATE   DIST.SPLIT  ZD(1)
      MOLS/HOUR                     MOLS/HOUR

       50.00005  .600024  .010000    30.10329     0.00000  .990000

     PRESSURE DROP/STAGE=0.1000    CONDENSER PRESSURE DROP=0.3000    REBOILER PRESSURE DROP=0.1000

           FLASHED FEED

           THE FRACTION FEED VAPORIZED= 0.2259

            XFEED=  0.53620    YFEED=  0.81869    HFEED= 0.11362550E 06    TFEED=-309.94897
```

```
                        AIR PLANT---SECOND COLUMN---ABSORBER SECTION

   STAGE     TEMPERATURE        PRESSURE       LIQUID RATE      VAPOR RATE       X(COMP,1)       Y(COMP,1)
             DEGREES F           PSIA          MOLES/HR.         MOLES/HR.


   REB.       -290.58301        20.09999        20.45505         54.94234         0.01000         0.01000
     2        -291.19800        20.00000        75.39738         54.33238         0.01000         0.03935
     3        -292.65454        19.89999        74.78745         53.28462         0.03132         0.11564
     4        -295.78418        19.79999        73.73965         52.19554         0.08634         0.27535
     5        -300.73657        19.69998        72.65059         52.27937         0.20064         0.49992
     6        -305.75342        19.59998        72.73444         53.44038         0.36214         0.69116
     7        -309.05981        19.49997        73.89543         54.31499         0.50260         0.79817
     8        -311.56104        19.39996        36.06630         66.58156         0.63228         0.86998
     9        -313.64771        19.29996        37.03658         67.38399         0.75947         0.92441
    10        -315.10083        19.19995        37.83922         68.15723         0.85873         0.95912
    11        -315.97559        19.09995        38.61220         68.33130         0.92132         0.97832
    12        -316.46704        18.99994        38.78647         68.53201         0.95531         0.98800
 TOP 13       -316.75000        18.89993        38.98763         68.74455         0.97244         0.99269
```

```
                 REVISED VALUES BASED ON TRUE PRESSURE PROFILE


                               TRIAL NUMBER 2
                     THE FEED IS INTRODUCED BETWEEN STAGES      7       AND       8


                      INPUT DATA USED IN CALCULATIONS
  ------------------------------------------------------------------------------


       FEED RATE   XF(1)    XB(1)     DIST.RATE   DIST.SPLIT  ZD(1)
       MOLS/HOUR                      MOLS/HOUR

        50.00003  .600024  .010000    30.10327     0.00000   .990000

                FLASHED FEED

                THE FRACTION FEED VAPORIZED= 0.2238

                 XFEED=  0.53686     YFEED=  0.81915     HFEED= 0.11364594E 06     TFEED=-309.74146
```

```
                    AIR PLANT---SECOND COLUMN---ABSORBER SECTION

   STAGE     TEMPERATURE      PRESSURE      LIQUID RATE     VAPOR RATE      X(COMP,1)       Y(COMP,1)
             DEGREES F         PSIA         MOLES/HR.         MOLES/HR.

   REB.       -290.58301      20.09999       20.45482        54.94257        0.01000         0.01000
     2        -291.19800      20.00000       75.39738        54.33247        0.01000         0.03935
     3        -292.65454      19.89999       74.78729        53.28482        0.03132         0.11564
     4        -295.78418      19.79999       73.73964        52.19566        0.08634         0.27536
     5        -300.73682      19.69998       72.65048        52.27979        0.20064         0.49992
     6        -305.75342      19.59998       72.73460        53.44037        0.36214         0.69116
     7        -309.06006      19.49997       73.89519        54.41493        0.50261         0.79816
     8        -311.56177      19.39996       36.05775        66.58514        0.63232         0.87000
     9        -313.64819      19.29996       37.03995        67.38974        0.75951         0.92442
    10        -315.10132      19.19995       37.84465        68.15680        0.85877         0.95914
    11        -315.97607      19.09995       38.61174        68.33745        0.92136         0.97832
    12        -316.46729      18.99994       38.79172        68.53700        0.95533         0.98800
 TOP 13       -316.75024      18.89993       38.99133        68.75125        0.97246         0.99270

              PRESSURE VARIATIONS HAVE BEEN DAMPED
```

```
      TRIAL     OVERHEAD FEED     OVERHEAD FEED      CONDENSER DUTY(1)      REBOILER DUTY(2)
                  REQUIRED           ACTUAL

        2        36.0231470        39.2046660             0.2113566E 06          0.2113566E 06
        3        36.0231470        33.9294730             0.2113566E 06          0.1985559E 06
        4        36.0231470        36.3501890             0.2113566E 06          0.2042268E 06
```

```
              THE SECOND TOWER IS INDEPENDENTLY CLOSED

             THE FEED IS INTRODUCED BETWEEN STAGES       7      AND       8

    STAGE     TEMPERATURE       PRESSURE       LIQUID RATE      VAPOR RATE       X(COMP.1)        Y(COMP.1)
              DEGREES F          PSIA          MOLES/HR.         MOLES/HR.


    REB.       -290.58301        20.09999        20.45482         52.39912         0.01000          0.01000
      2        -291.19800        20.00000        72.85394         51.78123         0.01000          0.03935
      3        -292.63745        19.89999        72.23605         50.74197         0.03104          0.11469
      4        -295.69775        19.79999        71.19678         49.62656         0.08461          0.27100
      5        -300.52417        19.69998        70.08138         49.79440         0.19482          0.49085
      6        -305.45898        19.59998        70.24922         50.69958         0.35084          0.68068
      7        -308.75610        19.49997        71.15440         44.67940         0.48788          0.78862
      8        -310.17188        19.39996        26.32222         56.22177         0.55478          0.82949
      9        -311.62891        19.29996        26.67657         63.86600         0.63122          0.86945
     10        -313.58911        19.19995        34.32079         64.74648         0.74974          0.92065
     11        -315.02808        19.09995        35.20125         65.28133         0.84691          0.95526
     12        -315.93335        18.99994        35.73651         65.51003         0.91124          0.97534
  TOP 13       -316.46289        18.89993        35.96489         65.89551         0.94808          0.98597
 --------------------------------ENTHALPY BALANCE (BTU/HR.)-------------------------

  FEED ENTHALPY= 0.11369438E 06     REBOILER DUTY= 0.20422675E 06     REFLUX ENTHALPY= 0.52586332E 05

                   TOTAL ENTHALPY IN = 0.37050744E 06

    BOTTOMS ENTHALPY 0.10507694E 06         TOP PRODUCT ENTHALPY 0.26556913E 06

                   TOTAL ENTHALPY OUT = 0.37064606E 06
 -----------------------------------------------------------------------------------

                        TOWER NUMBER TWO IS COMPLETE
```

```
------------------------------------------COLUMN-NUMBER---1=====PROBLEM-NUMBER---1-----

    FEED RATE   XF(1)     XB(1)     DIST.RATE    DIST.SPLIT  ZD(1)
    MOLS/HOUR                       MOLS/HOUR

    100.00000  .790000   .610000    48.64864      0.00000   .980000

   PRESSURE DROP/STAGE=0.1000      CONDENSER PRESSURE DROP=0.3000     REBOILER PRESSURE DROP=0.1000

            BUBBLE POINT FEED

            THE FRACTION FEED VAPORIZED= 0.0000

             XFEED=  0.79000      YFEED=  0.90603      HFEED= 0.22169163E 06      TFEED=-286.97925


 MINIMUM REFLUX =      0.63748          REFLUX RATIO=      0.92482

            THE FRACTION DISTILLATE VAPORIZED= 0.0007
 ------------------------------------------------------------------------------

                   TEMPERATURES---DEGREES FAHRENHEIT

       TOP          BOTTOM       FEED        CONDENSER

    -289.67944  -285.69678  -286.97925  -290.21606

               PRESSURES---PSIA

   PTOP=    73.80000     PBOTTOM=    74.39999

 ------------------------------------------------------------------------------
```

```
    FIRST PASS---DETERMINATION OF NUMBER OF STAGES

                RECTIFYING SECTION

    STAGE       TEMPERATURE       LIQUID RATE       VAPOR RATE           PRESSURE
                DEGREES F         MOLES/HR.         MOLES/HR.             PSIA

    COND.        -290.21606         48.64864          0.00000            73.50000
      1          -289.67944         44.80084         93.64000            73.80000
      2          -289.13721         44.28928         93.44917            73.89999
      3          -288.54297         43.99583         92.93791            73.99998
      4          -287.91943         43.56161         92.64436            74.09998
      5          -287.30054         43.22647         92.21024            74.19997

THE NET VAPOR ENTERING THE RECTIFYING SECTION IS   91.87506

     STAGE       X(1)            Y(1)

       1         0.9505087       0.9799910
       2         0.9172151       0.9658568
       3         0.8816059       0.9500753
       4         0.8453479       0.9332690
       5         0.8105482       0.9163834

    THE NUMBER OF STAGES IN THE RECTIFYING SECTION     ARE   5
```

```
                 STRIPPING SECTION

      STAGE      TEMPERATURE       LIQUID RATE      VAPOR RATE            PRESSURE
                 DEGREES F         MOLES/HR.        MOLES/HR.              PSIA


         6       -286.76025         142.62903         91.90302          74.29997
         7       -285.92139         141.06412         91.27766          74.39998
  REB.   8       -283.40308          51.35136         89.71275          74.49998

  THE NET LIQUID ENTERING THE STRIPPING SECTION IS  143.25438


       STAGE      X(1)             Y(1)

         6        0.7813481        0.9016141
         7        0.7365482        0.8777458
  REB.   8        0.6100000        0.8089840

       THE NUMBER OF STAGES IN THE STRIPPING SECTION      ARE  3


       THE TOTAL NUMBER OF STAGES IN TOWER ARE    8


       PASS NUMBER  1 IS COMPLETE
```

```
          REVISED VALUES BASED ON TRUE PRESSURE PROFILE

         BUBBLE POINT FEED

         THE FRACTION FEED VAPORIZED= 0.0000

          XFEED=  0.79000     YFEED=  0.90603     HFEED= 0.22166063E 06     TFEED=-286.99609


  MINIMUM REFLUX =      0.63752          REFLUX RATIO=      0.92487

         THE FRACTION DISTILLATE VAPORIZED= 0.0007
  ------------------------------------------------------------------------------


                   TEMPERATURES---DEGREES FAHRENHEIT

      TOP         BOTTOM      FEED        CONDENSER

    -289.67944  -285.92139  -286.99609  -290.21606

              PRESSURES---PSIA

    PTOP=    73.80000     PBOTTOM=    74.39999

  ------------------------------------------------------------------------------
```

```
                              PASS NUMBER   2

            THE VALUE OF THE REFLUX RATIO=   0.92487

      STAGE      TEMPERATURE       LIQUID RATE       VAPOR RATE             PRESSURE
                 DEGREES F         MOLES/HR.         MOLES/HR.               PSIA

      COND.       -290.21606          93.64241           0.00000           73.50000
        1         -289.67944          44.80200          93.64241           73.80000
        2         -289.13745          44.29147          93.45053           73.89999
        3         -288.54297          43.99529          92.94026           73.99998
        4         -287.91943          43.56296          92.64397           74.09998
        5         -287.30054          43.22844          92.21156           74.19997
        6         -286.71509          42.89503          91.87708           74.29996
        7         -286.18848         141.75359          91.54105           74.39995
  REB.  8         -284.36206          51.35136          90.40222           74.49994

       STAGE      X(1)              Y(1)

        1         0.9505086         0.9799908
        2         0.9172240         0.9658566
        3         0.8816091         0.9500788
        4         0.8453496         0.9332709
        5         0.8105480         0.9163832
        6         0.7787664         0.9002675
        7         0.7511820         0.8857015
  REB.  8         0.6568806         0.8313727

  -----PASS NUMBER  2 IS COMPLETE----------------------------------------------------
```

```
  PASS   REFLUX RATIO   BOTTOMS COMP.

     3        0.83239       0.7413213
     4        1.01736       0.5858468
     5        0.95675       0.6324053
     6        0.98648       0.6099548
```

```
        FINAL CONVERGENCE ACHIEVED ON BOTTOMS            COMPOSITION ---TOWER NUMBER 1

              THE FEED IS INTRODUCED BETWEEN STAGES       6      AND       7

             RLOW=  0.83239      R=  0.98648      RHIGH=  1.01736

    STAGE       TEMPERATURE       PRESSURE       LIQUID RATE      VAPOR RATE      X(COMP.1)       Y(COMP.1)
                DEGREES F         PSIA           MOLES/HR.         MOLES/HR.

    COND.       -290.21606        73.50000        48.64864          0.00000        0.97999         0.99205
      1         -289.67944        73.80000        47.62366         96.63976        0.95051         0.97999
      2         -289.12134        73.89999        47.16379         96.27255        0.91619         0.96541
      3         -288.48999        73.99998        46.78523         95.81218        0.87831         0.94858
      4         -287.81030        74.09998        46.31546         95.43393        0.83878         0.93014
      5         -287.11963        74.19997        45.83182         94.96405        0.80002         0.91112
      6         -286.45801        74.29996        45.46831         94.48053        0.76429         0.89269
      7         -285.85571        74.39995       143.71130         94.11440        0.73298         0.87578
 REB.  8        -283.40210        74.49994        51.35136         92.36002        0.60995         0.80135

                              ENTHALPY BALANCE (BTU/HR.)
   FEED ENTHALPY= 0.22166063E 06          REBOILER DUTY= 0.20419519E 06

                   TOTAL ENTHALPY IN = 0.42585581E 06

 DISTILLATE ENTHALPY = 0.10530550E 06  BOTTOMS ENTHALPY = 0.11661031E 06  CONDENSER DUTY =-0.20394000E 06

                   TOTAL ENTHALPY OUT = 0.42585581E 06

                       TOWER NUMBER 1 IS COMPLETE
```

```
                      COLUMN NUMBER   2-----PROBLEM NUMBER   [illegible]


           INPUT DATA USED IN CALCULATIONS
  ------------------------------------------------------------------------------

     FEED RATE   XF(1)    XB(1)    DIST.RATE   DIST.SPLIT  ZD(1)
     MOLS/HOUR                     MOLS/HOUR

      51.35135  .609954  .010000    31.43719    0.00000  .990000

    PRESSURE DROP/STAGE=0.1000    CONDENSER PRESSURE DROP=0.3000    REBOILER PRESSURE DROP=0.1000

           FLASHED FEED

           THE FRACTION FEED VAPORIZED= 0.2261

            XFEED=  0.54709    YFEED=  0.82510    HFEED= 0.11660025E 06    TFEED=-309.98218
```

```
                              AIR PLANT---SECOND COLUMN---ABSORBER SECTION
 STAGE      TEMPERATURE       PRESSURE       LIQUID RATE      VAPOR RATE       X(COMP.1)        Y(COMP.1)
            DEGREES F          PSIA          MOLES/HR.         MOLES/HR.

  REB.      -290.58301        20.09999        20.45711          52.29456         0.01000          0.01000
     2      -291.19800        20.00000        72.75166          51.68851         0.01000          0.03935
     3      -292.63672        19.89999        72.14561          50.66341         0.03103          0.11465
     4      -295.69458        19.79999        71.12050          49.54535         0.08455          0.27084
     5      -300.51660        19.69998        70.00246          49.69952         0.19462          0.49053
     6      -305.44775        19.59998        70.15663          50.60262         0.35041          0.68027
     7      -308.74414        19.49997        71.05972          51.48041         0.48731          0.78824
     8      -310.84692        19.39996        32.19862          63.77982         0.59143          0.84945
     9      -312.76953        19.29996        32.88557          64.68266         0.70123          0.90107
    10      -314.36401        19.19995        33.78835          65.23837         0.80401          0.94070
    11      -315.46899        19.09995        34.34436          65.70796         0.88085          0.96612
    12      -316.15894        18.99994        34.81355          65.95804         0.92964          0.98073
    13      -316.57324        18.89993        35.06271          66.23790         0.95738          0.98857
TOP 14      -316.82983        18.79993        35.34328          66.30322         0.97226          0.99264
```

```
           REVISED VALUES BASED ON TRUE PRESSURE PROFILE

                           TRIAL NUMBER 2
                THE FEED IS INTRODUCED BETWEEN STAGES       7      AND       8

                 INPUT DATA USED IN CALCULATIONS
  -------------------------------------------------------------------------------

      FEED RATE   XF(1)    XB(1)     DIST.RATE   DIST.SPLIT  ZD(1)
      MOLS/HOUR                      MOLS/HOUR

       51.35133  .609954  .010000    31.43718     0.00000  .990000

              FLASHED FEED

              THE FRACTION FEED VAPORIZED= 0.2257

               XFEED=  0.54723     YFEED=  0.82519     HFEED= 0.11659838E 06     TFEED=-309.94116
```

```
                        AIR PLANT---SECOND COLUMN---ABSORBER SECTION

   STAGE     TEMPERATURE      PRESSURE     LIQUID RATE    VAPOR RATE     X(COMP.1)      Y(COMP.1)
             DEGREES F         PSIA        MOLES/HR.       MOLES/HR.


   REB.      -290.58301      20.09999      20.45718       52.29448       0.01000        0.01000
     2       -291.19800      20.00000      72.75166       51.68848       0.01000        0.03935
     3       -292.63672      19.89999      72.14566       50.66336       0.03103        0.11465
     4       -295.69458      19.79999      71.12056       49.54538       0.08455        0.27084
     5       -300.51636      19.69998      70.00256       49.69934       0.19462        0.49053
     6       -305.44775      19.59998      70.15652       50.60252       0.35041        0.68028
     7       -308.74414      19.49997      71.05971       51.50160       0.48731        0.78825
     8       -310.84668      19.39996      32.19557       63.77882       0.59142        0.84945
     9       -312.76953      19.29996      32.88469       64.68185       0.70123        0.90107
    10       -314.36426      19.19995      33.78783       65.23860       0.80401        0.94069
    11       -315.46899      19.09995      34.34456       65.71259       0.88084        0.96610
    12       -316.15869      18.99994      34.81844       65.95798       0.92962        0.98072
    13       -316.57300      18.89993      35.06387       66.23743       0.95736        0.98856
 TOP 14      -316.82959      18.79993      35.34352       66.30034       0.97224        0.99263

                 PRESSURE VARIATIONS HAVE BEEN DAMPED
```

```
TRIAL    OVERHEAD FEED     OVERHEAD FEED     CONDENSER DUTY(1)     REBOILER DUTY(2)
           REQUIRED            ACTUAL

  2       35.0033720        35.4070580          0.2039400E 06         0.2039400E 06
```

```
                 THE SECOND TOWER IS INDEPENDENTLY CLOSED

                THE FEED IS INTRODUCED BETWEEN STAGES      7     AND      8

     STAGE      TEMPERATURE      PRESSURE      LIQUID RATE      VAPOR RATE      X(COMP.1)      Y(COMP.1)
                DEGREES F          PSIA        MOLES/HR.         MOLES/HR.


     REB.       -290.58301      20.09999       20.45718        52.29448        0.01000        0.01000
      2         -291.19800      20.00000       72.75166        51.68848        0.01000        0.03935
      3         -292.63672      19.89999       72.14566        50.66336        0.03103        0.11465
      4         -295.69458      19.79999       71.12056        49.54538        0.08455        0.27084
      5         -300.51636      19.69998       70.00256        49.69934        0.19462        0.49053
      6         -305.44775      19.59998       70.15652        50.60252        0.35041        0.68028
      7         -308.74414      19.49997       71.05971        51.50160        0.48731        0.78825
      8         -310.84668      19.39996       32.19557        63.77882        0.59142        0.84945
      9         -312.76953      19.29996       32.88469        64.68185        0.70123        0.90107
     10         -314.36426      19.19995       33.78783        65.23860        0.80401        0.94069
     11         -315.46899      19.09995       34.34456        65.71259        0.88084        0.96610
     12         -316.15869      18.99994       34.81844        65.95798        0.92962        0.98072
     13         -316.57300      18.89993       35.06387        66.23743        0.95736        0.98856
   TOP 14       -316.82959      18.79993       35.34352        66.30034        0.97224        0.99263
 ------------------------------ENTHALPY BALANCE (BTU/HR.)-------------------------

   FEED ENTHALPY= 0.11661031E 06     REBOILER DUTY= 0.20394000E 06     REFLUX ENTHALPY= 0.50925895E 05

                    TOTAL ENTHALPY IN = 0.37147619E 06

     BOTTOMS ENTHALPY 0.10508906E 06          TOP PRODUCT ENTHALPY 0.26657800E 06


                    TOTAL ENTHALPY OUT = 0.37166706E 06
 ---------------------------------------------------------------------------------

                      TOWER NUMBER TWO IS COMPLETE
```

```
FINAL CONVERGENCE HAS BEEN ACHIEVED FOR BOTH TOWERS
```

```
----------------------------------COLUMN NUMBER---1=====PROBLEM NUMBER---[illegible]-----

   FEED RATE   XF(1)    XB(1)     DIST.RATE   DIST.SPLIT  ZD(1)
   MOLS/HOUR                      MOLS/HOUR

   100.00000  .790000  .610000    48.64864     0.00000  .980000

  PRESSURE DROP/STAGE=0.1000     CONDENSER PRESSURE DROP=0.3000     REBOILER PRESSURE DROP=0.1000

          BUBBLE POINT FEED

          THE FRACTION FEED VAPORIZED= 0.0002

           XFEED=  0.78998     YFEED=  0.90602     HFEED= 0.22171769E 06     TFEED=-286.97900


 MINIMUM REFLUX =     0.63751         REFLUX RATIO=     0.92486

          THE FRACTION DISTILLATE VAPORIZED= 0.0007
 ---------------------------------------------------------------------------------


                    TEMPERATURES---DEGREES FAHRENHEIT

     TOP          BOTTOM       FEED         CONDENSER

  -289.67944  -285.92139  -286.97900  -290.21606

             PRESSURES---PSIA

  PTOP=    73.80000     PBOTTOM=    74.39999

 ---------------------------------------------------------------------------------
```

```
      FIRST PASS---DETERMINATION OF NUMBER OF STAGES


                 RECTIFYING SECTION

     STAGE       TEMPERATURE       LIQUID RATE       VAPOR RATE           PRESSURE
                 DEGREES F         MOLES/HR.         MOLES/HR.             PSIA


     COND.        -290.21606          48.64864           0.00000         73.50000
       1          -289.67944          44.80200          93.64157         73.80000
       2          -289.13745          44.29053          93.45053         73.89999
       3          -288.54297          43.99449          92.93924         73.99998
       4          -287.91943          43.56206          92.64325         74.09998
       5          -287.30054          43.22775          92.21059         74.19997

  THE NET VAPOR ENTERING THE RECTIFYING SECTION IS    91.87637


      STAGE       X(1)             Y(1)

        1        0.9505086        0.9799908
        2        0.9172240        0.9658566
        3        0.8816094        0.9500791
        4        0.8453500        0.9332714
        5        0.8105488        0.9163841

      THE NUMBER OF STAGES IN THE RECTIFYING SECTION      ARE   5
```

```
                STRIPPING SECTION

       STAGE    TEMPERATURE       LIQUID RATE      VAPOR RATE           PRESSURE
                DEGREES F         MOLES/HR.        MOLES/HR.             PSIA

         6      -286.76050        142.61810         91.89395          74.29997
         7      -285.92114        141.05507         91.26672          74.39998
   REB.  8      -283.40308         51.35136         89.70370          74.49998

   THE NET LIQUID ENTERING THE STRIPPING SECTION IS  143.24532

        STAGE     X(1)             Y(1)

         6        0.7813430        0.9015993
         7        0.7365435        0.8777494
   REB.  8        0.6100000        0.8089840

        THE NUMBER OF STAGES IN THE STRIPPING SECTION      ARE  3


        THE TOTAL NUMBER OF STAGES IN TOWER ARE    8


        PASS NUMBER  1 IS COMPLETE
```

```
          REVISED VALUES BASED ON TRUE PRESSURE PROFILE

         BUBBLE POINT FEED
         THE FRACTION FEED VAPORIZED= 0.0000
          XFEED=  0.79000     YFEED=  0.90603     HFEED= 0.22166063E 06     TFEED=-286.99609

  MINIMUM REFLUX =      0.63752          REFLUX RATIO=      0.92487
         THE FRACTION DISTILLATE VAPORIZED= 0.0007
 ---------------------------------------------------------------------------

                 TEMPERATURES---DEGREES FAHRENHEIT
       TOP        BOTTOM       FEED       CONDENSER
    -289.67944  -285.92114  -286.99609  -290.21606
              PRESSURES---PSIA
   PTOP=    73.80000     PBOTTOM=    74.39999
 ---------------------------------------------------------------------------
```

```
                         PASS NUMBER    2

          THE VALUE OF THE REFLUX RATIO=    0.92487

     STAGE      TEMPERATURE       LIQUID RATE      VAPOR RATE           PRESSURE
                DEGREES F         MOLES/HR.        MOLES/HR.             PSIA

     COND.       -290.21606         93.64241          0.00000          73.50000
       1         -289.67944         44.80200         93.64241          73.80000
       2         -289.13745         44.29147         93.45053          73.89999
       3         -288.54297         43.99529         92.94026          73.99998
       4         -287.91943         43.56296         92.64397          74.09998
       5         -287.30054         43.22844         92.21156          74.19997
       6         -286.71509         42.89503         91.87708          74.29996
       7         -286.18848        141.75359         91.54105          74.39995
  REB. 8         -284.36206         51.35136         90.40222          74.49994

      STAGE      X(1)             Y(1)

       1         0.9505086        0.9799908
       2         0.9172240        0.9658566
       3         0.8816091        0.9500788
       4         0.8453496        0.9332709
       5         0.8105480        0.9163832
       6         0.7787664        0.9002675
       7         0.7511820        0.8857015
  REB. 8         0.6568806        0.8313727

  -----PASS NUMBER  2 IS COMPLETE-----------------------------------------------
```

```
     PASS   REFLUX RATIO   BOTTOMS COMP.

        3         0.83239      0.7413213
        4         1.01736      0.5858468
        5         0.95675      0.6324053
        6         0.98648      0.6099548
```

```
        FINAL CONVERGENCE ACHIEVED ON BOTTOMS              COMPOSITION ---TOWER NUMBER 1

                 THE FEED IS INTRODUCED BETWEEN STAGES       6       AND       7

              RLOW=  0.83239      R=  0.98648      RHIGH=  1.01736

     STAGE     TEMPERATURE        PRESSURE        LIQUID RATE       VAPOR RATE       X(COMP.1)        Y(COMP.1)
               DEGREES F          PSIA            MOLES/HR.           MOLES/HR.


     COND.       -290.21606         73.50000          48.64864          0.00000          0.97999          0.99205
       1         -289.67944         73.80000          47.62366         96.63976          0.95051          0.97999
       2         -289.12134         73.89999          47.16379         96.27255          0.91619          0.96541
       3         -288.48999         73.99998          46.78523         95.81218          0.87831          0.94858
       4         -287.81030         74.09998          46.31546         95.43393          0.83878          0.93014
       5         -287.11963         74.19997          45.83182         94.96405          0.80002          0.91112
       6         -286.45801         74.29996          45.46831         94.48053          0.76429          0.89269
       7         -285.85571         74.39995         143.71130         94.11440          0.73298          0.87578
   REB.  8       -283.40210         74.49994          51.35136         92.36002          0.60995          0.80135

                          ENTHALPY BALANCE (BTU/HR.)
    FEED ENTHALPY= 0.22166063E 06          REBOILER DUTY= 0.20419519E 06

                      TOTAL ENTHALPY IN = 0.42585581E 06

  DISTILLATE ENTHALPY = 0.10530550E 06  BOTTOMS ENTHALPY = 0.11661031E 06  CONDENSER DUTY =-0.20394000E 06

                      TOTAL ENTHALPY OUT = 0.425855581E 06

                          TOWER NUMBER 1 IS COMPLETE
```

```
                              COLUMN NUMBER   2-----PROBLEM NUMBER   1


          INPUT DATA USED IN CALCULATIONS
 -----------------------------------------------------------------------

    FEED RATE   XF(1)     XB(1)     DIST.RATE    DIST.SPLIT  ZD(1)
    MOLS/HOUR                       MOLS/HOUR

     51.35136   .609954   .010000    31.43719     0.00000   .990000

   PRESSURE DROP/STAGE=0.1000    CONDENSER PRESSURE DROP=0.3000     REBOILER PRESSURE DROP=0.1000

           FLASHED FEED

           THE FRACTION FEED VAPORIZED= 0.2265

            XFEED=  0.54696      YFEED=  0.82501      HFEED= 0.11659275E 06     TFEED=-310.02368
```

```
                    AIR PLANT---SECOND COLUMN---ABSORBER SECTION

   STAGE     TEMPERATURE     PRESSURE     LIQUID RATE     VAPOR RATE     X(COMP.1)     Y(COMP.1)
             DEGREES F        PSIA        MOLES/HR.        MOLES/HR.

   REB.      -290.58301     20.09999      20.45718       52.29448       0.01000       0.01000
     2       -291.19800     20.00000      72.75166       51.68848       0.01000       0.03935
     3       -292.63672     19.89999      72.14566       50.66336       0.03103       0.11465
     4       -295.69458     19.79999      71.12056       49.54538       0.08455       0.27084
     5       -300.51636     19.69998      70.00256       49.69934       0.19462       0.49053
     6       -305.44775     19.59998      70.15652       50.60252       0.35041       0.68028
     7       -308.74414     19.49997      71.05971       51.45917       0.48731       0.78825
     8       -310.84668     19.39996      32.19836       63.77678       0.59142       0.84946
     9       -312.76953     19.29996      32.88261       64.67992       0.70124       0.90108
    10       -314.36426     19.19995      33.78568       65.23689       0.80401       0.94069
    11       -315.46875     19.09995      34.34291       65.70618       0.88084       0.96611
    12       -316.15894     18.99994      34.81168       65.95792       0.92963       0.98072
    13       -316.57300     18.89993      35.06361       66.23381       0.95736       0.98856
 TOP 14      -316.82959     18.79993      35.33998       66.29770       0.97225       0.99263
```

```
          REVISED VALUES BASED ON TRUE PRESSURE PROFILE


                        TRIAL NUMBER 2
            THE FEED IS INTRODUCED BETWEEN STAGES      7      AND      8


             INPUT DATA USED IN CALCULATIONS
 ----------------------------------------------------------------------------


   FEED RATE   XF(1)     XB(1)     DIST.RATE    DIST.SPLIT  ZD(1)
   MOLS/HOUR                       MOLS/HOUR

    51.35135  .609954   .010000    31.43716     0.00000   .990000

           FLASHED FEED

           THE FRACTION FEED VAPORIZED= 0.2257

            XFEED=  0.54723     YFEED=  0.82519     HFEED= 0.11659819E 06     TFEED=-309.94116
```

```
                       AIR PLANT---SECOND COLUMN---ABSORBER SECTION
   STAGE      TEMPERATURE       PRESSURE       LIQUID RATE       VAPOR RATE       X(COMP.1)        Y(COMP.1)
              DEGREES F          PSIA          MOLES/HR.          MOLES/HR.


    REB.       -290.58301       20.09999        20.45720          52.29445          0.01000          0.01000
      2        -291.19800       20.00000        72.75165          51.68845          0.01000          0.03935
      3        -292.63672       19.89999        72.14565          50.66342          0.03103          0.11465
      4        -295.69458       19.79999        71.12062          49.54532          0.08455          0.27084
      5        -300.51636       19.69998        70.00250          49.69937          0.19462          0.49053
      6        -305.44775       19.59998        70.15657          50.60242          0.35041          0.68028
      7        -308.74414       19.49997        71.05963          51.50163          0.48731          0.78825
      8        -310.84668       19.39996        32.19554          63.77888          0.59142          0.84945
      9        -312.76953       19.29996        32.88477          64.68240          0.70123          0.90107
     10        -314.36401       19.19995        33.78828          65.23833          0.80400          0.94069
     11        -315.46875       19.09995        34.34425          65.70795          0.88083          0.96611
     12        -316.15894       18.99994        34.81401          65.95979          0.92963          0.98071
     13        -316.57300       18.89993        35.06610          66.23701          0.95736          0.98856
  TOP 14       -316.82959       18.79993        35.34268          66.30185          0.97224          0.99263

                 PRESSURE VARIATIONS HAVE BEEN DAMPED
```

```
TRIAL     OVERHEAD FEED     OVERHEAD FEED     CONDENSER DUTY(1)     REBOILER DUTY(2)
             REQUIRED           ACTUAL

  2        35.0025780        35.4087520           0.2039400E 06        0.2039400E 06
```

```
                THE SECOND TOWER IS INDEPENDENTLY CLOSED

               THE FEED IS INTRODUCED BETWEEN STAGES      7      AND      8

   STAGE     TEMPERATURE         PRESSURE      LIQUID RATE      VAPOR RATE      X(COMP.1)       Y(COMP.1)
             DEGREES F            PSIA         MOLES/HR.         MOLES/HR.

   REB.       -290.58301         20.09999       20.45720        52.29445        0.01000         0.01000
     2        -291.19800         20.00000       72.75165        51.68845        0.01000         0.03935
     3        -292.63672         19.89999       72.14565        50.66342        0.03103         0.11465
     4        -295.69458         19.79999       71.12062        49.54532        0.08455         0.27084
     5        -300.51636         19.69998       70.00250        49.69937        0.19462         0.49053
     6        -305.44775         19.59998       70.15657        50.60242        0.35041         0.68028
     7        -308.74414         19.49997       71.05963        51.50163        0.48731         0.78825
     8        -310.84668         19.39996       32.19554        63.77888        0.59142         0.84945
     9        -312.76953         19.29996       32.88477        64.68240        0.70123         0.90107
    10        -314.36401         19.19995       33.78828        65.23833        0.80400         0.94069
    11        -315.46875         19.09995       34.34425        65.70795        0.88083         0.96611
    12        -316.15894         18.99994       34.81401        65.95979        0.92963         0.98071
    13        -316.57300         18.89993       35.06610        66.23701        0.95736         0.98856
 TOP 14       -316.82959         18.79993       35.34268        66.30185        0.97224         0.99263
 --------------------------ENTHALPY BALANCE (BTU/HR.)----------------------

 FEED ENTHALPY= 0.11661031E 06     REBOILER DUTY= 0.20394000E 06     REFLUX ENTHALPY= 0.50928340E 05

                     TOTAL ENTHALPY IN = 0.37147863E 06

   BOTTOMS ENTHALPY 0.10508919E 06          TOP PRODUCT ENTHALPY 0.26658419E 06

                     TOTAL ENTHALPY OUT = 0.37167338E 06
 --------------------------------------------------------------------------

                        TOWER NUMBER TWO IS COMPLETE
```

```
                    FINAL CONVERGENCE HAS BEEN ACHIEVED FOR BOTH TOWERS



**FORTRAN ** STOP

03RT  00:16:56
```

B. Example No. 2 - Single Fractional Distillation Column

The purpose of this example is to illustrate the use of the model in designing a single fractional distillation column to separate a binary mixture (benzene-toluene). Both this example and example three are bonus calculations since their solution results as a byproduct of the method used to calculate the Linde "Double Column" solution. The input data is as follows:

(1) Select system options

  (a) Tower type code = 1
  A single column is specified.
  (b) Feed thermal code = 3
  A bubble point feed was arbitrarily chosen. All other feed conditions have been tried and verified in separate runs.
  (c) Distillate thermal code = 3
  Same as for feed above.

(2) Tower parameters

  (a) Feed rate = 100 lb-moles/hour
  (b) Feed composition,light key = 0.50
  (c) Reflux factor = 1.5
  The value is usually between 1 and 10.

(d) Pressure drops--stage=0.1 psi., condenser=0.3 psi., reboiler=0.1 psi. Same values as in example number 1.

(e) Equilibrium reference pressure=14.7 psia.

(f) Tolerances = 10^{-6} and 10^{-4} Same values as in example number 1.

(g) Initial temperature and pressure estimates

	TOP	BOTTOM
T, °F.	190.0	220.0
P, psia.	14.7	16.9

(h) Product purities, light key: overhead =0.98 : bottoms = 0.10

(3) Basic data

(a) Enthalpy data

Enthalpy data [5] at 176°F. and 230.72°F. were supplied to the model in the same order as in example number 1.

(b) Equilibrium data

Vapor-liquid equilibrium data calculated from vapor pressure data[6] were entered at 176°F. and 230.72°F in the same order as in example number 1.

---

[5] Maxwell, J.B., Data Book on Hydrocarbons, First Edition, Princeton, N.J., D. Van Nostrand Company, 1958.

[6] Perry, J.H., Chemical Engineers' Handbook, Fourth Edition New York: Mc Graw-Hill Book Co., 1963, Table 13-1.

The results of the calculation are that the number of stages equals 12 plus a condenser and a reboiler. The feed enters between stages 8 and 9, and the condenser and reboiler duties are approximately 1,880,000 Btu/hour each. The reflux ratio is 2.07455 (see attached printout). As before, <u>DISTL</u> was used to check the solution with favorable results.

```
                                  _COLUMN_NUMBER___1-----PROBLEM NUMBER   2

   -------------TOTAL_CONDENSER===ALL_LIQUID_DISTILLATE---------------------------

                     INPUT DATA USED IN CALCULATIONS
   -------------------------------------------------------------------------------

       FEED RATE   XF(1)    XB(1)    DIST.RATE   DIST.SPLIT  ZD(1)
       MOLS/HOUR                     MOLS/HOUR

       100.00000  .500000  .100000    45.45451     0.00000  .980000

      PRESSURE DROP/STAGE=0.1000    CONDENSER PRESSURE DROP=0.3000    REBOILER PRESSURE DROP=0.1000

   ---------------------------------*****CONSTANTS*****-----TOWER_NUMBER_1-------
      EQUILIBRIUM               PRESSURE               ENTHALPY-LIQUID      ENTHALPY-VAPOR

   A1       13.20149           14.70000          -14482.75300           7871.65620

   B1    -6686.67960           14.70000              39.96346             25.69080

   A2       13.49274           14.70000          -17539.39400           7759.37500

   B2    -7463.15620           14.70000              47.12720             31.83479
   -------------------------------------------------------------------------------
```

```
              BUBBLE POINT FEED

              THE FRACTION FEED VAPORIZED=-0.0000

               XFEED=  0.50000      YFEED=  0.70703      HFEED= 0.12832080E 07     TFEED= 202.37442


    MINIMUM REFLUX =      1.31846          REFLUX RATIO=       1.97769

              THE FRACTION DISTILLATE VAPORIZED= 0.0001
  ----------------------------------------------------------------------------------------------------


                          TEMPERATURES---DEGREES FAHRENHEIT

           TOP         BOTTOM        FEED         CONDENSER

        190.00000   220.00000   202.37442   175.49054

                      PRESSURES---PSIA

      PTOP=     14.70000      PBOTTOM=     16.89999

  ----------------------------------------------------------------------------------------------------
```

```
     FIRST PASS---DETERMINATION OF NUMBER OF STAGES

               RECTIFYING SECTION

    STAGE      TEMPERATURE       LIQUID RATE      VAPOR RATE           PRESSURE
               DEGREES F         MOLES/HR.        MOLES/HR.             PSIA


    COND.        175.49054          45.45451           0.00000         14.40000
      1          177.82257          89.55740         135.34966         14.70000
      2          179.92676          88.63678         135.01279         14.80000
      3          182.79744          87.52528         134.09134         14.90000
      4          186.45186          86.22510         132.98007         15.00000
      5          190.64641          85.15283         131.67961         15.10000
      6          194.91656          84.03835         130.60725         15.20000
      7          198.75598          83.38620         129.49283         15.30000

 THE NET VAPOR ENTERING THE RECTIFYING SECTION IS  128.84074


     STAGE      X(1)               Y(1)

       1        0.9509960          0.9799982
       2        0.9068618          0.9607602
       3        0.8449672          0.9316537
       4        0.7671662          0.8911228
       5        0.6815289          0.8406337
       6        0.5994257          0.7854034
       7        0.5305905          0.7330140

     THE NUMBER OF STAGES IN THE RECTIFYING SECTION     ARE  7
```

```
              STRIPPING SECTION

       STAGE     TEMPERATURE       LIQUID RATE       VAPOR RATE             PRESSURE
                 DEGREES F         MOLES/HR.         MOLES/HR.               PSIA


          8        205.98503         183.67444         129.63266           16.49995
          9        209.11475         182.78584         129.12891           16.59996
         10        213.47939         181.71730         128.24037           16.69997
         11        218.99167         180.93781         127.17192           16.79997
         12        225.09351         179.84297         126.39232           16.89998
   REB.  13        232.23511          54.54549         125.29747           16.99998

   THE NET LIQUID ENTERING THE STRIPPING SECTION IS  184.17822


        STAGE      X(1)              Y(1)

          8        0.4840097         0.6922545
          9        0.4337068         0.6462196
         10        0.3642951         0.5756449
         11        0.2805433         0.4776542
         12        0.1940030         0.3584580
   REB.  13        0.1000000         0.2349251

        THE NUMBER OF STAGES IN THE STRIPPING SECTION        ARE   6


        THE TOTAL NUMBER OF STAGES IN TOWER ARE    13


        PASS NUMBER  1 IS COMPLETE
```

```
              REVISED VALUES BASED ON TRUE PRESSURE PROFILE

             BUBBLE POINT FEED

             THE FRACTION FEED VAPORIZED=-0.0000

              XFEED=  0.50000    YFEED=  0.70786    HFEED= 0.12734510E 07    TFEED= 200.13374


   MINIMUM REFLUX =      1.30928          REFLUX RATIO=     1.96392

             THE FRACTION DISTILLATE VAPORIZED= 0.0001
  ------------------------------------------------------------------------------


                      TEMPERATURES---DEGREES FAHRENHEIT

         TOP        BOTTOM      FEED        CONDENSER

       177.82257  225.09351  200.13374  175.49057

                  PRESSURES---PSIA

     PTOP=    14.70000     PBOTTOM=    15.80000

  ------------------------------------------------------------------------------
```

```
                         PASS NUMBER   2

          THE VALUE OF THE REFLUX RATIO=    1.96392

     STAGE      TEMPERATURE       LIQUID RATE       VAPOR RATE           PRESSURE
                DEGREES F         MOLES/HR.         MOLES/HR.              PSIA

     COND.        175.49057        134.72343          0.00000          14.40000
       1          177.82260         89.00259        134.72343          14.70000
       2          179.92345         88.10017        134.45793          14.80000
       3          182.78441         87.00748        133.55486          14.90000
       4          186.42134         85.69516        132.46196          15.00000
       5          190.59105         84.61742        131.14963          15.10000
       6          194.83398         83.51653        130.07191          15.20000
       7          198.65125         82.86130        128.97098          15.30000
       8          201.76521         82.42809        128.31586          15.40000
       9          204.13220        181.83028        127.88359          15.50000
      10          208.28995        180.56090        127.28484          15.59999
      11          213.65233        179.56866        126.01543          15.69999
      12          219.74643        179.25330        125.02295          15.79999
  REB. 13         225.72311         54.54549        124.70741          15.89999

      STAGE      X(1)              Y(1)

       1         0.9509960         0.9799982
       2         0.9069512         0.9608005
       3         0.8452916         0.9318123
       4         0.7678801         0.8915163
       5         0.6827453         0.8413970
       6         0.6011286         0.7866223
       7         0.5326386         0.7346573
       8         0.4808152         0.6911110
       9         0.4446200         0.6582447
      10         0.3782091         0.5922993
      11         0.2959069         0.4986304
      12         0.2083721         0.3813768
  REB. 13        0.1290751         0.2557716

      PASS NUMBER  2 IS COMPLETE
```

```
    PASS   REFLUX RATIO   BOTTOMS COMP.

       3        1.76753      0.2336791
       4        2.16031      0.0828395
       5        2.03977      0.1079320
       6        2.08895      0.0959463
       7        2.06834      0.1012725
       8        2.07596      0.0989923
       9        2.07237      0.1004747
      10        2.07384      0.1002142
      11        2.07455      0.1000913
```

```
          FINAL CONVERGENCE ACHIEVED ON BOTTOMS              COMPOSITION ---TOWER NUMBER 1

                THE FEED IS INTRODUCED BETWEEN STAGES       8      AND       9

              RLOW=  1.76753      R=  2.07455      RHIGH=  2.16031

     STAGE     TEMPERATURE        PRESSURE       LIQUID RATE     VAPOR RATE      X(COMP.1)       Y(COMP.1)
               DEGREES F           PSIA          MOLES/HR.        MOLES/HR.

     COND.      175.49057        14.40000        45.45451         0.00000        0.98000         0.99202
       1        177.82260        14.70000        93.95271       139.75229        0.95100         0.98000
       2        179.95355        14.80000        93.04195       139.40825        0.90618         0.96045
       3        182.90051        14.90000        91.75182       138.49698        0.84243         0.93041
       4        186.69380        15.00000        90.48480       137.20638        0.76153         0.88800
       5        191.08351        15.10000        89.08070       135.93921        0.67197         0.83458
       6        195.54637        15.20000        87.91554       134.53520        0.58650         0.77604
       7        199.54027        15.30000        87.09859       133.37007        0.51535         0.72061
       8        202.75594        15.40000        86.58336       132.55310        0.46235         0.67469
       9        205.16382        15.50000       185.84456       132.03882        0.42597         0.64055
      10        209.97350        15.59999       184.81569       131.29907        0.34957         0.56138
      11        215.87860        15.69999       183.94048       130.26993        0.26079         0.45406
      12        222.15012        15.79999       183.45955       129.39510        0.17340         0.32857
   REB. 13      227.86775        15.89999        54.54549       128.91383        0.10009         0.20446

                             ENTHALPY BALANCE (BTU/HR.)
    FEED ENTHALPY= 0.12734510E 07          REBOILER DUTY= 0.18966280E 07

                    TOTAL ENTHALPY IN = 0.31700790E 07

  DISTILLATE ENTHALPY = 0.49743413E 06  BOTTOMS ENTHALPY = 0.80130600E 06  CONDENSER DUTY =-0.18713390E 07

                    TOTAL ENTHALPY OUT = 0.31700790E 07

                         TOWER NUMBER 1 IS COMPLETE
```

C. Example No. 3 - Dual Distillation Column Complex

The purpose of this example is to illustrate the additional feature of the model to solve multiple column arrangements. Benzene and toluene are again separated, but the first column light component purities are set at 0.80 distillate and 0.20 bottoms. The second column, which uses the distillate of the first column as its feed stream, duplicates the separation obtained in example number 2, i.e. 0.98 distillate and 0.10 bottoms (light key composition). The data for the first column of the complex is the same as in example number 2 except that the operating pressure of the column is 5 psi. higher, and a dew point distillate is specified. The higher operating pressure is necessary for this column so that a pressure inversion at the feed inlet to the second tower is avoided. The input data to the second column follows the data for the first column but deletes the type and feed thermal codes since the former need be set only once, and the latter is calculated by the program. The distillate code for the second tower was set for a dew point distillate, and all the subsequent data matches the data supplied for example number 2. The results of the calculation appear on the next page.

	TOWER 1	TOWER 2
Stages*	5	10
Reflux Ratio	0.77999	1.07018
Condenser Duty (Btu/hr.)	547,018	575,062
Reboiler Duty (Btu/hr.)	1,224,696	1,120,673

* Excluding the condenser and reboiler

Please see the attached printout for further information. Both columns were checked using DISTL, with favorable results.

```
                              COLUMN NUMBER   1-----PROBLEM NUMBER  3

  -------------PARTIAL CONDENSER===ALL VAPOR DISTILLATE.-------------------------

                    INPUT DATA USED IN CALCULATIONS
  -------------------------------------------------------------------------------

      FEED RATE   XF(1)    XB(1)    DIST.RATE   DIST.SPLIT  ZD(1)
      MOLS/HOUR                     MOLS/HOUR

      100.00000  .500000  .200000   49.99998     1.00000  .800000

     PRESSURE DROP/STAGE=0.1000    CONDENSER PRESSURE DROP=0.3000    REBOILER PRESSURE DROP=0.1000

  ------------------------------*****CONSTANTS*****-----TOWER NUMBER 1-------
     EQUILIBRIUM              PRESSURE              ENTHALPY-LIQUID       ENTHALPY-VAPOR
  A1      13.20149            14.70000           -14482.75300           7871.65620
  B1   -6686.67960            14.70000               39.96346             25.69080
  A2      13.49274            14.70000           -17539.39400           7759.37500
  B2   -7463.15620            14.70000               47.12720             31.83479
  -------------------------------------------------------------------------------
```

```
            BUBBLE POINT FEED

            THE FRACTION FEED VAPORIZED= 0.0000

             XFEED=  0.50000     YFEED=  0.70170     HFEED= 0.13476670E 07     TFEED= 217.17380


   MINIMUM REFLUX =      0.48737          REFLUX RATIO=      0.73106
            THE FRACTION DISTILLATE VAPORIZED= 1.0000
  ---------------------------------------------------------------------------

                    TEMPERATURES---DEGREES FAHRENHEIT

        TOP          BOTTOM       FEED        CONDENSER

      190.00000   220.00000   217.17380   209.21852
               PRESSURES---PSIA

     PTOP=    19.70000     PBOTTOM=    20.00000

  ---------------------------------------------------------------------------
```

```
     FIRST PASS---DETERMINATION OF NUMBER OF STAGES

                  RECTIFYING SECTION

    STAGE         TEMPERATURE      LIQUID RATE      VAPOR RATE             PRESSURE
                  DEGREES F        MOLES/HR.        MOLES/HR.                PSIA

    COND.           209.21852          0.00000        49.99998             19.39999
      1             215.09871         36.02991        86.55287             19.70000

 THE NET VAPOR ENTERING THE RECTIFYING SECTION IS    86.02997

     STAGE       X(1)             Y(1)

       1       0.5297618        0.7267326

     THE NUMBER OF STAGES IN THE RECTIFYING SECTION      ARE   1
```

```
          STRIPPING SECTION

     STAGE    TEMPERATURE     LIQUID RATE     VAPOR RATE          PRESSURE
              DEGREES F       MOLES/HR.       MOLES/HR.            PSIA


          2     217.21938      135.63994        85.94817         19.69997
          3     219.62123      135.22533        85.63994         19.79997
          4     223.38692      134.55545        85.22531         19.89998
          5     228.85904      133.73505        84.55545         19.99998
   REB.   6     236.19579       50.00002        83.73503         20.09999

   THE NET LIQUID ENTERING THE STRIPPING SECTION IS  135.94818


      STAGE     X(1)            Y(1)

          2   0.4897830       0.6930556
          3   0.4520080       0.6589699
          4   0.3917152       0.5998561
          5   0.3066942       0.5050818
   REB.   6   0.2000000       0.3704036

      THE NUMBER OF STAGES IN THE STRIPPING SECTION      ARE  5


      THE TOTAL NUMBER OF STAGES IN TOWER ARE    6


      PASS NUMBER  1 IS COMPLETE
```

```
             REVISED VALUES BASED ON TRUE PRESSURE PROFILE

            BUBBLE POINT FEED

            THE FRACTION FEED VAPORIZED=-0.0000

             XFEED=  0.50000     YFEED=  0.70146     HFEED= 0.13505580E 07     TFEED= 217.83864


   MINIMUM REFLUX =      0.48911          REFLUX RATIO=      0.73366

            THE FRACTION DISTILLATE VAPORIZED= 1.0000
  ----------------------------------------------------------------------------


                    TEMPERATURES---DEGREES FAHRENHEIT

        TOP         BOTTOM        FEED         CONDENSER

      215.09871   228.85904   217.83864   209.21852

                PRESSURES---PSIA

     PTOP=    19.70000     PBOTTOM=    20.09999

  ----------------------------------------------------------------------------
```

```
                         PASS NUMBER   2

          THE VALUE OF THE REFLUX RATIO=   0.73366

     STAGE      TEMPERATURE     LIQUID RATE      VAPOR RATE           PRESSURE
                DEGREES F       MOLES/HR.        MOLES/HR.             PSIA

     COND.        209.21852        86.68300        49.99998          19.39999
       1          215.10840        36.30380        86.68300          19.70000
       2          217.96738        36.16454        86.30386          19.79999
       3          219.49060       135.49129        86.16489          19.89998
       4          222.98116       134.59044        85.49135          19.99997
       5          228.12146       133.80042        84.59035          20.09996
  REB. 6          234.87349        50.00002        83.80057          20.19995

      STAGE     X(1)             Y(1)

       1        0.5295762        0.7265821
       2        0.4821521        0.6862466
       3        0.4604177        0.6665953
       4        0.4044735        0.6127251
       5        0.3239396        0.5253351
  REB. 6        0.2243565        0.3978894

  -----PASS NUMBER  2 IS COMPLETE------------------------------------------------
```

```
PASS   REFLUX RATIO   BOTTOMS COMP.

   3        0.66030      0.2834946
   4        0.80703      0.1840401
   5        0.75857      0.2088265
   6        0.77931      0.1975552
   7        0.77188      0.2018718
   8        0.77535      0.2003850
   9        0.77661      0.1999303
```

```
         FINAL CONVERGENCE ACHIEVED ON BOTTOMS            COMPOSITION ---TOWER NUMBER 1

                   THE FEED IS INTRODUCED BETWEEN STAGES       2      AND      3

                RLOW=  0.66030      R=  0.77661      RHIGH=  0.80703

     STAGE      TEMPERATURE         PRESSURE       LIQUID RATE      VAPOR RATE       X(COMP.1)         Y(COMP.1)
                DEGREES F            PSIA          MOLES/HR.         MOLES/HR.


     COND.        209.21852          19.39999          0.00000         49.99998          0.62651           0.80000
       1          215.26318          19.70000         38.41827         88.83038          0.52662           0.72416
       2          218.27600          19.79999         38.10402         88.41820          0.47647           0.68121
       3          219.88206          19.89998        137.37163         88.10423          0.45334           0.66008
       4          223.80052          19.99997        136.54755         87.37155          0.39036           0.59832
       5          229.43332          20.09996        135.82042         86.54761          0.30287           0.50033
  REB.   6        236.53537          20.19995         50.00002         85.82036          0.19993           0.36281

                             ENTHALPY BALANCE (BTU/HR.)
    FEED ENTHALPY= 0.13505580E 07          REBOILER DUTY= 0.12322970E 07

                       TOTAL ENTHALPY IN = 0.25828550E 07

  DISTILLATE ENTHALPY = 0.12932130E 07  BOTTOMS ENTHALPY = 0.74499275E 06  CONDENSER DUTY =-0.54465000E 06

                       TOTAL ENTHALPY OUT = 0.25828550E 07

                           TOWER NUMBER 1 IS COMPLETE
```

```
                                  COLUMN NUMBER   2-----PROBLEM NUMBER  3

                              DOUBLE COLUMN---DISTILLATE(1)=FEED(2)

    -------------PARTIAL CONDENSER===ALL VAPOR DISTILLATE.-------------------------

    ------------------------------*****CONSTANTS*****-----TOWER NUMBER 2-------

       EQUILIBRIUM               PRESSURE               ENTHALPY-LIQUID       ENTHALPY-VAPOR

    A1       13.20149            14.70000            -14482.75300          7871.65620

    B1    -6686.67960            14.70000                39.96346            25.69080

    A2       13.49274            14.70000            -17539.39400          7759.37500

    B2    -7463.15620            14.70000                47.12720            31.83479
    -------------------------------------------------------------------------------
```

```
                    INPUT DATA USED IN CALCULATIONS
 --------------------------------------------------------------------------------

     FEED RATE   XF(1)    XB(1)    DIST.RATE   DIST.SPLIT  ZD(1)
     MOLS/HOUR                     MOLS/HOUR

      50.00000  .800000  .100000    39.77271     1.00000  .980000

    PRESSURE DROP/STAGE=0.1000     CONDENSER PRESSURE DROP=0.3000     REBOILER PRESSURE DROP=0.1000

             SUBCOOLED FEED

             THE FRACTION FEED VAPORIZED= 0.0000

              XFEED=  0.80000     YFEED=  0.90828     HFEED= 0.57080150E 06     TFEED= 180.39543


  MINIMUM REFLUX =      0.66237          REFLUX RATIO=      0.99356

             THE FRACTION DISTILLATE VAPORIZED= 1.0000
 --------------------------------------------------------------------------------


                       TEMPERATURES---DEGREES FAHRENHEIT

        TOP          BOTTOM       FEED         CONDENSER

     190.00000   220.00000   180.39543   176.57759

                 PRESSURES---PSIA

    PTOP=    14.70000      PBOTTOM=     16.89999

 --------------------------------------------------------------------------------
```

```
     FIRST PASS---DETERMINATION OF NUMBER OF STAGES

              RECTIFYING SECTION

    STAGE     TEMPERATURE     LIQUID RATE     VAPOR RATE          PRESSURE
              DEGREES F       MOLES/HR.       MOLES/HR.            PSIA

    COND.       176.57759         0.00000        39.77271        14.40000
      1         179.10501        39.36841        79.28918        14.70000
      2         180.94701        39.08357        79.14143        14.80000
      3         182.86255        38.65633        78.85622        14.90000
      4         184.75107        38.34421        78.42892        15.00000

THE NET VAPOR ENTERING THE RECTIFYING SECTION IS   78.11685

     STAGE     X(1)            Y(1)

      1        0.9174139       0.9654914
      2        0.8808656       0.9488668
      3        0.8433629       0.9308660
      4        0.8074348       0.9126540

     THE NUMBER OF STAGES IN THE RECTIFYING SECTION     ARE   4
```

```
              STRIPPING SECTION

      STAGE       TEMPERATURE        LIQUID RATE        VAPOR RATE             PRESSURE
                  DEGREES F          MOLES/HR,          MOLES/HR.               PSIA


        5           191.35066          89.39986           79.59860          16.39995
        6           193.88474          88.63200           79.17258          16.49995
        7           198.27934          87.52306           78.40471          16.59996
        8           205.18433          86.09061           77.29576          16.69997
        9           214.18745          84.96010           75.86333          16.79997
       10           223.42778          84.14328           74.73280          16.89998
   REB. 11          232.23511          10.22729           73.91599          16.99998

   THE NET LIQUID ENTERING THE STRIPPING SECTION IS   89.82590


       STAGE       X(1)              Y(1)

        5         0.7824071         0.8984956
        6         0.7329554         0.8705586
        7         0.6451916         0.8155196
        8         0.5137916         0.7173279
        9         0.3588517         0.5695757
       10         0.2185255         0.3942760
   REB. 11        0.1000000         0.2349251

       THE NUMBER OF STAGES IN THE STRIPPING SECTION      ARE  7



       THE TOTAL NUMBER OF STAGES IN TOWER ARE    11



       PASS NUMBER  1 IS COMPLETE
```

```
          REVISED VALUES BASED ON TRUE PRESSURE PROFILE

         SUBCOOLED FEED

         THE FRACTION FEED VAPORIZED= 0.0000

          XFEED=  0.80000     YFEED=  0.90778     HFEED= 0.57080156E 06     TFEED= 180.39543


  MINIMUM REFLUX =     0.67013          REFLUX RATIO=     1.00519

         THE FRACTION DISTILLATE VAPORIZED= 1.0000
 -----------------------------------------------------------------------------

                    TEMPERATURES---DEGREES FAHRENHEIT

       TOP       BOTTOM      FEED       CONDENSER

    179.10501  223.42778  180.39543  176.57747

              PRESSURES---PSIA

   PTOP=    14.70000     PBOTTOM=    15.60000
 -----------------------------------------------------------------------------
```

```
                              PASS NUMBER    2

            THE VALUE OF THE REFLUX RATIO=    1.00519

      STAGE       TEMPERATURE      LIQUID RATE      VAPOR RATE          PRESSURE
                  DEGREES F        MOLES/HR.        MOLES/HR.            PSIA

      COND.         176.57747        79.75182         39.77271          14.40000
        1           179.11238        39.78780         79.75182          14.70000
        2           180.96912        39.46754         79.56053          14.80000
        3           182.90559        39.06155         79.24034          14.90000
        4           184.82182        38.75809         78.83434          15.00000
        5           186.63271        38.52681         78.53072          15.10000
        6           188.27635        88.59364         78.29874          15.20000
        7           192.36449        87.47702         78.36627          15.30000
        8           198.94359        86.14452         77.24968          15.40000
        9           207.82092        84.77040         75.91710          15.50000
       10           217.24182        84.10313         74.54292          15.59999
   REB. 11          225.07204        10.22729         73.87541          15.69999

       STAGE       X(1)             Y(1)

         1        0.9172238        0.9654067
         2        0.8803047        0.9486059
         3        0.8423044        0.9303444
         4        0.8057379        0.9117733
         5        0.7725309        0.8939947
         6        0.7438999        0.8779156
         7        0.6619615        0.8279324
         8        0.5349498        0.7363611
         9        0.3792302        0.5935447
        10        0.2335880        0.4175403
   REB. 11        0.1267819        0.2520816

  -----PASS NUMBER  2 IS COMPLETE------------------------------------------
```

```
PASS   REFLUX RATIO   BOTTOMS COMP.

  3      0.90467      0.2018217
  4      1.10571      0.0892121
  5      1.04582      0.1088366
  6      1.07427      0.0988522
  7      1.06552      0.1014912
  8      1.07018      0.0999271
```

```
      FINAL CONVERGENCE ACHIEVED ON BOTTOMS          COMPOSITION ---TOWER NUMBER 2

              THE FEED IS INTRODUCED BETWEEN STAGES      5     AND      6

            RLOW=  0.90467      R=  1.07018      RHIGH=  1.10571

    STAGE     TEMPERATURE        PRESSURE       LIQUID RATE      VAPOR RATE       X(COMP.1)        Y(COMP.1)
              DEGREES F           PSIA          MOLES/HR.         MOLES/HR.

    COND.       176.57747        14.40000          0.00000         39.77271         0.95089          0.98000
      1         179.15225        14.70000         42.37041         82.33676         0.91619          0.96495
      2         181.09787        14.80000         42.04416         82.14288         0.87706          0.94709
      3         183.17255        14.90000         41.64676         81.81699         0.83575          0.92710
      4         185.26540        15.00000         41.22600         81.41951         0.79514          0.90622
      5         187.26007        15.10000         40.96257         80.99861         0.75791          0.88591
      6         189.07933        15.20000         90.83267         80.73448         0.72560          0.86732
      7         193.97829        15.30000         89.72934         80.60529         0.62753          0.80498
      8         201.50391        15.40000         88.24966         79.50211         0.48573          0.69539
      9         210.90388        15.50000         87.02844         78.02222         0.32724          0.53629
     10         220.03810        15.59999         86.52809         76.80130         0.19204          0.35750
  REB. 11       227.06107        15.69999         10.22729         76.30081         0.09993          0.20438

                     ENTHALPY BALANCE (BTU/HR.)
    FEED ENTHALPY= 0.57080156E 06          REBOILER DUTY= 0.11206730E 07

                 TOTAL ENTHALPY IN = 0.16914740E 07

  DISTILLATE ENTHALPY = 0.96654863E 06  BOTTOMS ENTHALPY = 0.14986531E 06  CONDENSER DUTY =-0.57506200E 06

                 TOTAL ENTHALPY OUT = 0.16914750E 07

                    TOWER NUMBER 2 IS COMPLETE
```

APPENDIX A

INPUT DATA SHEET

Card No.	Input	Column No.
1.	Tower Configuration code(integer) 1- Single column 2- Two columns-bottoms(1)= feed(2) 3- Two columns-distillate(1)= feed(2) 4- Linde "Double Column".	2
2.	Feed thermal code(integer) 0- Superheated feed 1- Dew point feed 2- Flashed feed 3- Bubble point feed 4- Subcooled feed	2
3.	Distillate thermal code (integer) 1- All vapor distillate 2- Liquid-vapor distillate 3- All liquid distillate 4- Subcooled distillate	2
4.	Fraction vapor distillate (optional) Value between (0-1)--input only when distillate code=2.	1-12

Card No.	Input	Column No.
5.	A. Feed rate,lb-moles/hr.	1-12
	B. Feed composition, mole frac.	13-24
6.	Reflux factor Rfactor= Ractual/Rmin	1-12
7.	Pressure drops, psi.	
	A. Stage pressure drop	1-12
	B. Condenser pressure drop	13-24
	C. Reboiler pressure drop	25-36
8.	Equilibrium reference pressure	1-12
9.	Tolerances	
	A. Bubble-dew point component summations	1-12
	B. Overall bottoms composition	13-24
10.	Initial temperature and pressure estimates	
	A. Temperature (top), °F.	1-12
	B. Pressure (top), psia	13-24
	C. Temperature (bottom), °F.	25-36
	D. Pressure (bottom), psia	37-48

Card No.	Input	Column No.
11.	Product purities, light component	
	A. Distillate composition	1-12
	B. Bottoms composition	13-24
12.	Enthalpy data (temperature 1), Btu/lb-mole	
	A. Temperature (1), °F.	1-12
	B. Liquid enthalpy-comp.(1)	13-24
	C. Liquid enthalpy-comp.(2)	25-36
	D. Vapor enthalpy-comp.(1)	37-48
	E. Vapor enthalpy-comp.(2)	49-56
13.	Enthalpy data (temperature 2), Btu/lb-mole	
	A. Temperature (2), °F.	1-12
	B. Liquid enthalpy-comp.(1)	13-24
	C. Liquid enthalpy-comp.(2)	25-36
	D. Vapor enthalpy- comp.(1)	37-48
	E. Vapor enthalpy-comp.(2)	49-56

Card No.	Input	Column No.
14.	Vapor-liquid equilibrium data (temperature 1)	
	A. Temperature (1),°F.	1-12
	B. Equilibrium constant-comp.1	13-24
	C. Equilibrium constant-comp.2	25-36
15.	Vapor-liquid equilibrium data (temperature 2)	
	A. Temperature (2),°F.	1-12
	B. Equilibrium constant-comp.1	13-24
	C. Equilibrium constant-comp.2	25-36
16.	Feed temperature,°F. (optional) Required with a flashed, subcooled or superheated feed.	1-12
17.	Distillate drum temperature,°F. (optional) Required with a subcooled distillate.	1-12

* This completes the data for tower configuration code (1). For a code of (2) or (3), the data for the second tower follows card number 17, beginning with the distillate thermal code card, and the feed rate,feed composition card is deleted. All other cards follow in the order outlined above. For a Linde "Double Column", the absorber data begins with the pressure drop card (card 7), deleting cards 1 to 6.

APPENDIX B

```
// JOB CC305/0018,SOREL,3000,50000,J.A.BAZAN
// PARAM LIST=YES,DEBUG=YES,MAP=NO
// FORTRN
      PROGRAM SOREL
      COMMON FPVAP
      COMMON A(2),B(2),PCON(2),FRATE,RFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      COMMON /TOLTOL/TOL,TOLH,TOLQA
      COMMON/VARBLS/ X(100),Y(100),T(100),RATEL(100),RATEV(100)
      COMMON/VARBLS/ P(100)
      COMMON/CONREP/ BL,DV,XD,YD,QC,QR,DISTH,BOTTH,XB1,XF1,TFEED
      COMMON/CONREP/ TCOND,XFEED,YFEED,HFEED,VV,BUT
      COMMON/PRSSR/ CONDPD,REBPD,CORECT
      DIMENSION HL(2,2),EK(2,2),TEMP(2),TEQ(2),HV(2,2)
      DIMENSION S(2,30)
C------------------------------------------------------------------------
C     INPUT SECTION
      READ 529,NPROB
C     NPROB IS THE NUMBER OF PROBLEMS TO BE SOLVED.
      IPROB=1
1605  IPRESS=1
      IND=0
      INDEX=0
      ITOWER=1
      ITRY=0
      IDBL=0
      ICONV=0
      READ 529,ITCODE
      READ 529,IFCODE
3175  READ 529,IDCODE
      IF(ITOWER.EQ.2) GO TO 900
      PRINT 400
      PRINT 566,ITOWER,IPROB
      PRINT 567
900   CONTINUE
C     IDCODE IS A DISTILLATE CODE.
C             IDCODE=1 FOR AN ALL VAPOR DISTILLATE
C             IDCODE=2 FOR A LIQUID-VAPOR  DISTILLATE
C             IDCODE=3 FOR AN ALL LIQUID DISTILLATE
C             IDCODE= 4 FOR A SUBCOOLED LIQUID DISTILLATE
C------------------------------------------------------------------------
C     IFCODE IS A FEED CODE
C             IFCODE=0 FOR A SUPERHEATED FEED
C             IFCODE=1 FOR A DEW POINT FEED
C             IFCODE=2 FOR A FLASHED FEED
C             IFCODE=3 FOR A BUBBLE POINT FEED
C             IFCODE=4 FOR A SUBCOOLED FEED
C------------------------------------------------------------------------
C     ITCODE IS A TYPE CODE
C          ITCODE= 1 FOR A SINGLE COLUMN---SOLVED BY SOREL
C          ITCODE=2 FOR A NORMAL DOUBLE COLUMN-B(1)=F(2)
C          ITCODE=3 FOR A NORMAL DOUBLE COLUMN-D(1)=F(2)
C          ITCODE=4 FOR LINDE"DOUBLE COLUMN"-D(1)=REFLUX(2)
C------------------------------------------------------------------------
      GO TO (301,302,303,304),IDCODE
301   PRINT 531
      PRINT 800
      DSPLIT=1.0
      GO TO 305
```

```
302   PRINT 532
      PRINT 800
      READ 530,DSPLIT
C     DSPLIT=DV/DIST=FRACTION VAPOR DISTILLATE
      GO TO 305
303   PRINT 533
      PRINT 800
      DSPLIT=0.0
      GO TO 305
304   PRINT 534
      PRINT 800
      DSPLIT=0.0
      GO TO 305
305   CONTINUE
      IF(ITOWER.EQ.2) GO TO 815
C-----------------------------------------------------------------------
C     ******* BASIC PARAMETERS*******
      READ 501,FRATE,XF1
C     FRATE IN LB.-MOLE/HR. UNITS ONLY!!!
815   READ 530,RFACTR
816   READ 502,DELTAP,CONDPD,REBPD
      READ 530,PREF
C     PREF= REFERENCE PRESSURE FOR EQUILIBRIUM DATA
C     DELTAP=PRESSURE DROP/STAGE;RFACTR=REFLUX FACTOR--R=RFACTR*RMIN
C     CONDPD AND REBPD ARE CONDENSER AND REBOILER PRESSURE DROPS
C     RESPECTIVELY
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
C     ***** ALL PRESSURE DROPS SHOULD BE EXPRESSED AS POSITIVE
C     NUMBERS---PSIA; ALL TEMPERATURES IN DEGREES FAHRENHEIT
C     *****AVERAGE PRESSURE IN SECOND COLUMN (PTOP+PBOT)/2. MUST
C     BE LESS THAN CONDENSER PRESSURE OF FIRST COLUMN*****
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
      READ 501,TOL,TOLCA
C **** TOL= TOLERANCE--BUBBLE,DEW PTS.---COMPONENT SUMMATION=1
C  ***** TOLCA=TOLERANCE ON COMPOSITION---MOLE FRACTION
      TOLH=0.001
      READ 503,TTOP,PTOP,TBOT,PBOT
      READ 501,ZD1,XB1
      PFEED=(PTOP+PBOT)/2.
      XTRA=XB1
      IF(ITOWER.EQ.2) GO TO 5656
      DIST=FRATE*(XF1-XB1)/(ZD1-XB1)
      BOT=FRATE-DIST
      BOTV=0
C-----------------------------------------------------------------------
C     INPUT OF BASIC DATA
C     ENTHALPY INPUT IN BTU/LB-MOLE UNITS ONLY !!!
5656  READ 504,(TEMP(I),HL(1,I),HL(2,I),HV(1,I),HV(2,I),I=1,2)
      READ 505,(TEQ(I),EK(1,I),EK(2,I),I=1,2)
C     HL AND HV ARE FOR BOTH COMPONENTS AT TEMP(1) AND TEMP(2);
C     EK(1) AND EK(2) AT TEQ(1) AND TEQ(2).
C-----------------------------------------------------------------------
C     ***** INPUT DATA PRINT OUT*****
      IF(ITOWER.EQ.2) GO TO 3275
3475  PRINT 506
      DIST=FRATE*(XF1-XB1)/(ZD1-XB1)
      BOT=FRATE-DIST
      BOTV=0
```

```
      PRINT 800
      PRINT 527
      PRINT 400
      PRINT 528,FRATE,XF1,YB1,DIST,DSPLIT,7D1
      IF(IPRESS.GT. 1) GO TO 2100
      PRINT 507,DELTAP,CONDPD,REBPD
      IF(ITOWER.EQ.2) GO TO 3575
C-----------------------------------------------------------------------
C     CALCULATION OF EQUILIBRIUM CONSTANTS
3275  DO 2 I=1,2
      B(I)=LOG(EK(I,1)/EK(I,2))*(TEQ(1)+460.)*(TEQ(2)+460.)/
     %(TEQ(2)-TEQ(1))
      A(I)=LOG(EK(I,1)*PREF)-B(I)/(TEQ(1)+460.)
2     CONTINUE
C-----------------------------------------------------------------------
C     CALCULATION OF ENTHALPY CONSTANTS
      DO 3 I=1,2
      BHL(I)=(HL(I,2)-HL(I,1))/(TEMP(2)-TEMP(1))
      AHL(I)=HL(I,1)-BHL(I)*(TEMP(1)+460.)
      BHV(I)=(HV(I,2)-HV(I,1))/(TEMP(2)-TEMP(1))
      AHV(I)=HV(I,1)-BHV(I)*(TEMP(1)+460.)
3     CONTINUE
      PRINT 513,ITOWER
      PRINT 900
      PRINT 514
      DO 1000 I=1,2
      PRINT 515,I,A(I),PREF,AHL(I),AHV(I)
      PRINT 516,I,B(I),PREF,BHL(I),BHV(I)
1000  CONTINUE
      PRINT 900
      PRINT 402
      IF(ITOWER.EQ.2) GO TO 3375
C-----------------------------------------------------------------------
C     CALCULATION OF FEED CONDITION AND REFLUX
3575  IPASS=1
C     IPASS IS A VARIABLE TO DETERMINE CALCULATIONAL CONTROL.
      PFEED=(PTOP+PBOT)/2.
2100  CONTINUE
      IF(ITOWER.EQ.1)  GO TO 637
      CALL BUBBLE(PFEED,XF1,TOL,TLO)
      CALL DEWPT(PFEED,XF1,TOL,TH1)
      IF(TH1-TFEED) 621,622,623
623   IF(TLO-TFEED) 624,626,627
621   IFCODE=0
      GO TO 637
622   IFCODE=1
      GO TO 637
624   IFCODE=2
      GO TO 637
626   IFCODE=3
      GO TO 637
627   IFCODE=4
      GO TO 637
637   CONTINUE
      IF(IFCODE.EQ.0) GO TO 610
      CONTINUE
      GO TO (611,612,613,614),IFCODE
610   CALL DEWPT(PFEED,XF1,TOL,TFSUDO)
      CALL FDFLSH(TFSUDO,PFEED,XF1,XFEED,YFEED)
      IF(IPASS.GT.1 .OR.ITOWER.EQ.2) GO TO 630
```

```
      READ 530,TFEED
      GO TO 630
611   CALL DEWPT(PFEED,XF1,TOL,TFDEW)
      TFEED=TFDEW
      GO TO 625
612   CONTINUE
      IF(IPASS.GT.1 .OR. ITOWER.EQ.2) GO TO 625
      READ 530,TFEED
      GO TO 625
613   CALL BUBPLE(PFEED,XF1,TOL,TFBUB)
      TFEED=TFBUB
      GO TO 625
614   CALL BUBPLE(PFEED,XF1,TOL,TFSUDO)
      CALL FDFLSH(TFSUDO,PFEED,XF1,XFEED,YFEED)
      IF(IPASS.GT.1 .OR.ITOWER.EQ.2) GO TO 630
      READ 530,TFEED
      GO TO 630
625   CALL FDFLSH(TFEED,PFEED,XF1,XFEED,YFEED)
630   VV=((XF1-XFEED)/(YFEED-XFEED))*FRATE
      HFEED=VV*HVAVG(YFEED,TFEED)+(FRATE-VV)*HLAVG(XFEED,TFEED)
      HFLIQ=(FRATE-VV)*HLAVG(XFEED,TFEED)
      HFVAP=VV*HVAVG(YFEED,TFEED)
      IF(IFCODE.EQ.0) GO TO 640
      CONTINUE
      GO TO (641,642,643,644),IFCODE
640   PRINT 650
      GO TO 660
641   PRINT 651
      GO TO 660
642   PRINT 652
      GO TO 660
643   PRINT 653
      GO TO 660
644   PRINT 654
660   CONTINUE
      PRINT 552,FRVAP
      PRINT 400,XFEED,YFEED,HFEED,TFEED
C----------------------------------------------------------------------------------
C     STORAGE OF CONSTANTS FOR TOWER
      S(ITOWER,1)=FRATE
      S(ITOWER,2)=XF1
      S(ITOWER,3)=DELTAP
      S(ITOWER,4)=CONDPD
      S(ITOWER,5)=REBPD
      S(ITOWER,6)=PREF
      S(ITOWER,7)=TOL
      S(ITOWER,8)=TOLDA
      S(ITOWER,9)=TOLH
      S(ITOWER,10)=TTOP
      S(ITOWER,11)=PTOP
      S(ITOWER,12)=TBOT
      S(ITOWER,13)=PBOT
      S(ITOWER,14)=ZD1
      S(ITOWER,15)=XB1
      S(ITOWER,16)=A(1)
      S(ITOWER,17)=A(2)
      S(ITOWER,18)=B(1)
      S(ITOWER,19)=B(2)
      S(ITOWER,20)=AHL(1)
      S(ITOWER,21)=AHL(2)
```

```
      S(ITOWER,22)=BHL(1)
      S(ITOWER,23)=BHL(2)
      S(ITOWER,24)= AHV(1)
      S(ITOWER,25)=AHV(2)
      S(ITOWER,26)=BHV(1)
      S(ITOWER,27)=BHV(2)
      S(ITOWER,28)=TFEED
      S(ITOWER,29)=IFCODE
      IF(ITCODE.EQ.4.AND.ITOWER.EQ.2) GO TO 820
      CONTINUE
      IF(IFCODE.EQ.0 .OR. IFCODE.EQ.4) GO TO 635
      CALL REFLUX(XF1,ZD1,RMIN,R,TFEED,PFEED)
      GO TO 638
635   CALL REFLUX(XF1,ZD1,RMIN,R,TFSUDO,PFEED)
638   CONTINUE
      PRINT 517,RMIN,R
      RLOW=0.9*R
      RHIGH=1.1*R
C---------------------------------------------------------------------
C     CALCULATION ---CONDENSER AND TOP STAGE
      PCOND=PTOP-CONDPD
55    CONTINUE
      DIST=FRATE*(XF1-XB1)/(ZD1-XB1)
      BOT=FRATE-DIST
      BOTV=0
      GO TO (51,52,53,54),IDCODE
51    DV=DIST
      DL=0
      CALL DEWPT(PCOND,ZD1,TOL,TCOND)
      GO TO 50
52    DV=DIST*DSPLIT
      DL=DIST-DV
      CALL FLASH(DSPLIT,PCOND,ZD1,TCOND)
      GO TO 50
53    DL=DIST
      DV=0
      CALL BUBBLE(PCOND,ZD1,TOL,TCOND)
      GO TO 50
54    DV=0
      DL=DIST
      CALL BUBBLE(PCOND,ZD1,TOL,TSEUDO)
      CALL FDFLSH(TSEUDO,PCOND,ZD1,XD,YD)
      IF(IPASS.GT.1) GO TO 65
      READ 530,TCOND
      GO TO 65
50    CALL FDFLSH(TCOND,PCOND,ZD1,XD,YD)
65    CONTINUE
      PRINT 553,FRVAP
      PRINT 800
      PRINT 508
      PRINT 509
      PRINT 510,TTOP,TBOT,TFEED,TCOND
      PRINT 511
      PRINT 512,PTOP,PBOT
      PRINT 800
1600  CONTINUE
      YY=(YD*(R*DIST+DL)+DV*YD)/(DIST+R*DIST)
      N=1
      Y(N)=YY
      CALL DEWPT(PTOP,YY,TOL,IDP)
```

```
      T(N)=TOP
      Y(N)=YY/EQK(TOP,PTOP,1)
      DISTH=DL*HLAVG(XD,TCOND)+DV*HVAVG(YD,TCOND)
      QC=R*DIST*HLAVG(XD,TCOND)+DISTH-DIST*(R+1.)*HVAVG(YY,TOP)
      RATEV(N)=DIST*(R+1.)
      P(N)=PTOP
821   CONTINUE
      IF(IPASS.GT.1) GO TO 1400
C______________________________________________________________________'____
C PLATE TO PLATE CALCULATION IN RECTIFYING SECTION---(TOP DOWN)
8     N=N+1
      CORECT=0
      CALL RTPDWN(N)
      IF(X(N)-XFEED) 9,9,8
9     CONTINUE
      NRECT=N-1
      NFD=NRECT+1
      NFD1=NFD+1
      VPLACE=RATEV(NRECT+1)
      PLACE1=VPLACE
      TPLACE=T(NRECT+1)
      YPLACE=Y(NRECT+1)
      XPLACE=X(NRECT+1)
      PPLACE=P(NRECT+1)
      IF(IPASS.EQ.1) GO TO 700
1400  CONTINUE
      NPLACE=NRECT+1
      DO 1090 N=2,NPLACE
      CORECT=0
1090  CALL RTPDWN(N)
      N=NPLACE
1500  CONTINUE
      CALL FTPDWN(N,YFEED,VV,HFVAP)
      N=N+1
      CALL FTPDWN(N,XFEED,FRATE-VV,HFLIQ)
      N=N+2
      NN=N
      IF(NN-NTOTAL) 3876,3878,3879
3879  CONTINUE
      CORECT=REBPD-DELTAP
      CALL FTPDWN(N-2,XFEED,FRATE-VV,HFLIQ)
      GO TO 3877
3876  CORECT=0
      NP=NTOTAL-1
      DO 1070 N=NN,NP
1070  CALL STPDWN(N)
3878  N=NTOTAL
      CORECT=REBPD-DELTAP
      CALL STPDWN(N)
3877  CORECT=0
      RATEL(NTOTAL)=FRATE-DIST
      IF(IPASS.EQ.3) GO TO 706
      CONTINUE
      IF(IPASS.GT.3) GO TO 1351
      PRINT 409
      PRINT 564,IPASS
      GO TO 705
706   PRINT 409
      PRINT 412
1351  PRINT 413,IPASS,P,X(NTOTAL)
```

```
      GO TO 157
705   PRINT 2000,R
      IF(IPASS.GE.3) GO TO 1350
      PRINT 519
      PRINT 563
      PRINT 562,TCOND,RATEV(1),DV,PCOND
      DO 1071 N=1,NTOTAL
1071   PRINT 520,N.T(N),RATEL(N),RATEV(N),P(N)
      PRINT 561
      PRINT 521
      DO 1072 N=1,NTOTAL
1072  PRINT 522,N,X(N),Y(N)
      PRINT 561
      PRINT 526,IPASS
      GO TO 150
1350  PRINT 568,X(NTOTAL)
      GO TO 150
700   CONTINUE
C-----------------------------------------------------------------------
C     CALCULAITON OF REBOILER DUTY.
      PP=POUT+REBPD
      CALL BUBBLE(PP,XB1,TBL,TREB)
      BOT=FRATE-DIST
      QR=DISTH+(FRATE-DIST)*HLAVG(XB1,TREB)-HFEED-QC
      BOTTH=(FRATE-DIST)*HLAVG(XB1,TREB)
      M=NRECT+1
      MM=NRECT+1
      T(M)=TREB
      X(M)=XB1
      Y(M)=EQK(TREB,P,1)*X(M)
      RATEL(M)=FRATE-DIST
      P(M)=PP
      CORECT=REBPD-DELTAP
C-----------------------------------------------------------------------
C     PLATE TO PLATE CALCULATIONS IN STRIPPING SECTION---(BOTTOM UP)
12    M=M+1
      CALL SBOTUP(M)
      CORECT=0
      IF(YFEED-Y(M)) 13,13,12
13    CONTINUE
      NSTRIP=M-NRECT-1
      NTOTAL=NRECT+NSTRIP
      PLACE2=RATEL(NTOTAL+1)
      NREV=NTOTAL
      J=NSTRIP
      K=MM
      KK=1
1005  EXTRA1=RATEL(K)
      EXTRA2=RATEV(K)
      EXTRA3=T(K)
      EXTRA4=X(K)
      EXTRA5=Y(K)
      EXTRA6=P(K)
      RATEL(K)=RATEL(NREV)
      RATEV(K)=RATEV(NREV)
      T(K)=T(NREV)
      X(K)=X(NREV)
      Y(K)=Y(NREV)
      P(K)=P(NREV)
      RATEL(NREV)=EXTRA1
```

```
      RATEV(NREV)=EXTRA2
      T(NREV)=EXTRA3
      X(NREV)=EXTRA4
      Y(NREV)=EXTRA5
      P(NREV)=EXTRA6
      K=K+1
      KK=KK+1
      NREV=NREV-1
      IF(KK-(J/2)) 1005,1005,1006
1006  PRINT 400
      PRINT 518
      PRINT 410
      PRINT 519
      PRINT 563
      PRINT 562,TCOND,DL,DV,PCOND
      DO 1001 N=1,NRECT
1001   PRINT 520,N,T(N),RATEL(N),RATEV(N),P(N)
      PRINT 602,PLACE1
      PRINT 521
      DO 1002 N=1,NRECT
1002  PRINT 522,N,X(N),Y(N)
      PRINT 523,NRECT
      PRINT 400
      PRINT 411
      PRINT 519
      PRINT 563
      DO 1003 M=MM,NTOTAL
1003  PRINT 520,M,T(M),RATEL(M),RATEV(M),P(M)
      PRINT 561
      PRINT 603,PLACE2
      PRINT 521
      DO 1004 M=MM,NTOTAL
1004  PRINT 522,M,X(M),Y(M)
      PRINT 561
      PRINT 524,NSTRIP
      PRINT 525,NTOTAL
      PRINT 526,IPASS
      IPASS=IPASS+1
      PDROP=NTOTAL-2
      PBOT=PTOP+DELTAP*PDROP
      PRINT 400
      PRINT 605
      TTOP=T(1)
      TBOT=T(NTOTAL-1)
      PFEED=(2.*P(NSTRIP)+DELTAP)/2.
      GO TO 2100
150   PRINT 800
157   IPASS=IPASS+1
      YXX=Y(NTOTAL)
      IF(IPASS.GT.3) GO TO 1091
      P=PLOW
      GO TO 1600
1091  IF(WAYA(YXX,YB1,TOLBA,P,PHIGH,3)) 1600,1900,9999
1900  PRINT 800
      PK=K
      PRINT 400
      PRINT 1100,ITOWER
      PRINT 2007,NFD,NFD1
      PRINT 2001,PLOW,P,PHIGH
      PRINT 1101
```

```
      PRINT 565
      PRINT 1103,TCOND,PCOND,DL,DV,XD,YD
      DO 1901 N=1,NTOTAL
1901  PRINT 1102,N,T(N),P(N),RATEL(N),RATEV(N),X(N),Y(N)
      PRINT 561
      PRINT 800
      PRINT 1105
      PRINT 1078
      TREB=T(NTOTAL)
      XB1=Y(NTOTAL)
      YB1=Y(NTOTAL)
      ZB1=XB1
      BOTTH=(FRATE-DIST)*HLAVG(XB1,TREB)
      TREB1=TREB
      BOTTH1=BOTTH
      BOT1=BOT
      BOTV1=BOTV
      QR=DISTH+BOTTH-HFEED-QC
      PRINT 1106,HFEED,QR
      SUMIN=HFEED+QR
      PRINT 1107,SUMIN
      PRINT 1108,DISTH,BOTTH,QC
      SUMOUT=DISTH+BOTTH+ABS(QC)
      PRINT 1109,SUMOUT
      PRINT 1079,ITOWER
      IF(ITCODE.EQ.1) GO TO 190
      QC1=ABS(QC)
      IPASS=1
9713  ITOWER=ITOWER+1
      IF(ITOWER.EQ.3) GO TO 190
      PRINT 400
      PRINT 566,ITOWER,IPROB
      PRINT 567
      IF(IND.GT.0) GO TO 4000
4001  PFEED=(PTOP+PBOT)/2.
      CONTINUE
      IF(IND.GT.0) GO TO 3375
      CONTINUE
      GO TO (190,572,573,574),ITCODE
572   PRINT 582
      GO TO 575
573   PRINT 583
      GO TO 575
574   PRINT 584
575   CONTINUE
      GO TO (190,3175,3175,816),ITCODE
3375  CONTINUE
C---------------------------------------------------------------------
C     VALVE CALCULATIONS
      GO TO (190,810,811,810),ITCODE
810   CALL VALVE(PFEED,TREB1,BOTTH1,BOT1,BOTV1,ZB1,YB1)
      FRATE=BOT1+BOTV1
      XF1=(BOT1*ZB1+BOTV1*YB1)/FRATE
      XB1=YTRA
      TFEED=TREB1
      HFEED=BOTTH1
      HFIN=HFEED
      IF(ITCODE.EQ.2) GO TO 3475
3675  CALL VALVE(PTOP,TCOND,DISTH,DL,DV,XD,YD)
      PTLO=DL
```

```
      HO=DL*HLAVG(XD,TCOND)
      YO=XD
      GO TO 3475
811   CALL VALVE(FFEED,TCOND,DISTH,DL,DV,XD,YD)
      FRATE=DL+DV
      XF1=(DL*XD+DV*YD)/(DL+DV)
      TFEED=TCOND
      HFEED=DISTH
      GO TO 3475
C-------------------------------------------------------------------------
9999  PRINT 99999
      PRINT 2001,RLOW,P,RHIGH
      IF(XXX-XB1) 9888,1900,9889
9888  R=RLOW
      RLOW=0.9*R
      RHIGH=1.1*R
      R=RLOW
      IF(IPASS.LT.30) GO TO 1600
      CONTINUE
      GO TO 190
9889  R=RHIGH
      RLOW=0.9*R
      RHIGH=1.1*R
      R=RLOW
      IF(IPASS.LT.20) GO TO 1600
      CONTINUE
      GO TO 190
C-------------------------------------------------------------------------
C     CALCULATIONS IN THE ABSORBER SECTION
820   QR=QC1
827   BOT=(FRATE*(ZD1-XF1)+KTLQ*(ZD1-XD))/(ZD1-XB1)
823   PP=PBOT+PERPD
      CALL DEWPT(PP,XB1,TOL,TREB)
      BOTTH=BOT*HVAVG(XB1,TREB)
      T(1)=TREB
      Y(1)=XB1
      P(1)=PP
      X(2)=XB1
      CALL BUBBLE(PBOT,XB1,TOL,TT)
      T(2)=TT
      RATEV(1)=(BOTTH-QR-BOT*HLAVG(XB1,TT))/(HLAVG(XB1,TT)-HVAVG(XB1,
     %TREB))
      RATEL(2)=BOT+RATEV(1)
      P(2)=PBOT
      Y(2)=EQK(TT,PBOT,1)*X(2)
      M=2
      IF(INDEX.GE.1) GO TO 8719
2500  M=M+1
      CORECT=0
      CALL SBOTUP(M)
      IF(X(M).EQ.X(M-1).AND.X(M-1).EQ.X(M-2)) GO TO 2504
      CONTINUE
      IF(YFEED-Y(M)) 2501,2501,2500
2501   CONTINUE
      M=M-1
      M=M+2
2504  M=M-2
      MFD=M
      MFD1=MFD+1
      CALL FROTUP(M,XFEED,FRATE-VV,HFLIQ)
```

```
      M=M+1
      CALL FROTUP(M,YFEED,VV,HEVAP)
      M=M+1
2502  M=M+1
      CALL RBOTUP(M)
      IF(M.GT.99) GO TO 190
      IF(X(M)-Y0) 2502,2503,2503
2503    CONTINUE
      MTOT=M-1
      PRINT 409
8735  PRINT 608
405   CALL RBOTUP(MTOT+1)
      VOVHDQ=RATEV(MTOT)*HVAVG(Y(MTOT),T(MTOT))
      ZLIQQ=RATEL(MTOT+1)*HLAVG(X(MTOT+1),T(MTOT+1))
      DVALIM=FRATE+RATEL(MTOT+1)-BOT-RATEV(MTOT)
      DVALIC= FRATE*XF1+RATEL(MTOT+1)*X(MTOT+1)-BOT*XB1-RATEV(MTOT)*
     %Y(MTOT)
      IF(INDEX.GE. 1) GO TO 8991
8993  PRINT 1101
      PRINT 565
      IF(INDEX.GE.1) GO TO 8994
      PRINT 609,TREB,P(1),BOT,RATEV(1),XB1,Y(1)
      DO 873 M=2,MTOT
873   PRINT 1102,M,T(M),P(M),RATEL(M),RATEV(M),X(M),Y(M)
      PRINT 402
      IF(INDEX.GE.1) GO TO 8994
      CONTINUE
      IF(IDBL.EQ.1) GO TO 8994
      IPRESS=IPRESS+1
      IF(INDEX.GE.1) GO TO 8737
      PF1=PFEED
      PBOT=P(2)
      PTOP=P(MTOT)
      PFEED=P(MFD)
      DIFP=ABS(PF1-PFEED)
      IF(DIFP.LT.0.01) GO TO 8737
      PRINT 402
      PRINT 605
      PRINT 2005,IPRESS
      PRINT 2007,MFD,MFD1
      IF(IPRESS.GT.30) GO TO 190
      CONTINUE
      IF(DIFP.GT.0.01) GO TO 610
8737  CONTINUE
      ICOR=IPRESS-1
      ISUM=INDEX+ICOR
      PRINT 402
      GO TO 8991
8994   PRINT 1105
      PRINT 800
      PRINT 2002,HFIN,QR,ZLIQQ
      SUMIN=HFIN+QR+ZLIQQ
      PRINT 1107,SUMIN
      PRINT 2003,BOTTH,VOVHDQ
      SUMOUT=BOTTH+VOVHDQ
      PRINT 1109,SUMOUT
      PRINT 800
      PRINT 1059
      PRINT 1060
      GO TO 8735
```

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8991  CONTINUE
      ISUM=INDEX+ICUR
      IF(INDEX.GE.1) GO TO 8992
      PRINT 409
      PRINT 590
      PRINT 591
8992  PRINT 592,ISUM,RTLO,RATEL(MTOT+1),QCL,QK
8990  CONTINUE
      DELTAH=((RTLO+FRATE-BOT)*HVAVG(Y(MTOT),T(MTOT))-VOVHDQ)
      QHIGH=QK+DELTAH
      INDEX=INDEX+1
8717  IF(WAYA(HO-ZLIOQ,0.,HO/100.,QR,QHIGH,3)) 827,8718,9173
8719  DO 8720 M=3,MFD
8720  CALL SROTUP(M)
      CONTINUE
      CALL FROTUP(MFD,XFEED,FRATE-VV,HFVAP)
      M=MFD
      M=M+1
      CALL FROTUP(M,YFEED,VV,HFVAP)
      M=M+2
      DO 8730 M=M,MTOT
8730  CALL RROTUP(M)
      CONTINUE
      GO TO 405
9173  PRINT 9115
      GO TO 190
8718  CONTINUE
      IDBL=1
      INDEX=0
      PRINT 409
      PRINT 406
      PRINT 2007,MFD,MFD1
      GO TO 8993
8725  CONTINUE
      ITOWER=ITOWER-1
      QR2=QR
      IDBL=0
      IPRESS=1
      INDEX=0
C------------------------------------------------------------------------------------------
C     RESTORATION OF CONSTANTS
4000  FRATE=S(ITOWER,1)
      XF1=S(ITOWER,2)
      DELTAP=S(ITOWER,3)
      CONDPB=S(ITOWER,4)
      REBPR=S(ITOWER,5)
      PREF=S(ITOWER,6)
      TOL=S(ITOWER,7)
      TOLDA=S(ITOWER,8)
      TOLH=S(ITOWER,9)
      TTOP=S(ITOWER,10)
      PTOP=S(ITOWER,11)
      TBOT=S(ITOWER,12)
      PBOT=S(ITOWER,13)
      ZD1=S(ITOWER,14)
      XB1=S(ITOWER,15)
      A(1)=S(ITOWER,16)
      A(2)=S(ITOWER,17)
      B(1)=S(ITOWER,18)
      B(2)=S(ITOWER,19)
```

```
      AHL(1)=S(ITOWER,20)
      AHL(2)=S(ITOWER,21)
      BHL(1)=S(ITOWER,22)
      BHL(2)=S(ITOWER,23)
      AHV(1)=S(ITOWER,24)
      AHV(2)=S(ITOWER,25)
      BHV(1)=S(ITOWER,26)
      BHV(2)=S(ITOWER,27)
      TFEED=S(ITOWER,28)
      IFCODE=S(ITOWER,29)
C---------------------------------------------------------------------
C     INTER-COLUMN CONVERGENCE
      IF(ITOWER.EQ.2) GO TO 4001
      CONTINUE
      IF(IND.GT.0) GO TO 20
      RFACTR=(((RR+1.)*QR/QC1)-1.)/RMIN
      GO TO 56
20    CONTINUE
      IF(ITRY.EQ.3) GO TO 23
      CONTINUE
      IF(ITRY.EQ.4) GO TO 24
      CONTINUE
      IF(QR2-QC1) 21,59,22
21    CONTINUE
      IF(ITRY.EQ.2) GO TO 23
      ITRY=1
      XB1H=XB1+.01
      XB1L=XB1
      XB1=XB1H
      GO TO 56
22    CONTINUE
      IF(ITRY.EQ.1) GO TO 24
      ITRY=2
      XB1L=XB1-.01
      XB1H=XB1
      XB1=XB1L
      GO TO 56
23    CONTINUE
      ITRY=3
      IF(WAYA(QC1,QR2,TOLH*ABS(QR2),XB1,XB1H,4)) 58,59,190
24    CONTINUE
      ITRY=4
      IF(WAYA(QC1,QR2,TOLH*ABS(QR2),XB1,XB1L,4)) 58,59,190
56    IND=IND+1
      IF(IND.GT.10) GO TO 190
      CONTINUE
      GO TO 3576
59    PRINT 409
      PRINT 407
      IF(ICONV.EQ.1) GO TO 190
      ICONV=1
C---------------------------------------------------------------------
C     DATA PRINTOUT---SECOND COLUMN
3576  DIST=FRATE*(YF1-XB1)/(ZJ1-XB1)
      BOT=FRATE-DIST
      BOTV=0
      PRINT 409
      PRINT 506,ITOWER,IPROB
      PRINT 800
      PRINT 527
```

```
      PRINT 400
      PRINT 528,FRATE,XF1,XB1,DIST,DSPLIT,ZD1
      PRINT 507,DELTAP,CONDPD,REBPD
      GO TO 3575
C------------------------------------------------------------------0-----
C     ***** FORMAT SECTION *****
400   FORMAT('+',5X,'MOLS/HOUR',21X,'MOLS/HOUR',/)
402   FORMAT('+',1X,'TOP')
403   FORMAT('0',20X,'PRESSURE VARIATIONS HAVE BEEN DAMPED',/)
406   FORMAT( 1X,20X,'THE SECOND TOWER IS INDEPENDENTLY CLOSED',/)
407   FORMAT(21X,'FINAL CONVERGENCE HAS BEEN ACHIEVED FOR BOTH TOWERS'
     %,/)
408   FORMAT(' ',15X,'XFEED=',F9.5,5X,'YFEED=',F9.5,5X,'HFEED=',E15.8,
     %5X,'TFEED=',F10.5,/)
409   FORMAT('1',6(/),80X)
410   FORMAT(15X,'RECTIFYING SECTION',/)
411   FORMAT(15X,'STRIPPING SECTION',/)
412   FORMAT(5X,'PASS',3X,'REFLUX RATIO',3X,'BOTTOMS COMP.',/)
413   FORMAT(7X,I2,5X,F10.5,5X,F10.7)
501   FORMAT(2F12.5)
502   FORMAT(3F12.5)
503   FORMAT(4F12.5)
504   FORMAT(5F12.5)
505   FORMAT(3F12.5)
506   FORMAT('0',20X,'INPUT DATA USED IN CALCULATIONS',/)
507   FORMAT(5X,'PRESSURE DROP/STAGE=',F6.4,5X,
     %'CONDENSER PRESSURE DROP=',F6.4,5X,
     %'REBOILER PRESSURE DROP=',F6.4,/)
508   FORMAT('0',25X,'TEMPERATURES---DEGREES FAHRENHEIT',/)
509   FORMAT(9X,'TOP',9X,'BOTTOM',6X,'FEED',8X,'CONDENSER',/)
510   FORMAT(5X,4(F11.5,1X),/)
511   FORMAT(20X,'PRESSURES---PSIA',/)
512   FORMAT(5X,'PTOP=',F12.5,5X,'PBOTTOM=',F12.5,//)
513   FORMAT('0',35X,'*****CONSTANTS*****      TOWER NUMBER',I2)
514   FORMAT(5X,'EQUILIBRIUM',15X,'PRESSURE',14X,'ENTHALPY-LIQUID',
     %7X,'ENTHALPY-VAPOR',/)
515   FORMAT(1X,'A',I1,2X,4(F12.5,9X),/)
516   FORMAT(1X,'B',I1,2X,4(F12.5,9X),/)
517   FORMAT(//,2X,'MINIMUM REFLUX =',F12.5,10X,'REFLUX RATIO=',F12.5,
     %/)
518   FORMAT( 1X,5X,'FIRST PASS---DETERMINATION OF NUMBER OF STAGES',
     %//)
519   FORMAT(5X,'STAGE',5X,'TEMPERATURE',5X,'LIQUID RATE',5X,
     %'VAPOR RATE',9X,' PRESSURE ')
520   FORMAT(5X,I3,7X,4(F11.5,5X))
521   FORMAT('0',5X,'STAGE',5X,'X(1)',12X,'Y(1)',/)
522   FORMAT(5X,I3,7X,2(F10.7,6X))
523   FORMAT('0',5X,'THE NUMBER OF STAGES IN THE RECTIFYING SECTION
     %ARE',I3,//)
524   FORMAT('0',5X,'THE NUMBER OF STAGES IN THE STRIPPING SECTION
     %ARE',I3,//)
525   FORMAT('0',5X,'THE TOTAL NUMBER OF STAGES IN TOWER ARE',I5,//)
526   FORMAT('0',5X,'PASS NUMBER',I3,' IS COMPLETE')
527   FORMAT('0',5X,'FEED RATE',3X,'XF(1)',4X,'XB(1)',4X,'DIST.RATE',
     %2X,'DIST.SPLIT',2X,'ZD(1)',/)
528   FORMAT(5X,F10.5,2(2X,F7.6),2(2X,F10.5),2X,F7.6,/)
529   FORMAT(I2)
530   FORMAT(F12.5)
531   FORMAT(15X,'PARTIAL CONDENSER---ALL VAPOR DISTILLATE.')
533   FORMAT(15X,'TOTAL CONDENSER---ALL LIQUID DISTILLATE')
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534   FORMAT(15X,'TOTAL CONDENSER---SUBCOOLED DISTILLATE')
552   FORMAT(15X,'THE FRACTION FEED VAPORIZED=',F7.4,/)
553   FORMAT(15X,'THE FRACTION DISTILLATE VAPORIZED=',F7.4,/)
561   FORMAT('+','REB.')
562   FORMAT(5X,'COND.',5X,4(F11.5,5X))
563   FORMAT(15X,'DEGREES F',7X,'MOLES/HR.',7X,'MOLES/HR.',12X,'PSIA'
     %,//)
564   FORMAT( 1X,30X,'PASS NUMBER',2X,I2)
565   FORMAT(15X,'DEGREES F',9X,'PSIA',9X,'MOLES/HR.',9X,'MOLES/HR.',
     %//)
566   FORMAT( 1X,35X,'COLUMN NUMBER',I4,'-----PROBLEM NUMBER',I4)
567   FORMAT('+',34X,17('_'),//)
568   FORMAT(15X,'THE BOTTOMS MOLE FRACTION LIQUID FOR THIS PASS IS',
     %F10.7,/)
569   FORMAT(30X,'PASS NUMBER',2X,I2)
582   FORMAT(30X,'DOUBLE COLUMN---BOTTOMS(1)=FEED(2)',/)
583   FORMAT(30X,'DOUBLE COLUMN---DISTILLATE(1)=FEED(2)',/)
584   FORMAT(30X,'AIR PLANT---D(1)=REFLUX(2)',/)
590   FORMAT( 1X,15X,'TRIAL',5X,'OVERHEAD FEED',5X,'OVERHEAD FEED',5X,
     %'CONDENSER DUTY(1)',5X,'REBOILER DUTY(2)')
591   FORMAT(28X,'REQUIRED',11X,'ACTUAL',/)
592   FORMAT(15X,I3,7X,2(F13.7,5X),5X,2(E17.7,5X))
602   FORMAT('0','THE NET VAPOR ENTERING THE RECTIFYING SECTION IS',
     %F11.5,/)
603   FORMAT('0','THE NET LIQUID ENTERING THE STRIPPING SECTION IS',
     %F11.5,/)
605   FORMAT( 1X,15X,'REVISED VALUES BASED ON TRUE PRESSURE PROFILE',
     %//)
608   FORMAT('0',30X,'AIR PLANT---SECOND COLUMN---ABSORBER SECTION',/)
609   FORMAT(5X,'REB. ',5X,6(F11.5,5X))
650   FORMAT(15X,'SUPERHEATED FEED',/)
651   FORMAT(15X,'DEW POINT FEED',/)
652   FORMAT(15X,'FLASHED FEED',/)
653   FORMAT(15X,'BUBBLE POINT FEED',/)
654   FORMAT(15X,'SUBCOOLED FEED',/)
800   FORMAT('+',80('_'),/)
1059  FORMAT(30X,'TOWER NUMBER TWO IS COMPLETE')
1060  FORMAT('+',30X,28('_'),//)
1078  FORMAT('+',30X,26('_'))
1079  FORMAT(30X,'TOWER NUMBER',I2,' IS COMPLETE')
1080  FORMAT('+',30X,28('_'),//)
1100  FORMAT( 1X,10X,'FINAL CONVERGENCE ACHIEVED ON BOTTOMS
     %COMPOSITION ---TOWER NUMBER',I2,/)
1101  FORMAT(5X,'STAGE',5X,'TEMPERATURE',5X,' PRESSURE ',5X,
     %'LIQUID RATE',5X,'VAPOR RATE',5X,' X(COMP.1) ',5X,' Y(COMP.1)')
1102  FORMAT(5X,I3,7X,6(F11.5,5X))
1103  FORMAT(5X,'COND.',5X,6(F11.5,5X))
1105  FORMAT(30X,'ENTHALPY BALANCE (BTU/HR.)')
1106  FORMAT(5X,'FEED ENTHALPY=',E15.8,10X,'REBOILER DUTY=',E15.8,/)
1107  FORMAT(25X,'TOTAL ENTHALPY IN =',E15.8,/)
1108  FORMAT(2X,'DISTILLATE ENTHALPY =',E15.8,2X,'BOTTOMS ENTHALPY =',
     %E15.8,2X,'CONDENSER DUTY =',E15.8,/)
1109  FORMAT(25X,'TOTAL ENTHALPY OUT =',E15.8,/)
2000  FORMAT('0',10X,'THE VALUE OF THE REFLUX RATIO=',F10.5,//)
2001  FORMAT('0',15X,'RLOW=',F9.5,5X,'R=',F9.5,5X,'RHIGH=',F9.5,//)
2002  FORMAT(2X,'FEED ENTHALPY=',E15.8, 5X,'REBOILER DUTY=',E15.8, 5X,
     %'REFLUX ENTHALPY=',E15.8,/)
2003  FORMAT(5X,'BOTTOMS ENTHALPY',E15.8,10X,'TOP PRODUCT ENTHALPY',
     %E15.8,//)
2005  FORMAT(30X,'TRIAL NUMBER',I2)
```

```
2007  FORMAT(20X,'THE FEED IS INTRODUCED BETWEEN STAGES      ',
     %I2,'      AND      ',I2,/)
8699  FORMAT(30X,'NO CONVERGENCE',///)
9115  FORMAT(30X,'NO CONVERGENCE IN SECOND TOWER',//)
99999 FORMAT(5X,'NO CONVERGENCE-BOTTOMS COMP.-RHIGH,RLOW REVISED')
C-----------------------------------------------------------------------
190    IPROB=IPROB+1
       IF(IPROB.LE.NPROB) GO TO 1605
       STOP
       END
```

```
      SUBROUTINE VALVE(PRESS,TTT,ENTLPY,ZLIQ,VAP,XV,YV)
      COMMON FRVAP
      COMMON A(2),B(2),PCON(2),FRATE,RFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      COMMON /TOLTOL/TOL,TOLH,TOLUA
      COMMON/VARBLS/ X(100),Y(100),T(100),RATEL(100),RATEV(100)
      COMMON/VARPLS/ P(100)
      COMMON/CONREP/ DL,DV,XD,YD,QC,QR,DISTH,BOTTH,XB1,XF1,TFEED
      COMMON/CONPER/ TCOND,XFEED,YFEED,HFEED,VV,BOT
      COMMON/PRSSR/ CONDPD,REBPD,CORECT
C     SUBROUTINE TO CALCULATE TEMPERATURE AND COMPOSITION ON UNKNOWN
C     SIDE OF EXPANSION VALVE(CONSTANT ENTHALPY ASSUMED ACROSS VALVE).
C-----------------------------------------------------------------------
      IVALVE=1
      RATE=ZLIQ+VAP
      Z=(ZLIQ*XV+VAP*YV)/RATE
C     PRINT 541,PRESS,TTT,ENTLPY,ZLIQ,VAP
C     PRINT 541,XV,YV,RATE,Z,ENTLPY
541   FORMAT(5X,'VALVE',3X,5E20.7)
      CALL BUBBLE(PRESS,Z,TOL,TLOW)
      CALL DEWPT(PRESS,Z,TOL,THIGH)
4     TTT=TLOW
1     CALL FDFLSH(TTT,PRESS,Z,XV,YV)
      VAP=RATE*(Z-XV)/(YV-XV)
      ZLIQ=RATE-VAP
      HTOT=(RATE-VAP)*HLAVG(XV,TTT)+VAP*HVAVG(YV,TTT)
      IF(WAYA(HTOT,ENTLPY,TOLH*ABS(ENTLPY),TTT,THIGH,1)) 1,2,3
2     RETURN
3     TLOW=0.9*TLOW
      THIGH=1.1*THIGH
      IVALVE=IVALVE+1
      IF(IVALVE-30) 4,4,5
5     PRINT 6,TTT,XV,YV,HTOT
6     FORMAT(30X,'THE VALVE WILL NOT CONVERGE---T='F12.5,2X,'X='F9.5,
     %2X,'Y=',F9.5,2X,'H=',E14.7,/)
      RETURN
      END
```

```
      SUBROUTINE RTPDOWN(N)
      COMMON FPVAP
      COMMON A(2),B(2),PCOM(2),FRATE,KFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      COMMON /TOLTOL/TOL,TOLH,TOLUA
      COMMON/VARBLS/ X(100),Y(100),T(100),RATEL(100),RATEV(100)
      COMMON/VARBLS/ P(100)
      COMMON/CONPER/ DL,DV,XD,YD,QC,QR,DISTH,BOTTH,XB1,XF1,TFEED
      COMMON/CONPER/ TCOND,XFEED,YFEED,HFEED,VV,BUT
      COMMON/PRSSR/ CONDPD,REBPD,CORECT
C     PLATE TO PLATE CALCULATION IN RECTIFYING SECTION---(TOP DOWN)
C---------------------------------------------------------------------------
7     XX=X(N-1)
      YLIM=X(N-1)+.0002
      YY=Y(N-1)
      TT=T(N-1)
      PP=P(N-1)+DELTAP+CORECT
4     CONTINUE
      CALL DEWPT(PP,YY,TOL,TOP)
      RATEL(N-1)=(DL*XD-DL*YY+DV*YD-DV*YY)/(YY-X(N-1))
      RATEV(N)=(DL*XD-DL*X(N-1)+DV*YD-DV*X(N-1))/(YY-X(N-1))
      FQN=RATEV(N)*HVAVG(YY,TOP)-RATEL(N-1)*HLAVG(XX,TT)+QC
      TOLT1=TOLH*(ABS(QC)+ABS(DISTH))
      IF(WAYA(FQN,DISTH,TOLT1,YY,YLIM,2)) 4,5,9999
5     Y(N)=YY
      T(N)=TOP
      X(N)=Y(N)/EQK(TOP,PP,1)
      P(N)=PP
      GO TO 2230
9999  PRINT 99990,N,DISTH,FQN,TOLT1
99990 FORMAT(5X,'ERR-RTPDWN',3X,'STAGE=',I2,'TRUE VALUE=',
     %F15.7,'CALC.VALUE=',F15.7,'TOL=',F10.5,/)
      GO TO 5
2230  RETURN
      END
```

```
      SUBROUTINE FTPDWN(N,YYZ,FEED,HF)
      COMMON FPVAP
      COMMON A(2),B(2),PCON(2),FRATE,RFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      COMMON /TOLTOL/TOL,TOLH,TOLDA
      COMMON/VARBLS/ X(100),Y(100),T(100),RATEL(100),RATEV(100)
      COMMON/VARBLS/ P(100)
      COMMON/CONREP/ DL,DV,XD,YD,QC,QR,DISTH,BOTTH,XB1,XF1,TFEED
      COMMON/CONREP/ TCOND,XFEED,YFEED,HFEED,VV,BOT
      COMMON/PRSSR/ CONDPD,REBPD,CORECT
C     FEED ZONE---TOP DOWN
C-----------------------------------------------------------------------
      YPLACE=Y(N)
      TPLACE=T(N)
      VPLACE=RATEV(N)
      HPLACE=RATEV(N)*HVAVG(YPLACE,TPLACE)
      PPLACE=P(N)
      XSTRIP=X(N-1)
      STRIPL=RATEL(N-1)
      TSTRIP=T(N-1)
      HSTRIP=STRIPL*HLAVG(XSTRIP,TSTRIP)
      XX=YPLACE/EQK(TPLACE,PPLACE,1)
      PP=PPLACE+DELTAP+CORECT
      YY=YPLACE
      YLIM=XX+0.0002
710   CONTINUE
      CALL DEWPT(PP,YY,TOL,TT)
      EQN1=(VPLACE*YPLACE-FEED*XYZ-STRIPL*XSTRIP+(FEED+STRIPL-VPLACE)
     %*XX)/(YY-XX)
      EQN2=(HPLACE-HF-HSTRIP+(STRIPL+FEED-VPLACE)*HLAVG(XX,TPLACE))
     %/(HVAVG(YY,TT)-HLAVG(XX,TPLACE))
      DIFF=EQN1-EQN2
C     PRINT 540,PP,TT,EQN1,EQN2,DIFF,YY
540   FORMAT(6(F12.6,3X))
      IF(WAYA(DIFF,0.,TOLH*ABS(EQN1),YY,YLIM,2)) 710,711,9999
711   T(N)=TPLACE
      Y(N+1)=YY
      X(N+1)=YY/EQK(TT,PP,1)
      T(N+1)=TT
      P(N+1)=PP
      X(N)=XX
      RATEV(N+1)=EQN1
      RATEL(N)=RATEL(N-1)-RATEV(N)+FEED+RATEV(N+1)
      GO TO 2230
9999  TOLF=TOLH*ABS(EQN1)
      PRINT 99999,EQN1,EQN2,DIFF,TOLF
99999 FORMAT(5X,'ERR-FTPDWN',3X,'EQN1=',E15.7,'EQN2=',E15.7,
     %3X,'DIFF=',F10.5,5X,'TOL=',F10.5,/)
      GO TO 711
2230  RETURN
      END
```

```
      SUBROUTINE STPDWN(N)
      COMMON FRVAP
      COMMON A(2),B(2),PCOM(2),FRATE,RFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      COMMON /TOLTOL/TOL,TOLH,TOLDA
      COMMON/VARBLS/ X(100),Y(100),T(100),RATEL(100),RATEV(100)
      COMMON/VARBLS/ P(100)
      COMMON/CONREB/ DL,DV,XD,YD,QC,QR,DISTH,BOTTH,XB1,XF1,TFEED
      COMMON/CONREB/ TCOND,XFEED,YFEED,HFEED,VV,OUT
      COMMON/PRSSR/ CONDPD,REBPD,CORECT
C     PLATE TO PLATE CALCULATION IN STRIPPING SECTION---(TOP DOWN)
C-------------------------------------------------------------------------
7     XX=X(N-1)
      YLIM=X(N-1)+.0002
      YY=Y(N-1)
      TT=T(N-1)
      PP=P(N-1)+DELTAP+CORECT
4     CONTINUE
      CALL DEWPT(PP,YY,TOL,TOP)
      RATEL(N-1)=(DL*XD-DL*YY+DV*YD-DV*YY+FRATE*YY-FRATE*XF1)/(YY-X(N-
     %))
      RATEV(N)=(DL*XD-DL*X(N-1)+DV*YD-DV*X(N-1)+FRATE*X(N-1)-FRATE*XF1
     %/(YY-X(N-1))
      EQN=RATEV(N)*HVAVG(YY,TOP)-RATEL(N-1)*HLAVG(XX,TT)+QC+HFEED
      TOLT2=TOLH*(ABS(QC)+ABS(DISTH)+ABS(HFEED))
      IF(WAYA(EQN,DISTH,TOLT2,YY,YLIM,2)) 4,5,9999
5     Y(N)=YY
      T(N)=TOP
      X(N)=Y(N)/EQK(TOP,PP,1)
      P(N)=PP
      GO TO 2230
9999  PRINT 99999,N,DISTH,EQN,TOLT2
99999 FORMAT(5X,'ERR-STPDWN',3X,'STAGE=',I2,'TRUE VALUE=',
     %F15.7,'CALC.VALUE=',F15.7,'TOL=',F10.5,/)
      GO TO 5
2230  RETURN
      END
```

```
      SUBROUTINE SBOTUP(M)
      COMMON FPVAP
      COMMON A(2),B(2),PCON(2),FRATE,KFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      COMMON /TOLTOL/TOL,TOLH,TOLUA
      COMMON/VARBLS/ X(100),Y(100),T(100),RATEL(100),RATEV(100)
      COMMON/VARBLS/ P(100)
      COMMON/CONREB/ DL,DV,XD,YD,QC,QK,DISTH,BOTTH,XB1,XF1,TFEED
      COMMON/CONREB/ TCOND,XFEED,YFEED,HFEED,VV,BOT
      COMMON/PRSSR/ CONDPD,REBPD,CORECT
C     PLATE TO PLATE  CALCULATIONS IN STRIPPING SECTION-(BOTTOM UP)
C---------------------------------------------------------------------------
15    YY=Y(M-1)
      XLIM=Y(M-1)-.0002
      XX=X(M-1)
      TT=T(M-1)
      PP=P(M-1)-DELTAP-CORECT
10    CONTINUE
      CALL BUBBLE(PP,XX,TOL,TBP)
      RATEL(M)=(BOT)*(XB1-Y(M-1))/(XX-Y(M-1))
      RATEV(M-1)=BOT*(XB1-XX)/(XX-Y(M-1))
      EQN=RATEL(M)*HLAVG(XX,TBP)-RATEV(M-1)*HVAVG(YY,TT)+QR
      TOLB1=TOLH*(ABS(QK)+ABS(BOTTH))
C     PRINT 540,M,TBP,PP,XX,EQN,BOTTH
540   FORMAT(5X,'SBOTUP',3X,I2,2X,5E20.5)
541   FORMAT(5X,F10.5)
      IF(WAYA(EQN,BOTTH,TOLB1,XX,XLIM,2)) 10,11,9999
11    X(M)=XX
C     PRINT 541,TOLB1
      T(M)=TBP
      Y(M)=EQK(TBP,PP,1)*X(M)
      P(M)=PP
      GO TO 2230
9999  PRINT 99999,M,BOTTH,EQN,TOLB1
99999 FORMAT(5X,'ERR-SBOTUP',3X,'STAGE=',I2,'TRUE VALUE=',
     %F15.7,'CALC.VALUE=',F15.7,'TOL=',F10.5,/)
      GO TO 11
2230  RETURN
      END
```

```
      SUBROUTINE FBOTUP(M,XYZ,FEED,HF)
      COMMON FPVAP
      COMMON A(2),B(2),PCON(2),FRATE,RFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      COMMON /TOLTOL/TOL,TOLH,TOLDA
      COMMON/VARBLS/ X(100),Y(100),T(100),RATEL(100),RATEV(100)
      COMMON/VARBLS/ P(100)
      COMMON/CONRES/ DL,DV,XD,YD,QC,QR,DISTH,BOTTH,XB1,XF1,TFEED
      COMMON/CONRES/ TCOND,XFEED,YFEED,HFEED,VV,BUT
      COMMON/PRSSR/ CONDPD,REBPD,CORECT
C     FEED ZONE---BOTTOM UP
C-----------------------------------------------------------------------
      YPLACE=Y(M-1)
      TPLACE=T(M-1)
      VPLACE=RATEV(M-1)
      HPLACE=VPLACE*HVAVG(YPLACE,TPLACE)
      XSTRIP=X(M)
      STRIPL=RATEL(M)
      TSTRIP=T(M)
      HSTRIP=STRIPL*HLAVG(XSTRIP,TSTRIP)
      PSTRIP=P(M)
      YY=EQK(TSTRIP,PSTRIP,1)*XSTRIP
      PP=PSTRIP-DELTAP
      XX=XSTRIP
      YLIM=YY-.0002
C     PRINT 540,YPLACE,TPLACE,VPLACE,HPLACE,XYZ,FEED
C     PRINT 540,XSTRIP,STRIPL,TSTRIP,HSTRIP,PSTRIP,YY
C     PRINT 540,HF,XX,XLIM,XYZ,FEED,HF
710   CONTINUE
      CALL BUBPLF(PP,XX,TOL,TT)
      EQN1=(STRIPL*XSTRIP-FEED*XYZ -VPLACE*YPLACE+(FEED +VPLACE-STRIP
     %L)*YY)/(XX-YY)
      EQN2=(HSTRIP-HF    -HPLACE+(FEED +VPLACE-STRIPL)*HVAVG(YY,TSTRIP
     %))/(HLAVG(XX,TT)-HVAVG(YY,TSTRIP))
      DIFF=EQN1-EQN2
C     PRINT 540,PP,TT,EQN1,EQN2,DIFF,XX
540   FORMAT(6(F12.6,3X))
      IF(WAYA(DIFF,0.,TOLH*ABS(EQN1),XX,XLIM,2)) 710,711,9999
711   T(M)=TSTRIP
      X(M+1)=XX
      Y(M+1)=EQK(TT,PP,1)*XX
      T(M+1)=TT
      P(M+1)=PP
      Y(M)=YY
      RATEL(M+1)=EQN1
      RATEV(M)=RATEL(M+1)+FEED +RATEV(M-1)-RATEL(M)
      GO TO 2230
9999  TOLF=TOLH*ABS(EQN1)
      PRINT 99999,EQN1,EQN2,DIFF,TOLF
99999 FORMAT(5X,'ERR-FBOTUP',3X,'EQN1=',E15.7,'EQN2=',E15.7,
     %3X,'DIFF=',F10.5,5X,'TOL=',F10.5,/)
      GO TO 711
2230  RETURN
      END
```

```
      SUBROUTINE RBUTUP(M)
      COMMON FRVAP
      COMMON A(2),B(2),PCON(2),FRATE,RFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      COMMON /TOLTOL/TOL,TOLH,TOLUA
      COMMON/VARBLS/ X(100),Y(100),T(100),RATEL(100),RATEV(100)
      COMMON/VARBLS/ P(100)
      COMMON/CONREB/ DL,DV,XD,YD,QC,QR,DISTH,BOTTH,XB1,XF1,TFEED
      COMMON/CONREB/ TCOND,XFEED,YFEED,HFEED,VV,BUT
      COMMON/PRSSR/ CONDPD,REBPD,CORECT
C     PLATE TO PLATE CALCULATIONS IN RECTIFYING SECTION-(BOTTOM UP)
C---------------------------------------------------------------------------
15    YY=Y(M-1)
      YLIM=Y(M-1)-.0002
      XX=X(M-1)
      TT=T(M-1)
      PP=P(M-1)-DELTAP-CORECT
10    CONTINUE
      CALL BUBBLE(PP,XY,TOL,TBP)
      RATEL(M)=(BUT*(XB1-Y(M-1))+FRATE*(Y(M-1)-XF1))/(XX-Y(M-1))
      RATEV(M-1)=(BUT*(XB1-XX)+FRATE*(XX-XF1))/(XX-Y(M-1))
      FQN=RATEL(M)*HLAVG(XX,TBP)-RATEV(M-1)*HVAVG(YY,TT)+QR+HFEED
      TOLB2=TOLH*(ABS(QR)+ABS(HFEED)+ABS(BOTTH))
C     PRINT 540,M,TBP,PP,XY,FQN,BOTTH
C     PRINT 540,M,TBP,QR,RATEL(M),RATEV(M-1),HFEED
540   FORMAT(5X,'RBUTUP',3X,I2,2X,5E20.5)
541   FORMAT(5X,F10.5)
      IF(WAYA(FQN,BOTTH,TOLB2,XX,XLIM,2)) 10,11,9909
11    X(M)=XX
C     PRINT 541,TOLB2
      T(M)=TBP
      Y(M)=EQK(TBP,PP,1)*X(M)
      P(M)=PP
      GO TO 2230
9909  PRINT 99999,M,BOTTH,FQN,TOLB2
99999 FORMAT(5X,'ERR-RBUTUP',3X,'STAGE=',I2,'TRUE VALUE=',
     %F15.7,'CALC.VALUE=',F15.7,'TOL=',F10.5,/)
      GO TO 11
2230  RETURN
      END
```

```
      SUBROUTINE FDFLSH(T,P,Z,X,Y)
      COMMON FRVAP
C     FEED FLASH ROUTINE
C-----------------------------------------------------------------------
      E1=EQK(T,P,1)
      E2=EQK(T,P,2)
      X=(1.-E2)/(E1-E2)
      Y=E1*X
      FRVAP=(Z-X)/(Y-X)
      RETURN
      END
```

```
      SUBROUTINE REFLUX(ZF1,ZD1,RMIN,R,TFEED,PFEED)
      COMMON FRVAP
      COMMON A(2),B(2),PCUM(2),FRATE,RFACTR,DIST
C     REFLUX RATIO CALCULATION
C-----------------------------------------------------------------------
      F1=EQK(TFEED,PFEED,1)
      F2=EQK(TFEED,PFEED,2)
      SLOPEL=(ZD1-F1*ZF1)/(ZD1-ZF1)
      SLOPEV=(ZD1-ZF1)/(ZD1-ZF1/F1)
      RMINL=SLOPEL/(1.-SLOPEL)
      RMINV=SLOPEV/(1.-SLOPEV)
      RMIN=((1.-FRVAP)*RMINL)+(FRVAP*RMINV)
      R=RFACTR*RMIN
      RETURN
      END
```

```
      SUBROUTINE FLASH(SPLIT,P,Z,T)
      COMMON /TOLTOL/TOL
C     FLASH CALCULATION
C----------------------------------------------------------------------------------
      CALL DEWPT(P,Z,TOL,T1)
      CALL BUBBLE(P,Z,TOL,T2)
      T=T2+0.05
      TBIG=T1-0.05
1     E1=EOK(T,P,1)
      E2=EOK(T,P,2)
      A=((Z*(E1-E2)/(1.0-E2))-1.0)/(E1-1.0)
      IF(WAYA(A,SPLIT,TOL,T,TBIG,1)) 1,2,3
2     RETURN
3     PRINT 999,T
999   FORMAT(15X,'ERROR IN FLASH CALCULATION---THE LAST TEMPERATURE
     %WAS'.F12.7)
      PRINT 99999
99999 FORMAT(10X,'THIS TEMPERATURE GIVES LEAST ERROR AND WILL BE USED
     %TO CONTINUE THE CALCULATIONS')
      RETURN
      END
```

```
      SUBROUTINE DEWPT(P,Y,TOL,T)
      COMMON SLOP(11),TTOP,TBOT
C     DEW POINT CALCULATION
C-------------------------------------------------------------------
      DT=AMAX1(TBOT-TTOP,50.)
      T=TTOP-DT
      TBIG=TBOT+DT
1     E1=EQK(T,P,1)
      E2=EQK(T,P,2)
      A=(Y/E1)*(1./E2)-(Y/E2)
      IF(WAYA(A,1.,TOL,T,TBIG,1)) 1,2,3
2     RETURN
3     PRINT 999,T
999   FORMAT(15X,'ERROR IN DEW POINT CALCULATION-THE LAST TEMPERATURE
     % WAS',3X,F12.7)
      PRINT 99999
99999 FORMAT(10X,'THIS TEMPERATURE GIVES LEAST ERROR AND WILL BE USED
     %TO CONTINUE THE CALCULATIONS')
      RETURN
      END
```

```
      SUBROUTINE BUBBLE(P,X,TOL,T)
      COMMON SLOP(11),TTOP,TBOT
C     BUBBLE POINT CALCULATION
C-------------------------------------------------------------------------
      DT=AMAX1(TBOT-TTOP,50.)
      T=TTOP-DT
      TBIG=TBOT+DT
1     E1=EQK(T,P,1)
      E2=EQK(T,P,2)
      A=X*(E1-E2)+E2
      IF(WAYA(A,1.,TOL,T,TBIG,1)) 1,2,3
2     RETURN
3     PRINT 999,T
999   FORMAT(15X,'ERROR IN BUBBLE POINT CALCULATION-THE LAST TEMP.WAS'
     %3X,F12.7)
      PRINT 99999
99999 FORMAT(10X,'THIS TEMPERATURE GIVES LEAST ERROR AND WILL BE USED
     %TO CONTINUE THE CALCULATIONS')
      RETURN
      END
```

```
      FUNCTION EQK(T,P,J)
      COMMON FRVAP
      COMMON A(2),B(2),PCUM(2)
C     CALCULATION OF EQUILIBRIUM CONSTANT
C-----------------------------------------------------------------------
      EQK=EXP(A(J)+B(J)/(T+460.))/P
      RETURN
      END
```

```
      FUNCTION HLAVG(X,T)
C     CALCULAITON OF LIQUID MOLAL AVERAGE ENTHALPY.
C------------------------------------------------------------------------
      COMMON FEVAP
      COMMON A(2),B(2),FCOM(2),FRATE,KFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      DIMENSION HLIQ(2)
      DO 1 I=1,2
1     HLIQ(I)=AHL(I)+BHL(I)*(T+460.)
      HLAVG=X*(HLIQ(1)-HLIQ(2))+HLIQ(2)
      RETURN
      END
```

```
      FUNCTION HVAVG(Y,T)
C     CALCULATION OF VAPOR MOLAL AVERAGE ENTHALPY.
C-------------------------------------------------------------------------------
      COMMON FRVAP
      COMMON A(2),B(2),PCON(2),FRATE,RFACTR,DIST
      COMMON DELTAP,TTOP,TBOT
      COMMON AHL(2),BHL(2),AHV(2),BHV(2)
      DIMENSION HVAP(2)
      DO 1 I=1,2
1     HVAP(I)=AHV(I)+BHV(I)*(T+460.)
      HVAVG=Y*(HVAP(1)-HVAP(2))+HVAP(2)
      RETURN
      END
```

```
      FUNCTION WAYA(A,ANS,TOL,START,STOP,LEVEL)
C     ROUTINE TO CONVERGE ON SINGLEVALUED FUNCTION
C     A=CURRENT VALUE OF DEPENDENT VARIABLE
C     ANS=DESIRED VALUE OF DEPENDENT VARIABLE
C     TOL=TOLERANCE
C     START=CURRENT VALUE OF INDEPENDENT VARIABLE
C     A BETTER VALUE RETURNED
C     STOP=LIMIT OF INDEPENDENT VARIABLE. ANSWER BETWEEN START AND
C          STOP.
C     LEVEL=1,2,OR 3 AS AN INDEX FOR MULTILEVEL USE.
C
C     WAYA WILL VARY START BETWEEN ITS INITIAL VALUE AND STOP UNTIL
C     ABS(ANS-A).LE.TOL OR 30 TRIALS TAKEN
C     ON EXIT WAYA IS:
C          -FOR NOT CONVERGED. REPEAT CALCS. WITH NEW VALUE IN START.
C          0  FOR CONVERGED IN LIMITS OR 30 TRIALS TAKEN.
C          + FOR CANNOT CONVERGE.START=INITIAL VALUE OR STOP
C     ---WHICHEVER GIVES LESSER ERROR, OR ITS INITIAL VALUE IF LEVEL
C     IS NEGATIVE.
C----------------------------------------------------------------------
C
      DIMENSION X1(4),X2(4),Y1(4),Y2(4),KOUNT(4)
      DATA KOUNT/4*0/
C     SET X,Y,AND LEVEL
      X=START
      Y=ANS-A
      L=IABS(LEVEL)
      WAYA=1.0
C     SEE IF CONVERGED
      IF(ABS(Y).LE.TOL) GO TO 70
C     NOT CONVERGED.SEE WHICH CALL.
      IF(KOUNT(L)) 80,30,10
C     SECOND OR HIGHER CALL. SEE IF Y ANDY1(L) BRACKET ANSWER.
10    IF(Y*Y1(L).LT.0.0) GO TO 20
C     NO Y-Y1 BRACKET. SEE IF SECOND OR HIGHER CALL
      IF(KOUNT(L).GT.1) GO TO 30
C     NO BRACKET AT ALL.  RE-DO AT START IF THAT LIMIT IS CLOSER OR IF
C     LEVEL IS MINUS.
      IF(ABS(Y).LE.ABS(Y1(L)).AND.LEVEL.GT.0) GO TO 80
      X=X1(L)
      KOUNT(L)=-1.
      GO TO 60
C     Y-Y1 BRACKET. STORE X&Y IN X2(L) AND Y2(L).
20    X2(L)=X
      Y2(L)=Y
      GO TO 40
C     FIRST CALL OR CONVERGING Y-Y2 BRACKET CALL. STORE X&Y IN X1 &Y1.
30    X1(L)=X
      Y1(L)=Y
      X=STOP
      IF(KOUNT(L).EQ.0) GO TO 50
C     INTERPOLATE NEW X AND CONTINUE OR QUIT DEPENDING ON KOUNT(L).
40    X=(X1(L)*(3.*Y2(L)-Y1(L))+X2(L)*(Y2(L)-3.*Y1(L)))/(4.*(Y2(L)-
     %Y1(L)))
      IF(KOUNT(L).GE.30) GO TO 70
50    KOUNT(L)=KOUNT(L)+1
60    WAYA=-1.0
      GO TO 90
C     CONVERGED OR TOO MANY TRIALS
70    WAYA=0.0
```

```
80    KOUNT(L)=0
C     SET NEW VALUE OF INDEPENDENT VARIABLE.
90    START=X
      RETURN
      END
```

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