CASE STUDY FOR INSTALLATION OF A RETROFITTED INTERMEDIATE REBOILER ON AN INDUSTRIAL DEPROPANIZER FOR MINIMUM ENERGY CONSUMPTION

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PREFACE

Due to escalating fuel prices beginning in the early 1970's refinery, petrochemical, and chemical plant management personnel have had to shift their philosophy from one of building larger production units to that of upgrading or retrofitting existing units to improve their energy efficiency.

In order to examine one possiblity of a distillation retrofit, a case study has been performed on the installation of a retrofitted intermediate reboiler on an industrial depropanizer for minimum energy consumption.

I would like to express my sincere thanks to Dr. Ruth Erbar for her patience, time and constructive criticism that are evident throughout this work. I would also like to thank Jay Rhoades, John Howell and Carlos Ruiz for their help and comments in this work.

Finally, I would like to thank my parents, Gene and Adeline Johnson, for their encouragement without which this work would not have been possible.

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NOMENCLATURE

English Letters

B	=	bottom product flowrate, lbmoles/hr
CE	=	annual electrical cost, $/yr
C_p	=	heat capacity of reflux, Btu/(lbmole deg. F.)
CS	=	annual steam cost, $/yr
CW	=	annual cooling water cost, $/yr
D	=	distillate product flowrate, lbmoles/hr
F	=	feed flowrate, lbmoles/hr
H_C	=	heat of condensation, Btu/lbmole
H_V	=	heat of vaporation, Btu/lbmole
L	=	internal liquid rate below feed plate and above intermediate reboiler, lbmoles/hr
L_{IR}	=	liquid pumparound circulation rate from intermediate reboiler, lbmoles/hr
L_{min}	=	minimum liquid downflow rate, lbmoles/hr
L_R	=	liquid rate below intermediate reboiler, lbmoles/hr
Q_C	=	main condenser heat load, KBtu/hr
Q_{min}	=	minimum heat addition, KBtu/hr
Q_R	=	main reboiler heat load, KBtu/hr
R_E	=	external reflux rate, lbmoles/hr
R_I	=	internal reflux rate, lbmoles/hr
R_{TT}	=	liquid condensed from top tray vapor, lbmoles/hr
S	=	entropy, Btu/(lbmole deg. R)

T_C = condenser temperature, deg. R

T_o = ambient temperature, deg. R

T_R = reboiler temperature, deg. R

W_n = net work consumption, KBtu/hr

W_{min} = reversible work consumption, KBtu/hr

V_B = internal vapor rate below feed plate, lbmoles/hr

V_{IR} = product vapor pumparound circulation rate from intermediate reboiler, lbmoles/hr

V_f = feed fraction vapor

V_R = internal vapor rate from main reboiler, lbmoles/hr

V_T = vapor rate entering top tray, lbmoles/hr

V_{TT} = vapor rate leaving top tray, lbmoles/hr

z_F = feed composition, mole fraction

Greek Letters

η = thermodynamic efficiency

λ = latent heat of vaporization, KBtu/lbm

CHAPTER I

INTRODUCTION

Beginning in the early 1970's, retrofit projects designed to improve a units energy efficiency have become economically more feasible due to rising fuel prices. Since distillation has been shown to be an extremely inefficient user of energy (39), it has been the target of many energy improvement studies.

One possibility of a distillation retrofit is the use of intermediate reboilers and condensers. To further investigate their possible applications, the objective of this work was to evaluate both the economic and design implications associated with the installation of a retrofitted intermediate reboiler on an industrial depropanizer for minimum energy consumption.

Process flow and process and instrumentation diagrams of the depropanizer have been provided and are located in Appendices B and C, respectively. Column equipment specifications and 1983 test run results of the depropanizer are located in Appendices D and E, respectively.

It should be noted that the results of this study are not to be generalized to other depropanizers as they would have to be evaluated individually.

CHAPTER II

REVIEW OF THE LITERATURE

The literature contains an enormous amount of information concerning distillation energy consumption and techniques for its reduction. The following is a brief review of the literature concerning the application of intermediate reboilers and condensers.

In 1947 Benedict (4) noted that in a thermodynamically ideal distillation a minimum net flow of heat, given by:

$$Q_{min} = \quad L_{min} \tag{2.1}$$

where Q_{min} = minimum heat input, KBtu/hr

λ = latent heat of vaporization, KBtu/lbm

L_{min} = minimum liquid downflow rate, lbm/hr

would be maintained at every tray in the column by the installation of intermediate reboilers in the stripping section and a minimum net flow of heat removed by intermediate condensers in the enriching section. This would theoretically permit only the minimum vapor and liquid interstage flows to be maintained.

In a conventional column, however, an excess amount of heat must be added in the reboiler to maintain the necessary vapor and liquid interstage flows. Because a signficant percentage of this added heat must be removed in the condenser, only a fraction of the added heat would be required to perform the work of the separation.

In 1947 Edmister (11) noted that this method of adding intermediate reboilers and condensers in the column did not impair the fractionation efficiency but improved the thermodynamic efficiency and decreased the column loading at points where the vapor or liquid interstage flows are high.

In 1961 Freshwater (19) evaluated the use of a heat pump which incorporated an intermediate reboiler and condenser in a multicomponent distillation column. By placing the heat pump across a pinch zone, (region in which the Δ temperature/Δ tray is negligible), instead of across the entire column, the efficiency and feasibility of using the heat pump would be greatly improved.

In 1965 Niedzwiecki (38) investigated the use of intermediate reboilers and condensers on an industrial debutanizer. He observed the following:

1. In designs which deviated from constant molal overflow, the fractionation efficiency could be improved.

2. For columns operating at maximum capacity, the column capacity could be increased.

In 1969 Timmers (51) determined that a minimum column volume could be obtained by adjusting the reflux at every tray by using intermediate reboilers and condensers. However, since the use of these intermediate systems added to the complexity of the design, there would only be a few cases where a payout could be achieved.

In 1977 Petterson and Wells (42) discussed energy saving techniques in distillation and emphasized the importance of understanding the relationships between capital, operating cost and plant operability. With respect to intermediate reboilers and condensers the following points were mentioned for study when investigating their use for energy conservation:

1. The heating and cooling levels available to the engineer will determine the point of application of intermediate condensers and intermediate reboilers.

2. The use of intermediate reboilers and condensers alters the overall tower height, diameter and heat transfer area.

3. The overall operating cost of a distillation system is modified by the use of intermediate reboilers and condensers.

4. The system should be evaluated for flexibility and reliability with respect to changes in feed rate and feed composition.

In 1980 Naka, et al. (37) presented a paper on the energy saving effects of intermediate reboilers and condensers using the concept of "exergy". The American term for this concept is "available energy". Exergy, in terms of heat flow is defined as:

$$\text{Exergy} = Q_i\,[1 - (T_o/T_i)] \qquad (2.2)$$

where Exergy = (Useful Work), KBtu/hr

Q_i = heat flow, KBtu/hr

T_o = ambient temperature, deg. R

T_i = temperature of heat source, deg. R

They proved that the exergy loss of a column with either an intermediate reboiler or condenser is less than a conventional column.

In 1980 Kayihan (24) determined that the use of intermediate reboilers and condensers is:

1. Equivalent in magnitude with respect to their improvement of thermodynamic efficiency.

2. Operate independently of each other.

3. Symmetric about a feed composition, z=0.5.

4. The more dominant improvement in thermodynamic efficiency is due to the addition of the first intermediate reboiler or condenser with subsequent ones having decreasing effects.

In 1980 Bannon and Marple (1) noted that the use of intermediate condensers or pumparounds is common in columns with sidedraws (crude columns and catalytic cracking unit main fractionators). The pumparound steams on these columns being used to extract heat for reuse and to balance the column vapor loading.

Three factors were involved in the design of the intermediate condenser/pumparound:

1. The number of pumparound systems.

2. Placement of the pumparound.

3. Circulation rate.

In 1980 Stephenson and Anderson (50) restated the concepts of Benedict (4) and Edmister (11) that the thermodynamic efficiency could be improved by maintaining the minimum reflux ratio for each plate in each section of the column. This could theoretically be achieved by having an infinite number of plates and either a small reboiler or condenser on each plate.

They mentioned three cases where the use of intermediate reboilers/condensers could be justified:

1. Columns having a wide temperature difference between the distillate and bottom product.

2. Columns which could use a cheaper steam source at an intermediate location in the column.

3. Columns which operate with a refrigerated condenser.

In 1981 Mix, et al. (36) presented an extensive review of energy conservation techniques in distillation. They reported that the large inefficiency associated with distillation is a result of two factors:

1. The large temperature difference between the reboiler and condenser.

2. The vapor and liquid flows not being in equilibrium.

Intermediate reboilers and condensers would improve both of these inefficiencies by reducing the total temperature difference of the column. Consequently, the separation is accomplished with a less expensive energy input. Mix et al. (36) listed the following guidelines for possible application of intermediate reboilers and condensers:

1. Intermediate condenser - condenser coolant temperature less than 100 deg. F or less than 0.3 mole fraction heavy key in the feed.

2. Intermediate reboiler - reboiler heating medium temperature greater than 300 deg. F. or less than 0.3 mole fraction light key in the feed.

In 1983 Lieberman (28) discussed the design aspects of retrofitting a column with a lower temperature intermediate reboiler to reduce the energy consumption. He noted that the installation of the intermediate reboiler would require a new draw-off nozzle and trap-out pan with the liquid from the new draw-off nozzle being piped to the intermediate reboiler set at grade.

In 1983 Linnhoff, et al. (30) observed that for an isolated column intermediate reboilers and condensers are only likely to be advantageous for a large temperature difference across the column, for example, a wide boiling feed.

Two cases were mentioned for application of the intermediate reboilers and condensers:

Case 1. Distillation across the process pinch. If the column is situated across the process pinch it should be shifted away by lowering the column pressure. However, if this is not feasible, intermediate reboilers and condensers could be used to achieve energy saving through energy integration.

Case 2. Distillation not across the pinch. If the column is not operating across the pinch but there is insufficient heat flow at some temperature level to integrate the total heat load, then intermediate reboilers and condensers would help the situation.

In 1983 Payne (41), listed the following guidelines for application of intermediate reboilers and condensers:

1. Since significant changes occur in the vapor and liquid interstage flows, their use is generally applicable only to new column design. However, their use could be considered if done concurrently with retraying.

2. Strong consideration should be given to columns exhibiting significant degrees of nonideality.

3. Columns where other intermediate levels of heating and cooling are available.

4. Columns with a large temperature difference and which use expensive forms of energy such as high-pressure steam or refrigeration.

5. Columns where a heat pump is being considered but the overall column temperature difference is too large.

The majority of the previous work that has been done on this subject has consisted of providing guidelines for the application of intermediate reboilers and condensers. The depropanizer selected in this study had not been previously evaluated for the installation of a retrofitted intermediate reboiler for minimum energy consumption. The following specific items were analyzed for the retrofit:

1. Overall process heat integration.
2. Column internal loading.
3. Optimum side draw and return trays for the intermediate reboiler.
4. Optimum duty for the intermediate reboiler.
5. Optimum circulation rate for the intermediate reboiler.
6. Equipment constraints.
7. Annual operating cost.
8. Project payout period.

CHAPTER III

THERMODYNAMIC ASPECTS OF DISTILLATION ENERGY CONSUMPTION

There are four important thermodynamic identities to consider with respect to distillation energy consumption.

1. 1st Law of Thermodynamics.
2. Lost Work.
3. Availability.
4. Thermodynamic Efficiency.

1st Law of Thermodynamics

System: Contents of the tower, condenser, reboiler and interconnecting piping, Figure 1.

Accounting Period: Steady State

The Energy Balance

$$\Sigma Q + \Sigma M_i(H + KE + PE)_i = \Sigma W + \Sigma M_o(H + KE + PE)_o + \frac{dU}{dt} \qquad (3.1)$$

where ΣQ = summation of heat transfer rates across the system boundaries, KBtu/hr

$(H + KE + PE)_i$ = enthalpy, kinetic energy and potential energy, respectively, entering the system boundary, KBtu/lbmole

$(H + KE + PE)_o$ = enthalpy, kinetic energy and potential energy, respectively, leaving the system boundary, KBtu/lbmole

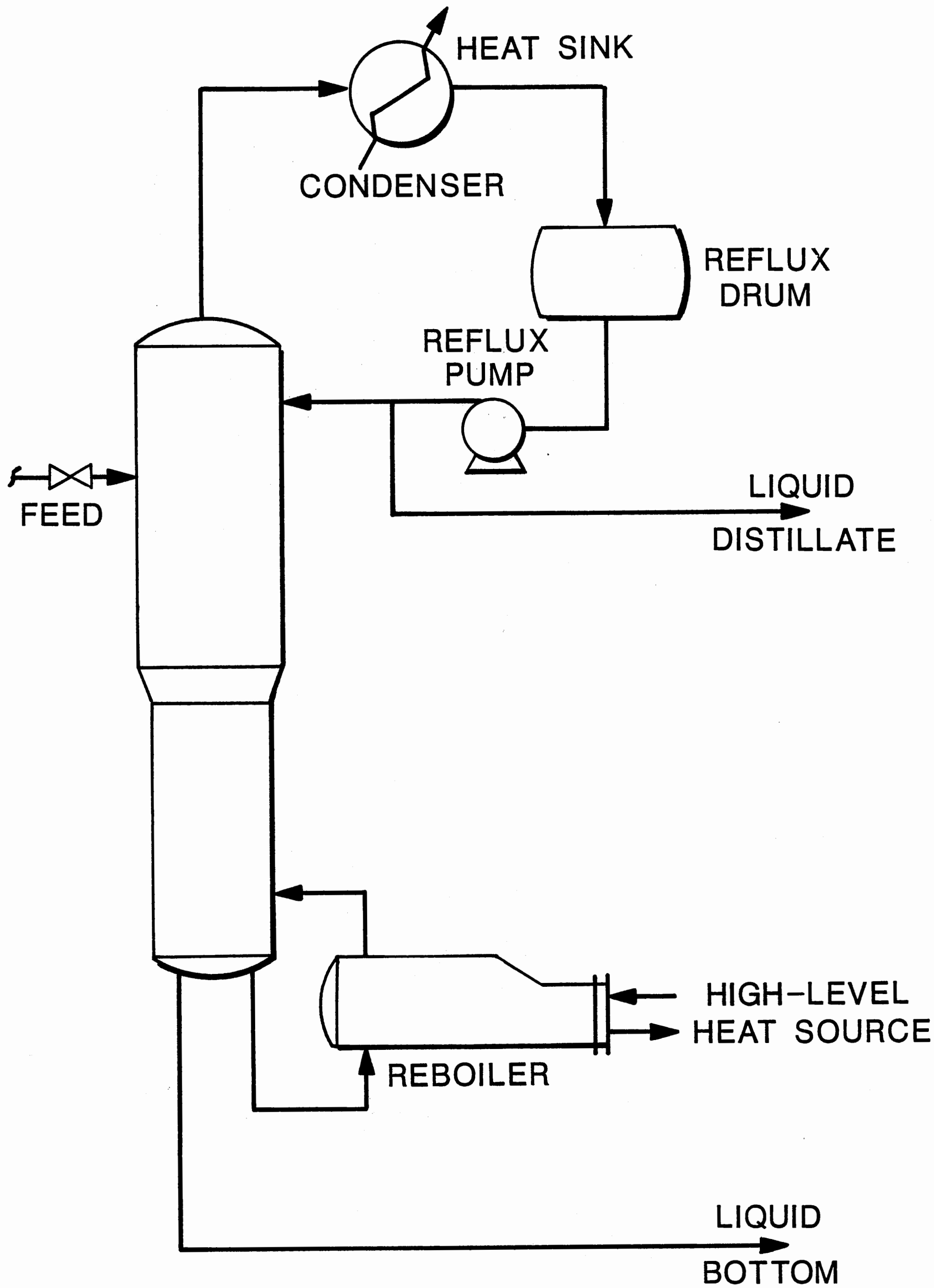

Figure 1. Conventional Distillation System

M = molar flow rate of stream entering (i) or leaving (o) the system boundaries, lbmoles/hr

W = summation of work performed either by the system or on the system, KBtu/hr

$\frac{dU}{dt}$ = differential change in internal energy within the system boundaries, KBtu/hr

For a steady state process and neglecting any potential or kinetic energy effects, the energy balance reduces to the following for a typical distillation column.

$$Q_R - Q_C + M_F H_F = - W_P + M_D H_D + M_B H_B \tag{3.2}$$

A distillation column with a retrofitted intermediate reboiler is shown in Figure 2 and the energy balance for this system reduces to the following:

$$Q_{IR} + Q_R - Q_C + M_F H_F = -W_P - W_{CP} + M_D H_D + M_B H_B \tag{3.3}$$

where Q_R = reboiler heat load, KBtu/hr

Q_{IR} = intermediate reboiler heat load, KBtu/hr

Q_C = condenser heat load, KBtu/hr

H_F = enthalpy of the feed, KBtu/lbmole

W_P = pump work, KBtu/hr

W_{CP} = pumparound circulation pump work, KBtu/hr

H_D = enthalpy of the distillate, KBtu/lbmole

H_B = enthalpy of the bottom, KBtu/lbmole

M = molar flow rate of feed (F), distillate (D) and bottom (B), lbmoles/hr

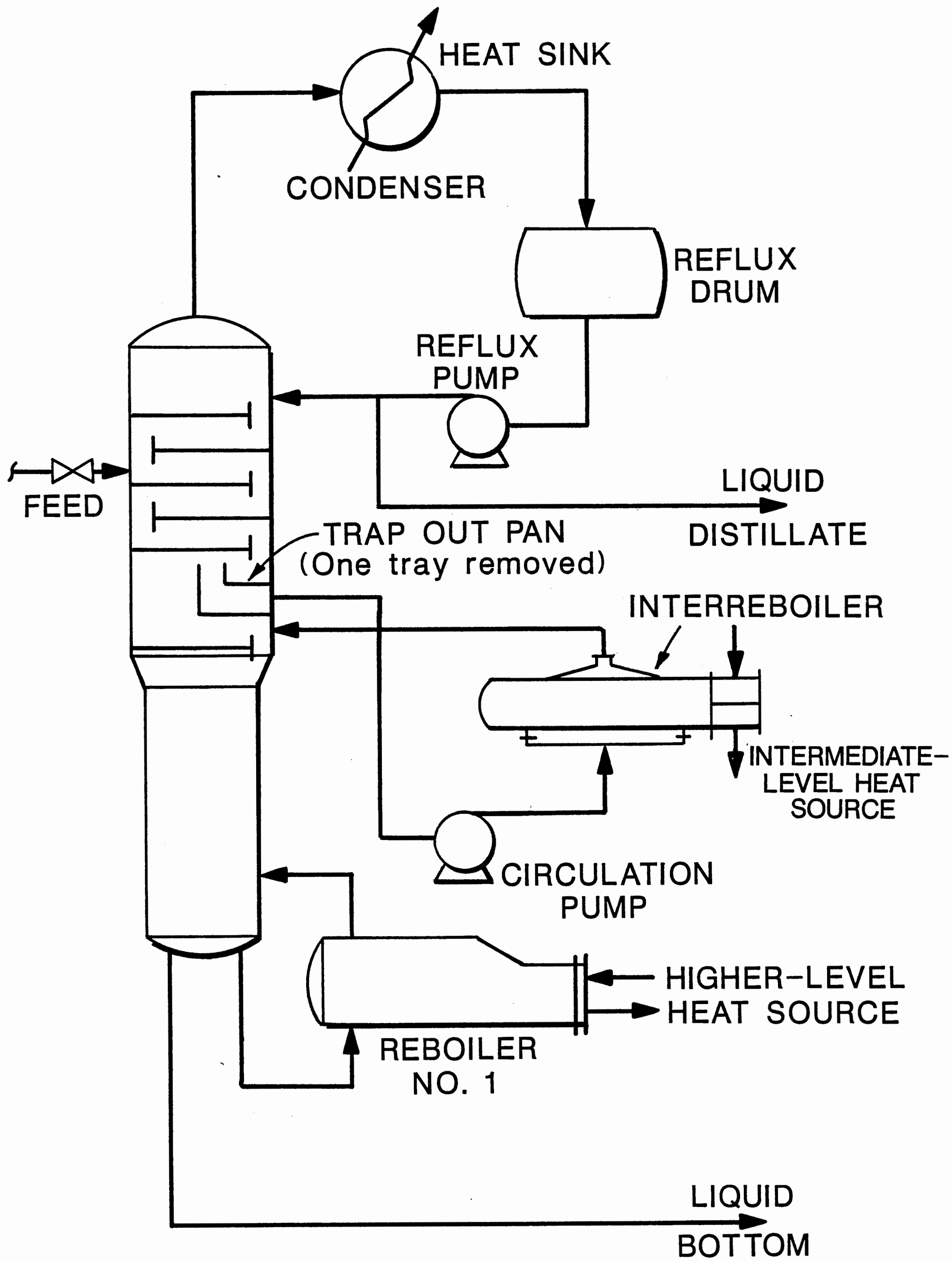

Figure 2. Distillation Column Using A Retrofitted Intermediate Reboiler

Lost Work

The concept of "Lost Work" will be calculated from the entropy balance given below:

$$S_E - S_B = S_t + \Sigma \frac{Q}{T_b} + S_P - S_C \qquad (3.4)$$

where S_E = entropy within the system boundaries at the end of the accounting period, KBtu/Hr deg. R

S_B = entropy within the system boundaries at the beginning of the accounting period, KBtu/Hr deg. R

S_t = entropy transferred across the system boundaries as a result of mass transfer, KBtu/Hr deg. R

$\Sigma \frac{Q}{T_B}$ = entropy transferred across the system boundary which is not a direct result of any mass transfer, KBtu/Hr deg. R

T_B = temperature of the boundary, deg. R

S_P = entropy production within the system boundaries during the accounting period, KBtu/Hr deg. R

S_C = entropy consumption within the system boundaries during the accounting period KBtu/Hr deg. R

For a steady state process and neglecting the entropy of consumption the "entropy balance" reduces to the following:

$$S_0 - S_I - \Sigma \frac{Q}{T_B} = S_P \qquad (3.5)$$

where S_I = entropy of process stream entering the system boundary, KBtu/Hr deg. R

S_0 = entropy of process stream leaving the system boundary, KBtu/Hr deg. R

Rearranging equation 3.5 the following expression is obtained for the Lost Work, $T_B S_p$:

$$\text{Work}_{\text{Lost}} = T_B\,(S_0 - S_I) - \Sigma\, Q \qquad (3.6)$$

where $Work_{Lost}$ = work lost due to irreversibilities within the system, KBtu/hr

Availability

The concept of availability described briefly in Chapter II is a second means of analyzing the energy utilization of a distillation system. Several papers have been written on the subject (17,37,55).

Thermodynamic Efficiency

Thermodynamic efficiencies for distillation have been reported in terms of both 1st and 2nd Law expressions.

A. 1st Law Efficiency (26,10)

The following equation (3.7) is a ratio of the minimum reversible work to the actual work required to accomplish the separation.

$$\eta = \frac{W_{min,T_o}}{W_n} = \frac{\Delta H - T_o \Delta S}{\Sigma W_p + \Sigma Q_i (1 - \frac{T_o}{T_i})} \qquad (3.7)$$

Equation 3.7 will be used to calculate the thermodynamic efficiency in this report.

CHAPTER IV

MINIMUM ENERGY CONSUMPTION DEFINED

Minimum energy consumption in a typical two product column is achieved by controlling product compositions on both ends of the column (34). By specifying both product compositions, x_D (heavy key) and x_B (light key), the energy balance, which is a function of the reflux rate and vapor boilup, is determined.

This can be explained by the following mathematical analysis:

Overall Material Balance

$$F = D + B \quad (4.1)$$

Heavy Key Material Balance

$$x_F(HK)F = x_D(HK)D + x_B B \quad (4.2)$$

Light Key Material Balance

$$x_F(LK)F = x_D D + x_B(LK)B \quad (4.3)$$

Summation of Mole Fractions

Distillate $\quad \Sigma\, x_i = 1.0 \quad (4.4)$

Bottom $\quad \Sigma\, x_i = 1.0 \quad (4.5)$

Energy Balance

$$Q_R - Q_C + FH_F = W_P + DH_D + BH_B \quad (4.6)$$

where: H_F = enthalpy of the feed, KBtu/lbmole

H_D = enthalpy of the distillate, KBtu/lbmole

H_B = enthalpy of the bottom, KBtu/lbmole

Equation 4.6 can also be rewritten as follows:

$$(V_R\ H_V) - (R_E + D)\ H_C + FH_F = DH_D + BH_B \tag{4.7}$$

where only the thermal energies have been taken into consideration.

In the above set of equations (4.1,4.2,4.3,4.4,4.5,4.7) the following variables are unknown:

1. D, distillate rate, lbmoles/hr.
2. B, bottom rate, lbmoles/hr.
3. $x_D(LK)$, mole fraction light key in the distillate.
4. $x_B(HK)$, mole fraction heavy key in the bottom.
5. V_R, vapor boilup rate from partial reboiler, lbmoles/hr.
6. R_E, external reflux rate, lbmoles/hr.

There are, however, six equations and six unknowns meaning that the system of equations has zero degrees of freedom and the material and energy balance are thus specified.

It is important to note that of the unknown variables listed in Equations 4.1-4.7, V_R and R_E are determined by the energy balance and are consequently the primary variables used to manipulate the energy balance of the column as well as the internal vapor and liquid interstage flows.

CHAPTER V

STEADY STATE INTERNAL FLOW MODEL FOR A DISTILLATION COLUMN USING A RETROFITTED INTERMEDIATE REBOILER

As described in Chapter IV, a typical two product columns energy balance is manipulated primarily by the vapor boilup and external reflux rate. These variables provide a means of manipulating the columns internal circulation rate.

Following the approach of Smith et al (48), a steady state internal flow model for a two product distillation column using a retrofitted intermediate reboiler has been developed.

Figure 3 depicts a steady state internal flow model using a retrofitted intermediate reboiler.

With the assumption of constant molal overflow, the steady state internal flow model would consist of the following mathematical relationships.

Vapor Boilup Rate

The vapor boilup rate V_R equals the heat added by the reboiler divided by the heat of vaporization.

$$V_R = Q_B/H_V \tag{5.1}$$

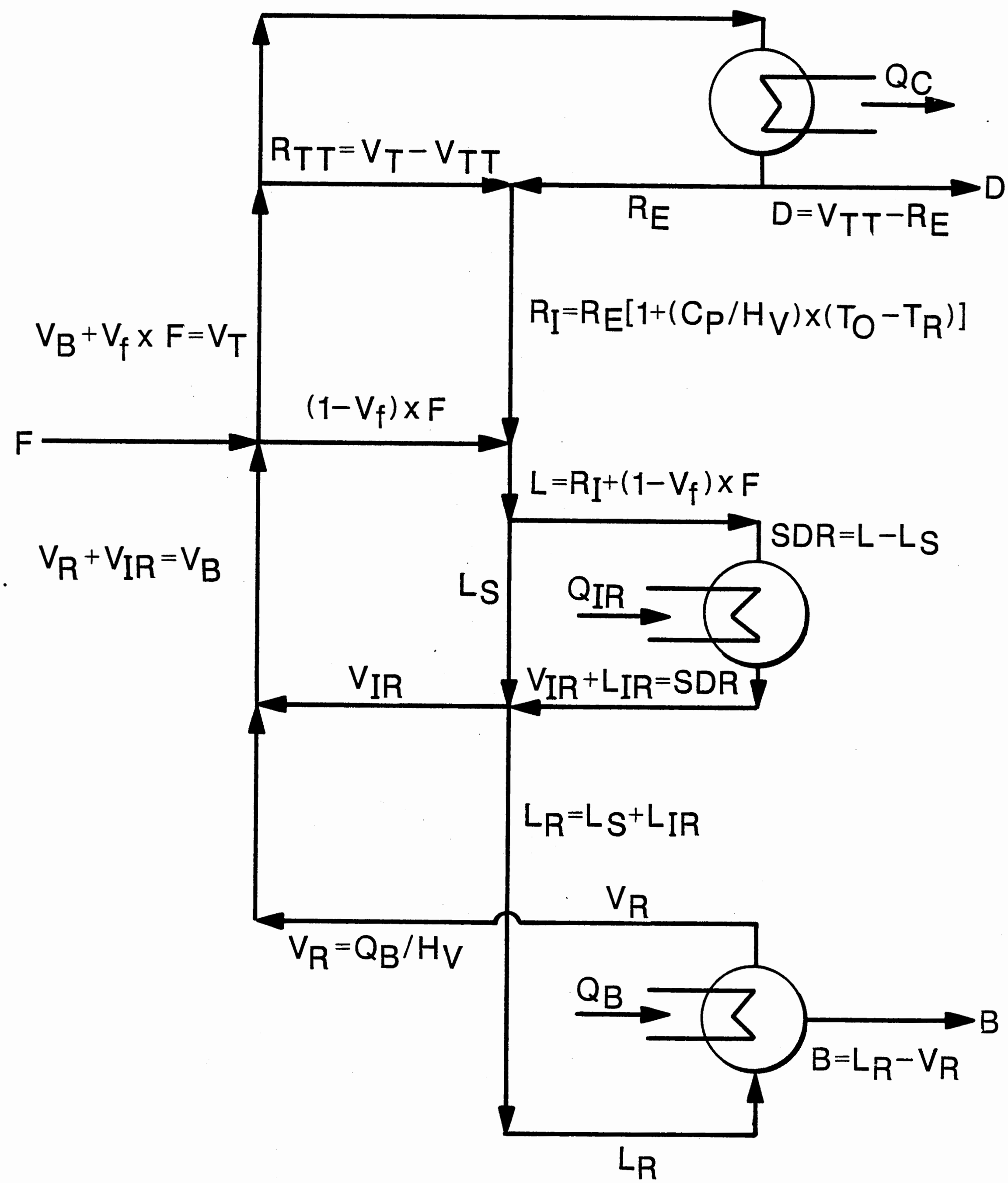

Figure 3. Steady State Internal Flow Model For Distillation Column Using A Retrofitted Intermediate Reboiler

Vapor Rate Entering Top Tray

The vapor rate entering the top tray equals the vapor rate below the feed plate plus the fraction of vapor in the feed.

$$V_T = V_B + V_f F \quad (5.2)$$

Internal Reflux Rate

The internal reflux rate equals the external reflux rate R_E plus the vapor condensed in order to raise the reflux to its bubble point,

$$R_I = R_E [1 + (C_p/H_V) (T_o - T_R)] \quad (5.3)$$

Liquid Rate Below Feed Plate and Above Intermediate Reboiler Side Draw

The liquid rate equals the internal reflux rate plus the fraction of liquid in the feed.

$$L = R_I + (1 - V_f) F \quad (5.4)$$

Liquid Rate Below Intermediate Reboiler

The liquid rate below the intermediate reboiler equals the liquid not removed in the side draw plus the liquid not vaporized in the intermediate reboiler.

$$L_R = L_S + L_{IR} \quad (5.5)$$

Vapor Rate Below The Feed Plate

The vapor rate below the feed plate equals the vapor boilup rates from the reboiler and intermediate reboiler.

$$V_B = V_R + V_{IR} \quad (5.6)$$

Distillate Rate

The distillate rate equals the top tray vapor rate minus the external reflux rate.

$$D = V_{TT} - R_E \tag{5.7}$$

Bottom Rate

The bottom rate equals the liquid rate L_R minus the vapor boilup V_R.

$$B = L_R - V_B \tag{5.8}$$

The above provides a brief explanation of the internal flows in a distillation column using a retrofitted intermediate reboiler.

CHAPTER VI

COMPUTER SIMULATION AND DESIGN RATIONALE

Column Choice

The column chosen for experimental study was an industrial depropanizer. Appendices B and C contain a process flow diagram and a process and instrumentation diagram of the column, respectively. Appendix E contains the equipment specification for the column. This column was chosen because a depropanizer resembles many other column designs and would therefore serve as a good basis for analysis.

The column contains parallel reboilers (a steam heated reboiler and a process heated reboiler), of which only one is operational. The steam reboiler does not have any bottom circulation through it and is only operational for brief periods during the winter months. The process heated reboiler has as its heating medium a debutanizer bottom product and is therefore using "free energy" to maintain the interstage vapor/liquid flows.

Product Specifications

As stated in Chapter IV, energy is minimized by controlling compositions at both ends of the column. The depropanizer will be simulated for the following split:

1. $x_D(1\text{-}C_4H_8) = 0.042$

2. $x_B(C_3H_8) = 0.039$

These correspond to the distillate and bottom product specifications which were obtained during the July 27-29, 1983 test run of the depropanizer, Appendix D. These product specifications will be taken as maximum impurity specifications. Other column operating parameters, such as column pressure and feed % vaporization, will be specified to be identical to specifications obtained from the process flow diagram Appendix B.

Intermediate Reboiler Options

Three options are available for the choice of an intermediate reboiler (3,9):

1. Kettle reboiler.
2. Thermosiphon reboiler.
3. Pumparound reboiling by means of an oversized bottom pump.

In order to provide for both ease of operation and low rates of vaporization the most appropriate choice for the intermediate reboiler is the forced circulation reboiler.

Pumparound Simulation

The pumparound loop will be simulated as two unit operations:

1. Pump Unit Operation - A side draw will be removed from the column and the side draw liquid will be pumped to a discharge pressure of 190 psia. This will allow for any pressure drop through the pumparound system and also allow the heated liquid to be returned to a

tray two trays below the side draw which would operate at a higher pressure.

2. Heater/Cooler Unit Operation (Intermediate Reboiler) - The liquid leaving the pump will be heated in a heater/cooler unit operation. This unit will be specified to have an L/F of 0.85 or 15 molar percent vaporization and a pressure drop of 1 psi.

Optimum Column Operation

Optimum column operation will be defined in this study as a minimum in total system operating cost, given by:

$$TCO = CS + CW + CE \qquad (6.1)$$

where TCO = annual operating cost, \$/year

CS = annual steam cost, \$/year

CW = annual water cost, \$/year

CE = annual electrical cost, \$/year

and also within the operating constraints of the major equipment, (column, condenser and reboiler).

The following items are to be determined:

1. Optimum feed tray location
2. Optimum feed enthalpy
3. Optimum side tray and return tray for the intermediate reboiler
4. Optimum duty for intermediate reboiler
5. Optimum circulation rate for the intermediate reboiler

Computer Simulation System

MAXISIM (14), a dual purpose complete process design simulation system/simple equilibrium calculation program, was used for simulation purposes. The tray x tray distillation program in the system is a rigorous distillation column simulation which can accept up to 10 feeds, produce up to 10 products and accept up to 8 side heater/coolers in addition to the reboiler and condenser.

The system uses the Soave-Redlich-Kwong equation of state for thermodynamic property predictions. For a simple discrete component fractionator such as a depropanizer, the K values and enthalpies predicted by the equation of state should be in good agreement with experimental values and would therefore give an accurate representation of the column energy usage (13,15).

Graphics

In order to better visualize the internal column operation, the tray x tray results were written to a file and graphed using SAS. SAS is a multipurpose software system available on the Oklahoma State University Computer Network that can be used for data analysis, graphics and forecasting. The following results were graphed:

1. Temperature Profile - the distillation column operates by using a controlled temperature profile from reboiler to condenser (40). The slopes of the temperature profile curve may also indicate appropriate locations for temperature controlling elements.

2. Liquid and Vapor Profiles - the liquid and vapor profiles will be altered substantially by the use of the intermediate reboiler. This may affect the mechanical design of the column.

3. Liquid and Vapor Compositions Profiles - the profiles represent the composition profiles leaving the tray and also provide a means for understanding the distillation process.

Economic Analysis

The economics of the project will be evaluated by the payout period since only utility costs and fixed capital investment prices were known.

$$\underset{\text{(Years)}}{\text{Payout}} = \frac{\text{Fixed Capital Investment}}{\text{TC01} - \text{TC02}} \tag{6.2}$$

where TC01 = annual operating cost for the existing distillation column, \$/year

TC02 = annual operating cost for the retrofitted distillation column, \$/year

Fixed Capital Investment = 1987 installed cost of the intermediate reboiler and circulation pump, \$

Table I (45) lists the operating costs used in this study.

A basic computer program (Appendix F) was written to calculate the operating and 1987 installed equipment costs. The program is interactive and requires data from the tray x tray output.

Guthrie's method (22) of capital cost estimating was used to calculate the fixed capital investment of the retrofitted equipment, (intermediate reboiler and circulation pump). The Marshall and Swift equipment cost index was used to update the equipment costs to 1987. Assumptions used in calculating the cost of the retrofitted intermediate reboiler and circulation pump were as follows:

TABLE I

1987 OPERATING COSTS (45)

Utility	Cost
600 PSIG Steam	\$3.45/1000 lb
175 PSIG Steam	\$2.31/1000 lb
20 PSIG Steam	\$1.18/1000 lb
Cooling Water	\$0.07/1000 Gal
Electricity	\$0.05/KWHR

Intermediate Reboiler

1. Overall heat transfer coefficient = 243 Btu/Ft^2 Hr F (3).

2. Temperature driving force = 30 F (based on 20 lb saturated steam).

Circulation Pump

1. Pump and motor efficiency = 75%.

CHAPTER VII

DISCUSSION OF RESULTS

Based upon information obtained from the Process Flow Diagram (Appendix B) and discussions with operations personnel at the plant, August 11, 1987 the following results are cited:

1. The steam reboiler is used only sparingly during the winter months.

2. The depropanizer uses "free energy", that is, the debutanizer bottom stream is used for both vapor boilup and feed preheat.

3. The column appears to be well heat integrated with the overall process.

Computer Simulations Results

The key points in the following simulations are:

1. A constant average column pressure, (182 psia). Any reduction in column pressure will improve the relative volatility and hence the separation.

2. Dual product composition control.

The computer simulation results and Figures 16-95 (temperature profile, liquid and vapor flow rate profiles, liquid and vapor composition profiles) are located in Appendix A and will be divided into four sections.

I. Optimum Feed Plate Location.

II. Intermediate Reboiler Application (Side Heater Return Located Two Trays Below Side Heater Draw).

III. Intermediate Reboiler Application (Side Heater Draw Located Two Trays Below Side Heater Return).

IV. Intermediate Reboiler Application (Side Heater Return Located Two Trays Below Side Heater Draw, Variable Heat Addition).

These simulations were performed in order to determine the optimum feed plate location and optimum location for the pumparound loop. Finally, simulations were performed in order to determine the optimum duty and circulation rate for the pumparound loop.

I. Optimum Feed Plate Location

A. Temperature Profile (Figures 16,20,24,28,32,36,40,44).

1. Discontinuities are observed in the tray x tray output in the vicinity of the feed plate. This is consistent with the introduction of a nonequilibrium mixture into the column.

2. The majority of the fractionation, $\Delta T/\Delta$stage, appears to be occurring on:

a) Stages 20-26 (Rectifying Section).

b) Stages 1-8 (Stripping Section).

relatively little fractionation is occurring on stages 8-20.

B. Liquid and Vapor Flow Rate Profiles (Figures 17,21,25,29,33, 37,41,45).

1. Discontinuities are observed in the tray x tray output in the vicinity of the feed stage.

2. Liquid and vapor interstage flows above and below the feed plate approach constant molal overflow.

C. Liquid and Vapor Composition Profiles (Figures 18,19,22,23,26, 27,30,31,34,35,38,39,42,43,46,47).

1. Discontinuities are observed in the tray x tray output of the $I\text{-}C_4H_{10}$ and $N\text{-}C_4H_{10}$ composition profiles.

2. Beginning at approximately tray 19 and continuing to the condenser (tray 27), the light key (C_3H_8) increases steadily in concentration.

3. Beginning at the condenser (tray 27) and continuing to approximately tray 19, the heavy key ($1\text{-}C_4H_8$) increases steadily in concentration. Between trays 19 and 7 no appreciable change in concentration is observed. Below tray 7 and proceeding to the reboiler (tray 0) the heavy key increases in concentration.

4. Proceeding from the reboiler (tray 0) to the condenser (tray 27) $N\text{-}C_4H_{10}$ and $I\text{-}C_4H_{10}$ decrease in concentration. C_3H_6 increases in concentration from the reboiler to the condenser.

5. H_2S, C_2H_6, $N\text{-}C_5H_{12}$, $1\text{-}C_5H_{10}$ and $I\text{-}C_5H_{12}$ are the non-distributed components and proceed through the column, reboiler to condenser, with no appreciable change in concentration.

D. Annual Operating Cost, Figure 4.

1. The annual operating cost curve forms a minimum at feed tray number 10.

E. System Thermodynamic Efficiency, Figure 5.

1. The system thermodynamic efficiency increases as the feed is moved from the lowest feed tray (7) to the highest feed tray (17).

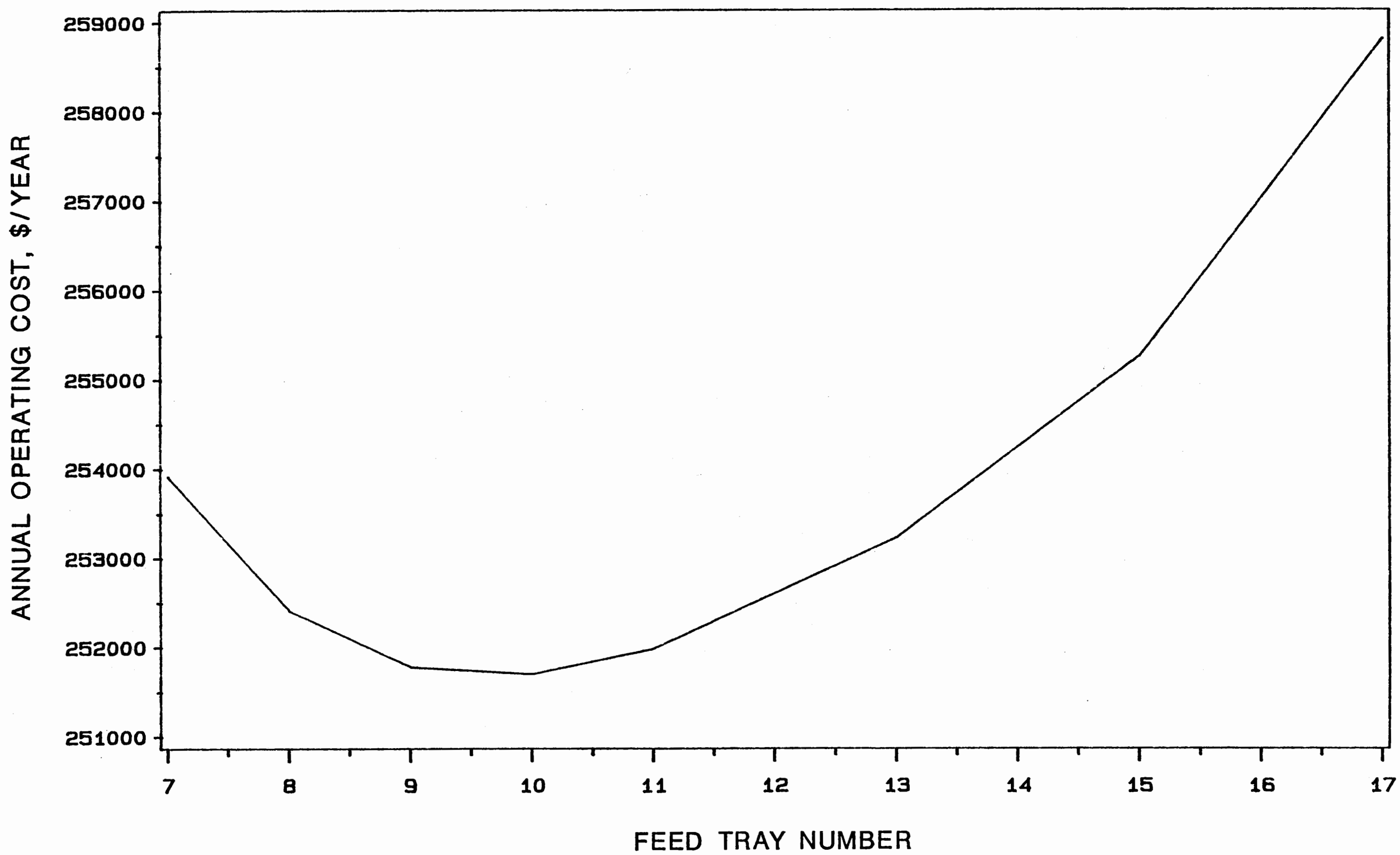

Figure 4. Annual Operating Cost as a Function of Feed Tray Location.

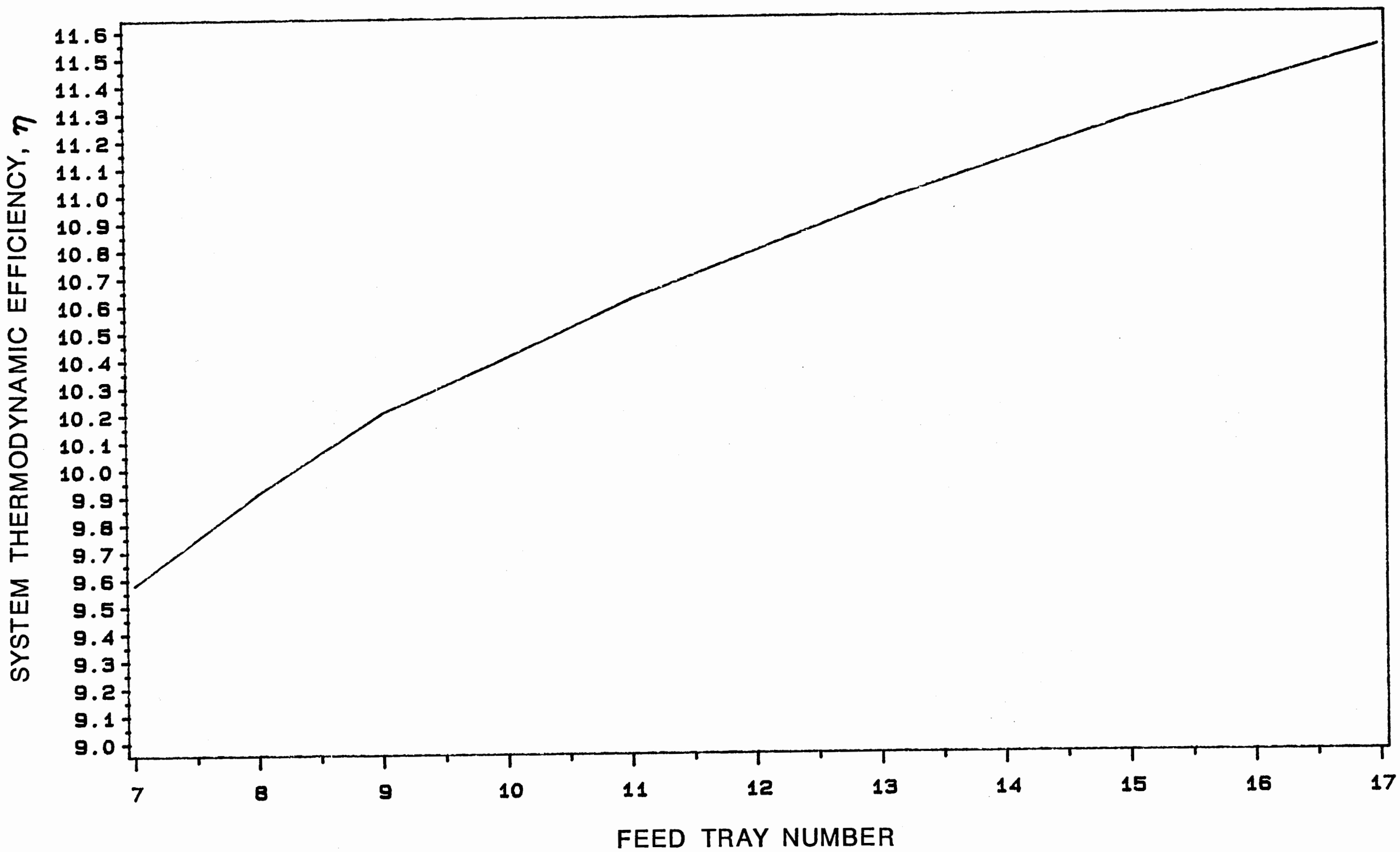

Figure 5. System Thermodynamic Efficiency as a Function of Feed Tray Location

II. Intermediate Reboiler Application (Side Heater Return Located Two Trays Below Side Heater Draw)

The purpose of this step was to determine the optimum location for the pumparound loop on the column.

With a pumparound circulation rate of 469 lbmoles/hr, a heater/cooler unit operation duty of 504 KBtu/Hr was specified in order to maintain a 15 molar percent vaporization of the entering liquid. This was held constant in order to permit a comparison of the results. The pumparound location was then varied along the side of the column.

A. Temperature Profile (Figures 48,52,56,60).

1. Discontinuities are observed in the vicinity of the feed stage.

2. Little improvement, if any, is observed in the fractionation process due to the intermediate reboiler.

B. Liquid and Vapor Flow Rate Profiles (Figures 49,53,57,61).

1. Discontinuites are observed at the feed stage, side heater draw and side heater return.

2. The liquid profile shows a decrease in molar flow rate at the side heater draw tray and an increase at the side heater return tray. The vapor profile exhibits an increase in molar flow rate at the side heater return tray.

3. The liquid and vapor streams approach constant molal overflow above the feed stage and below the side heater return stage.

C. Liquid and Vapor Composition Profiles (Figures 50,51,54, 55,58,59,62,63).

1. No appreciable difference from the results as stated in Section I.C, above.

D. Annual Operating Cost, Figure 6.

1. The retrofitted intermediate reboiler tray number listed in the above mentioned figure corresponds to the tray number of the removed tray. These tray numbers are "ideal" tray numbers as determined from the tray x tray results. This tray would be removed for the installation of the trap out pan. For example, a retrofitted intermediate reboiler tray number of 6 would correspond to a side heater draw tray of 7 and side heater return tray of 5.

2. The annual operating cost was a minimum at tray number 6.

E. System Thermodynamic Efficiency, Figure 7.

1. The system thermodynamic efficiency decreases with increasing retrofitted intermediate reboiler tray numbers.

III. Intermediate Reboiler Application (Side Heater Draw Located Two Trays Below Side Heater Return)

As stated in Section II, with a pumparound circulation rate of 469 lbmoles/Hr, a heater/cooler unit operation duty of 504 KBtu/Hr was specified in order to maintain a 15 molar percent vaporization of the entering liquid. This was held constant to permit a comparison of the results. The pumparound location was then varied along the side of the column.

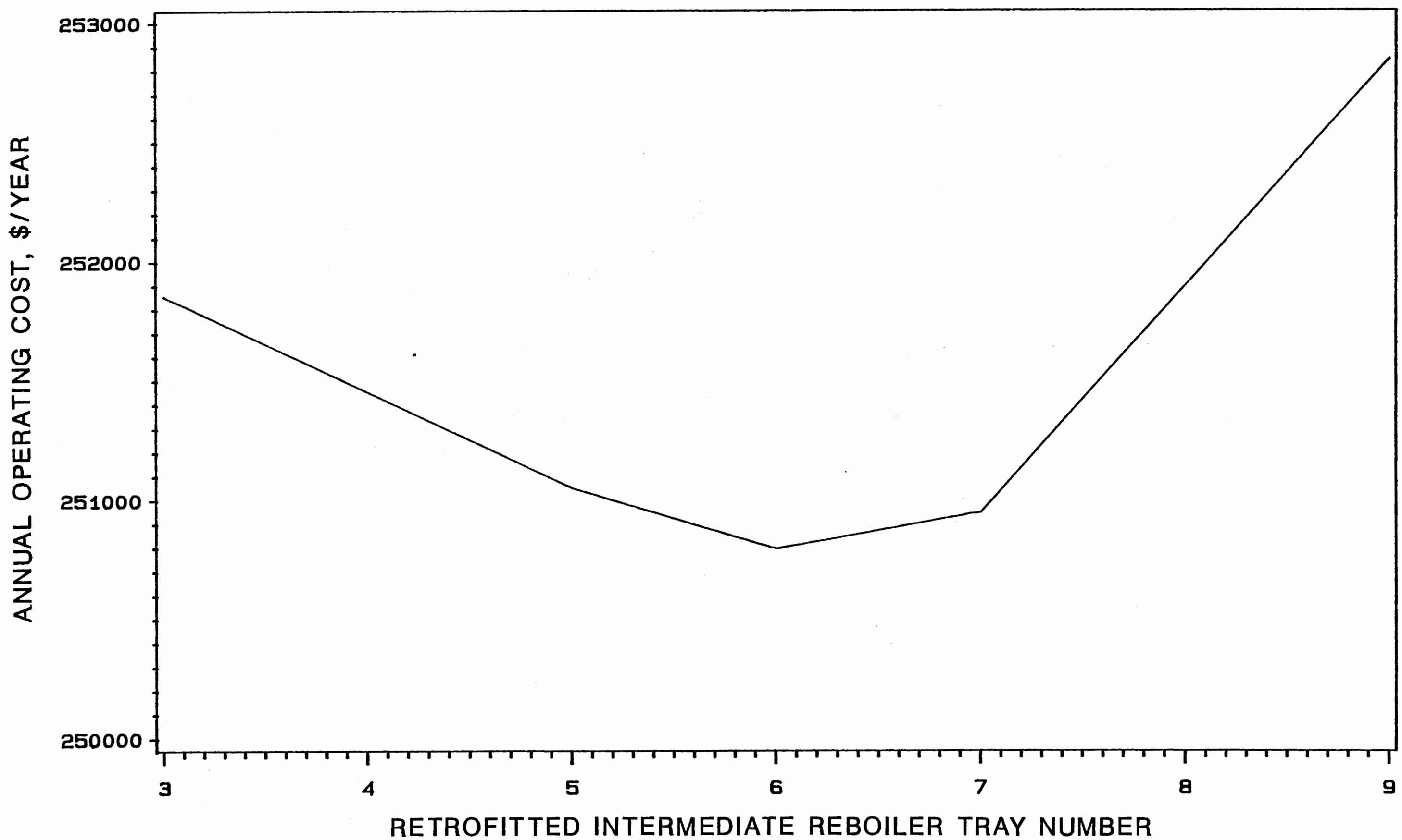

Figure 6. Annual Operating Cost as a Function of Retrofitted Intermediate Reboiler Location (Return Tray 2 Trays Below Side Draw)

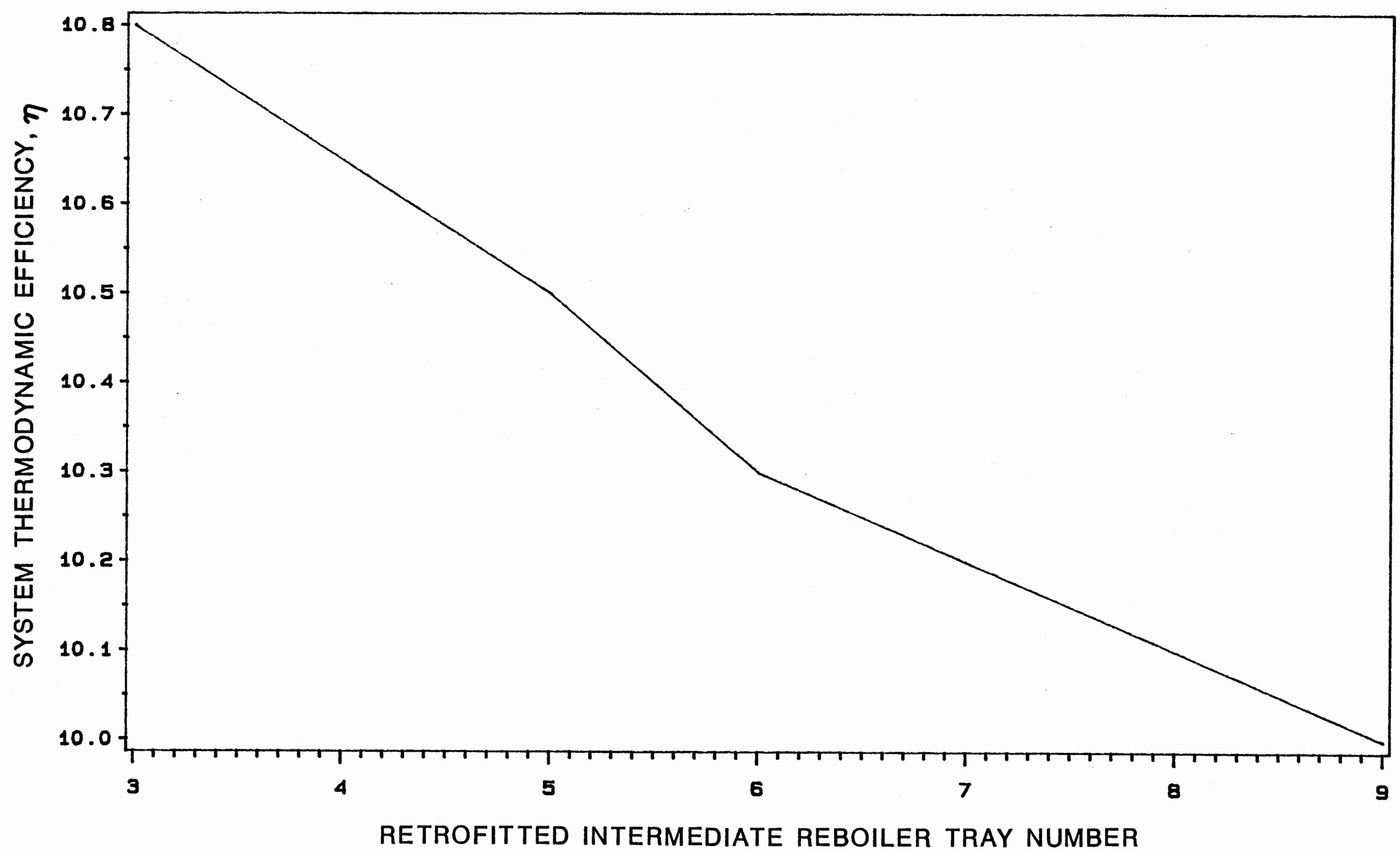

Figure 7. System Thermodynamic Efficiency as a Function of Retrofitted Intermediate Reboiler Location (Return Tray 2 Trays Below Side Draw)

The results for this application:

A. Temperature Profile, Figure 64,68,72,76.

B. Liquid and Vapor Flow Rate Profiles, Figure 65,69,73,77.

C. Liquid and Vapor Composition Profiles, Figure 66,67,70,71, 74,75, 78,79.

are consistent with those cited in Section II above.

D. Annual Operating Cost, Figure 8.

1. The annual operating cost decreases with increasing retrofitted intermediate reboiler tray numbers.

E. System Thermodynamic Efficiency, Figure 9.

1. The system thermodynamic efficiency decreases with increasing retrofitted intermediate reboiler tray numbers.

IV. Intermediate Reboiler Application (Side Heater Return Located Two Trays Below Side Heater Draw, Variable Heat Addition)

Once the optimum side heater draw tray and side heater return tray (pumparound loop location) have been determined, the next step was to determine the payout period as a function of the intermediate reboiler area.

The following results:

A. Temperature Profile, Figures 80,84,88.

B. Liquid and Vapor Flow Rate Profiles, Figures 81,85,89.

C. Liquid and Vapor Composition Profiles, Figures 82,83,86, 87,90,91.

are consistent with those cited in Sections II and III above.

D. Annual Operating Cost, Figure 10.

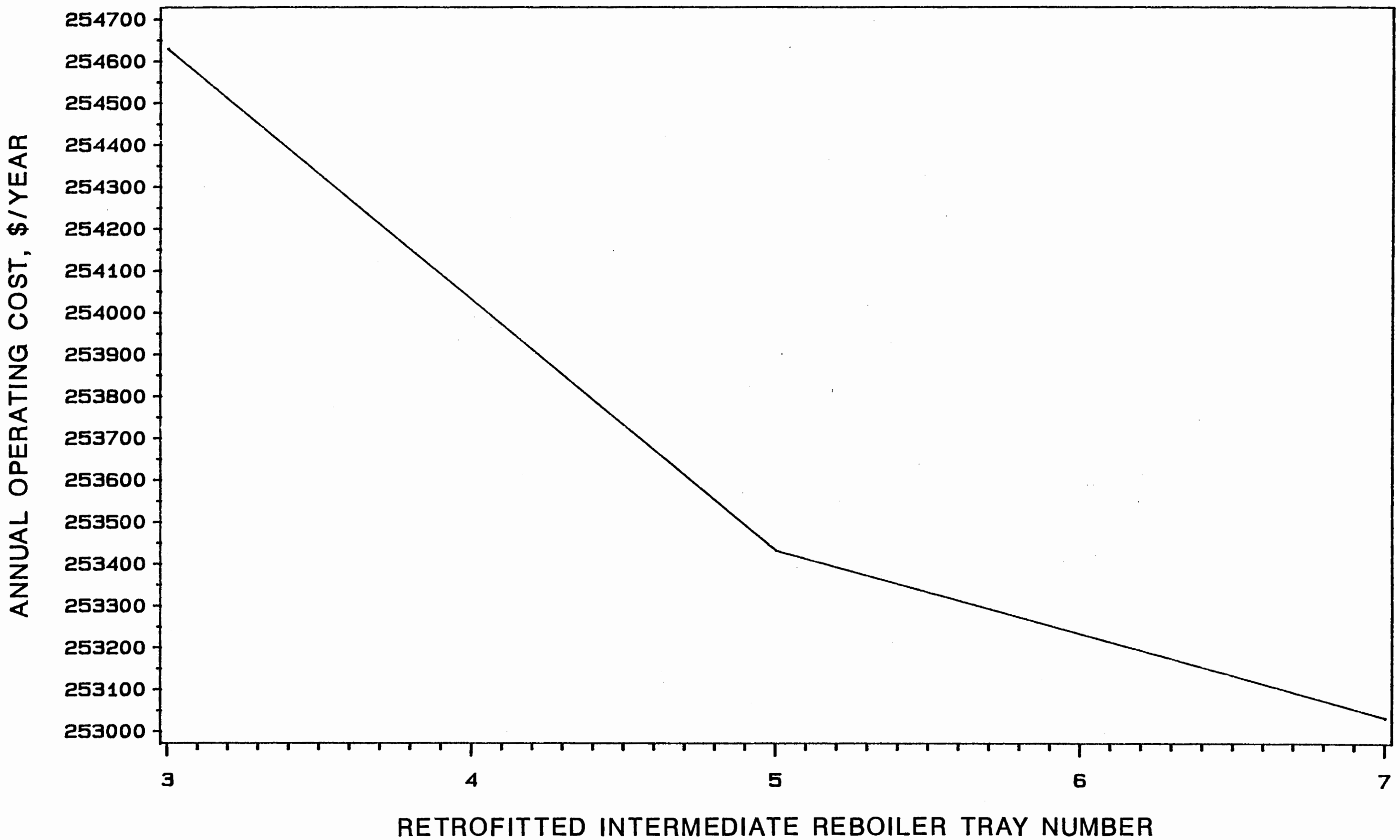

Figure 8. Annual Operating Cost as a Function of Retrofitted Intermediate Reboiler Location (Return Tray 2 Trays Above Side Draw)

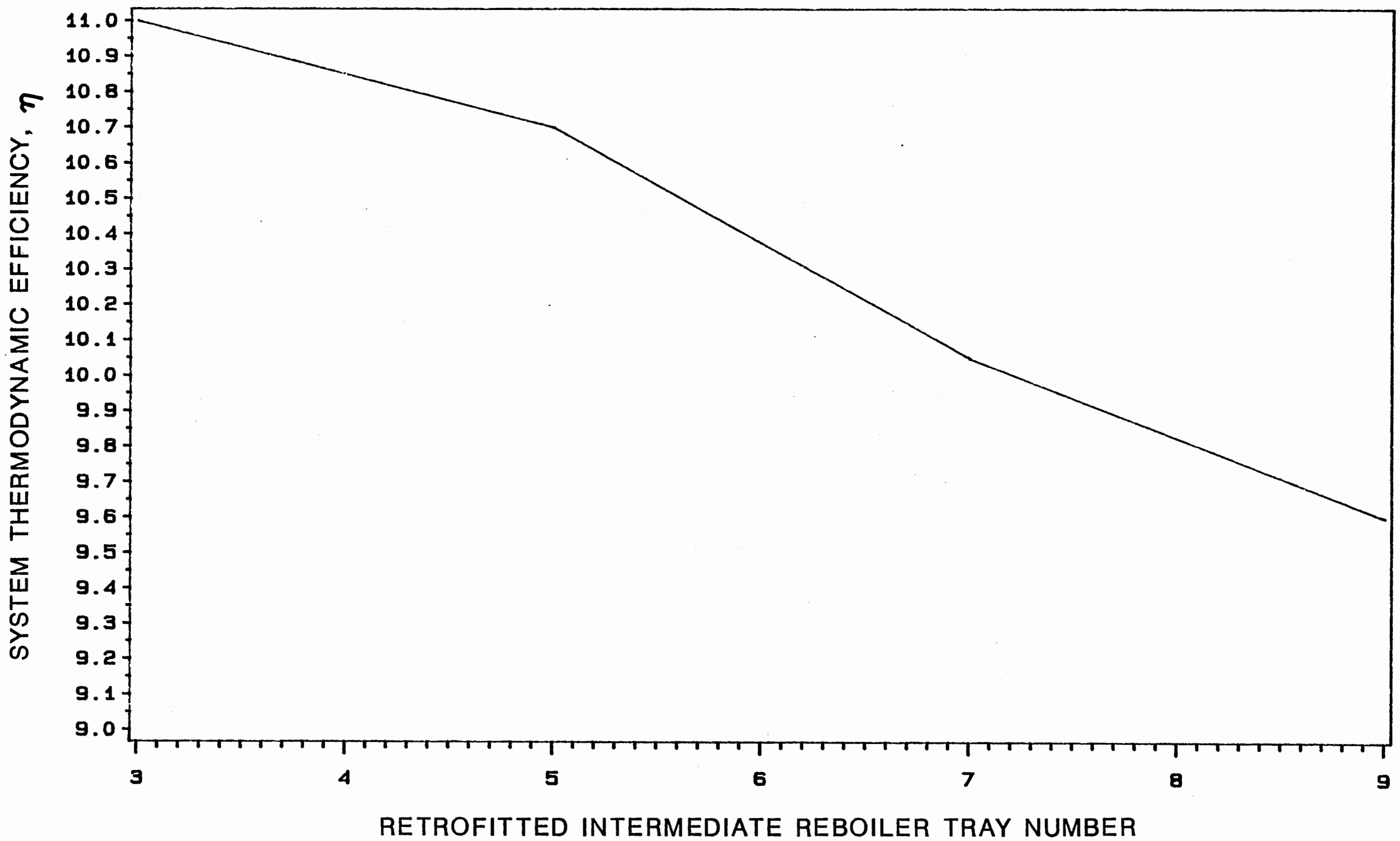

Figure 9. System Thermodynamic Efficiency as a Function of Retrofitted Intermediate Reboiler Location (Return Tray 2 Trays Above Side Draw)

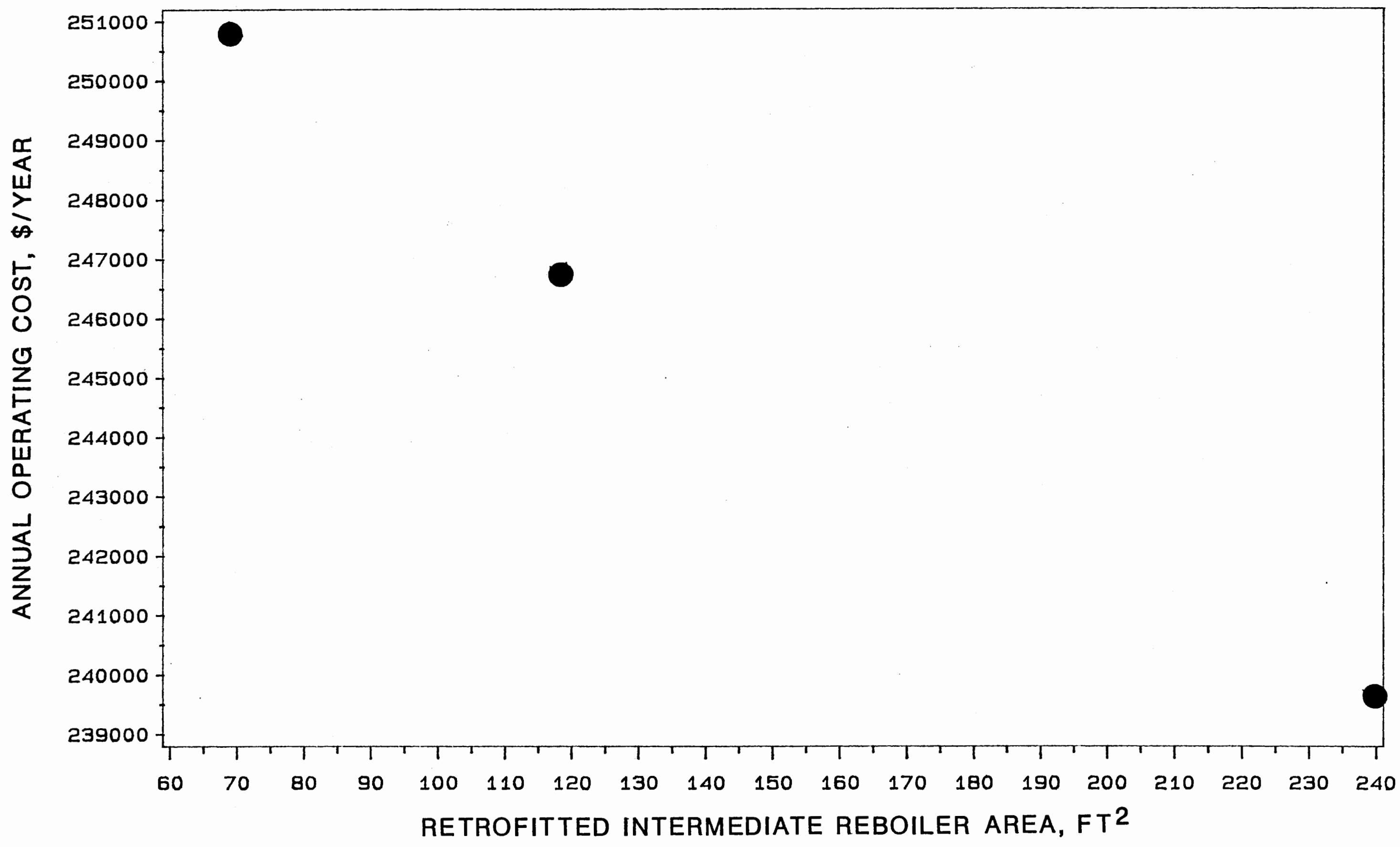

Figure 10. Annual Operating Cost as a Function of Retrofitted Intermediate Reboiler Area

1. The annual operating cost decreases with increasing retrofitted intermediate reboiler area. This is a consequence of the increased heat duty.

E. System Thermodynamic Efficiency, Figure 11.

1. The system thermodynamic efficiency increases with increasing retrofitted intermediate reboiler area. This result is consistent with Edmister's (11) conclusion mentioned in Chapter II.

F. Payout Period, Figure 12.

1. The project payout period decreases rapidly initially (70 Ft^2 to 115 Ft^2) and then more gradually (115 Ft^2 to 240 Ft^2).

2. The last data point shows that the area requirement is small (240 Ft^2 with a payout period of 3.5 years). Borras-Garcia (20) reported that most capital projects with a payout period greater than 2 years have a low chance for success.

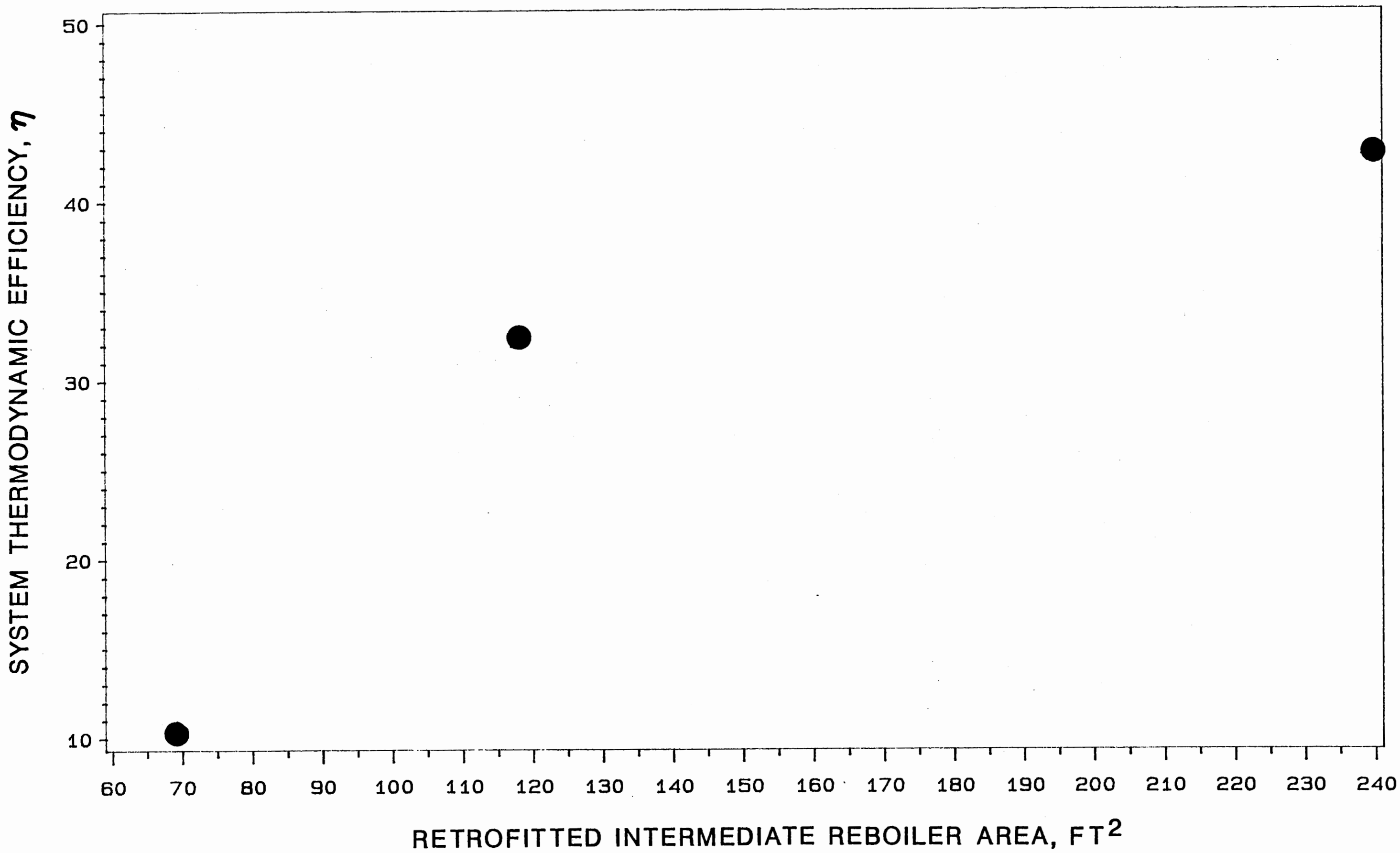

Figure 11. System Thermodynamic Efficiency as a Function of Retrofitted Intermediate Reboiler Area

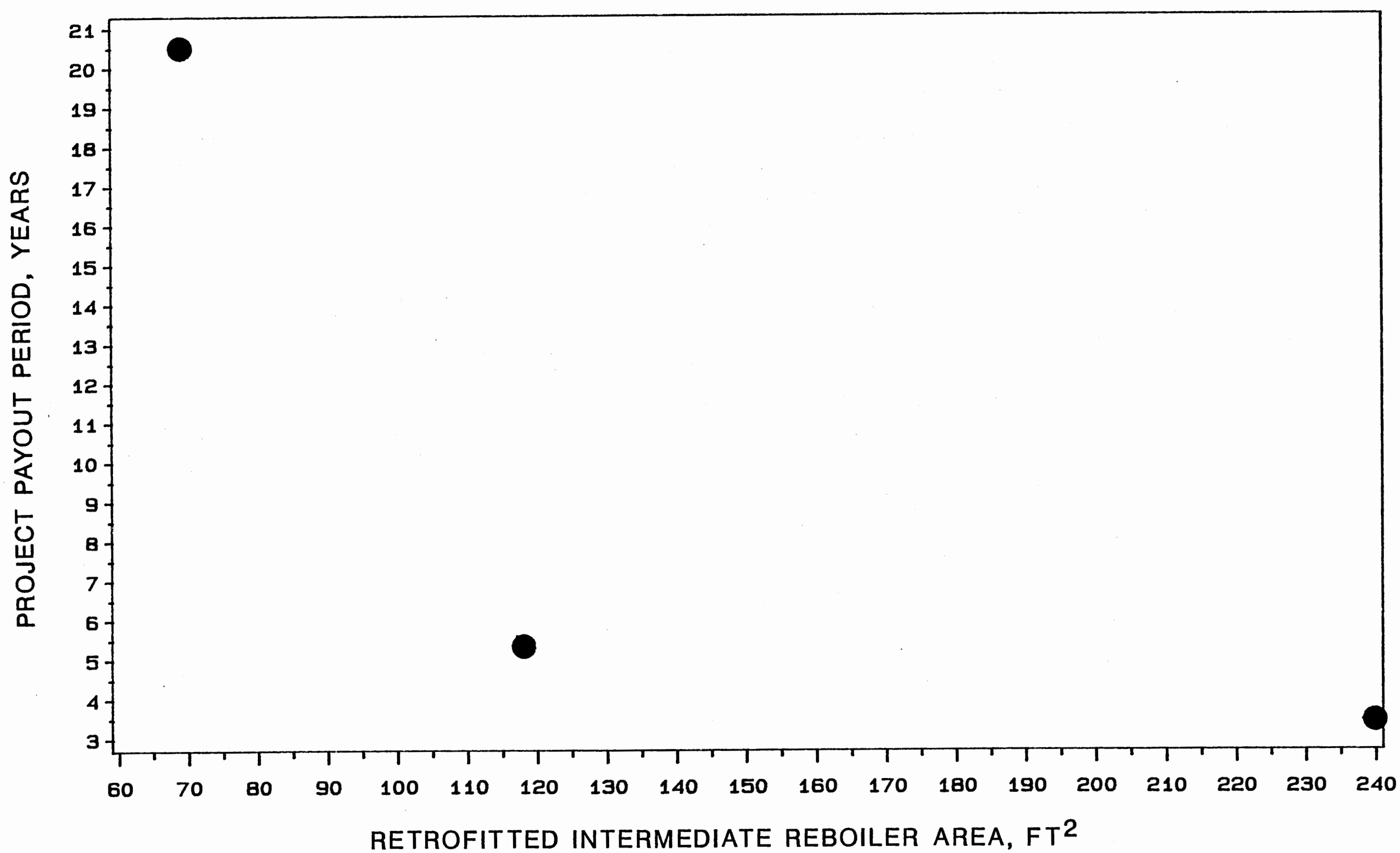

Figure 12. Project Payout Period as a Function of Retrofitted Intermediate Reboiler Area Exchanger Area

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

The following conclusions may be drawn from the results of this study.

I. At an 85% tray efficiency with an optimally placed feed and a feed quality identical with the test run results of July 27-29, 1983, the distillation tray x tray model, MAXISIM (14), simulated the industrial depropanizer reasonably well.

A. The following distillate composition discrepancies were noted:

	Tray x Tray (lbmoles/hr)	Depropanizer (lbmoles/hr)
H_2S	1.5997	1.60
C_2H_6	0.9000	0.90
C_3H_6	518.8619	527.90
C_3H_8	210.1048	210.60
C_4H_8	32.0256	32.80
IC_4H_{10}	56.1254	65.50
NC_4H_{10}	1.5444	3.60
C_5H_{10}	0.0000	0.00
IC_5H_{12}	0.0000	0.00
NC_5H_{12}	0.0000	0.00

B. The following bottom composition discrepancies were noted:

	Tray x Tray (lbmoles/hr)	Depropanizer (lbmoles/hr)
H_2S	0.0003	0.00
C_2H_6	0.0000	0.00
C_3H_6	48.8381	39.80
C_3H_8	44.2952	43.80
C_4H_8	465.2744	464.50
IC_4H_{10}	322.2746	312.90
NC_4H_{10}	133.1556	131.10
C_5H_{10}	14.8000	14.80
IC_5H_{12}	25.1000	25.10
NC_5H_{12}	0.9000	0.90

C. The following product flow rate discrepancies were noted:

	Tray x Tray (lbmoles/hr)	Depropanizer (lbmoles/hr)
Distillate	821.166	842.90
Bottom	1054.6371	1032.90

II. The most appropriate locations for temperature controlling elements would be the following:

	Distillation Column Ideal	Actual (85% Tray Efficiency)
Rectifying Section	22	26
Stripping Section	7	8

These stages exhibit the most rapid change in slope as shown from the tray x tray output and would be the most sensitive to column disturbances.

III. Feed Plate Location.

A. Operating costs are minimized by operating the column with the feed entering on theoretical plate number 10, Figure 4.

B. The annual operating cost was of the order of $252,000.00/year.

C. Based upon an 85% tray efficiency, the actual column feed appears to be misplaced and should enter on tray 17, Appendix B.

IV. Feed Enthalpy.

A. Total overhead condenser area is 9620 Ft^2.

B. Any increase in feed enthalpy will result in the following for this particular column:

1. Annual operating cost will decrease.
2. Condenser operating cost will increase.
3. Reboiler operating cost will decrease.

C. The feed percent vaporization (July 27-29, 1983) was 52 percent. Based on an overall heat transfer coefficient of 125 $Btu/Ft^2\ hr\ ^oF$ (3), and a temperature driving force of 15 deg. F, the required condenser area was 8200 Ft^2.

D. Condenser equipment constraints may be reached before column constraints.

V. Pumparound Simulation.

A. Annual column operating costs are minimized by operation of the pumparound loop with the return tray two trays below the side draw tray, Figure 8.

B. Annual column operating costs are minimized by operating the pumparound at the following locations:

	Ideal	Actual, 85% Tray Efficiency
Side Heater Draw Tray -	7	8
Side Heater Return Tray -	5	6

C. Annual column operating costs were of the order of $240,000.00 /year.

VI. Column Loading.

A. Significant changes occur in the column internal loading due to the pumparound loop.

VII. Optimum Project Payout Period was 3.5 years, Figure 12.

VIII. The retrofitted intermediate reboiler should be designed for 115% of design capacity and preliminary specifications are as follows:

A. Duty - 2014 KBtu/hr.

B. Circulation rate - 1415 lbmoles/hr.

C. 15 molar percent vaporization.

IX. Circulation Pump Specification.

A. Brake horsepower - 2.0 at 115% of design.

X. The retrofitted intermediate reboiler should not be installed on the depropanizer in this study.

It is not appropriate for this column based upon:

A. Overall process heat integration.

B. Project payout period.

XI. Recommendations for Further Study.

A. Simulate a column with a wide boiling feed range mixture, for example, a Naptha fractionator. The wide boiling feed would yield a wide temperature spread on the column, (reboiler to condenser), and consequently, the application of intermediate reboilers or condensers may be more appropriate.

1. Determine the minimum column operating pressure and hold constant.
2. Determine the optimum feed plate location and feed enthalpy.
3. Determine the "degrees of freedom of control" for the column.
4. Determine the optimum pumparound side heater draw and side heater return trays, using a constant intermediate reboiler duty and molar % vaporization.
5. Determine the project payout period for an optimally placed intermediate reboiler with variable heat addition.
6. If the project payout period is within company requirements, simulate the following control strategies on the column for disturbances in feed composition:

   a). Dual Composition Control.

   Two strategies appear to be used to achieve this control scheme:

   1a). Strategic tray temperature control, Figure 13.

   2a). Double differential temperature control.

Since temperature is an inferential measure of composition, the double differential temperature control would act to eliminate the

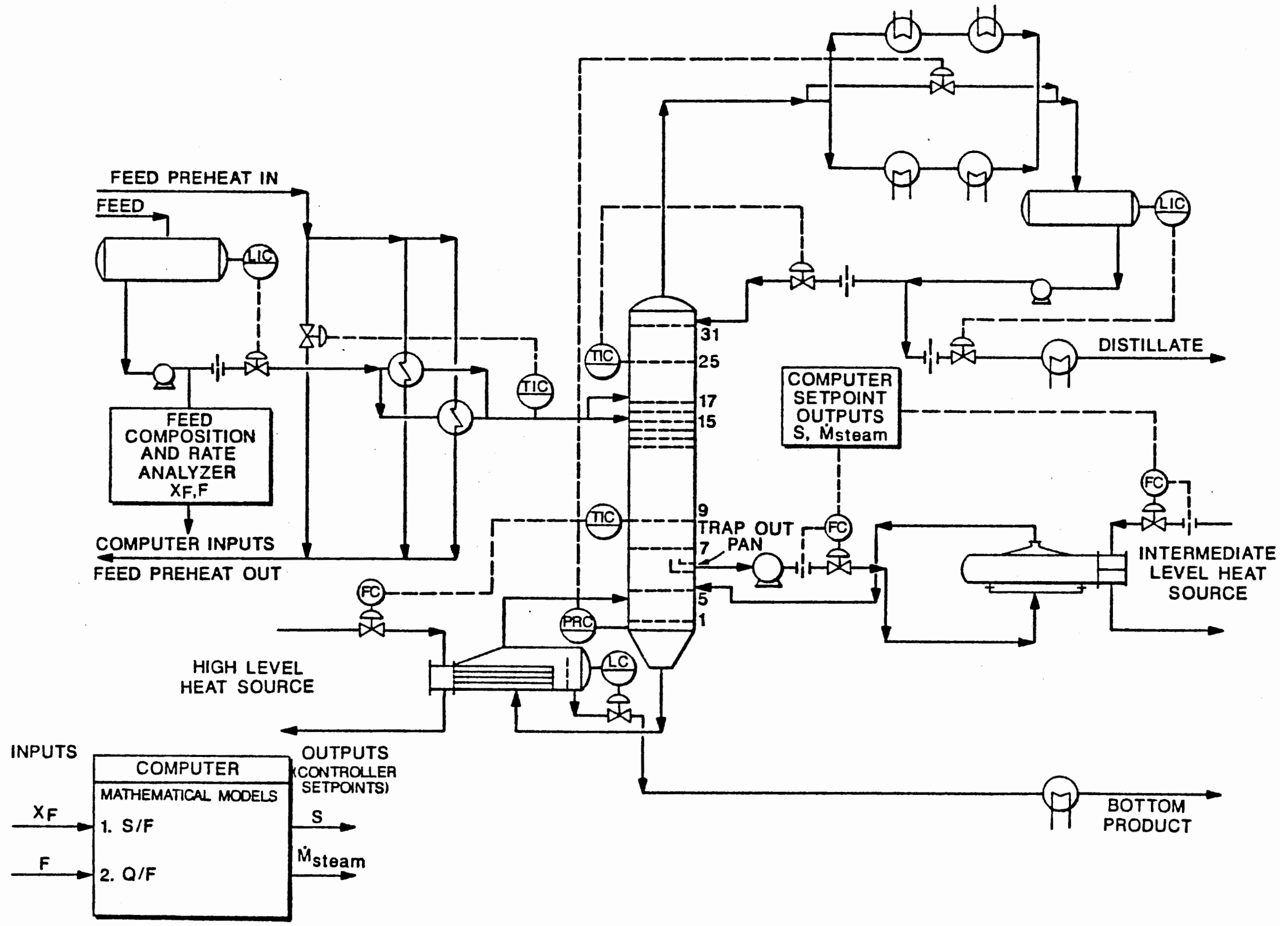

Figure 13. Controls Schematic For Dual Composition Control

effect of pressure on composition and, therefore, be a more accurate means of column control (5).

b). Constant Reflux/Feed Ratio Control, Figure 14.

c). Constant Vapor Boilup/Feed Ratio Control, Figure 15.

Repeat the above control strategies for feed rate disturbances. Determine the corresponding pressure drop and simulate the column with the specified pressure drop.

7. Develop mathematical models which may be statistically curve fit for the following;

a). Internal reflux/feed ratio control.

b). Side draw/feed ratio control.

c). Bottom/feed ratio control.

With the controls mentioned in point H above, both the material and energy balances could be manipulated independently.

The computer would have different inputs and outputs (controller setpoints) based upon the column control scheme.

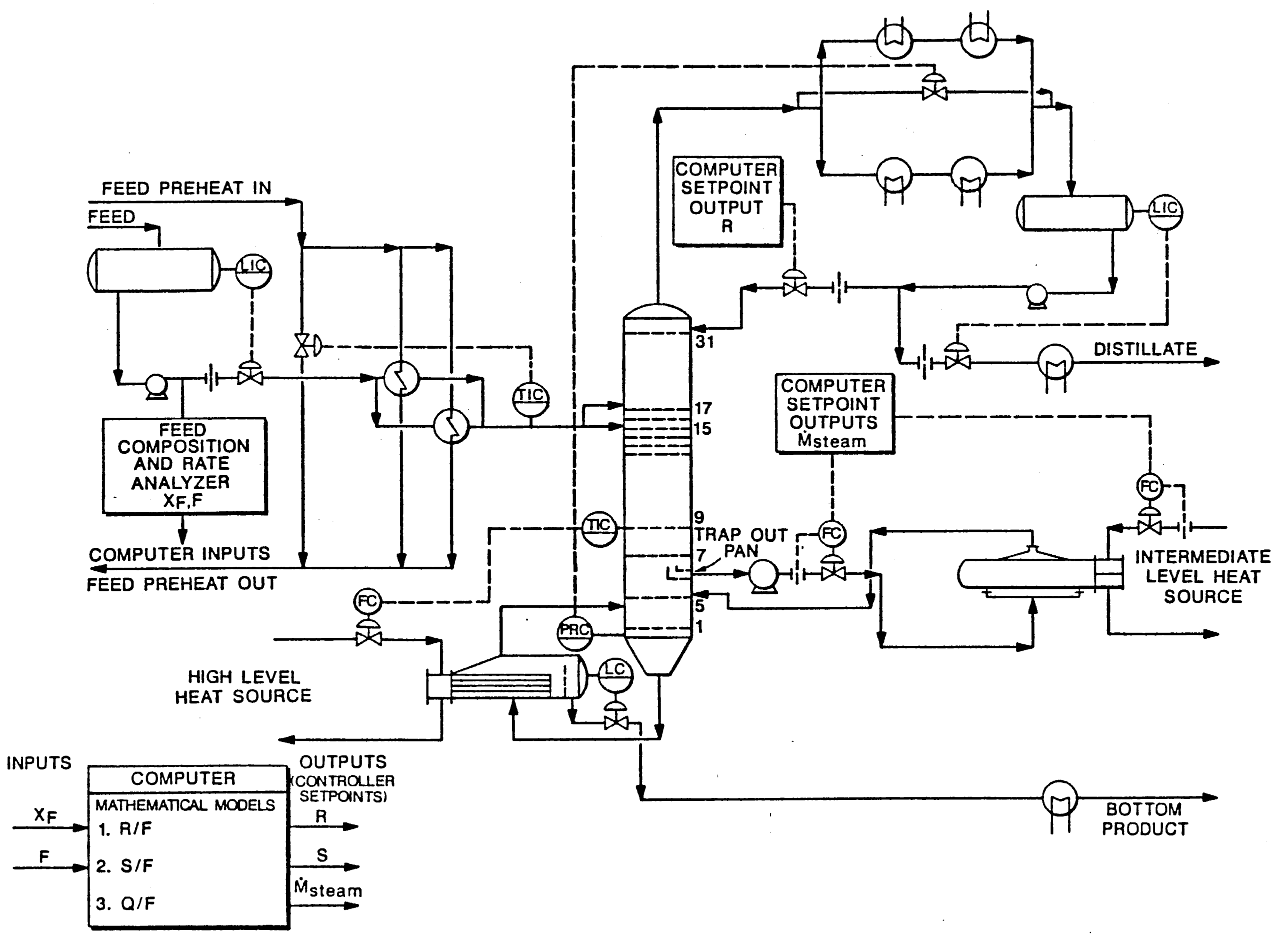

Figure 14. Controls Schematic For Constant Reflux/Feed Ratio Control

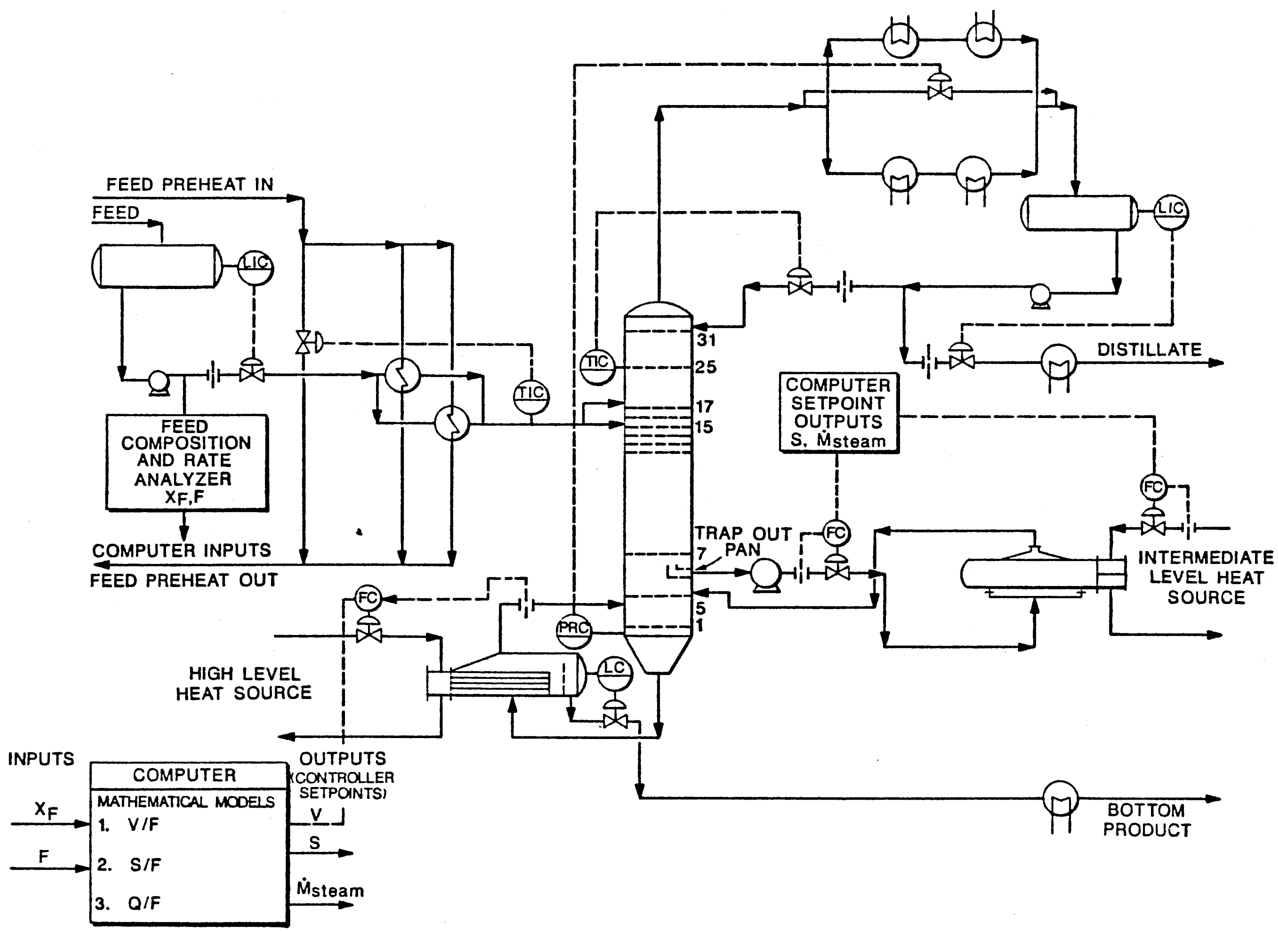

Figure 15. Controls Schematic For Constant Vapor Boilup/Feed Ratio Control

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APPENDIX A

STEADY STATE COMPUTER SIMULATION RESULTS

TABLE II

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 1

FEED PLATE = 15

Number of Plates in Column	26
Number of Feed Plates	1
Number of Products	2
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	15

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.00
Top Plate	180.00	
Reboiler	185.00	174.00

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	25
Max Delta T Per Plate	15.000
Max Fractional Liquid Change Per Plate	0.300

Plate Spacing
Top Section 21.00 In.
Bottom Section 21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
1.100 (L/F)

Estimated Bottoms Rate 0.500 (B/F)

TABLE III

STEADY STATE RESULTS FOR SIMULATION 1

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Distillate	Bottoms
H2S	1.60	1.6000	0.0000
C2H6	0.90	0.9000	0.0000
C3H6	567.70	526.2352	41.4648
C3H8	254.40	210.2394	44.1606
1-C4H8	497.30	32.1510	465.1489
IC4H10	378.40	50.8900	327.5100
NC4H10	134.70	2.3834	132.3166
1-C5H10	14.80	0.0001	14.7999
IC5H12	25.10	0.0002	25.0998
NC5H12	0.90	0.0000	0.9000
Total lbmols/hr	1875.80	824.4017	1051.4000
T., Deg. F.	140.00	90.47	170.82
P., Psia	183.00	179.00	185.00
H, KBtu	7504.98	-384.49	2207.71
S, KBtu/R	117.2065	41.2405	64.8075
Mol. Weight	51.0851	44.1492	56.5242
D, Lb/FT3	3.5280	31.1149	30.8830
L/F (Molar)	0.51764	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15472.48
Reboiler, KBtu/hr	9790.379
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	0
Feed Plate	15
Operating Cost, $/Year	$255,254.00
Column Thermodynamic Efficiency	11.26%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.58 Ft	7.00 Ft
Bottom Section	5.83 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

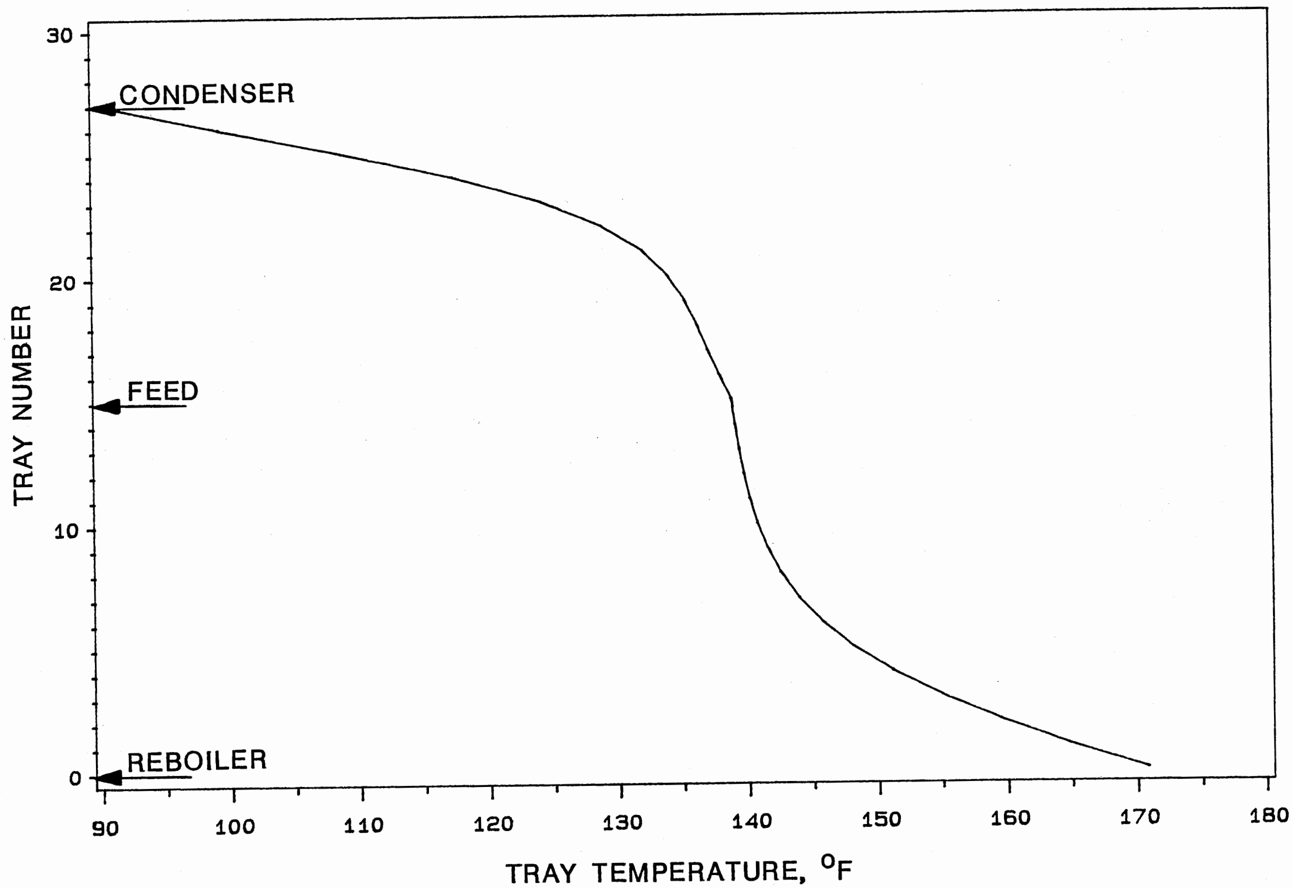


Figure 16. Steady State Simulation Results For Run 1

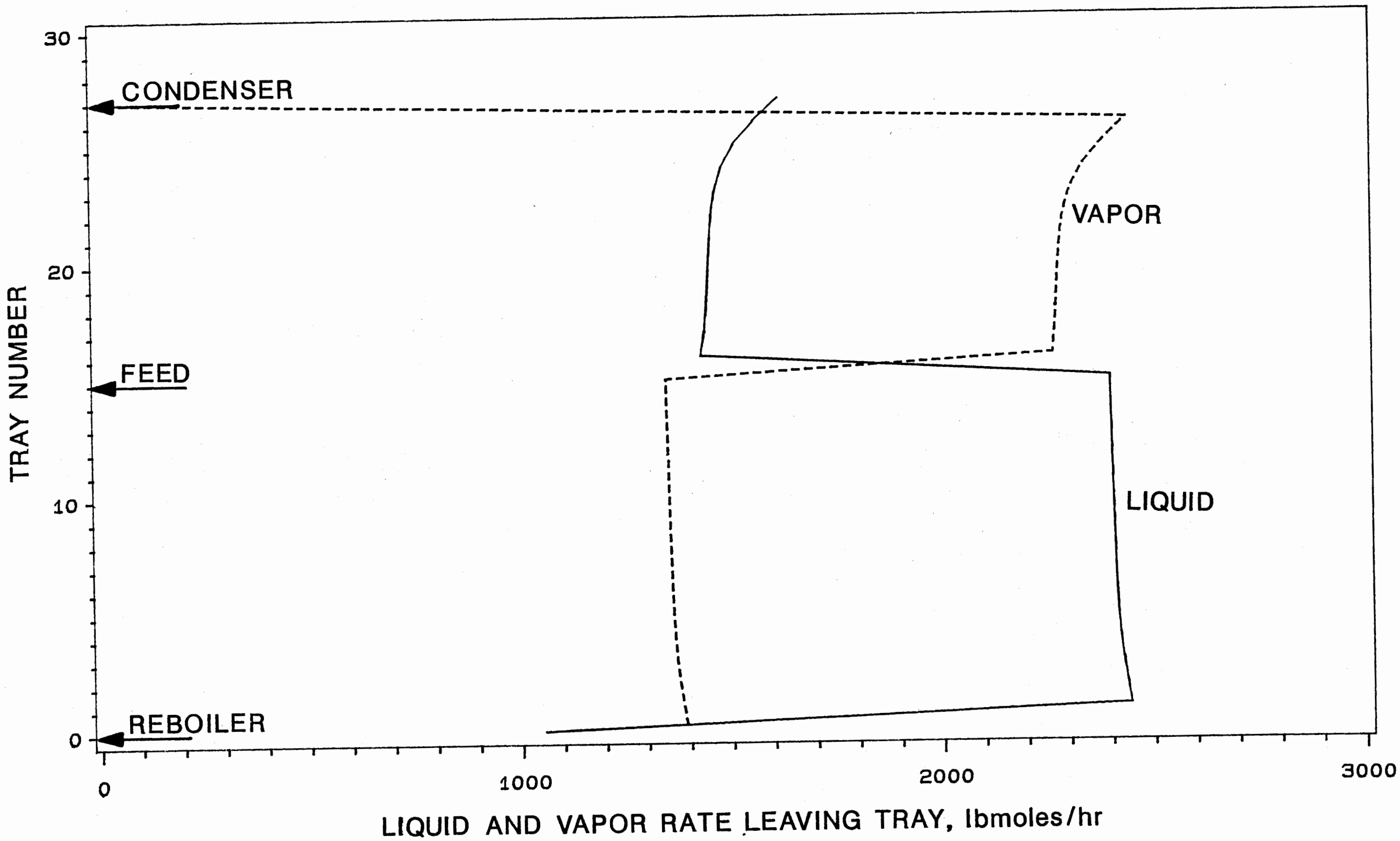


Figure 17. Steady State Simulation Results For Run 1

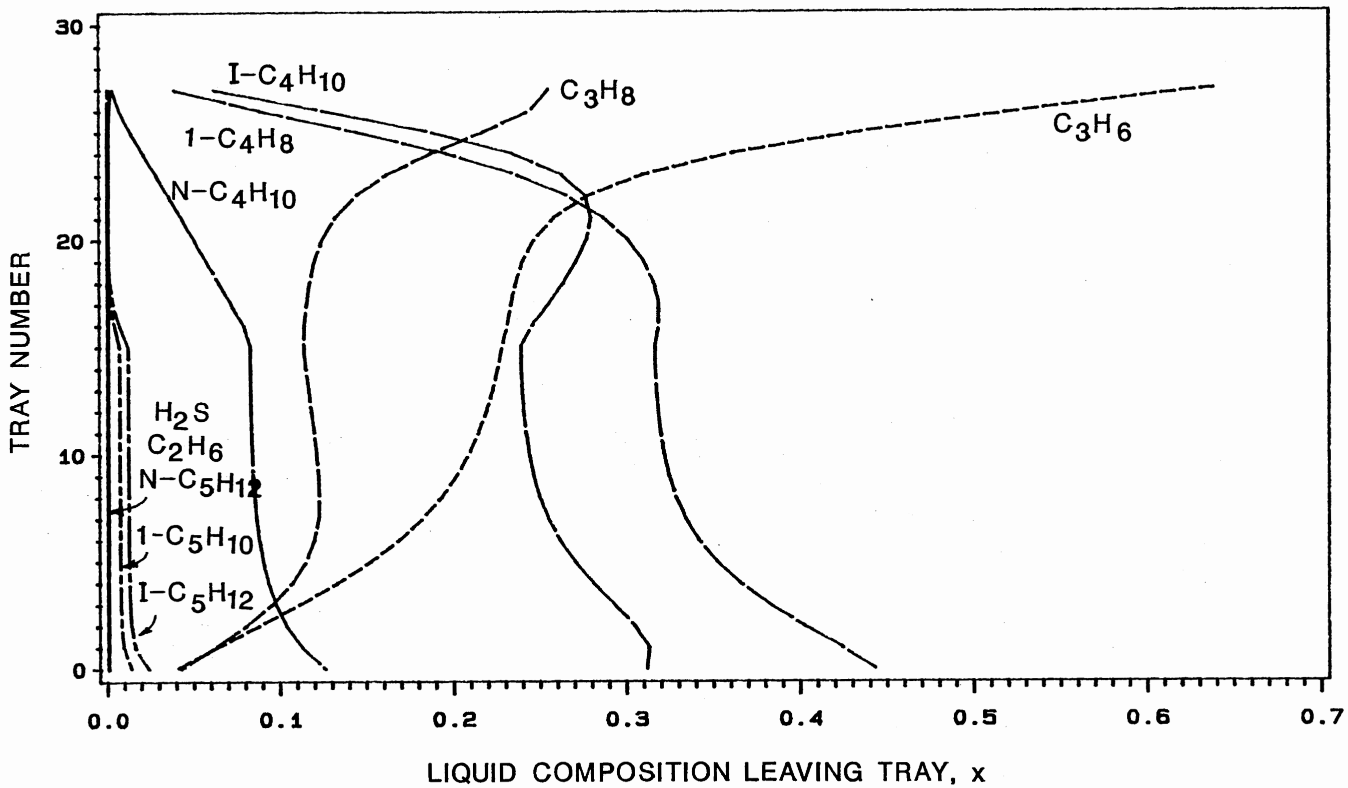


Figure 18. Steady State Simulation Results For Run 1

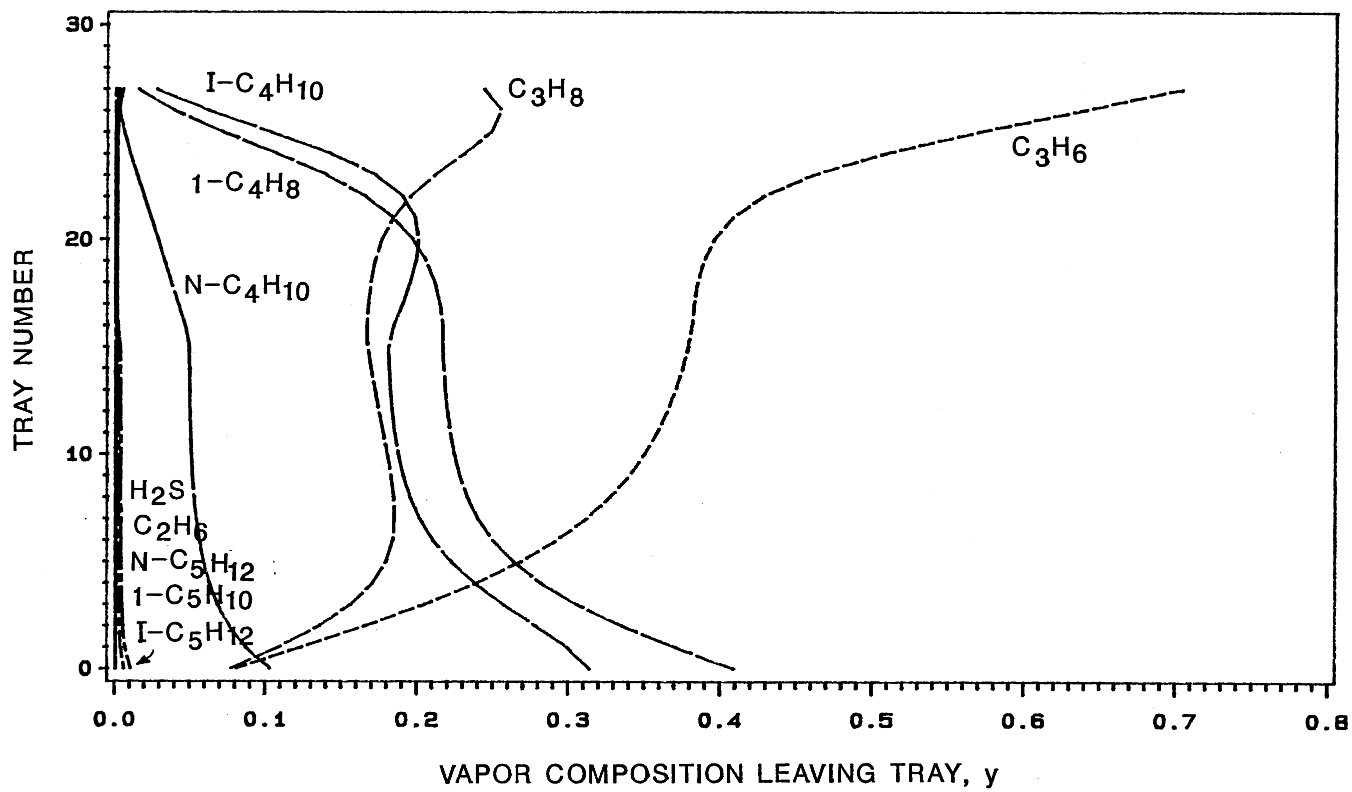


Figure 19. Steady State Simulation Results For Run 1

TABLE IV

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 2

FEED PLATE = 17

Number of Plates in Column	26
Number of Feed Plates	1
Number of Products	2
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	17

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.00
Top Plate	180.00	
Reboiler	185.00	174.00

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	25
Max Delta T Per Plate	15.000
Max Fractional Liquid Change Per Plate	0.300

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
1.100 (L/F)

Estimated Bottoms Rate 0.500 (B/F)

TABLE V

STEADY STATE RESULTS FOR SIMULATION 2

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Distillate	Bottoms
H2S	1.60	1.6000	0.0000
C2H6	0.90	0.9000	0.0000
C3H6	567.70	528.9352	38.7648
C3H8	254.40	210.2509	44.1491
1-C4H8	497.30	32.1615	465.1385
IC4H10	378.40	47.9496	330.4504
NC4H10	134.70	2.8484	131.8516
1-C5H10	14.80	0.0003	14.7997
IC5H12	25.10	0.0007	25.0993
NC5H12	0.90	0.0000	0.9000
Total lbmols/hr	1875.80	824.6528	1051.1495
T., Deg. F.	140.00	90.28	171.13
P., Psia	183.00	179.00	185.00
H, KBtu	7504.98	-389.55	2222.12
S, KBtu/R	117.2065	41.2236	64.8170
Mol. Weight	51.0851	44.1007	56.5652
D, Lb/FT3	3.5280	31.1152	30.8718
L/F (Molar)	0.51764	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15612.144
Reboiler, KBtu/hr	9940.684
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	0
Feed Plate	17
Operating Cost, $/Year	$258,812.00
Column Thermodynamic Efficiency	11.52%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.61 Ft	7.00 Ft
Bottom Section	5.87 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

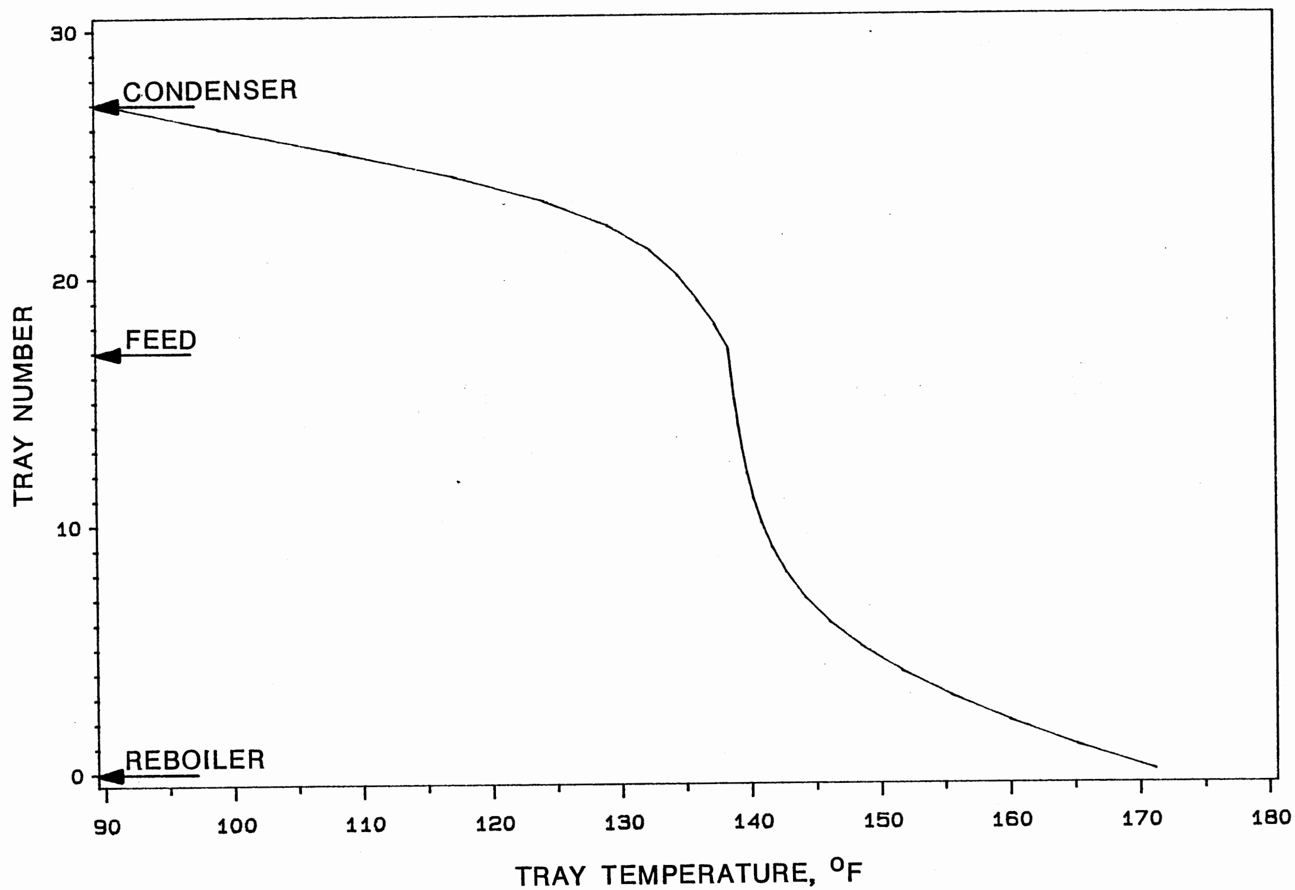


Figure 20. Steady State Simulation Results For Run 2

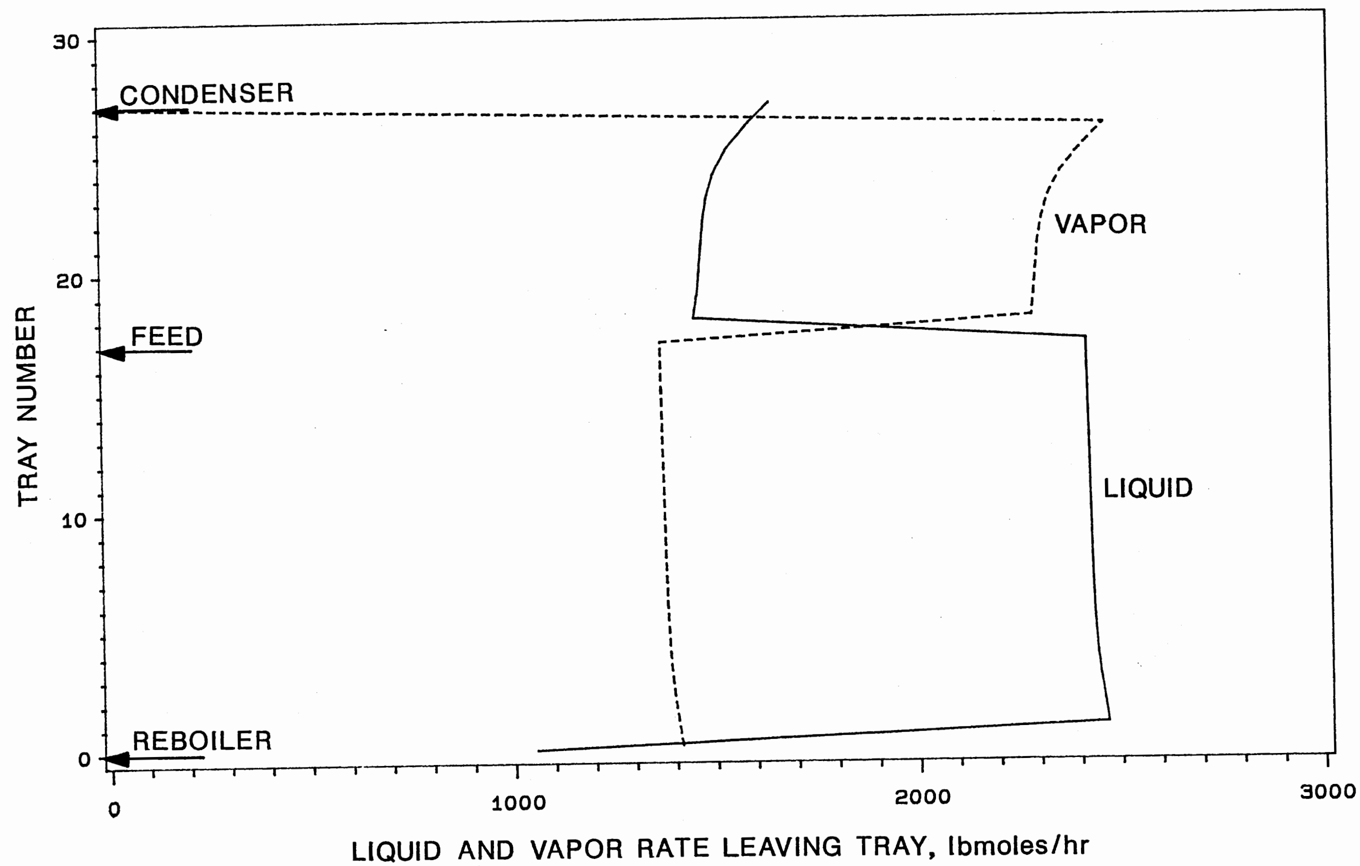


Figure 21. Steady State Simulation Results For Run 2

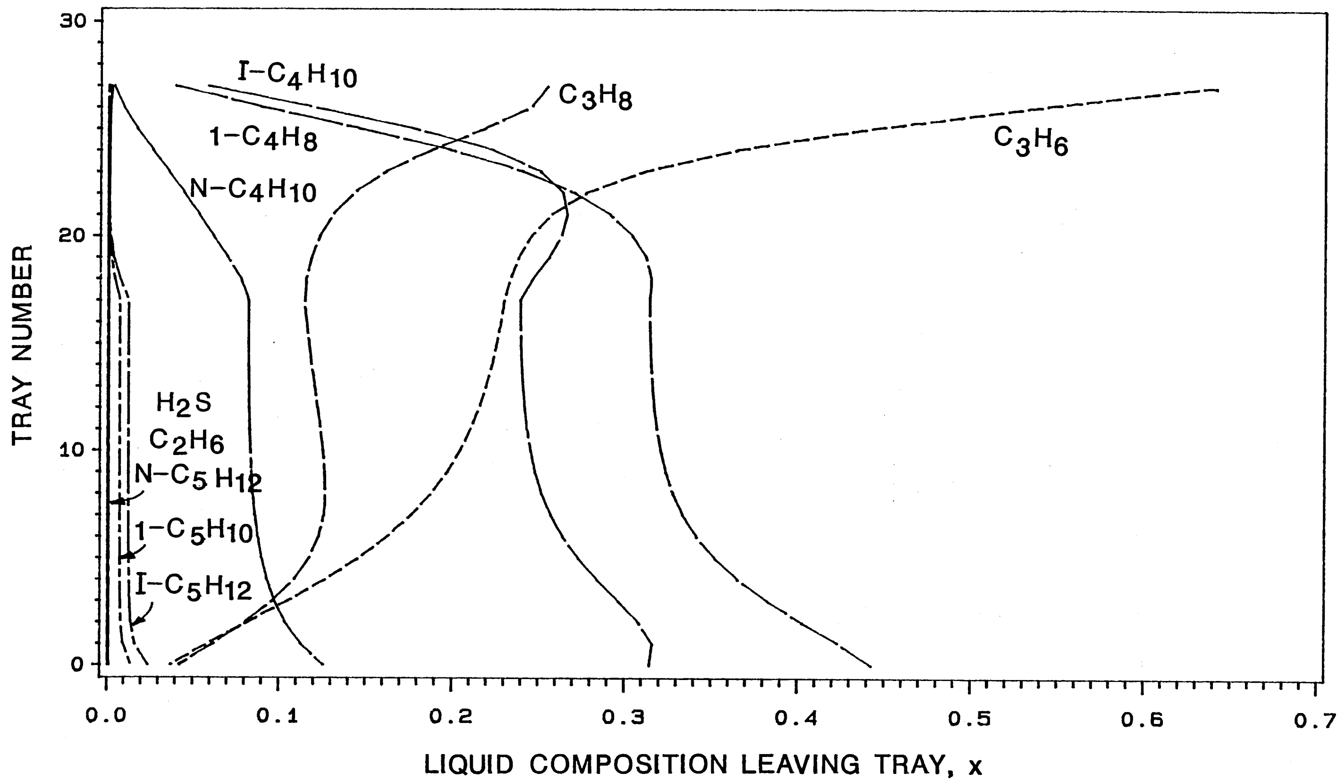


Figure 22. Steady State Simulation Results For Run 2

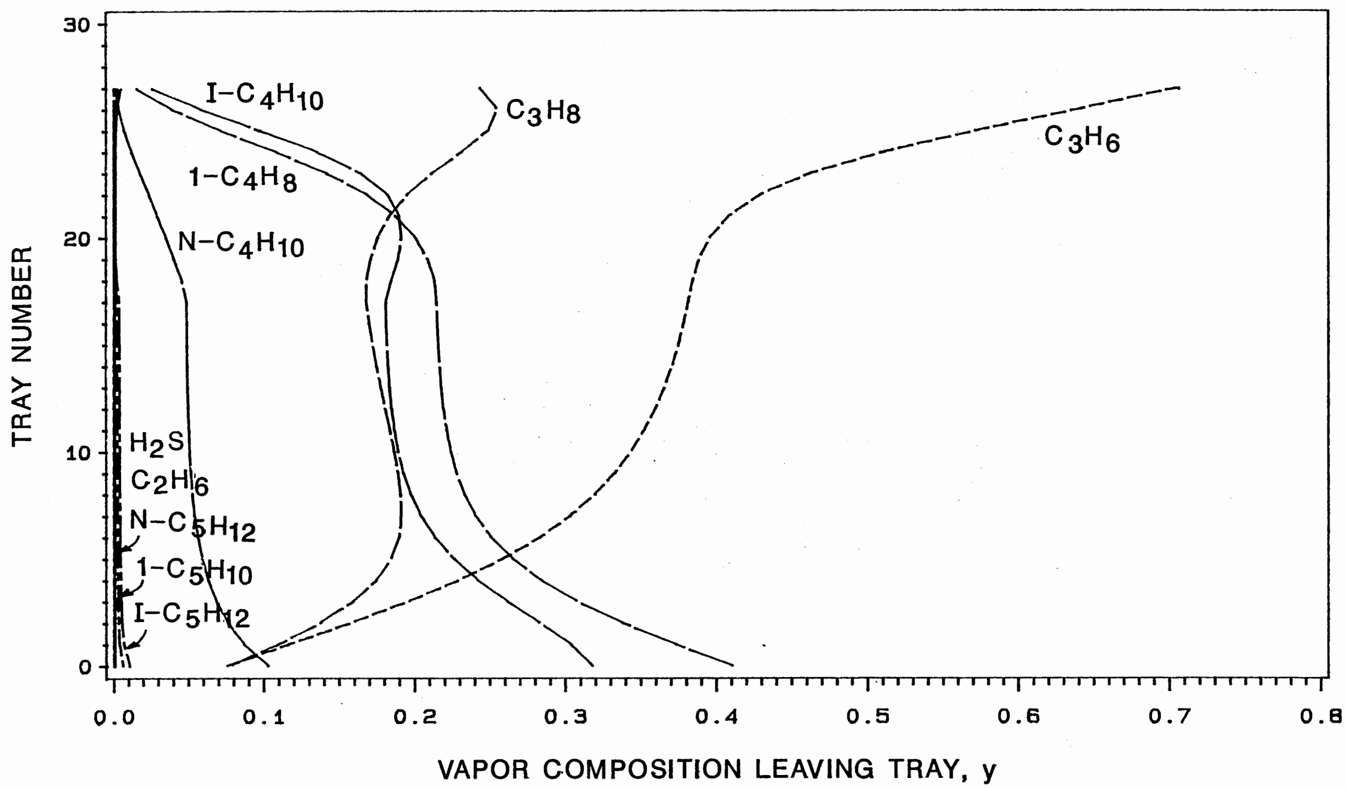


Figure 23. Steady State Simulation Results For Run 2

TABLE VI

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 3

FEED PLATE = 13

Number of Plates in Column	26
Number of Feed Plates	1
Number of Products	2
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	13

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.00
Top Plate	180.00	
Reboiler	185.00	174.00

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	25
Max Delta T Per Plate	15.000
Max Fractional Liquid Change Per Plate	0.300

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
1.100 (L/F)

Estimated Bottoms Rate 0.500 (B/F)

TABLE VII

STEADY STATE RESULTS FOR SIMULATION 3

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Distillate	Bottoms
H2S	1.60	1.5999	0.0001
C2H6	0.90	0.9000	0.0000
C3H6	567.70	523.5899	44.1101
C3H8	254.40	210.2124	44.1876
1-C4H8	497.30	32.1251	465.1749
IC4H10	378.40	53.3065	325.0934
NC4H10	134.70	2.0025	132.6975
1-C5H10	14.80	0.0000	14.8000
IC5H12	25.10	0.0000	25.1000
NC5H12	0.90	0.0000	0.9000
Total lbmols/hr	1875.80	823.7350	1052.0669
T., Deg. F.	140.00	90.63	170.51
P., Psia	183.00	179.00	185.00
H, KBtu	7504.98	-379.96	2194.69
S, KBtu/R	117.2065	41.2319	64.8228
Mol. Weight	51.0851	44.1900	56.4845
D, Lb/FT3	3.5280	31.1145	30.8933
L/F (Molar)	0.51764	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15394.402
Reboiler, KBtu/hr	9704.219
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	0
Feed Plate	13
Operating Cost, $/Year	$253,224.00
Column Thermodynamic Efficiency	10.96%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.57 Ft	7.00 Ft
Bottom Section	5.80 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

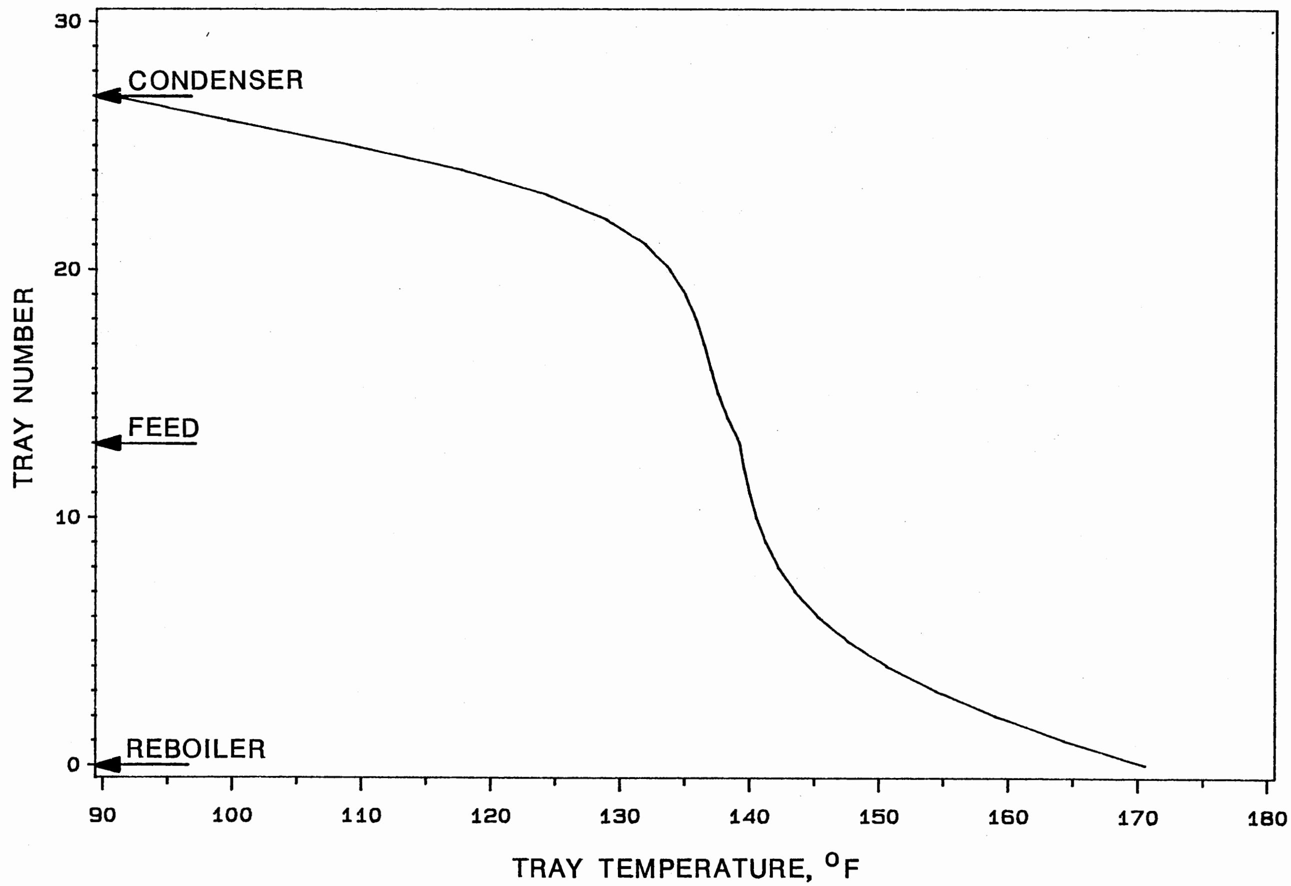


Figure 24. Steady State Simulation Results For Run 3

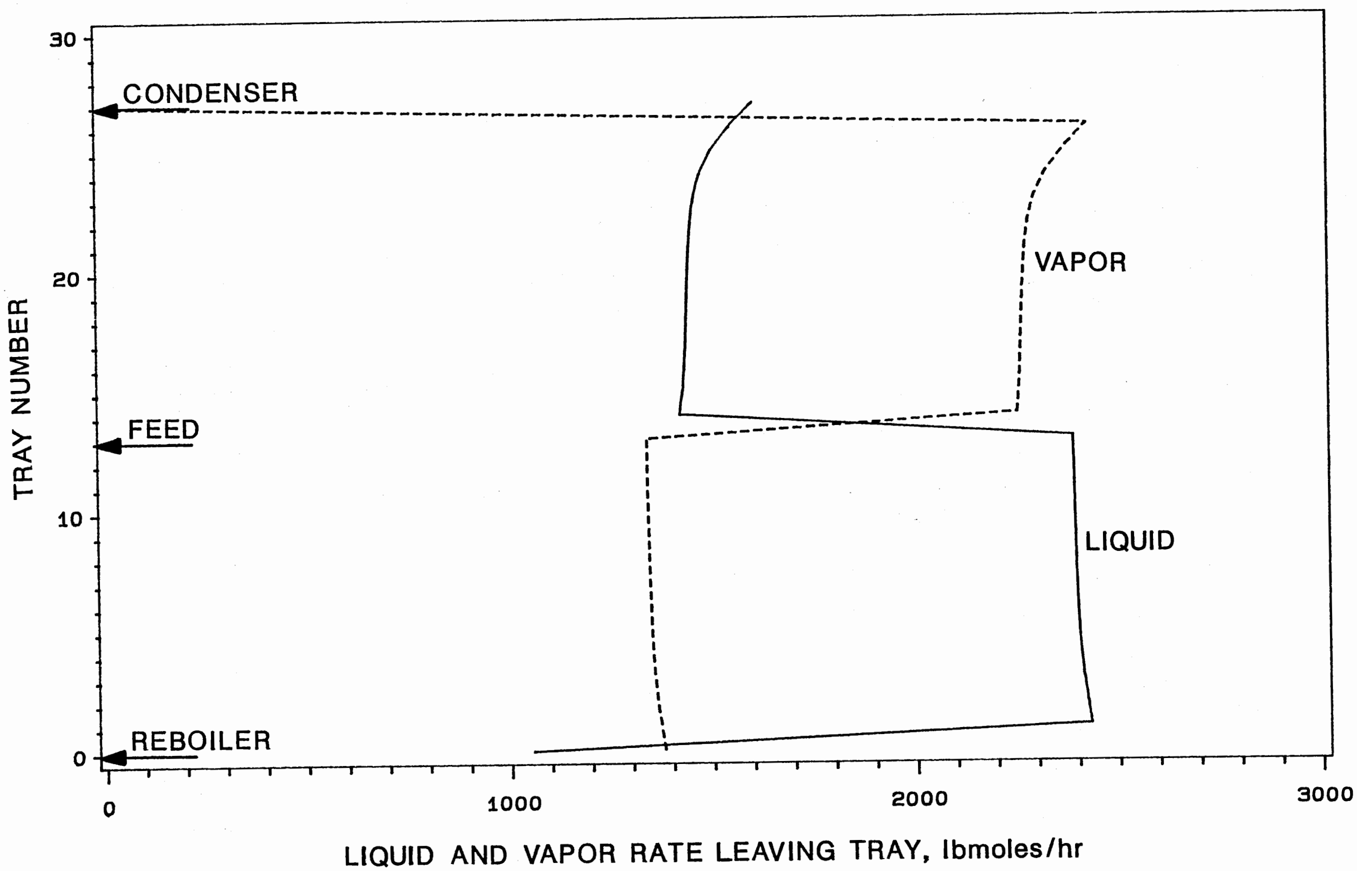


Figure 25. Steady State Simulation Results For Run 3

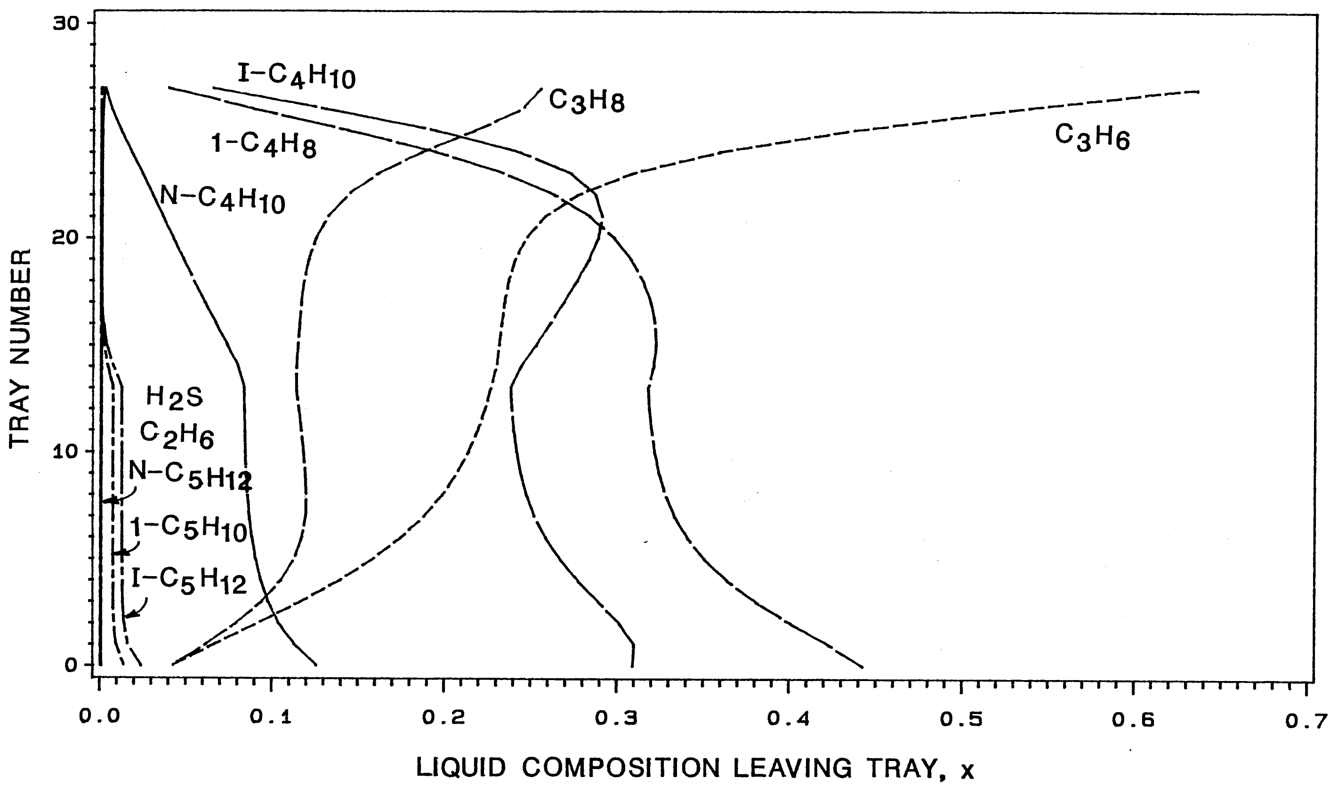


Figure 26. Steady State Simulation Results For Run 3

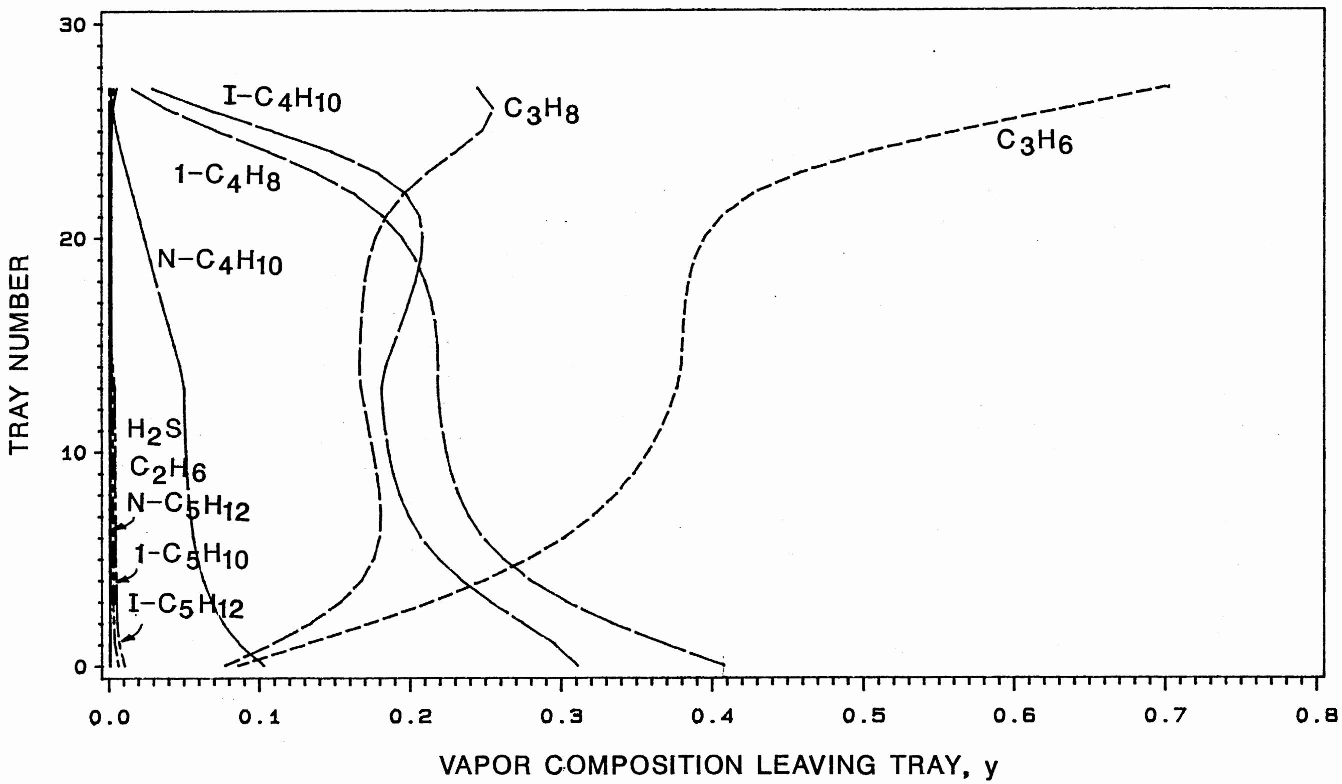


Figure 27. Steady State Simulation Results For Run 3

TABLE VIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 4

FEED PLATE = 11

Number of Plates in Column	26
Number of Feed Plates	1
Number of Products	2
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	11

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.00
Top Plate	180.00	
Reboiler	185.00	174.00

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	25
Max Delta T Per Plate	15.000
Max Fractional Liquid Change Per Plate	0.300

Plate Spacing
Top Section 21.00 In.
Bottom Section 21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
1.100 (L/F)

Estimated Bottoms Rate 0.500 (B/F)

TABLE IX

STEADY STATE RESULTS FOR SIMULATION 4

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Distillate	Bottoms
H2S	1.60	1.5998	0.0002
C2H6	0.90	0.9000	0.0000
C3H6	567.70	520.5732	47.1268
C3H8	254.40	210.1506	44.2494
1-C4H8	497.30	32.0683	465.2317
IC4H10	378.40	55.2689	323.1311
NC4H10	134.70	1.6847	133.0153
1-C5H10	14.80	0.0000	14.8000
IC5H12	25.10	0.0000	25.1000
NC5H12	0.90	0.0000	0.9000
Total lbmols/hr	1875.80	822.2451	1053.5563
T., Deg. F.	140.00	90.77	170.16
P., Psia	183.00	179.00	185.00
H, KBtu	7504.98	-375.59	2181.52
S, KBtu/R	117.2065	41.1785	64.8827
Mol. Weight	51.0851	44.2248	56.4399
D, Lb/FT3	3.5280	31.1137	30.9042
L/F (Molar)	0.51764	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15349.540
Reboiler, KBtu/hr	9650.781
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	0
Feed Plate	11
Operating Cost, $/Year	$251,979.00
Column Thermodynamic Efficiency	10.61%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.56 Ft	7.00 Ft
Bottom Section	5.78 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

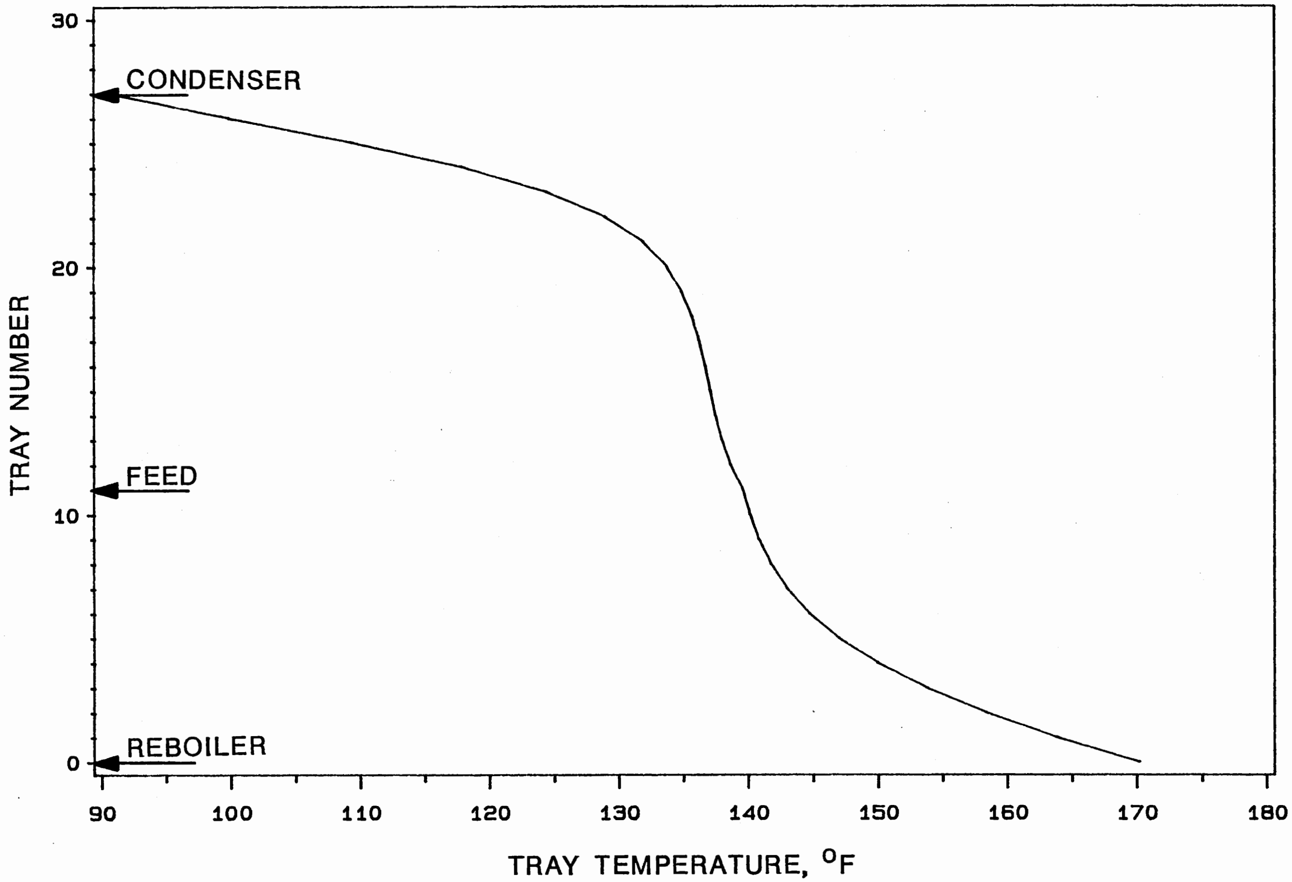


Figure 28. Steady State Simulation Results For Run 4

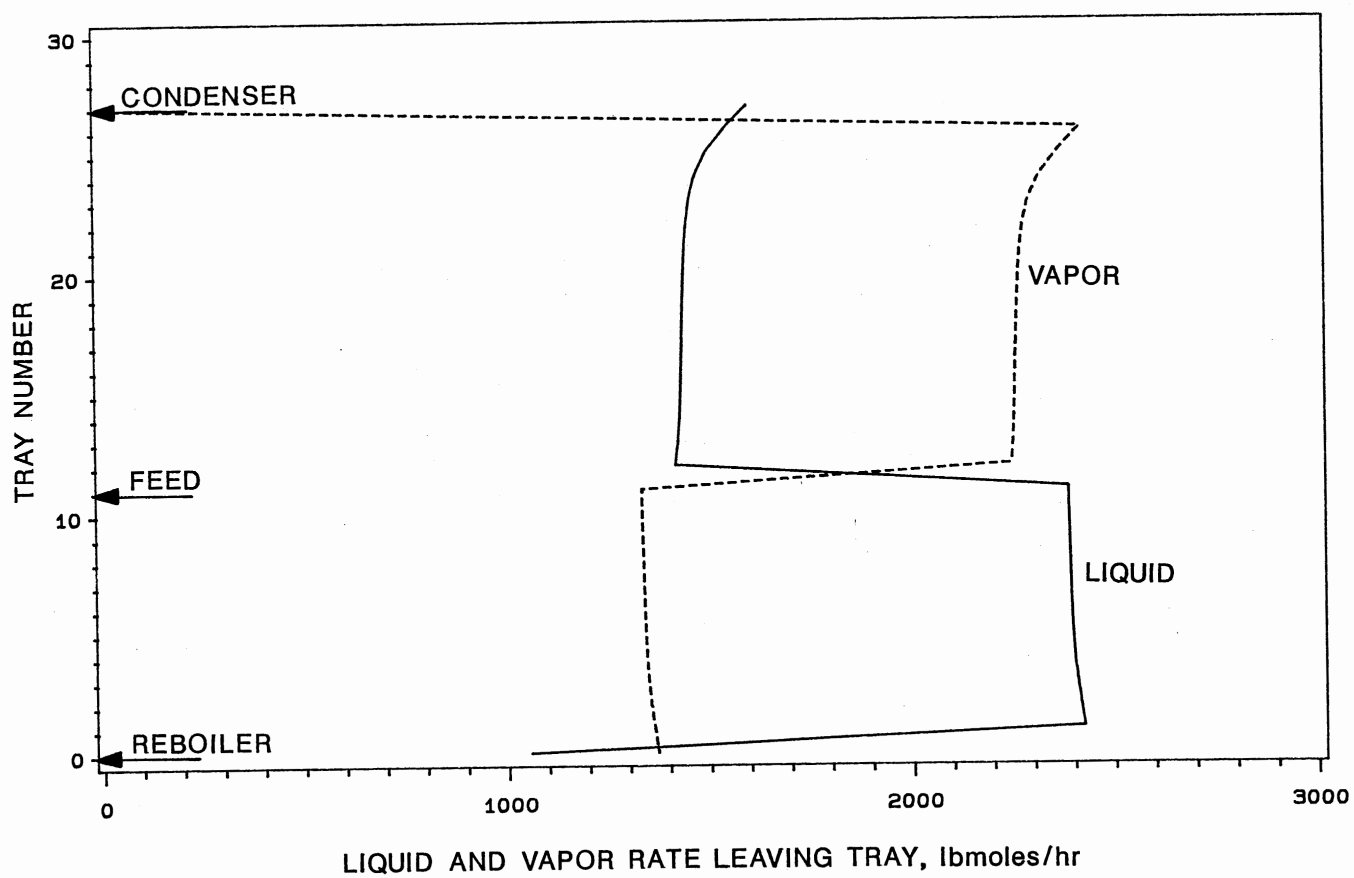


Figure 29. Steady State Simulation Results For Run 4

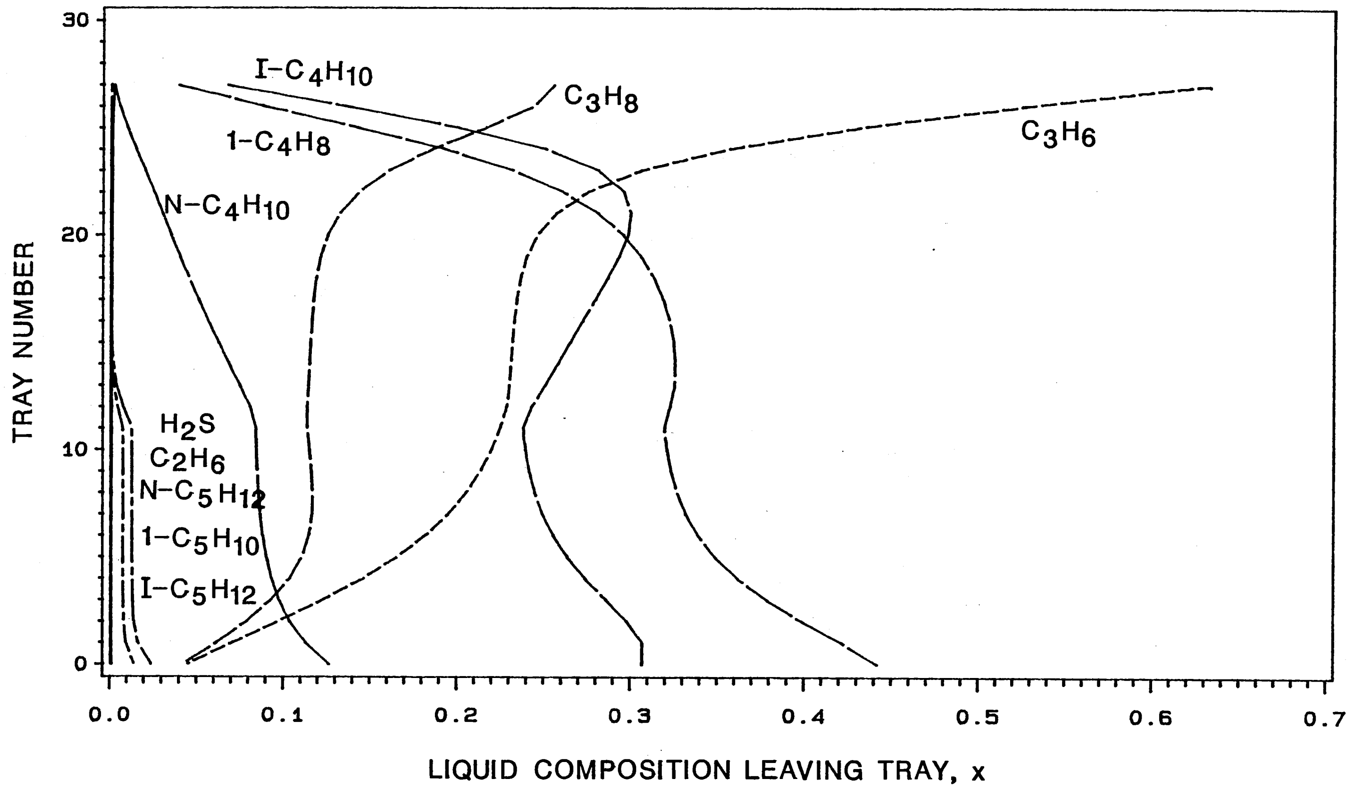


Figure 30. Steady State Simulation Results For Run 4

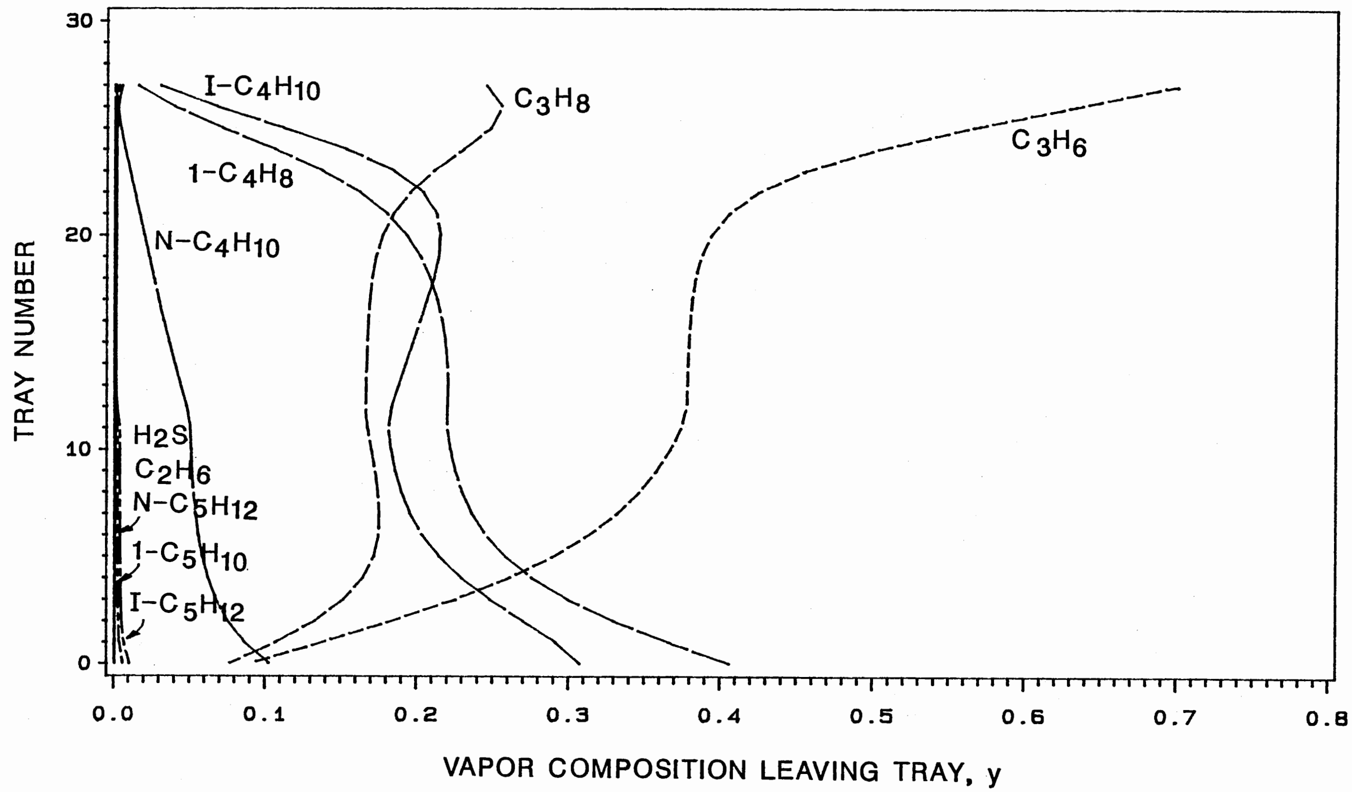


Figure 31. Steady State Simulation Results For Run 4

TABLE X

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 5

FEED PLATE = 9

Number of Plates in Column	26
Number of Feed Plates	1
Number of Products	2
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	9

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.00
Top Plate	180.00	
Reboiler	185.00	174.00

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	25
Max Delta T Per Plate	15.000
Max Fractional Liquid Change Per Plate	0.300

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
1.100 (L/F)

Estimated Bottoms Rate 0.500 (B/F)

TABLE XI

STEADY STATE RESULTS FOR SIMULATION 5

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Distillate	Bottoms
H2S	1.60	1.5994	0.0006
C2H6	0.90	0.8999	0.0001
C3H6	567.70	516.9955	50.7045
C3H8	254.40	210.0507	44.3493
1-C4H8	497.30	31.9758	465.3242
IC4H10	378.40	56.9374	321.4626
NC4H10	134.70	1.4140	133.2859
1-C5H10	14.80	0.0000	14.8000
IC5H12	25.10	0.0000	25.1000
NC5H12	0.90	0.0000	0.9000
Total lbmols/hr	1875.80	819.8741	1055.9276
T., Deg. F.	140.00	90.90	169.74
P., Psia	183.00	179.00	185.00
H, KBtu	7504.98	-371.06	2167.36
S, KBtu/R	117.2065	41.0794	64.9889
Mol. Weight	51.0851	44.2565	56.3878
D, Lb/FT3	3.5280	31.1125	30.9163
L/F (Molar)	0.51764	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15348.589
Reboiler, KBtu/hr	9641.223
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	0
Feed Plate	9
Operating Cost, $/Year	$251,785.00
Column Thermodynamic Efficiency	10.2%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.56 Ft	7.00 Ft
Bottom Section	5.78 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

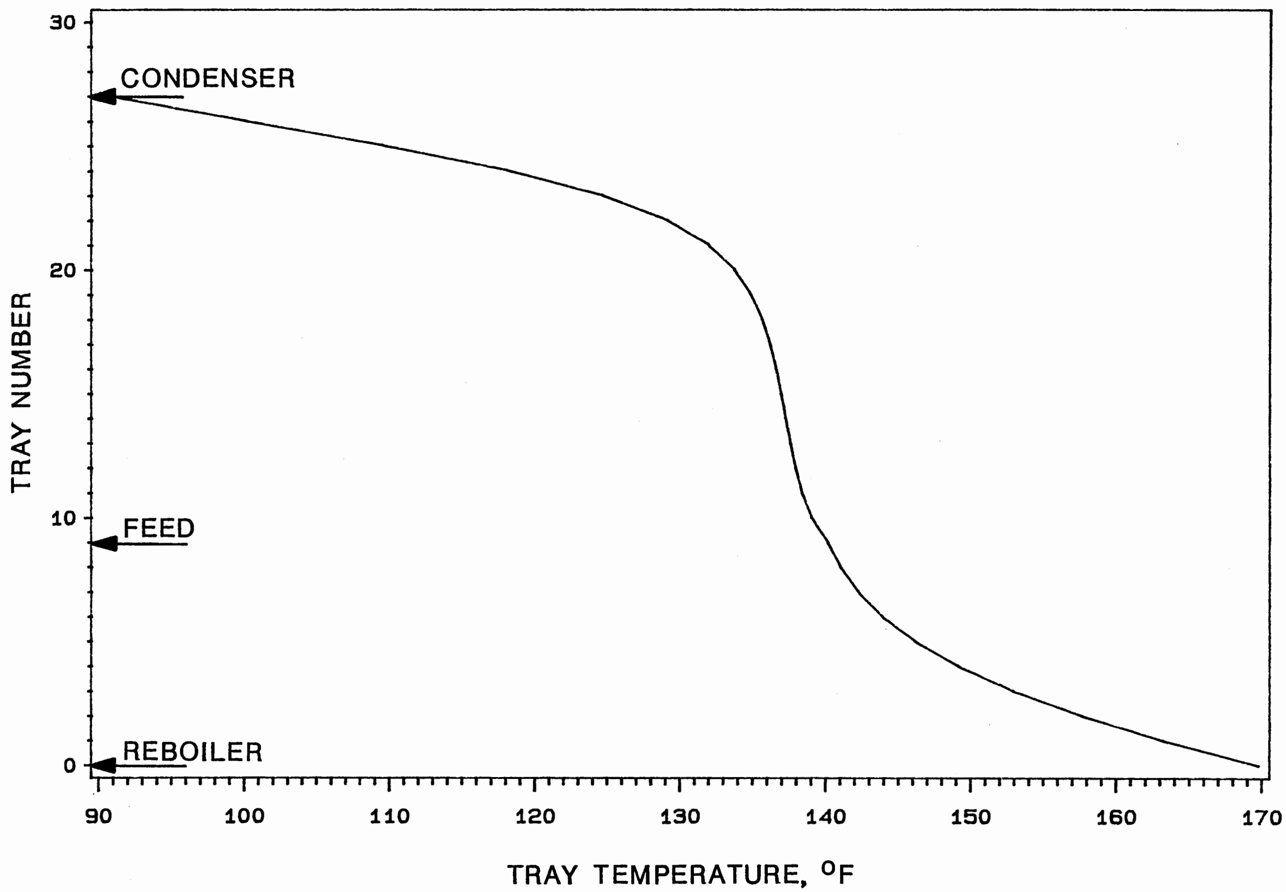


Figure 32. Steady State Simulation Results For Run 5

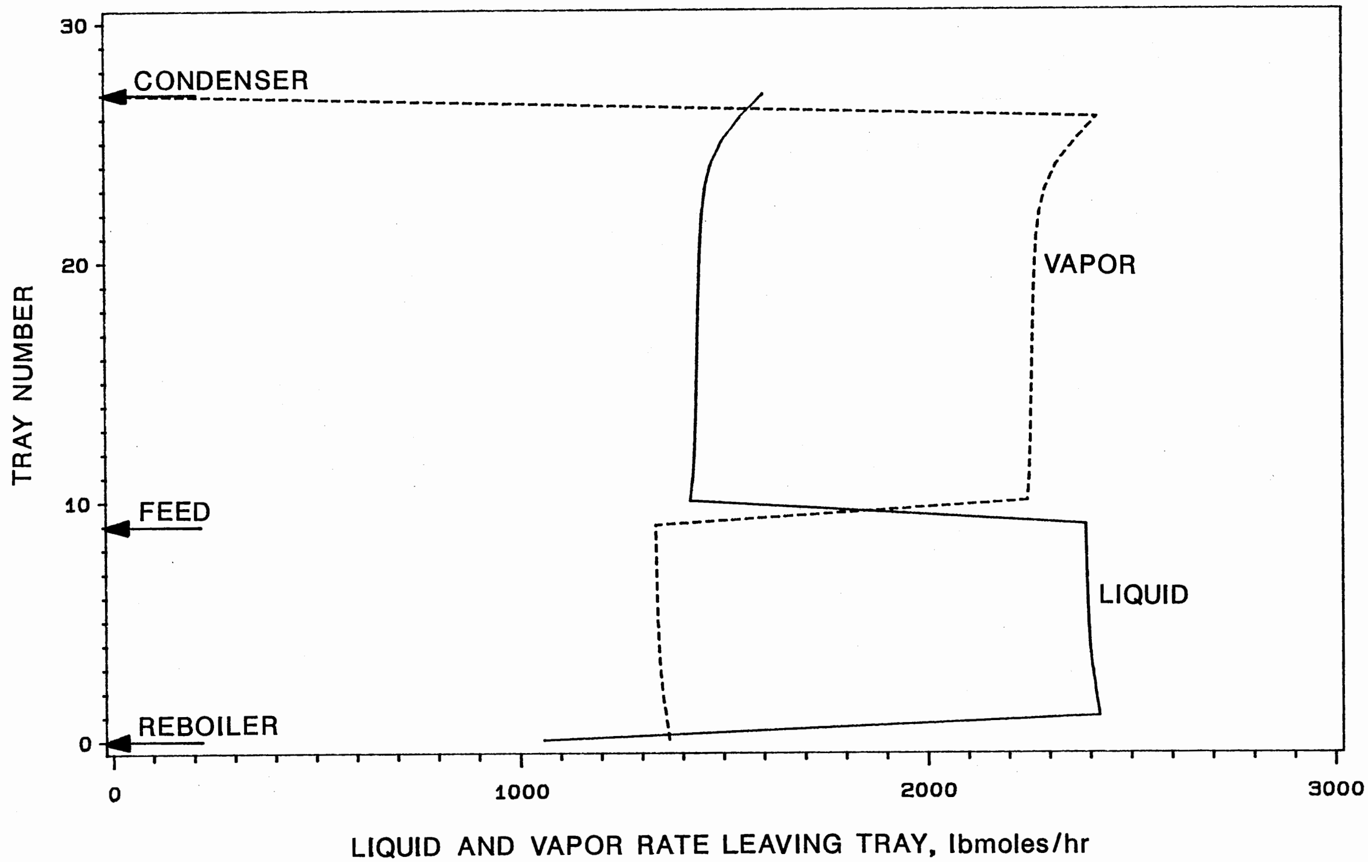


Figure 33. Steady State Simulation Results For Run 3

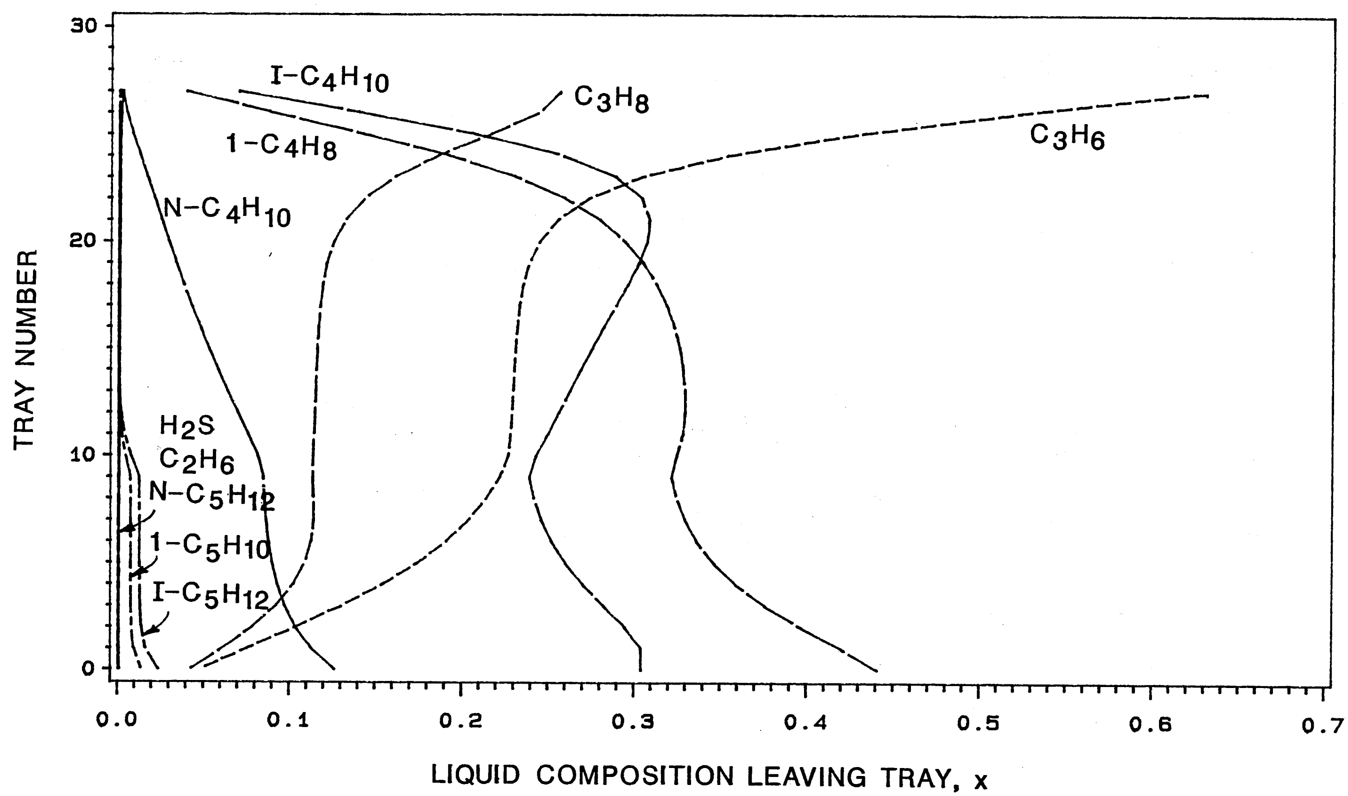


Figure 34. Steady State Simulation Results For Run 5

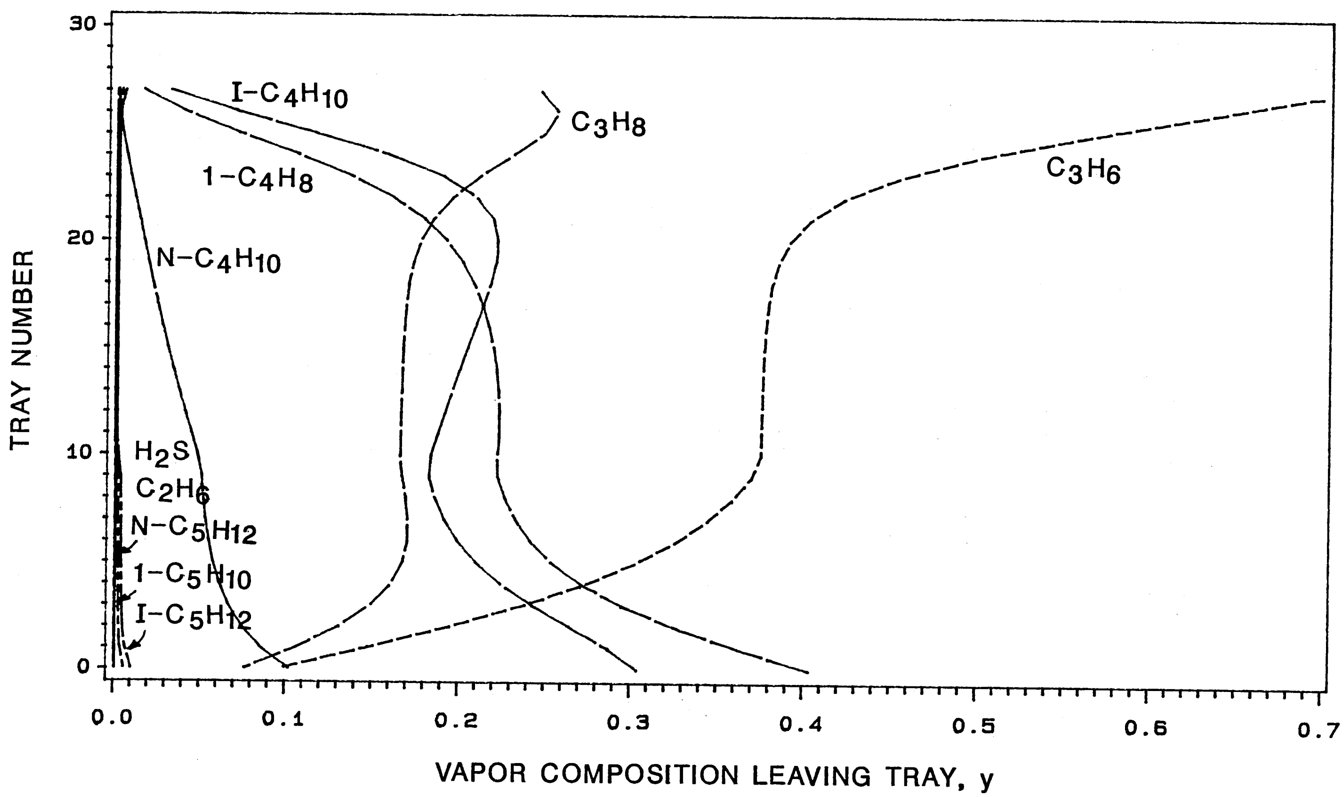


Figure 35. Steady State Simulation Results For Run 5

TABLE XII

DISTILLATION COLUMN SPECIFICATIONS FOR SIMULATION 6

FEED PLATE = 7

Number of Plates in Column	26
Number of Feed Plates	1
Number of Products	2
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	7

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.00
Top Plate	180.00	
Reboiler	185.00	174.00

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	25
Max Delta T Per Plate	15.000
Max Fractional Liquid Change Per Plate	0.300

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
1.100 (L/F)

Estimated Bottoms Rate 0.500 (B/F)

TABLE XIII

STEADY STATE RESULTS FOR SIMULATION 6

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Distillate	Bottoms
H2S	1.60	1.5983	0.0017
C2H6	0.90	0.8997	0.0003
C3H6	567.70	512.7250	54.9750
C3H8	254.40	209.9233	44.4767
1-C4H8	497.30	31.8577	465.4423
IC4H10	378.40	58.6264	319.7736
NC4H10	134.70	1.1761	133.5239
1-C5H10	14.80	0.0000	14.8000
IC5H12	25.10	0.0000	25.1000
NC5H12	0.90	0.0000	0.9000
Total lbmols/hr	1875.80	816.8117	1058.9910
T., Deg. F.	140.00	91.04	169.24
P., Psia	183.00	179.00	185.00
H, KBtu	7504.98	-365.88	2151.06
S, KBtu/R	117.2065	40.9477	65.1285
Mol. Weight	51.0851	44.2908	56.3262
D, Lb/FT3	3.5280	31.1112	30.9303
L/F (Molar)	0.51764	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15447.527
Reboiler, KBtu/hr	9728.260
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	0
Feed Plate	7
Operating Cost, $/Year	$253,915.00
Column Thermodynamic Efficiency	9.58%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.58 Ft	7.00 Ft
Bottom Section	5.79 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

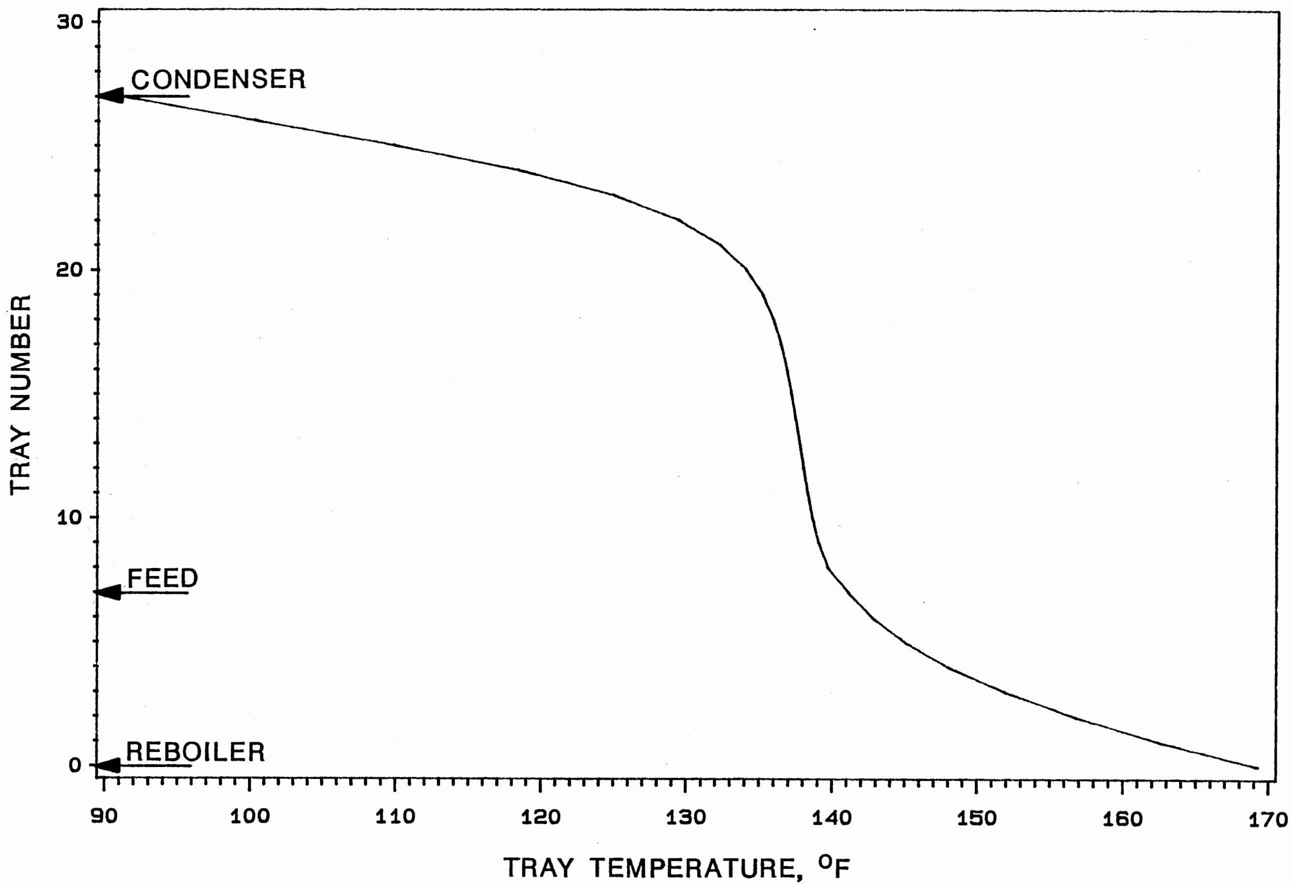


Figure 36. Steady State Simulation Results For Run 6

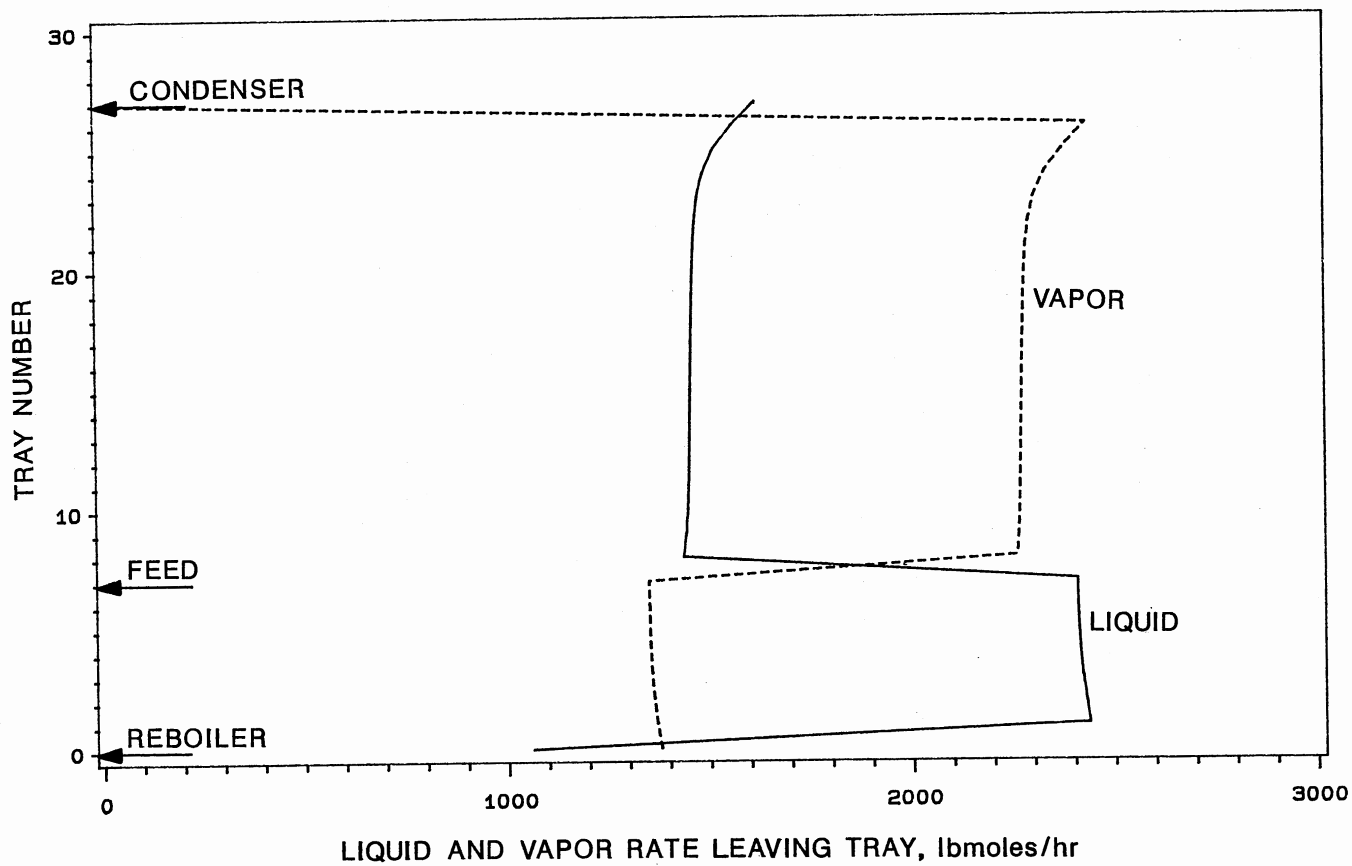


Figure 37. Steady State Simulation Results For Run 6

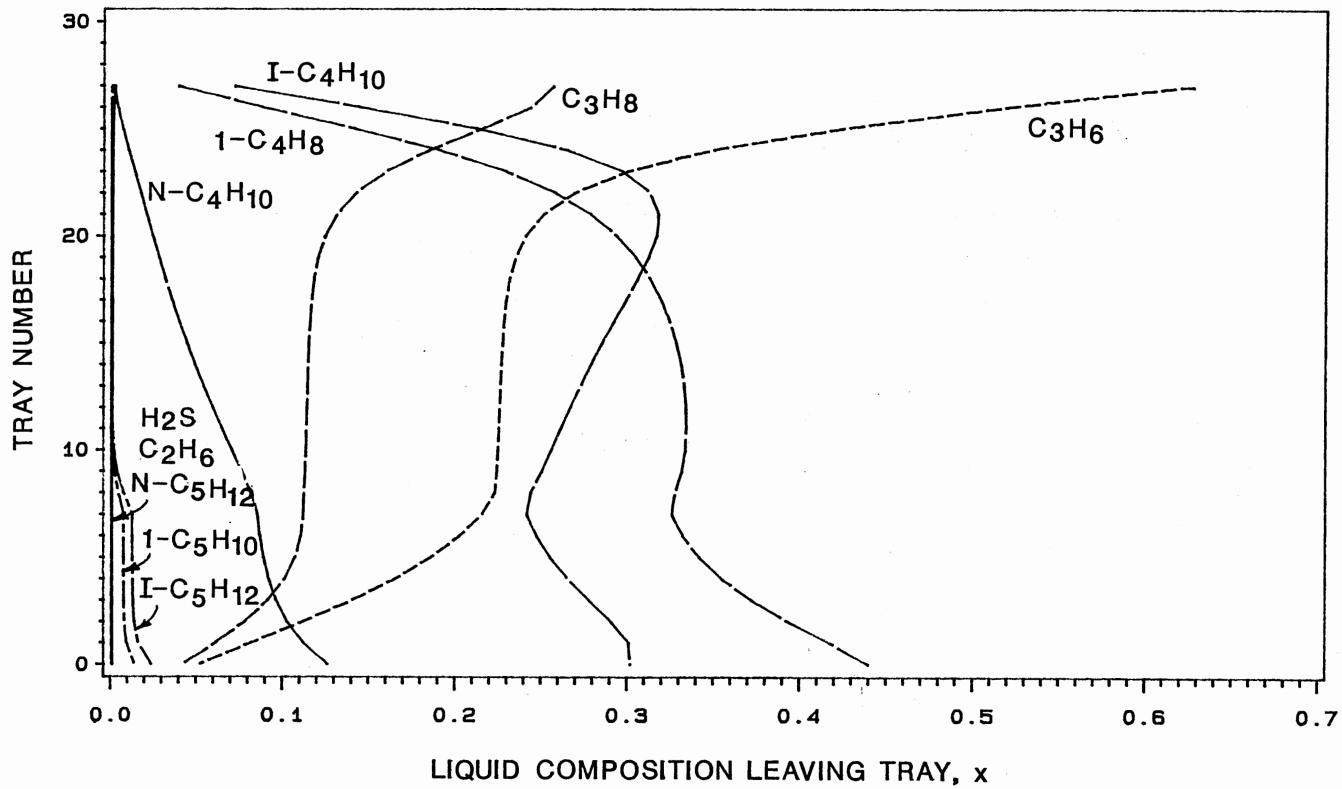


Figure 38. Steady State Simulation Results For Run 6

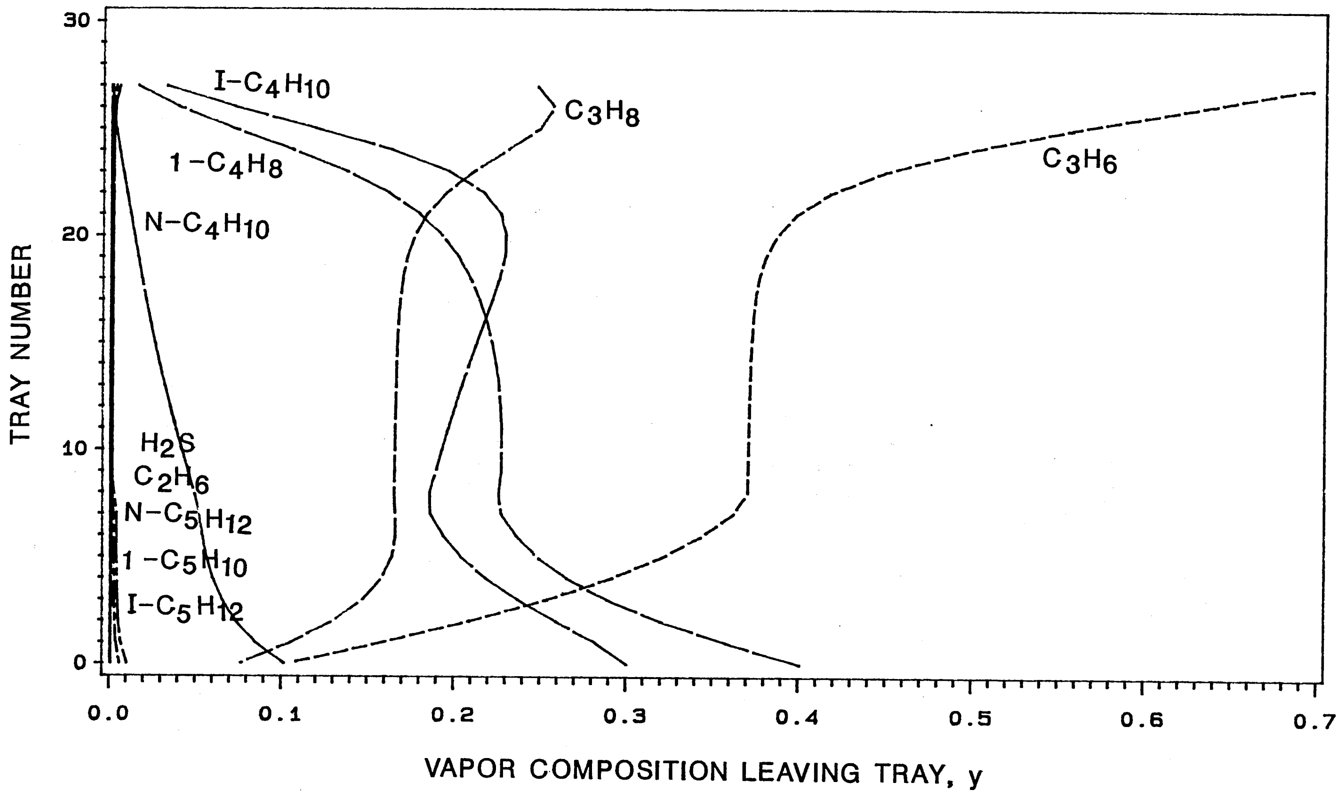


Figure 39. Steady State Simulation Results For Run 6

TABLE XIV

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 7

FEED PLATE = 8

Number of Plates in Column	26
Number of Feed Plates	1
Number of Products	2
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	8

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.00
Top Plate	180.00	
Reboiler	185.00	174.00

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	25
Max Delta T Per Plate	15.000
Max Fractional Liquid Change Per Plate	0.300

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
1.100 (L/F)

Estimated Bottoms Rate 0.500 (B/F)

TABLE XV

STEADY STATE RESULTS FOR SIMULATION 7

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Distillate	Bottoms
H2S	1.60	1.5990	0.0010
C2H6	0.90	0.8999	0.0001
C3H6	567.70	514.9548	52.7452
C3H8	254.40	209.9897	44.4103
1-C4H8	497.30	31.9188	465.3813
IC4H10	378.40	57.7507	320.6494
NC4H10	134.70	1.2919	133.4081
1-C5H10	14.80	0.0000	14.8000
IC5H12	25.10	0.0000	25.1000
NC5H12	0.90	0.0000	0.9000
Total lbmols/hr	1875.80	818.4070	1057.3953
T., Deg. F.	140.00	90.97	169.50
P., Psia	183.00	179.00	185.00
H, KBtu	7504.98	-368.57	2159.57
S, KBtu/R	117.2065	41.0162	65.0559
Mol. Weight	51.0851	44.2729	56.3583
D, Lb/FT3	3.5280	31.1118	30.9230
L/F (Molar)	0.51764	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15379.728
Reboiler, KBtu/hr	9666.455
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	0
Feed Plate	8
Operating Cost, $/Year	$252,413.00
Column Thermodynamic Efficiency	9.91%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.57 Ft	7.00 Ft
Bottom Section	5.78 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

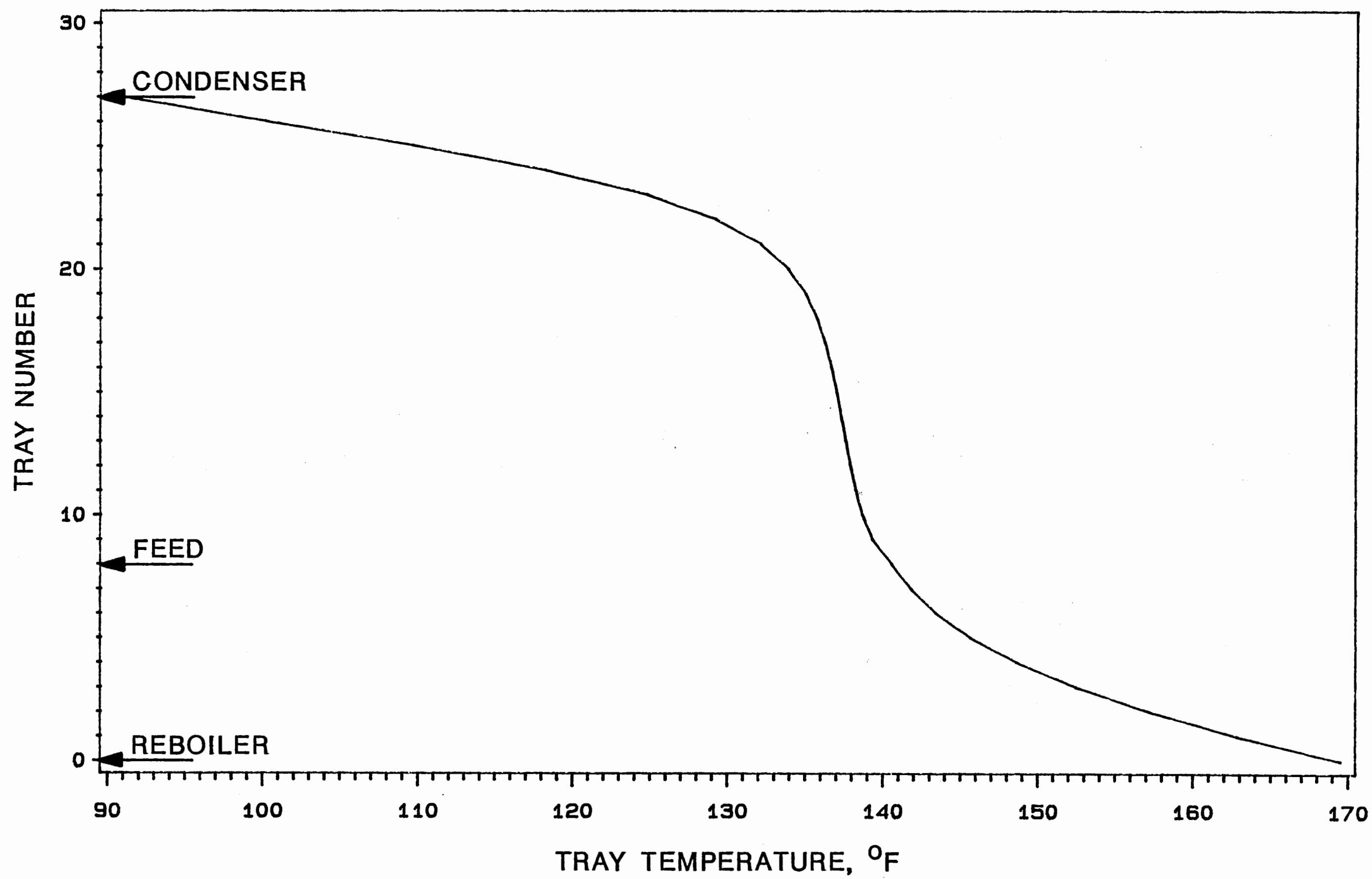


Figure 40. Steady State Simulation Results For Run 7

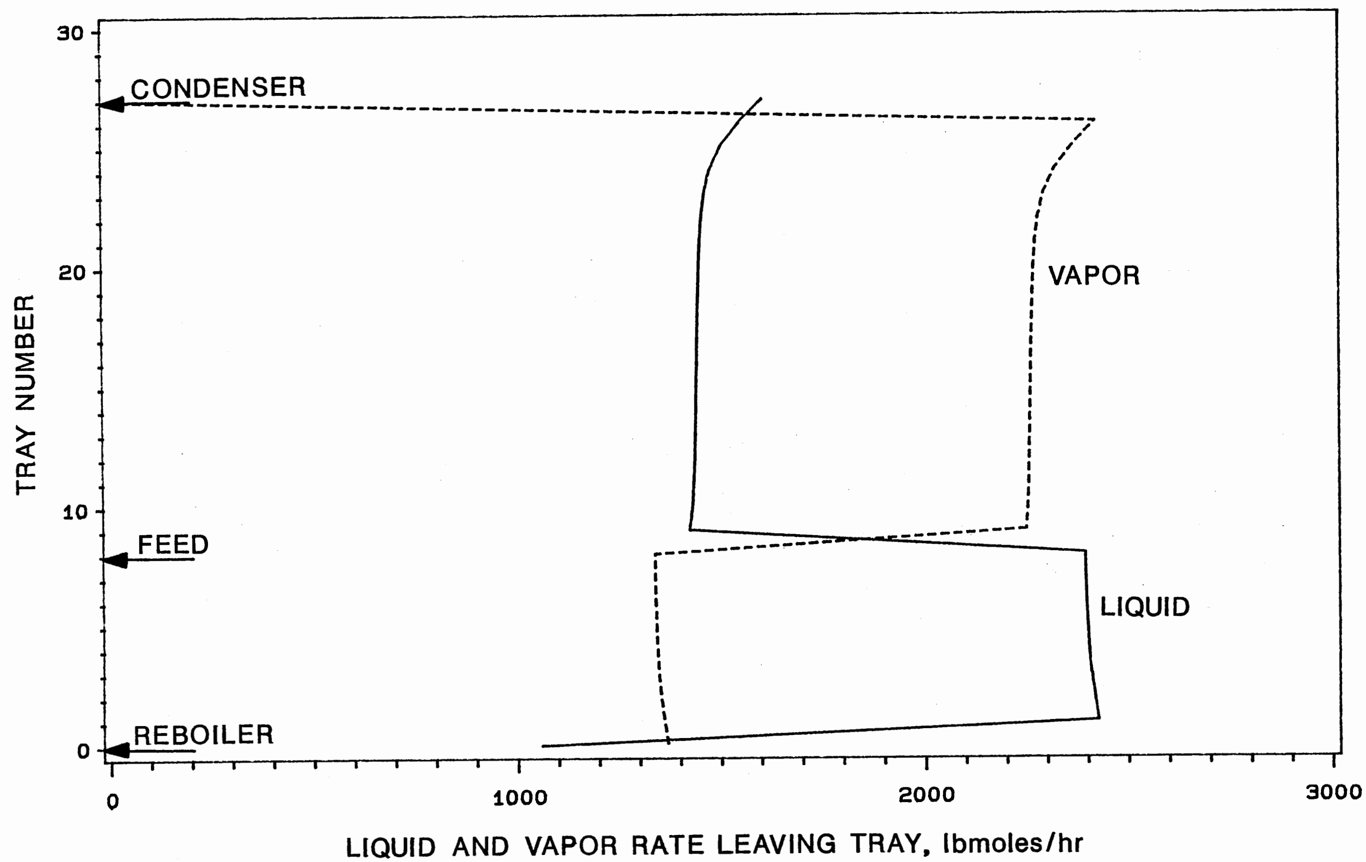


Figure 41. Steady State Simulation Results For Run 7

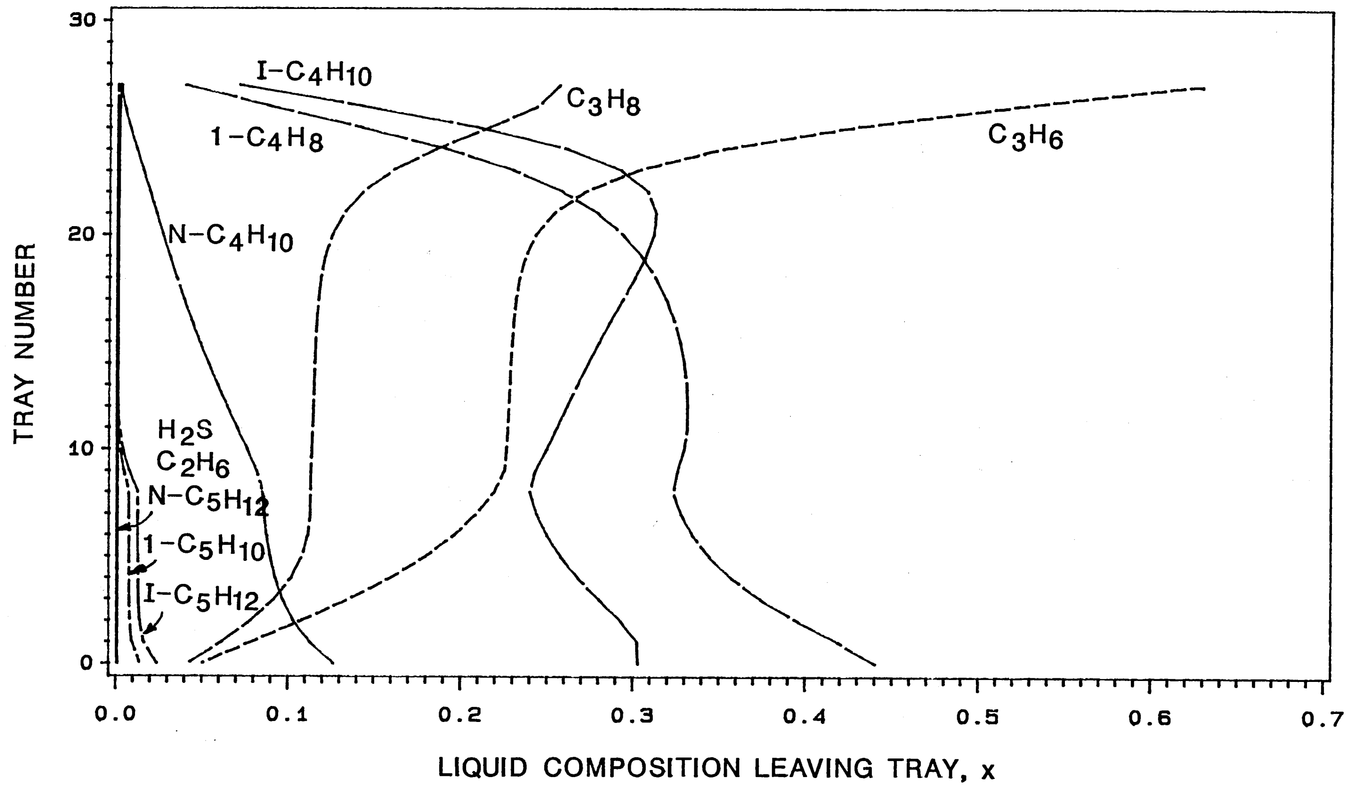


Figure 42. Steady State Simulation Results For Run 7

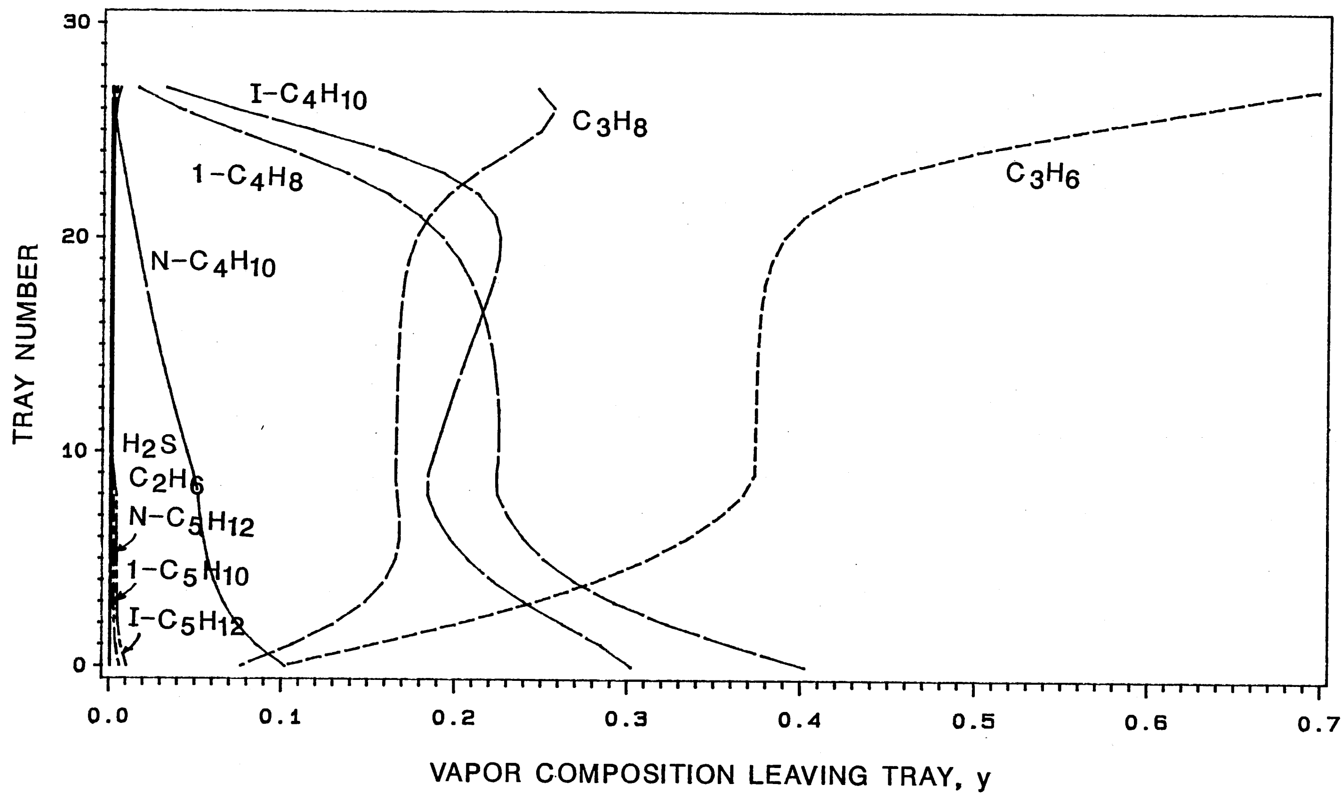


Figure 43. Steady State Simulation Results For Run 7

TABLE XVI

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 8

FEED PLATE = 10

Number of Plates in Column	26
Number of Feed Plates	1
Number of Products	2
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.00
Top Plate	180.00	
Reboiler	185.00	174.00

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	25
Max Delta T Per Plate	15.000
Max Fractional Liquid Change Per Plate	0.300

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
1.100 (L/F)

Estimated Bottoms Rate 0.500 (B/F)

TABLE XVII

STEADY STATE RESULTS FOR SIMULATION 8

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Distillate	Bottoms
H2S	1.60	1.5997	0.0003
C2H6	0.90	0.9000	0.0000
C3H6	567.70	518.8619	48.8381
C3H8	254.40	210.1048	44.2952
1-C4H8	497.30	32.0256	465.2744
IC4H10	378.40	56.1254	322.2746
NC4H10	134.70	1.5444	133.1556
1-C5H10	14.80	0.0000	14.8000
IC5H12	25.10	0.0000	25.1000
NC5H12	0.90	0.0000	0.9000
Total lbmols/hr	1875.80	821.1660	1054.6371
T., Deg. F.	140.00	90.84	169.96
P., Psia	183.00	179.00	185.00
H, KBtu	7504.98	-373.37	2174.61
S, KBtu/R	117.2065	41.1343	64.9304
Mol. Weight	51.0851	44.2408	56.4149
D, Lb/FT3	3.5280	31.1131	30.9101
L/F (Molar)	0.51764	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15341.672
Reboiler, KBtu/hr	9638.219
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	0
Feed Plate	10
Operating Cost, $/Year	$251,697.00
Column Thermodynamic Efficiency	10.4%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.56 Ft	7.00 Ft
Bottom Section	5.78 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

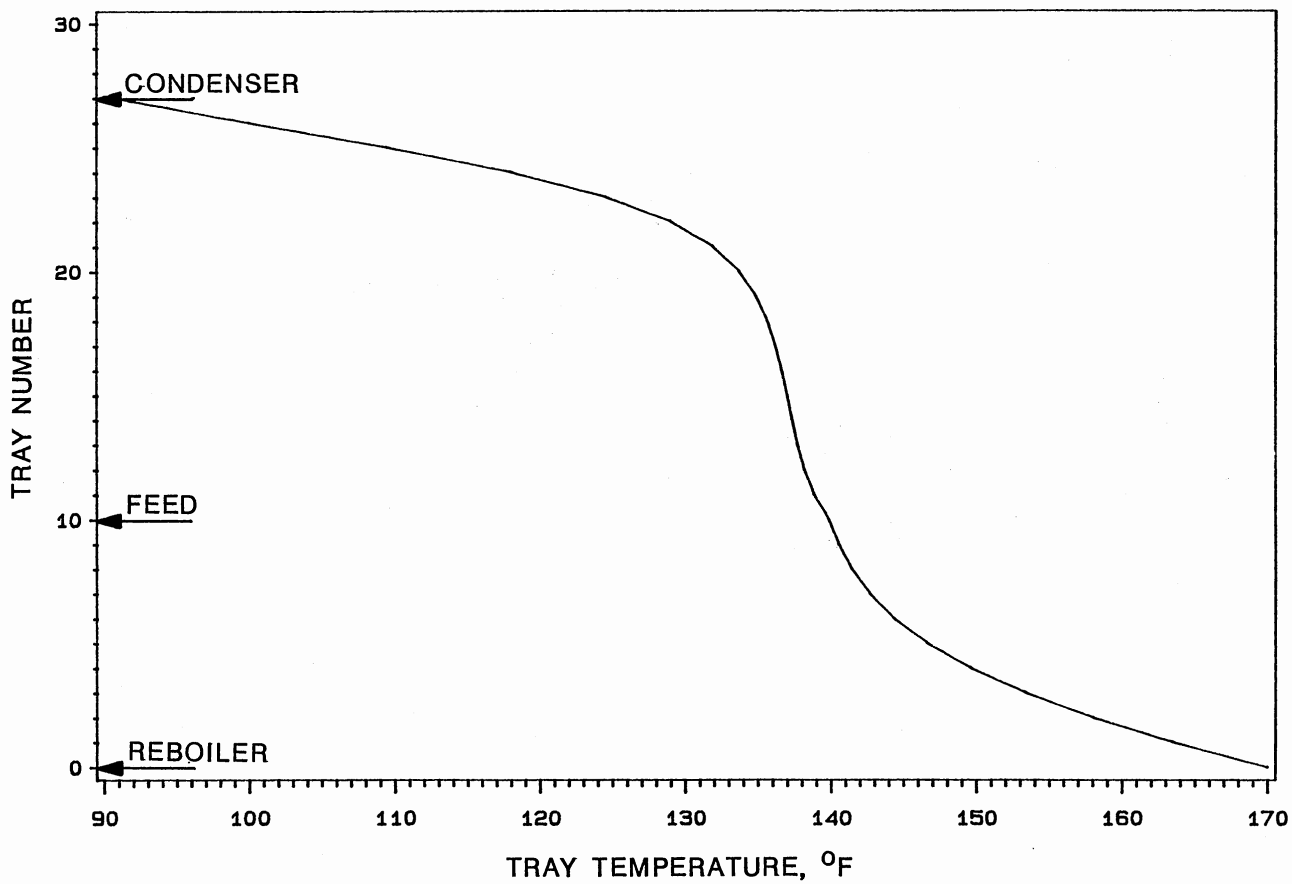


Figure 44. Steady State Simulation Results For Run 8

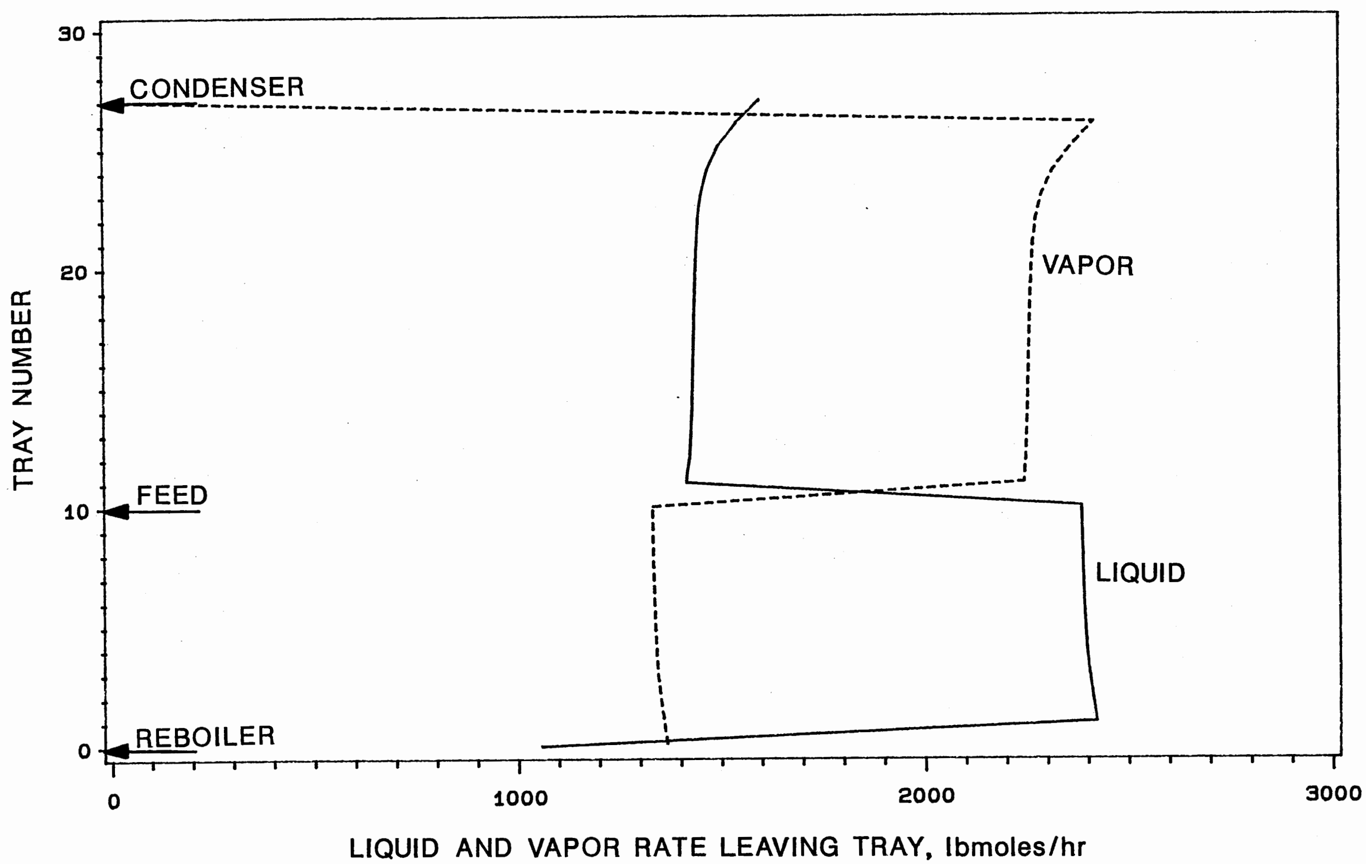


Figure 45. Steady State Simulation Results For Run 8

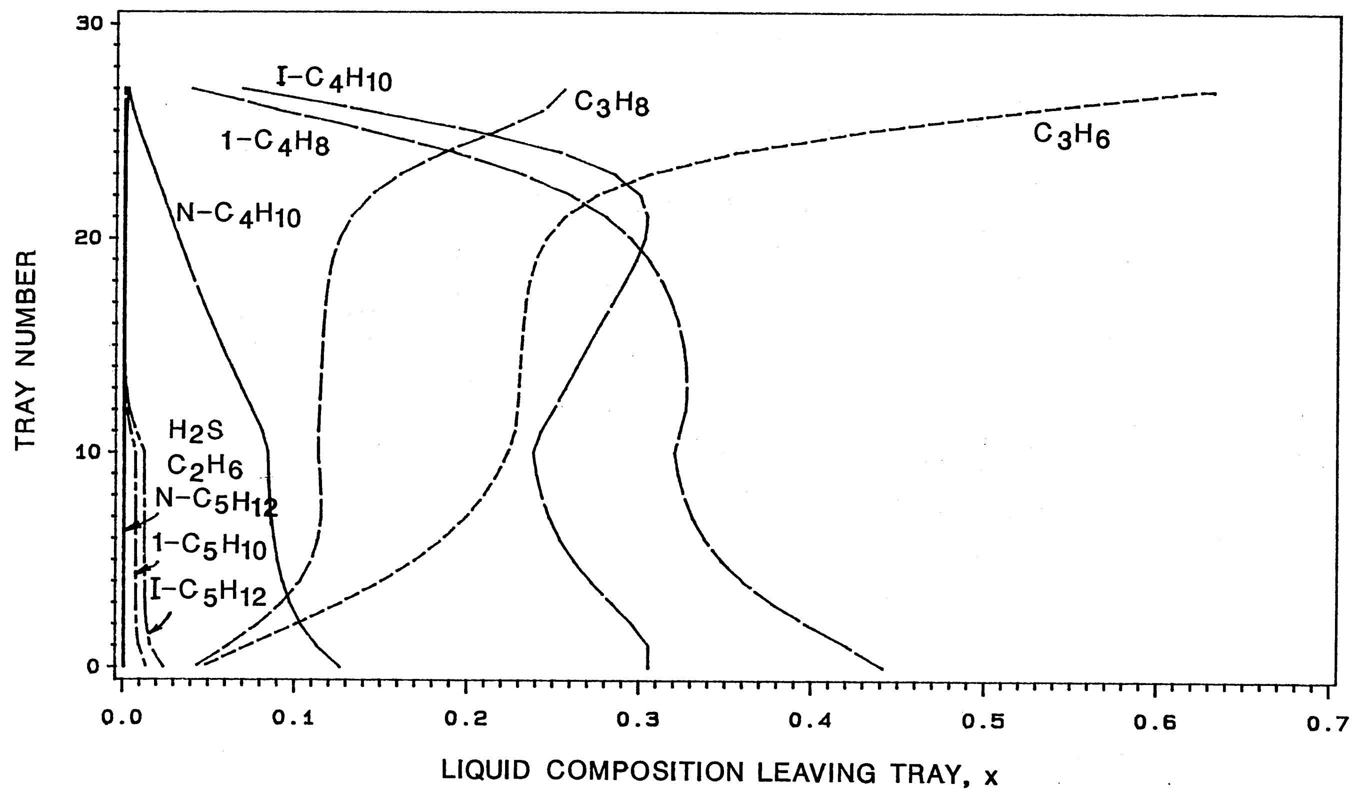


Figure 46. Steady State Simulation Results For Run 8

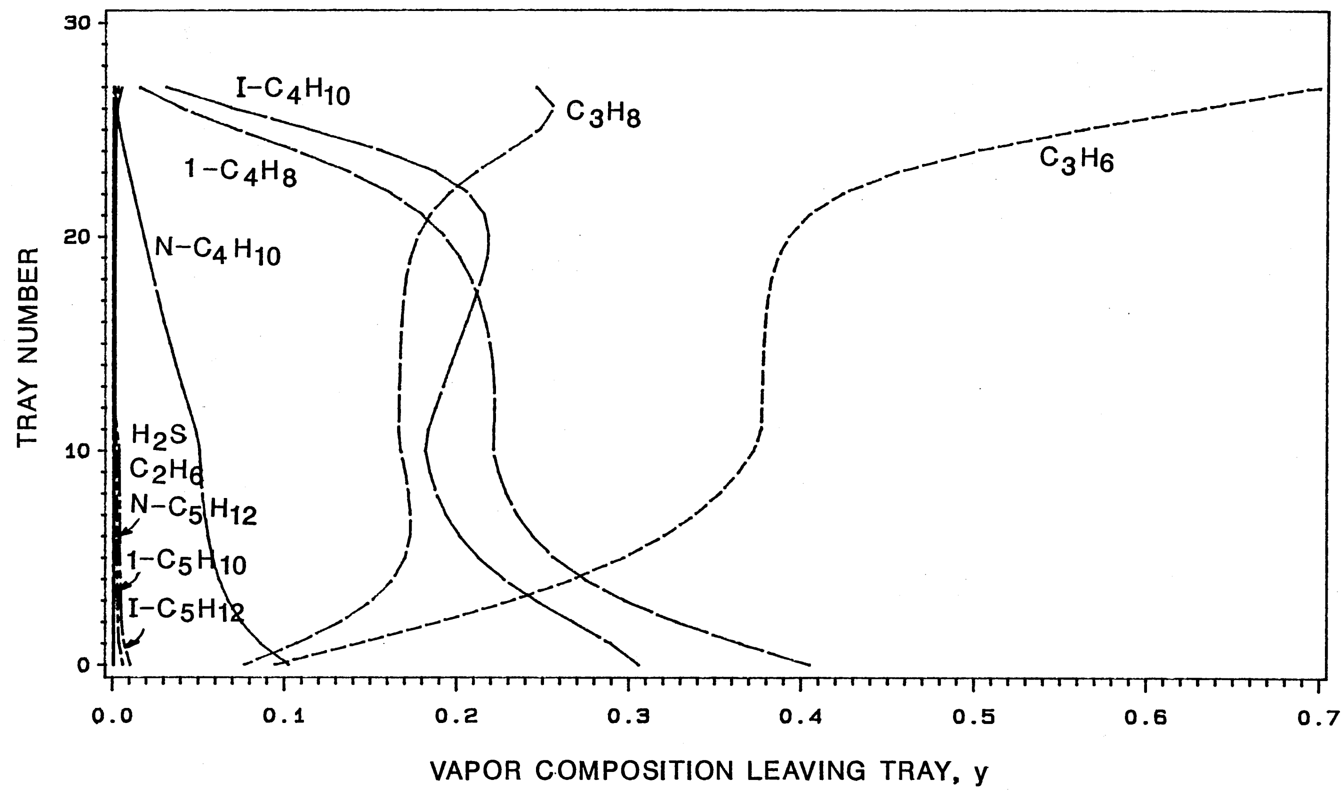


Figure 47. Steady State Simulation Results For Run 8

TABLE XVIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 9

FEED PLATE = 10, SIDE DRAW = 8, RETURN = 10

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	10

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	8	0.20000
3	6	0	

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	174.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE XIX

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 9

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		504.00 KBTU
Specific Delta P		1.00 PSIA

TABLE XX

STEADY STATE RESULTS FOR SIMULATION 9

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Draw	Distillate	Side Heater Return	Bottoms
H2S	1.60	0.343	1.5994	0.0345	0.0003
C2H6	0.90	0.0116	0.9000	0.0115	0.0000
C3H6	567.70	90.1632	518.5324	94.5815	44.7493
C3H8	254.40	51.0134	212.5668	52.0703	40.7763
1-C4H8	497.30	158.2581	34.8692	155.6496	465.0392
IC4H10	378.40	118.2062	60.0492	115.7776	320.7793
NC4H10	134.70	41.4250	1.7181	40.9880	133.4189
1-C5H10	14.80	3.5409	0.0000	3.5497	14.7912
IC5H12	25.10	6.0579	0.0000	6.0712	25.0866
NC5H12	0.90	0.2089	0.0000	0.2096	0.8993
Total lbmols/hr	1875.80	468.9194	830.2367	468.9439	1045.5405
T., Deg. F.	140.00	149.26	91.33	142.61	170.77
P., Psia	183.00	189.00	179.00	183.46	185.00
H, KBtu	7504.98	1016.65	-367.17	490.76	2188.50
S, KBtu/R	117.2065	28.2942	41.6778	27.3968	64.4526
Mol. Weight	51.0851	53.1066	44.3503	52.9362	56.5102
D, Lb/FT3	3.5280	10.0061	31.1204	31.3013	30.8977
L/F (Molar)	0.51764	0.86053	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15758.529 KBTU
Reboiler, KBtu/hr	9549.042 KBTU
Intermediate Reboiler, KBtu/hr	0
Intermediate Reboiler Side Draw and Return Tray Numbers	
Intermediate Reboiler Pumparound Rate, Lbmol/hr	8
Feed Plate	10
Operating Cost, $/Year	$257,132.00
Column Thermodynamic Efficiency	9.6%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.64 FT	7.00 Ft
Bottom Section	5.76 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE XXI

STEADY STATE RESULTS FOR SIMULATION 9
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0345	0.0343
C2H6	0.0115	0.0116
C3H6	94.5815	90.1632
C3H8	52.0703	51.0134
1-C4H8	155.6496	158.2581
IC4H10	115.7776	118.2062
NC5H10	40.9880	41.4250
1-C5H12	3.5497	3.5409
IC5H12	6.0712	6.0579
NC5H12	0.2096	0.2089
Total	468.9439	468.9194
T., Deg. F.	142.61	143.95
P., Psia	183.46	190.00
H. KBtu	490.76	512.70
S, KBtu/R	27.3968	27.4641
Mol. Weight	52.9362	53.1068
D, Lb/Ft3	31.3013	31.2767
L/F (Molar)	1.00000	1.00000

WORK = -0.54 HP at 75% Efficiency

TABLE XXII

STEADY STATE RESULTS FOR SIMULATION 9
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0343	0.0343
C2H6	0.0116	0.0116
C3H6	90.1632	90.1632
C3H8	51.0134	51.0134
1-C4H8	158.2581	158.2581
IC4H10	118.2062	118.2062
NC5H10	41.4250	41.4250
1-C5H12	3.5409	3.5409
IC5H12	6.0579	6.0579
NC5H12	0.2089	0.2089
Total	468.9194	468.9194
T., Deg. F.	143.95	149.26
P., Psia	190.00	189.00
H. KBtu	512.70	1016.65
S, KBtu/R	27.4641	28.2942
Mol. Weight	53.1068	53.1066
D, Lb/Ft3	31.2767	10.0061
L/F (Molar)	1.00000	1.00000
Heat Transferred	503.95 KBTU	

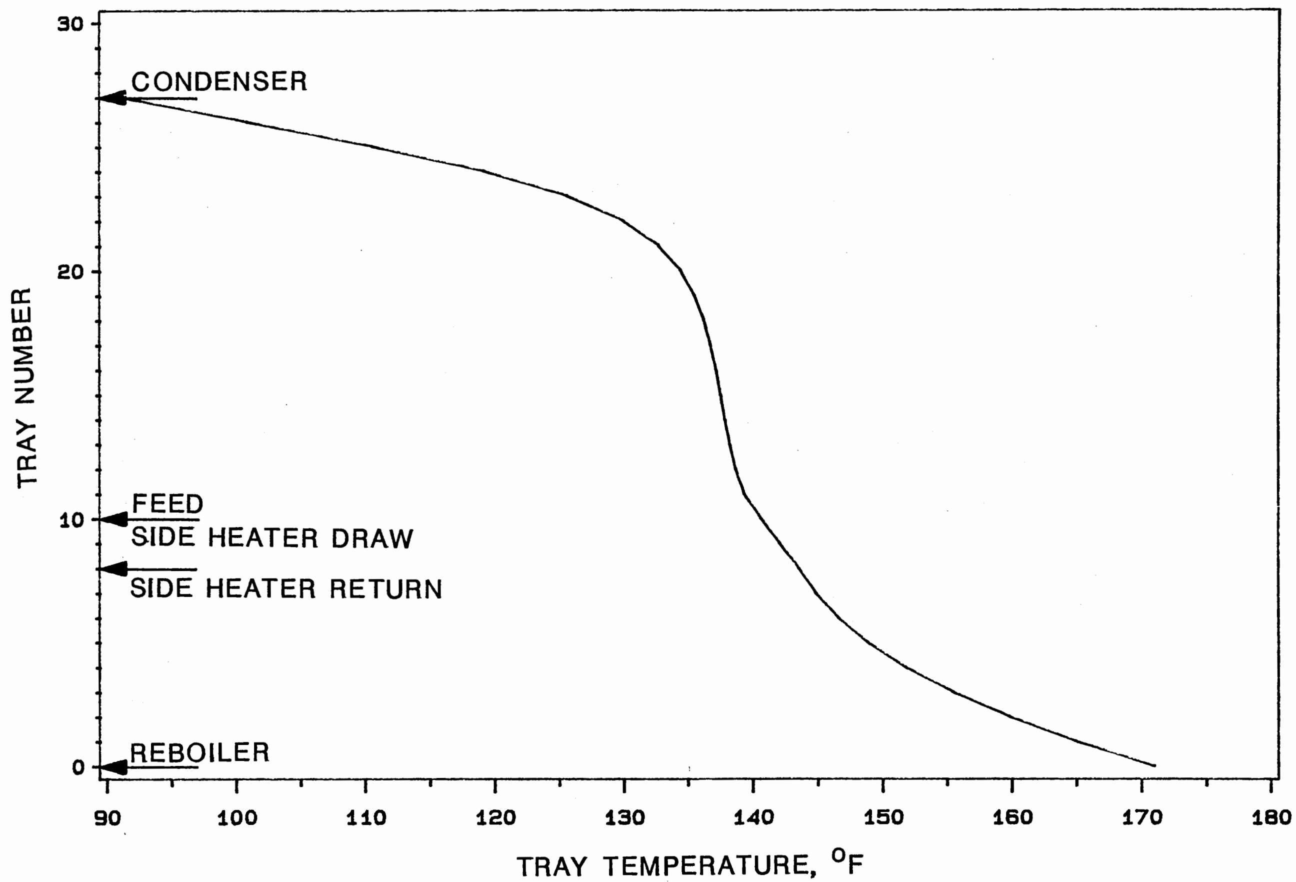


Figure 48. Steady State Simulation Results For Run 9

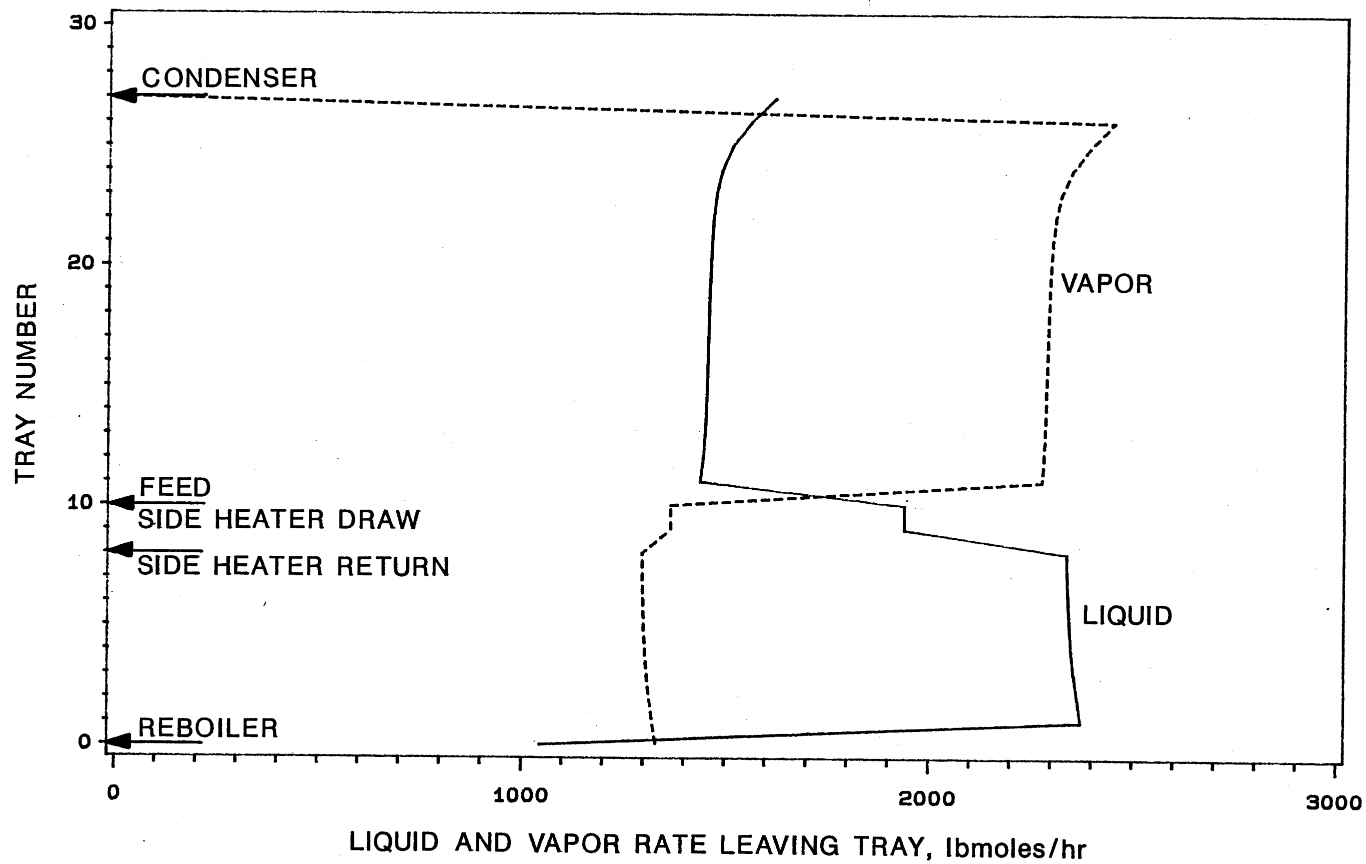


Figure 49. Steady State Simulation Results For Run 9

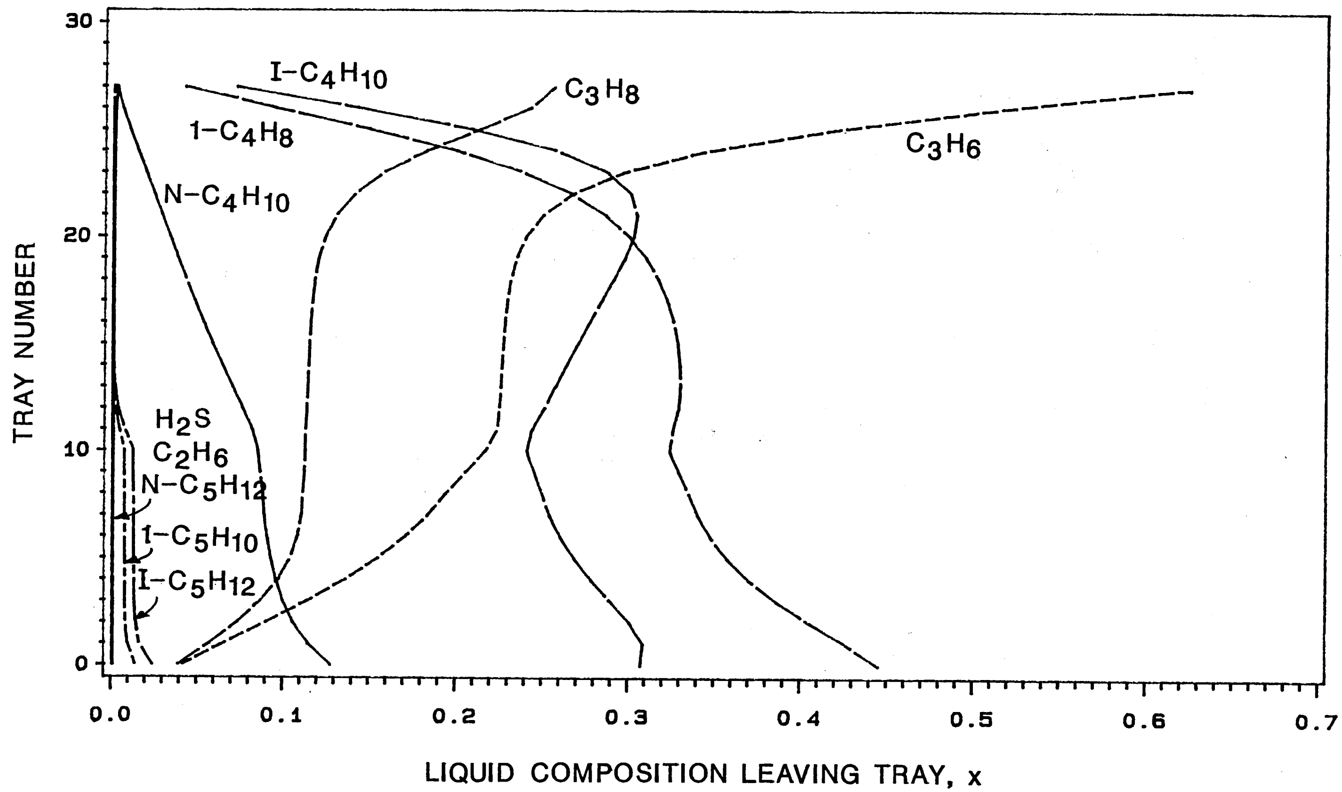


Figure 50. Steady State Simulation Results For Run 9

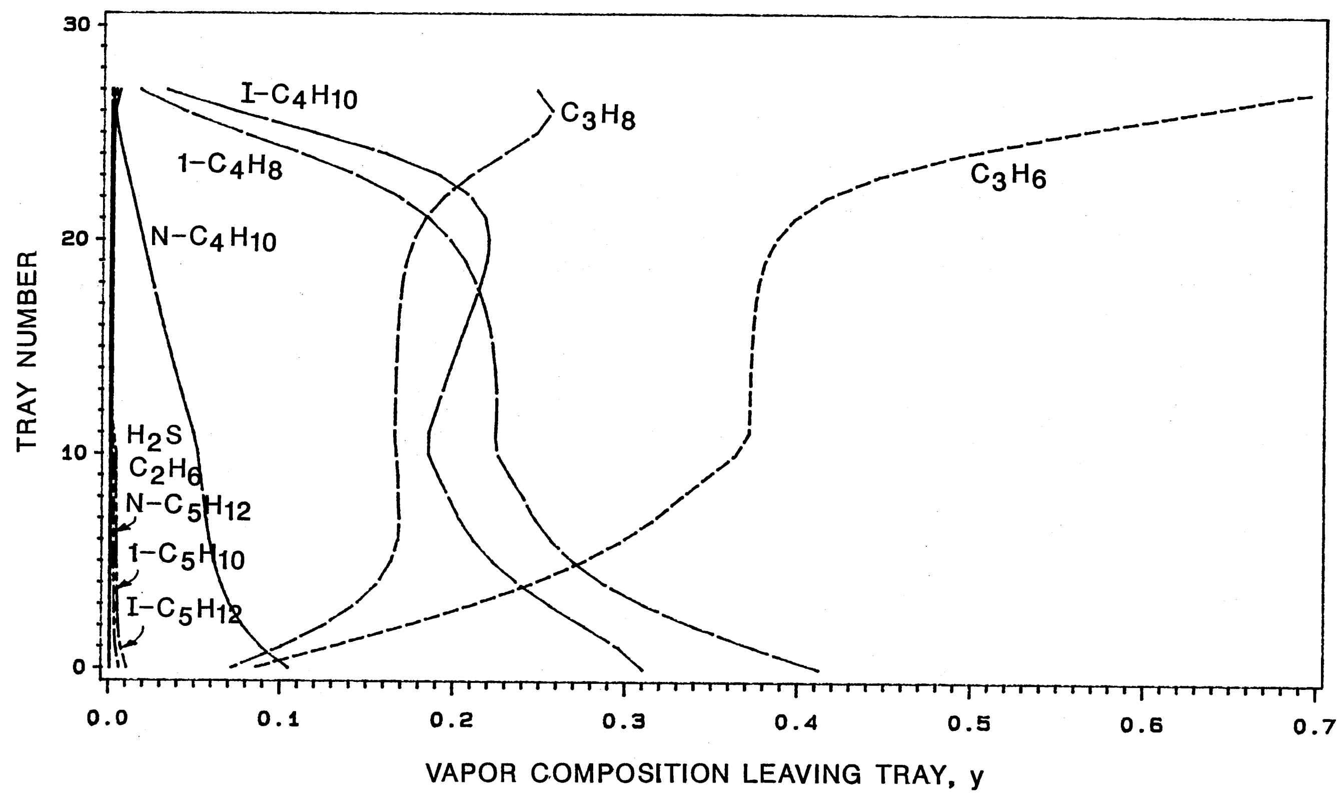


Figure 51. Steady State Simulation Results For Run 9

TABLE XXIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 10

FEED PLATE = 10, SIDE DRAW = 8, RETURN = 6

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	6

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	8	0.20000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE XXIV

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 10

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		504.00 KBTU
Specific Delta P		1.00 PSIA

TABLE XXV

STEADY STATE RESULTS FOR SIMULATION 10

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0255	1.5980	0.0272	0.0003
C2H6	0.90	0.0085	0.8996	0.0089	0.0000
C3H6	567.70	88.6594	520.7791	92.8400	42.7403
C3H8	254.40	52.6496	213.1609	53.2057	40.6830
1-C4H8	497.30	157.9950	34.9703	155.8267	464.4980
IC4H10	378.40	118.2312	59.4556	116.2946	320.8811
NC4H10	134.70	41.4564	1.7570	40.9731	133.4263
1-C5H10	14.80	3.5724	0.0000	3.5265	14.8458
IC5H12	25.10	6.1106	0.0000	6.0331	25.1775
NC5H12	0.90	0.2109	0.0000	0.2081	0.9028
Total lbmols/hr	1875.80	468.9195	832.6232	468.9439	1043.1542
T., Deg. F.	140.00	149.31	91.27	142.80	171.02
P., Psia	183.00	189.00	179.00	183.46	185.00
H, KBtu	7504.98	1018.49	-369.68	494.66	2194.73
S, KBtu/R	117.2065	28.2998	41.7883	27.4074	64.3327
Mol. Weight	51.0851	53.1133	44.3363	52.9598	56.5416
D, Lb/FT3	3.5280	10.0067	31.1203	31.2921	30.8916
L/F (Molar)	0.51764	0.86053	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15496.175
Reboiler, KBtu/hr	9292.125
Intermediate Reboiler, KBtu/hr	503.95
Intermediate Reboiler Side Draw	8
Intermediate Reboiler Return	6
Intermediate Reboiler Pumparound Rate, Lbmol/hr	468.9195
Feed Plate	10
Operating Cost, $/Year	$250,949.00
Column Thermodynamic Efficiency	10.2%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.58 Ft	7.00 Ft
Bottom Section	5.71 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE XXVI

STEADY STATE RESULTS FOR SIMULATION 10
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0272	0.0255
C2H6	0.0089	0.0085
C3H6	92.8400	88.6594
C3H8	53.2057	52.6496
1-C4H8	155.8267	157.9950
IC4H10	116.2946	118.2312
NC5H10	40.9731	41.4564
1-C5H12	3.5265	3.5724
IC5H12	6.0331	6.1106
NC5H12	0.2081	0.2109
Total	468.9439	468.9195
T., Deg. F.	142.80	144.01
P., Psia	183.46	190.00
H. KBtu	494.66	514.54
S, KBtu/R	27.4074	27.4698
Mol. Weight	52.9598	53.1136
D, Lb/Ft3	31.2921	31.2697
L/F (Molar)	1.00000	1.00000

WORK = -0.51 HP at 75% Efficiency

TABLE XXVII

STEADY STATE RESULTS FOR SIMULATION 10
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0255	0.0255
C2H6	0.0085	0.0085
C3H6	88.6594	88.6594
C3H8	52.6496	52.6496
1-C4H8	157.9950	157.9950
IC4H10	118.2312	118.2312
NC5H10	41.4564	41.4564
1-C5H12	3.5724	3.5724
IC5H12	6.1106	6.1106
NC5H12	0.2109	0.2109
Total	468.9195	468.9195
T., Deg. F.	144.01	149.31
P., Psia	190.00	189.00
H. KBtu	514.54	1018.49
S, KBtu/R	27.4698	28.2998
Mol. Weight	53.1136	53.1133
D, Lb/Ft3	31.2697	10.0067
L/F (Molar)	1.00000	0.86053
Heat Transferred	503.95 KBTU	

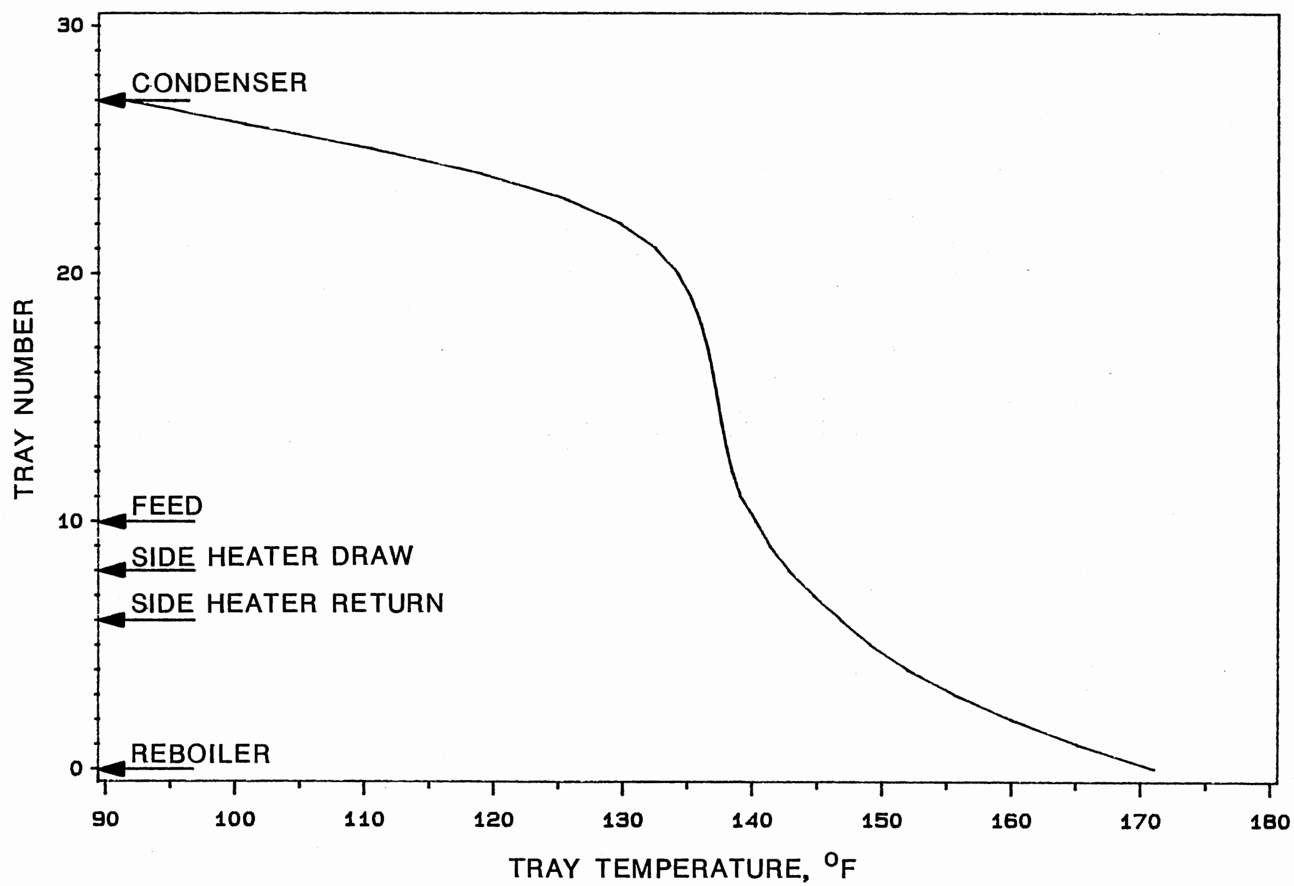


Figure 52. Steady State Simulation Results For Run 10

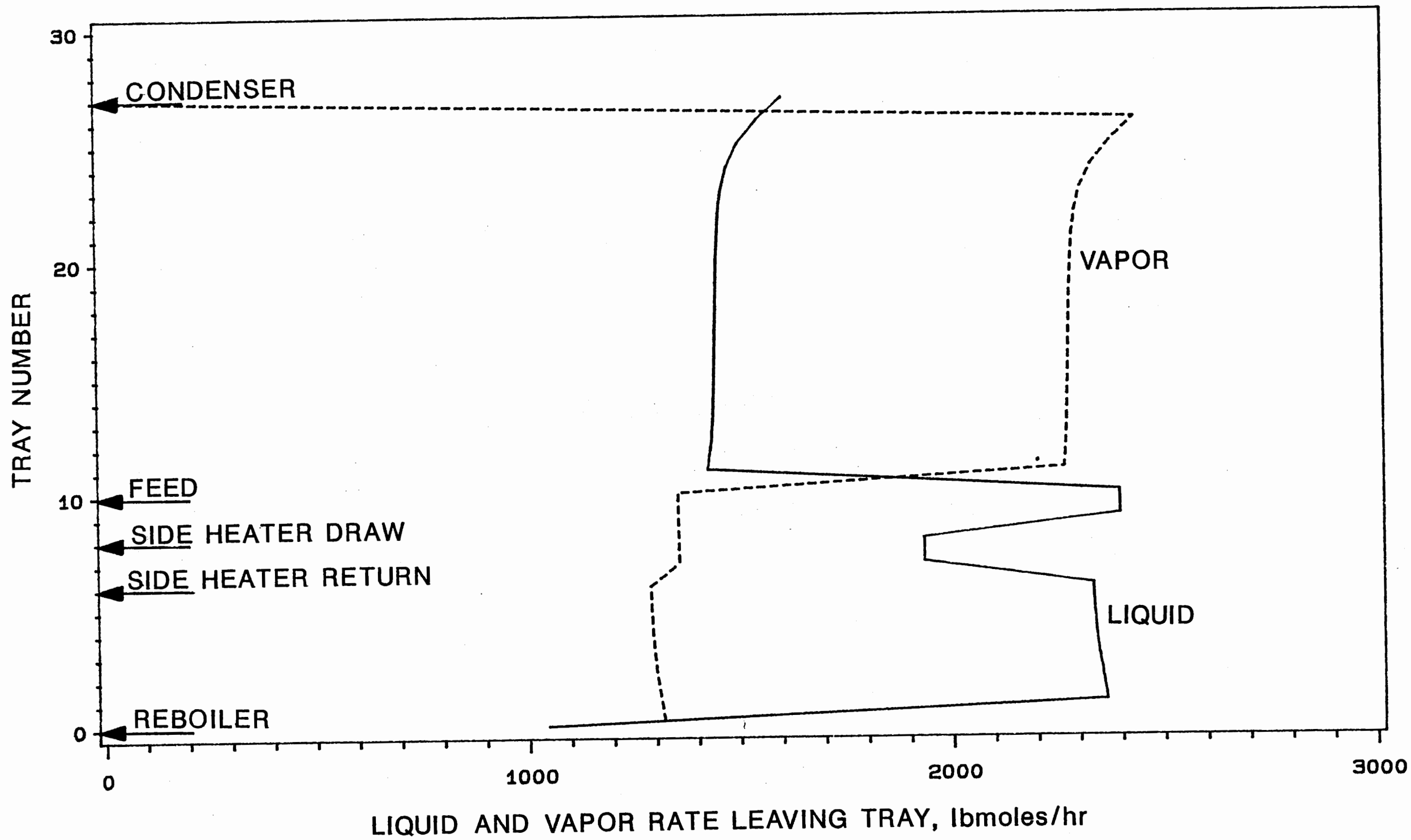


Figure 53. Steady State Simulation Results For Run 10

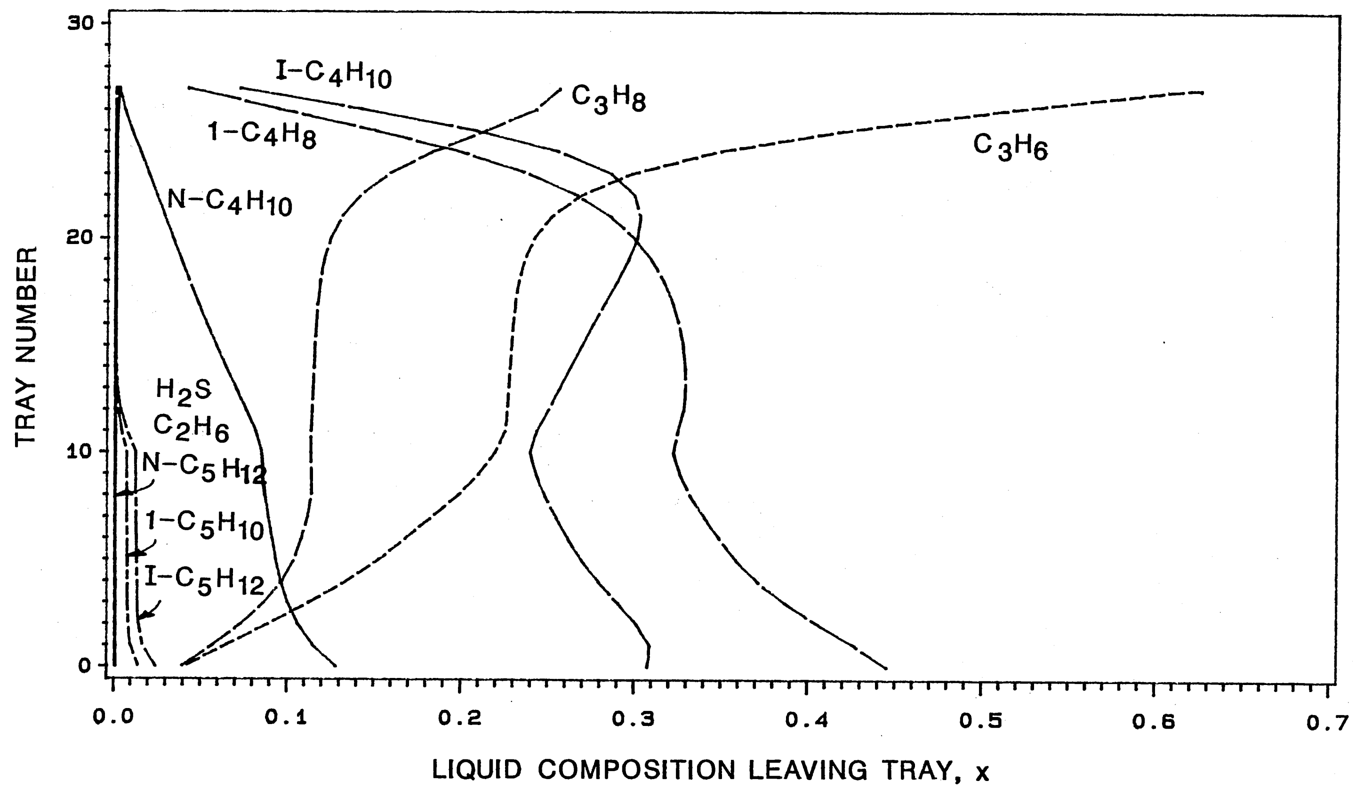


Figure 54. Steady State Simulation Results For Run 10

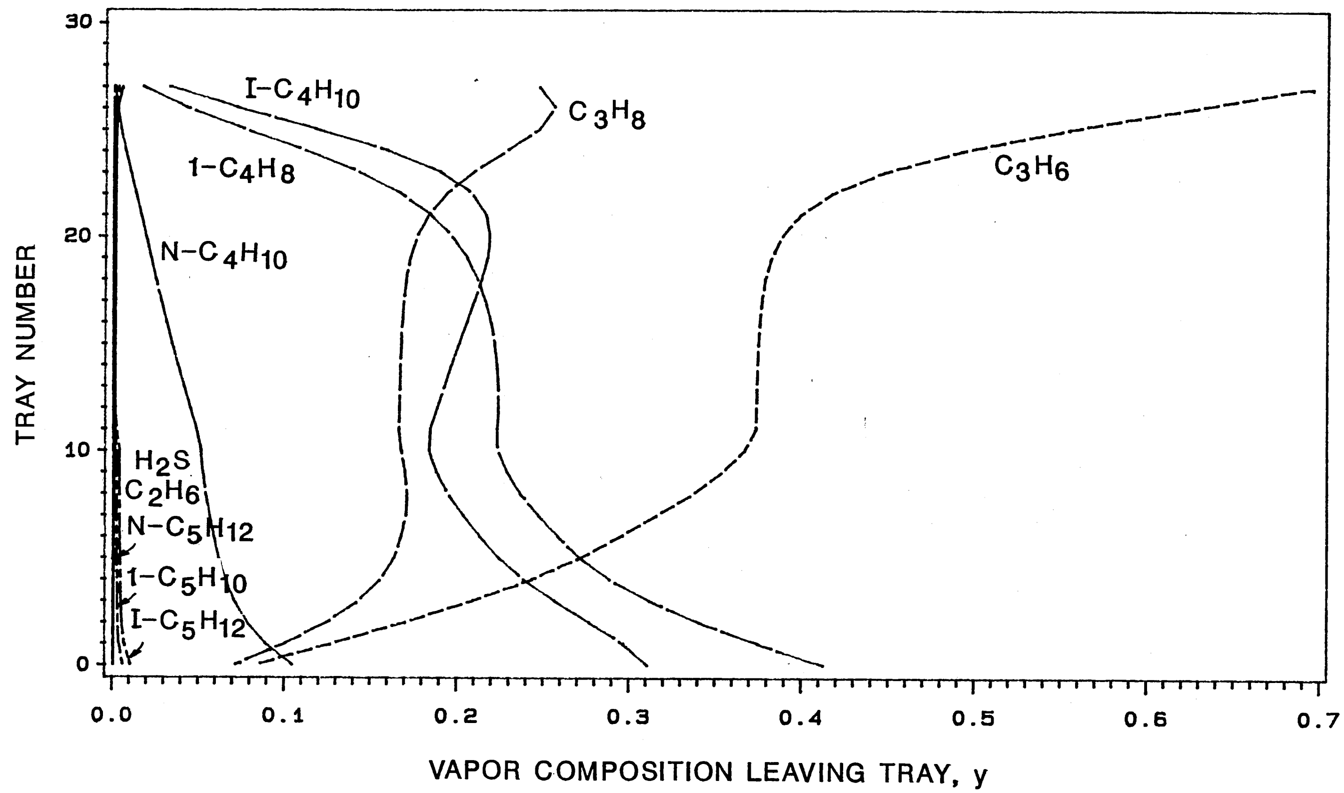


Figure 55. Steady State Simulation Results For Run 10

TABLE XXVIII

DISTILLATION COLUMN SPECIFICATIONS FOR SIMULATION 11

FEED PLATE = 10, SIDE DRAW = 6, RETURN = 4

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	4

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	6	0.2000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.04200 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.03900 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE XXIX

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 11.0

PUMP UNIT OPERATION			
Discharge Pressure	=	190.00	PSIA
Efficiency	=	75.00	%
Work Bal Option	=	0.00	
From Unit	=	0.00	
or Spec	=	0.00	HP
HEATER/COOLER SPECIFICATION			
Specific Duty		504.00	KBTU
Specific Delta P		1.00	PSIA

TABLE XXX

STEADY STATE RESULTS FOR SIMULATION 11

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0082	1.5996	0.0083	0.0003
C2H6	0.90	0.0020	0.9000	0.0020	0.0000
C3H6	567.70	79.4032	522.8748	81.3858	42.8427
C3H8	254.40	51.3388	213.4420	51.7131	40.5837
1-C4H8	497.30	163.0681	35.0768	162.0213	463.2699
IC4H10	378.40	122.5952	59.5052	121.6495	319.8405
NC4H10	134.70	42.5263	1.7678	42.2750	133.1834
1-C5H10	14.80	3.6019	0.0000	3.5694	14.8326
IC5H12	25.10	6.1639	0.0000	6.1091	25.1548
NC5H12	0.90	0.2122	0.0000	0.2102	0.9020
Total lbmols/hr	1875.80	468.9198	835.1691	468.9440	1040.6095
T., Deg. F.	140.00	151.72	91.26	146.00	171.01
P., Psia	183.00	189.00	179.00	183.85	185.00
H, KBtu	7504.98	1063.71	-371.32	549.01	2188.47
S, KBtu/R	117.2065	28.4392	41.9132	27.5821	64.1752
Mol. Weight	51.0851	53.4510	44.3330	53.3744	56.5394
D, Lb/FT3	3.5280	10.0022	31.1210	31.2342	30.8925
L/F (Molar)	0.51764	0.85990	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15500.107
Reboiler, KBtu/hr	9297.334
Intermediate Reboiler, KBtu/hr	504.02
Intermediate Reboiler Side Draw	6
Intermediate Reboiler Return	4
Intermediate Reboiler Pumparound Rate, Lbmol/hr	468.9440
Feed Plate	10
Operating Cost, $/Year	$251,054.00
Column Thermodynamic Efficiency	10.5%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.58 Ft	7.00 Ft
Bottom Section	5.70 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE XXXI

STEADY STATE RESULTS FOR SIMULATION 11
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0083	0.0082
C2H6	0.0020	0.0020
C3H6	81.3858	79.4032
C3H8	51.7131	51.3388
1-C4H8	162.0213	163.0681
IC4H10	121.6495	122.5952
NC5H10	42.2750	42.5263
1-C5H12	3.5694	3.6019
IC5H12	6.1091	6.1639
NC5H12	0.2102	0.2122
Total	468.9440	468.9198
T., Deg. F.	146.00	146.66
P., Psia	183.85	190.00
H. KBtu	549.01	559.69
S, KBtu/R	27.5821	27.6125
Mol. Weight	53.3744	53.4513
D, Lb/Ft3	31.2342	31.2203
L/F (Molar)	1.00000	1.00000

WORK = -0.48 HP at 75% Efficiency

TABLE XXXII

STEADY STATE RESULTS FOR SIMULATION 11
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0082	0.0082
C2H6	0.0020	0.0020
C3H6	79.4032	79.4032
C3H8	51.3388	51.3388
1-C4H8	163.0681	163.0681
IC4H10	122.5952	122.5952
NC5H10	42.5263	42.5263
1-C5H12	3.6019	3.6019
IC5H12	6.1639	6.1639
NC5H12	0.2122	0.2122
Total	468.9198	468.9198
T., Deg. F.	146.66	151.72
P., Psia	190.00	189.00
H. KBtu	559.69	1063.71
S, KBtu/R	27.6125	28.4392
Mol. Weight	53.4513	53.4510
D, Lb/Ft3	31.2203	10.0022
L/F (Molar)	1.00000	0.85990
Heat Transferred	504.02 KBTU	

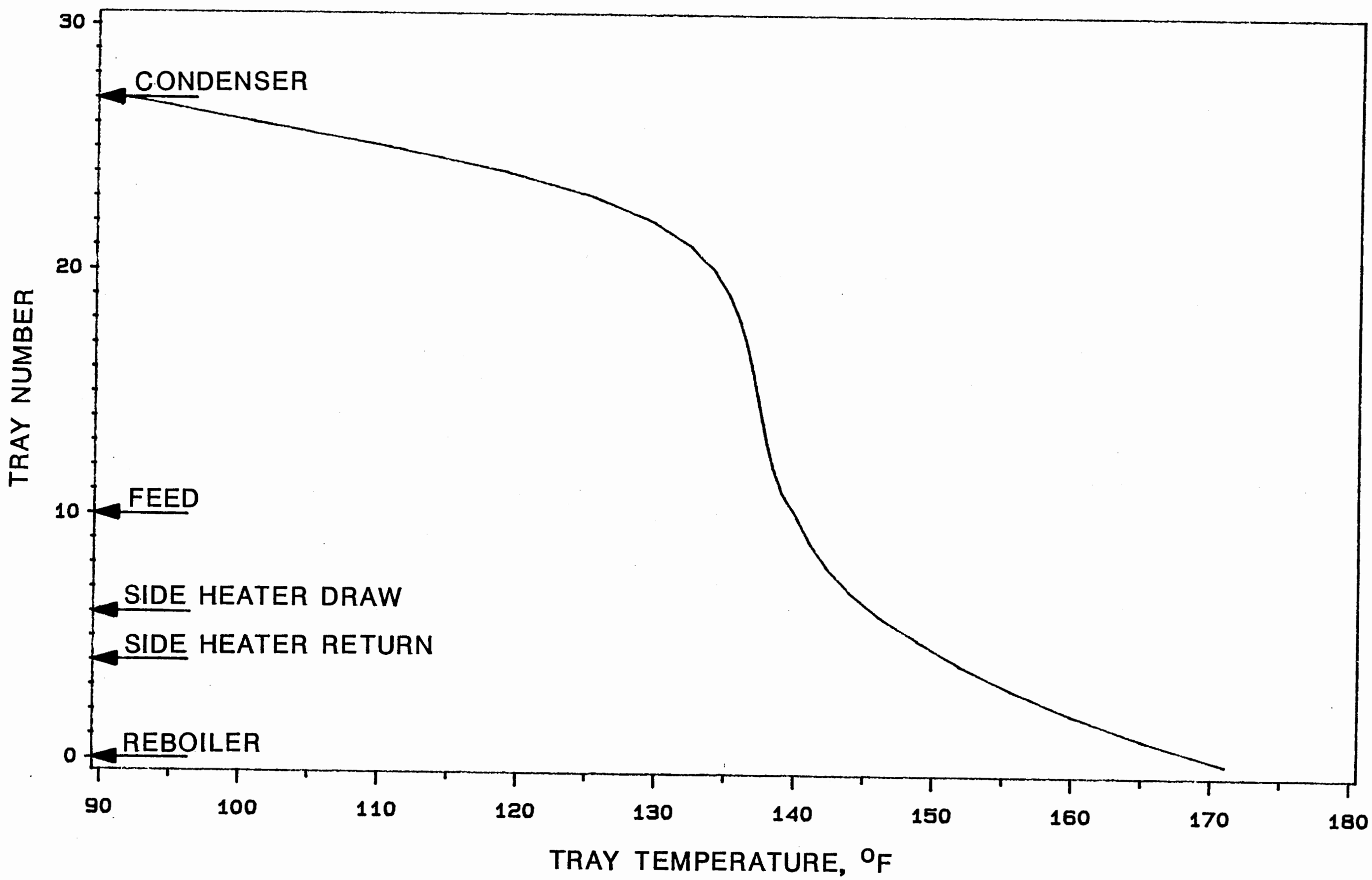


Figure 56. Steady State Simulation Results For Run 11

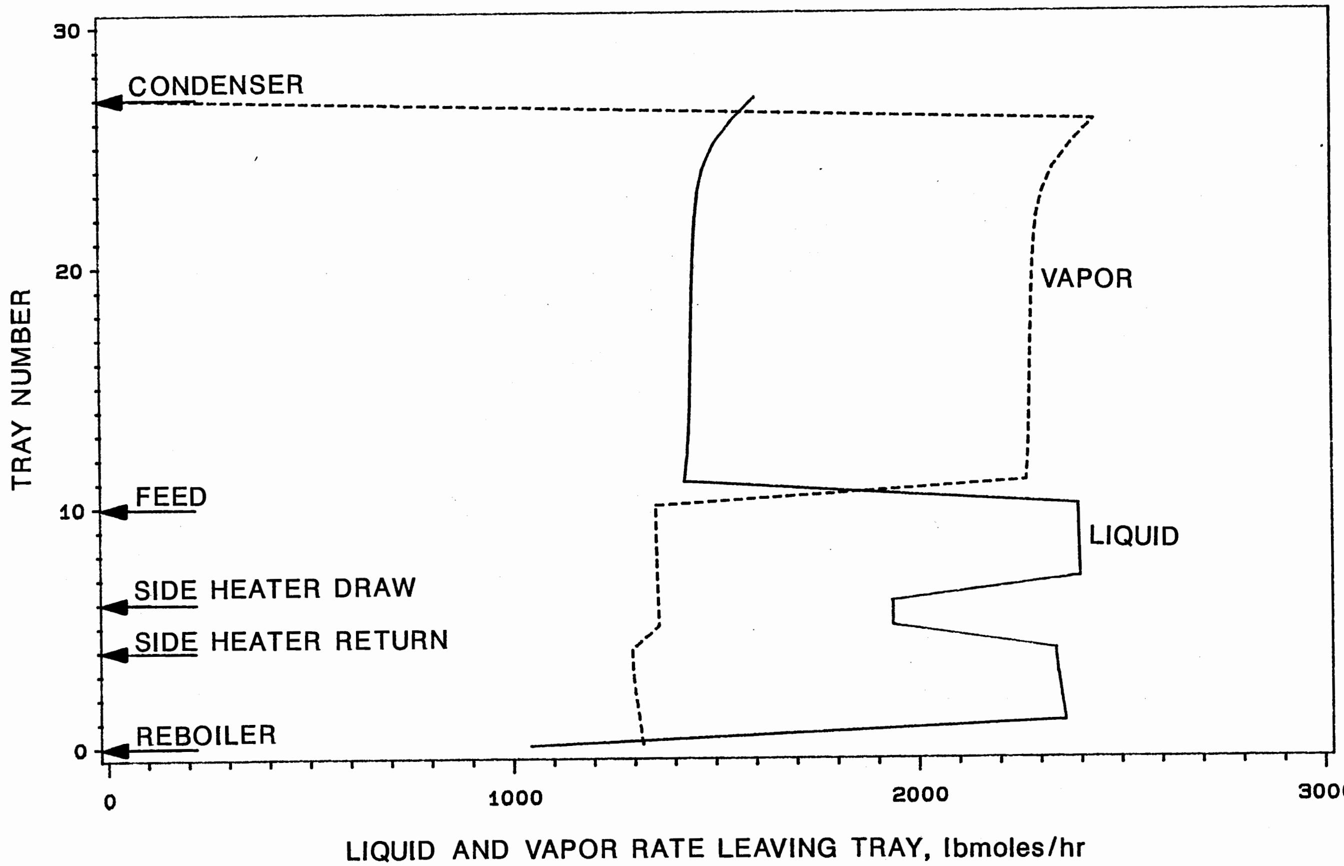


Figure 57. Steady State Simulation Results For Run 11

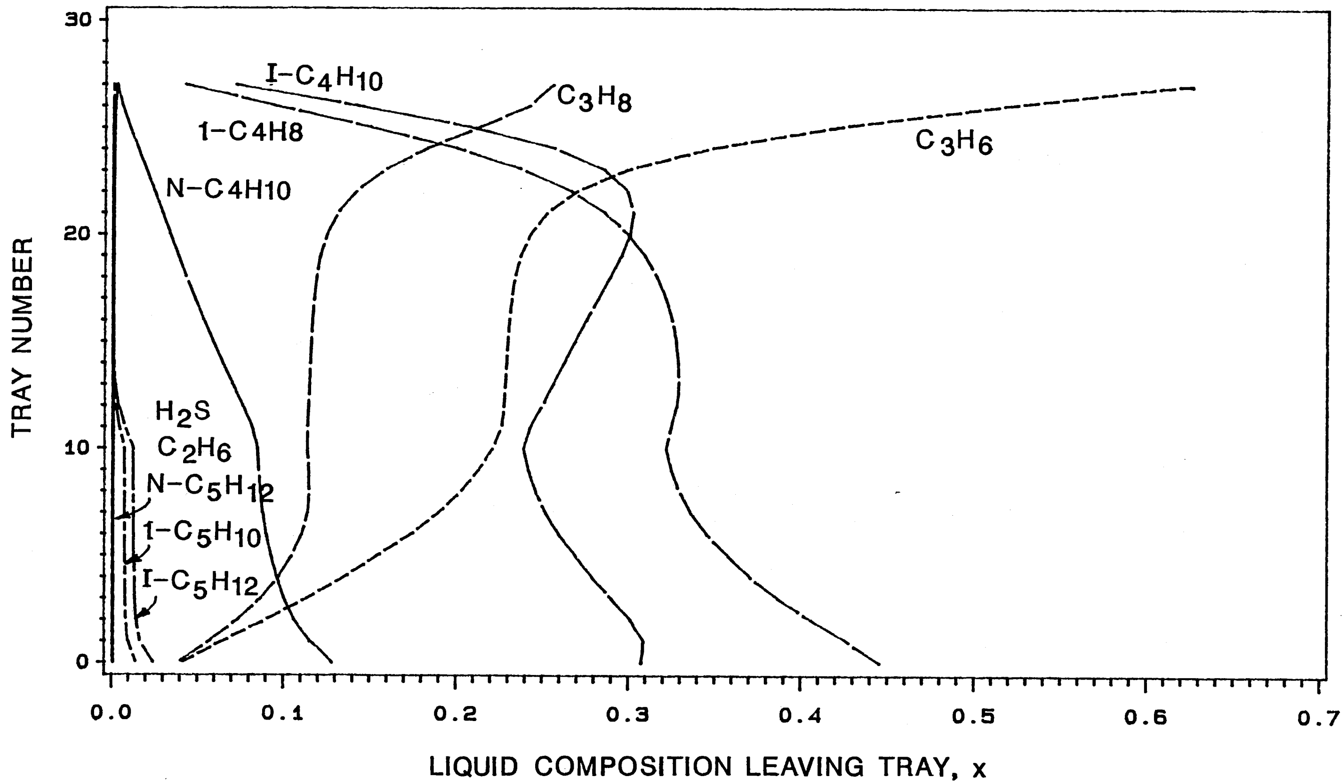


Figure 58. Steady State Simulation Results For Run 11

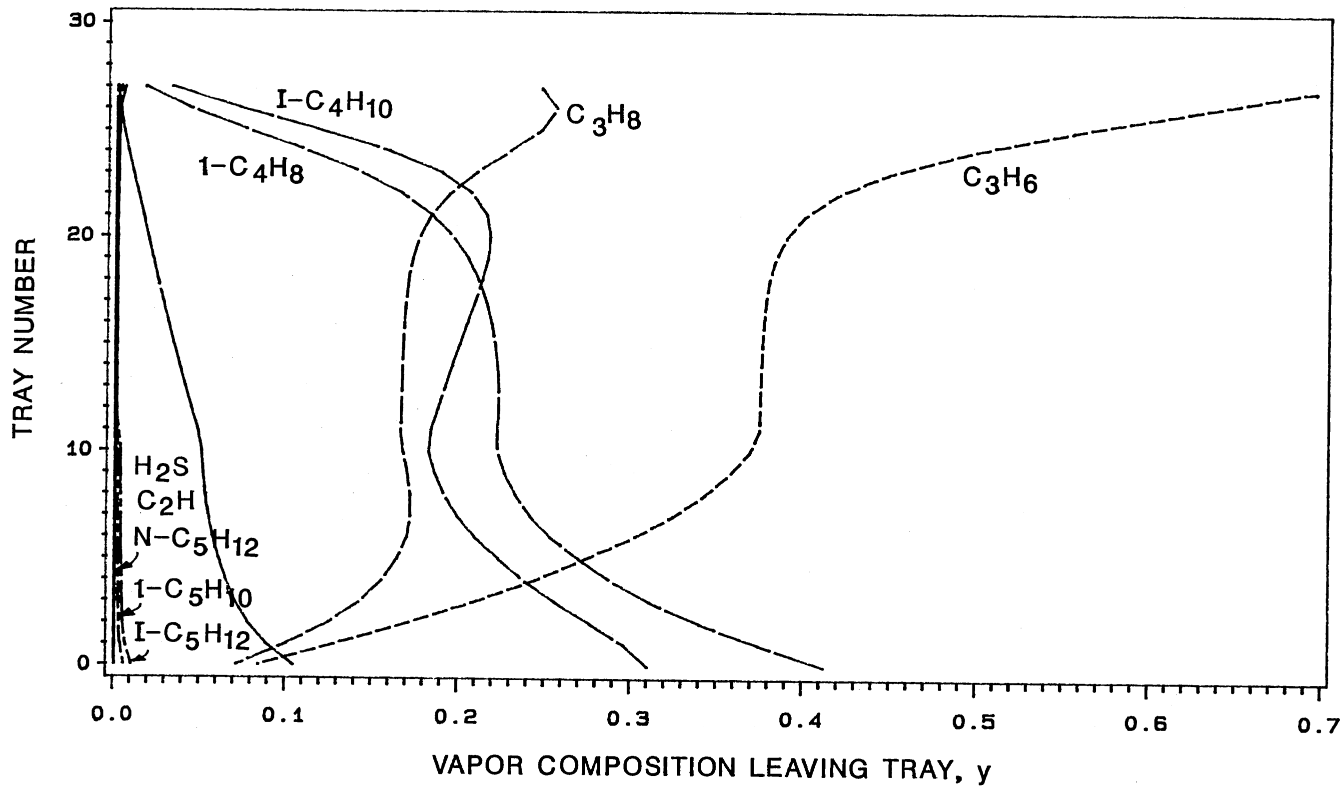


Figure 59. Steady State Simulation Results For Run 11

TABLE XXXIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 12

FEED PLATE = 10, SIDE DRAW = 4, RETURN = 2

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	2

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	4	0.2000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE XXXIV

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 12.0

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		504.00 KBTU
Specific Delta P		1.00 PSIA

TABLE XXXV

STEADY STATE RESULTS FOR SIMULATION 12

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0024	1.5998	0.0023	0.0003
C2H6	0.90	0.0005	0.9000	0.0004	0.0000
C3H6	567.70	64.1480	524.6160	64.3058	42.9263
C3H8	254.40	46.0589	213.9757	45.9976	40.4857
1-C4H8	497.30	173.2182	35.1822	173.1935	462.1425
IC4H10	378.40	130.7104	59.6426	130.5796	318.8882
NC4H10	134.70	44.7165	1.7746	44.7642	132.8777
1-C5H10	14.80	3.6309	0.0000	3.6438	14.7871
IC5H12	25.10	6.2208	0.0000	6.2428	25.0780
NC5H12	0.90	0.2130	0.0000	0.2138	0.8992
Total lbmols/hr	1875.80	468.9196	837.6926	468.9440	1038.0853
T., Deg. F.	140.00	156.31	91.26	151.49	170.98
P., Psia	183.00	189.00	179.00	184.23	185.00
H, KBtu	7504.98	1148.11	-372.58	642.62	2182.05
S, KBtu/R	117.2065	28.6926	42.0390	27.8732	64.0172
Mol. Weight	51.0851	54.0897	44.3321	54.0880	56.5362
D, Lb/FT3	3.5280	10.0273	31.1210	31.1428	30.8932
L/F (Molar)	0.51764	0.85937	1.00000	0.99999	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15533.149
Reboiler, KBtu/hr	9332.001
Intermediate Reboiler, KBtu/hr	504.03
Intermediate Reboiler Side Draw	4
Intermediate Reboiler Return	0
Intermediate Reboiler Pumparound Rate, Lbmol/hr	468.9440
Feed Plate	10
Operating Cost, $/Year	$251,858.00
Column Thermodynamic Efficiency	10.8%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.59 Ft	7.00 Ft
Bottom Section	5.71 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE XXXVI

STEADY STATE RESULTS FOR SIMULATION 12
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0023	0.0024
C2H6	0.0004	0.0005
C3H6	64.3058	64.1480
C3H8	45.9976	46.0589
1-C4H8	173.1935	173.2182
IC4H10	130.5796	130.7104
NC5H10	44.7642	44.7165
1-C5H12	3.6438	3.6309
IC5H12	6.2428	6.2208
NC5H12	0.2138	0.2130
Total	468.9440	468.9196
T., Deg. F.	151.49	151.61
P., Psia	184.23	190.00
H. KBtu	642.62	644.07
S, KBtu/R	27.8732	27.8723
Mol. Weight	54.0880	54.0903
D, Lb/Ft3	31.1428	31.1395
L/F (Molar)	0.99999	1.00000

WORK = -0.44 HP at 75% Efficiency

TABLE XXXVII

STEADY STATE RESULTS FOR SIMULATION 12
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0024	0.0024
C2H6	0.0005	0.0005
C3H6	64.1480	64.1480
C3H8	46.0589	46.0589
1-C4H8	173.2182	173.2182
IC4H10	130.7104	130.7104
NC5H10	44.7165	44.7165
1-C5H12	3.6309	3.6309
IC5H12	6.2208	6.2208
NC5H12	0.2130	0.2130
Total	468.9196	468.9196
T., Deg. F.	151.61	156.31
P., Psia	190.00	189.00
H. KBtu	644.07	1148.11
S, KBtu/R	27.8723	28.6926
Mol. Weight	54.0903	54.0897
D, Lb/Ft3	31.1395	10.0273
L/F (Molar)	1.00000	0.85937
Heat Transferred	504.03 KBTU	

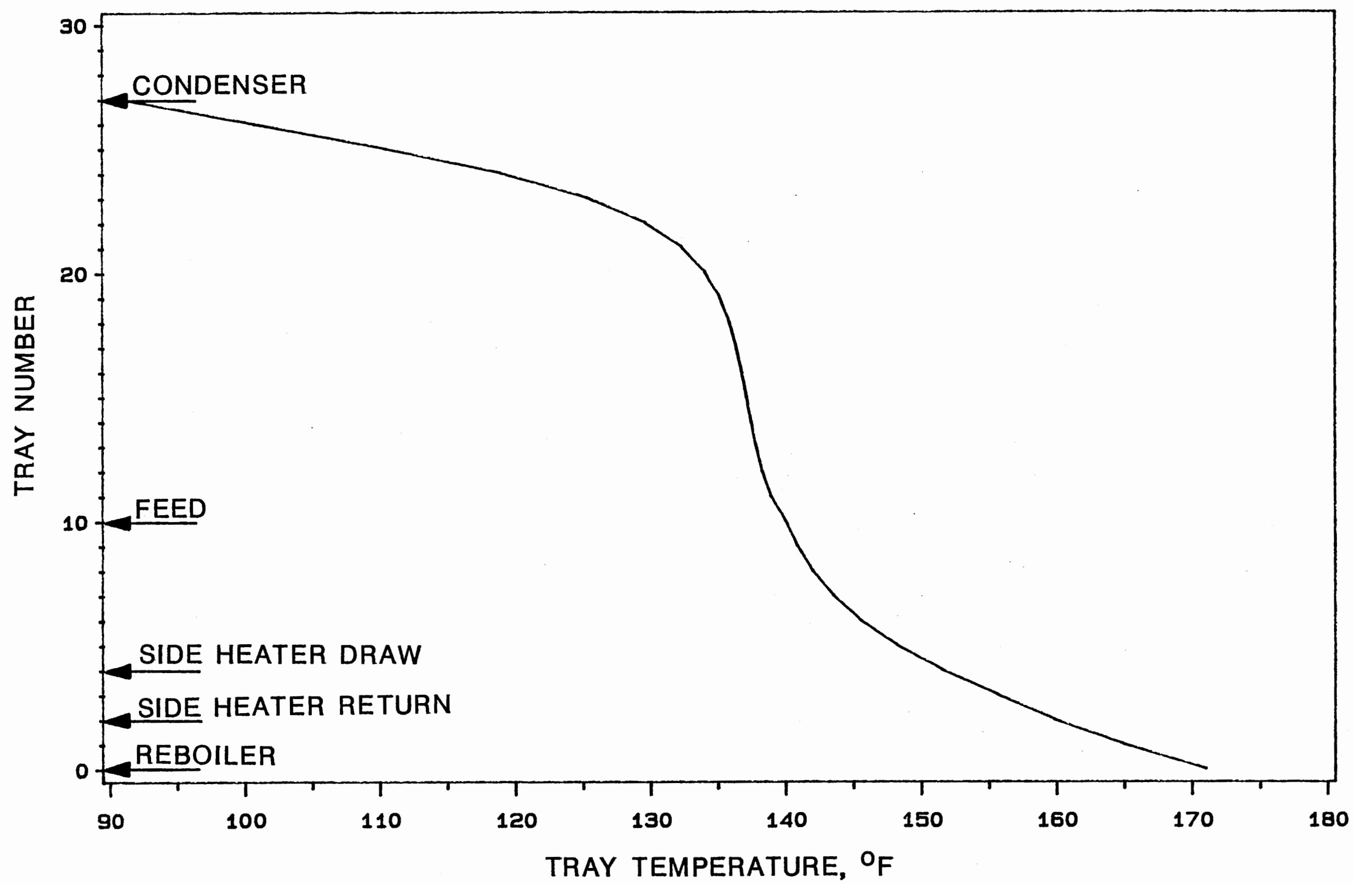


Figure 60. Steady State Simulation Results For Run 12

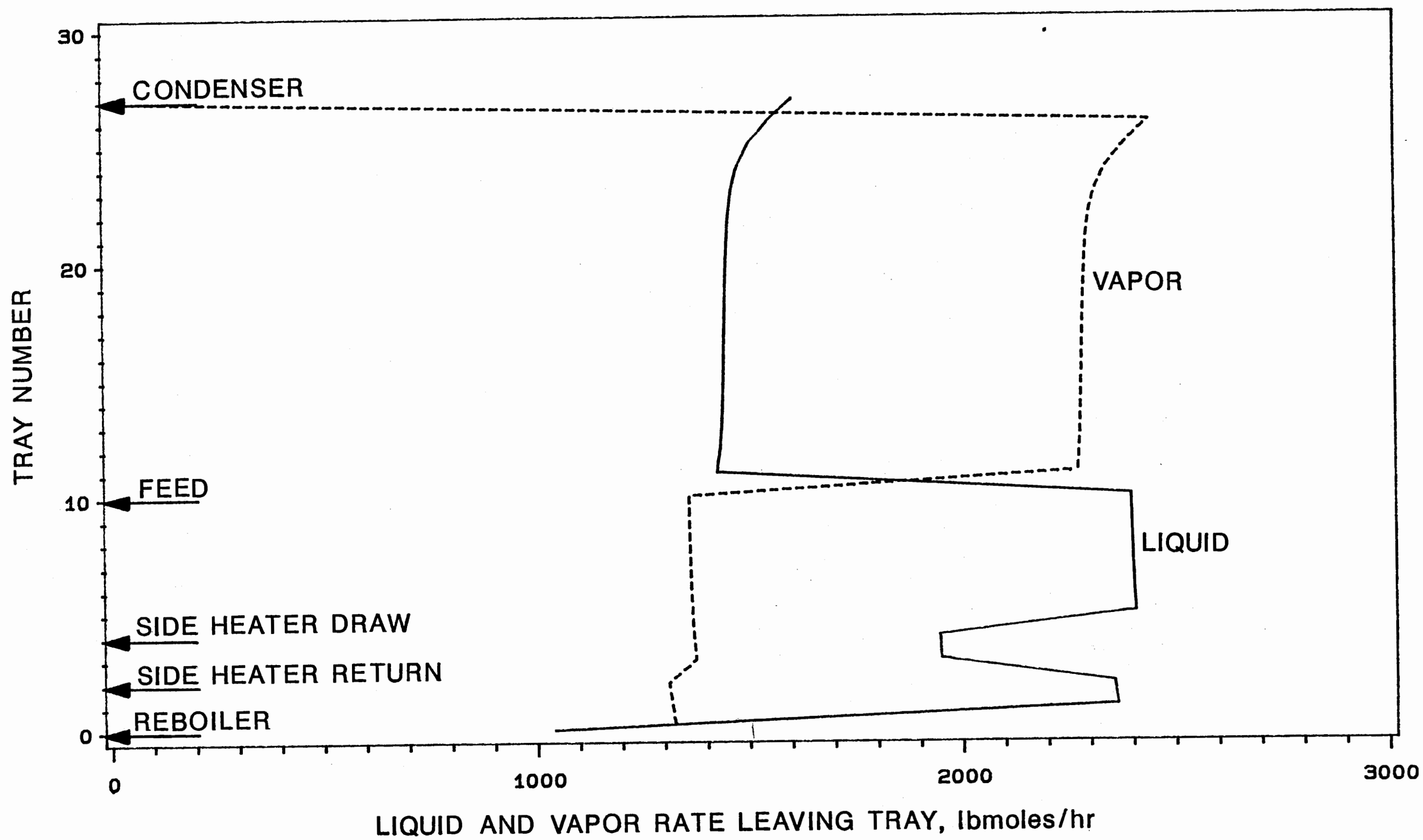


Figure 61. Steady State Simulation Results For Run 12

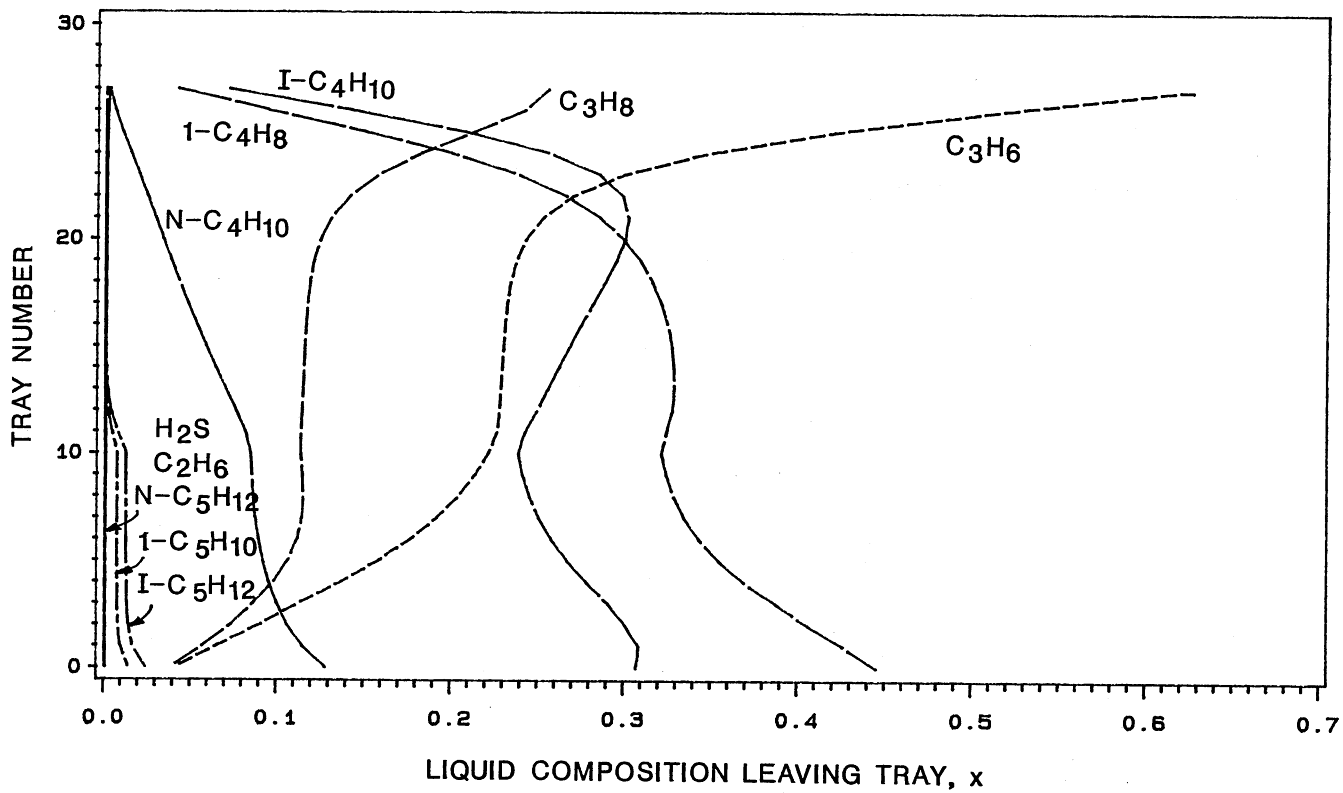


Figure 62. Steady State Simulation Results For Run 12

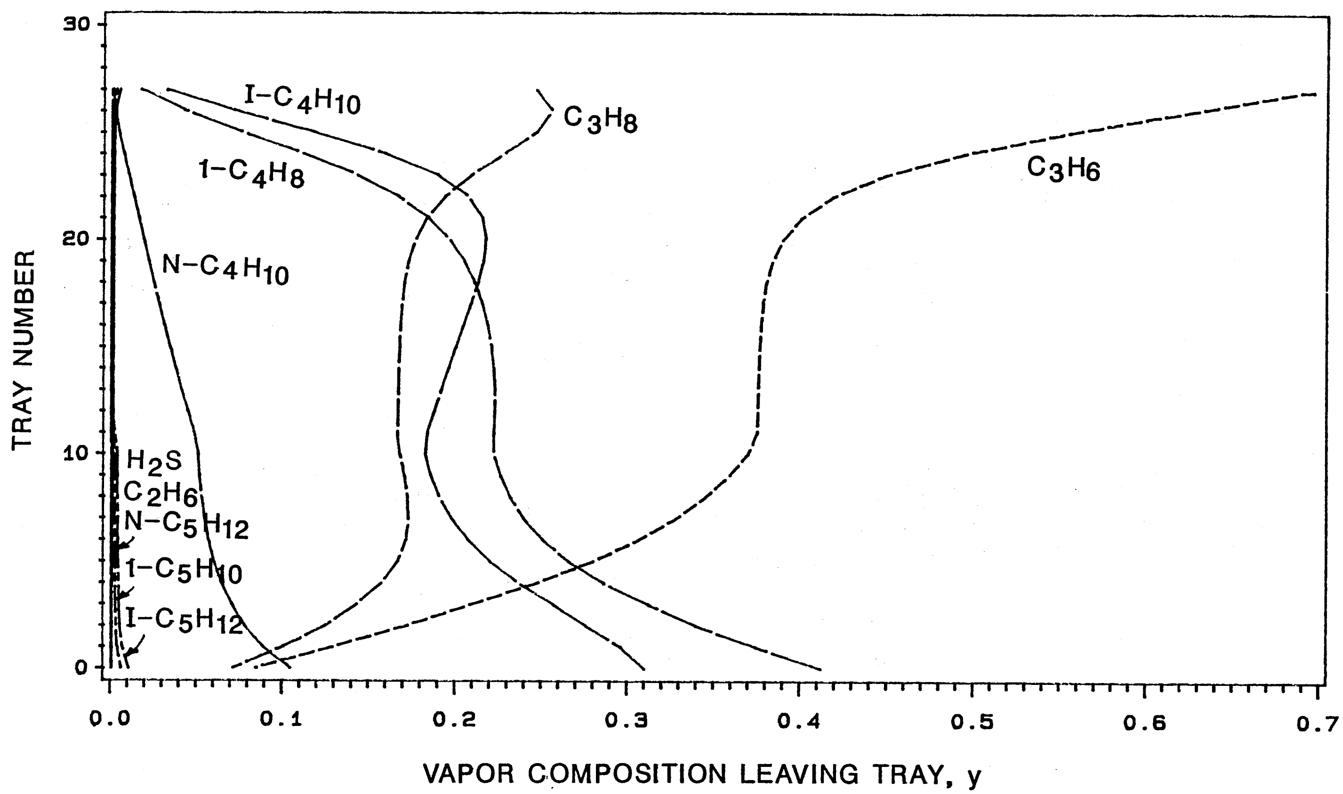


Figure 63. Steady State Simulation Results For Run 12

TABLE XXXVIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 13

FEED PLATE = 10, SIDE DRAW = 2, RETURN = 4

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	4

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	2	0.20000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section 21.00 In.
Bottom Section 21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE XXXIX

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 13

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		504.00 KBTU
Specific Delta P		1.00 PSIA

TABLE XL

STEADY STATE RESULTS FOR SIMULATION 13

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0007	1.5996	0.0007	0.0003
C2H6	0.90	0.0001	0.8999	0.0001	0.0000
C3H6	567.70	42.6953	526.0842	42.6253	42.8434
C3H8	254.40	34.6267	215.3831	34.6267	40.3509
1-C4H8	497.30	190.0264	35.3282	190.0264	460.6858
IC4H10	378.40	141.0318	60.0525	141.0318	317.7770
NC4H10	134.70	49.6375	1.7747	49.6375	132.4137
1-C5H10	14.80	3.9368	0.0000	3.9368	14.7207
IC5H12	25.10	6.7592	0.0000	6.7592	24.9661
NC5H12	0.90	0.2289	0.0000	0.2289	0.8951
Total lbmols/hr	1875.80	468.9435	841.1246	468.9438	1034.6538
T., Deg. F.	140.00	163.86	91.28	159.67	170.97
P., Psia	183.00	189.00	179.00	184.62	185.00
H, KBtu	7504.98	1289.09	-373.36	784.11	2174.33
S, KBtu/R	117.2065	29.1028	42.2152	28.2926	63.8040
Mol. Weight	51.0851	55.1181	44.3365	55.1186	56.5345
D, Lb/FT3	3.5280	10.0659	31.1199	31.0221	30.8935
L/F (Molar)	0.51764	0.85845	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15646.839
Reboiler, KBtu/hr	9448.320
Intermediate Reboiler, KBtu/hr	503.88
Intermediate Reboiler Side Draw	2
Intermediate Reboiler Return	4
Intermediate Reboiler Pumparound Rate, Lbmol/hr	468.9438
Feed Plate	10
Operating Cost, $/Year	$254,630.00
Column Thermodynamic Efficiency	11.0%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.61 Ft	7.00 Ft
Bottom Section	5.73 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE XLI

STEADY STATE RESULTS FOR SIMULATION 13
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0007	0.0007
C2H6	0.0001	0.0001
C3H6	42.6953	42.6953
C3H8	34.6267	34.6267
1-C4H8	190.0264	190.0264
IC4H10	141.0318	141.0318
NC5H10	49.6375	49.6375
1-C5H12	3.9368	3.9368
IC5H12	6.7592	6.7592
NC5H12	0.2289	0.2289
Total	468.9438	468.9435
T., Deg. F.	159.67	159.77
P., Psia	184.62	190.00
H. KBtu	784.11	785.21
S, KBtu/R	28.2926	28.2929
Mol. Weight	55.1186	55.1186
D, Lb/Ft3	31.0221	31.0173
L/F (Molar)	1.00000	1.00000

WORK = -0.44 HP at 75% Efficiency

TABLE XLII

STEADY STATE RESULTS FOR SIMULATION 13
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0007	0.0007
C2H6	0.0001	0.0001
C3H6	42.6953	42.6953
C3H8	34.6267	34.6267
1-C4H8	190.0264	190.0264
IC4H10	141.0318	141.0318
NC5H10	49.6375	49.6375
1-C5H12	3.9368	3.9368
IC5H12	6.7592	6.7592
NC5H12	0.2289	0.2289
Total	468.9435	468.9435
T., Deg. F.	159.77	163.86
P., Psia	190.00	189.00
H. KBtu	785.21	1289.09
S, KBtu/R	28.2929	29.1028
Mol. Weight	55.1186	55.1181
D, Lb/Ft3	31.0173	10.0659
L/F (Molar)	1.00000	0.85845
Heat Transferred 503.88 KBTU		

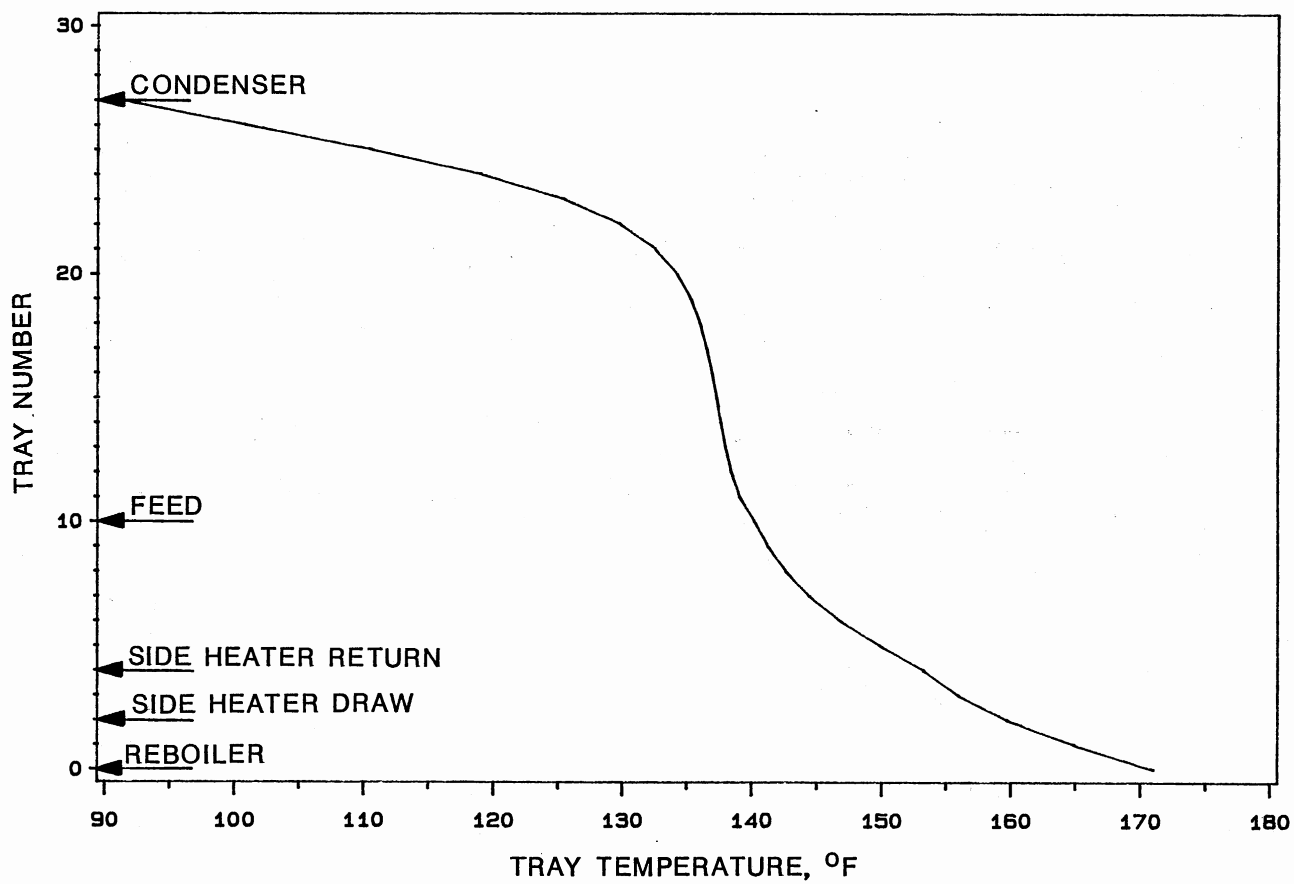


Figure 64. Steady State Simulation Results For Run 13

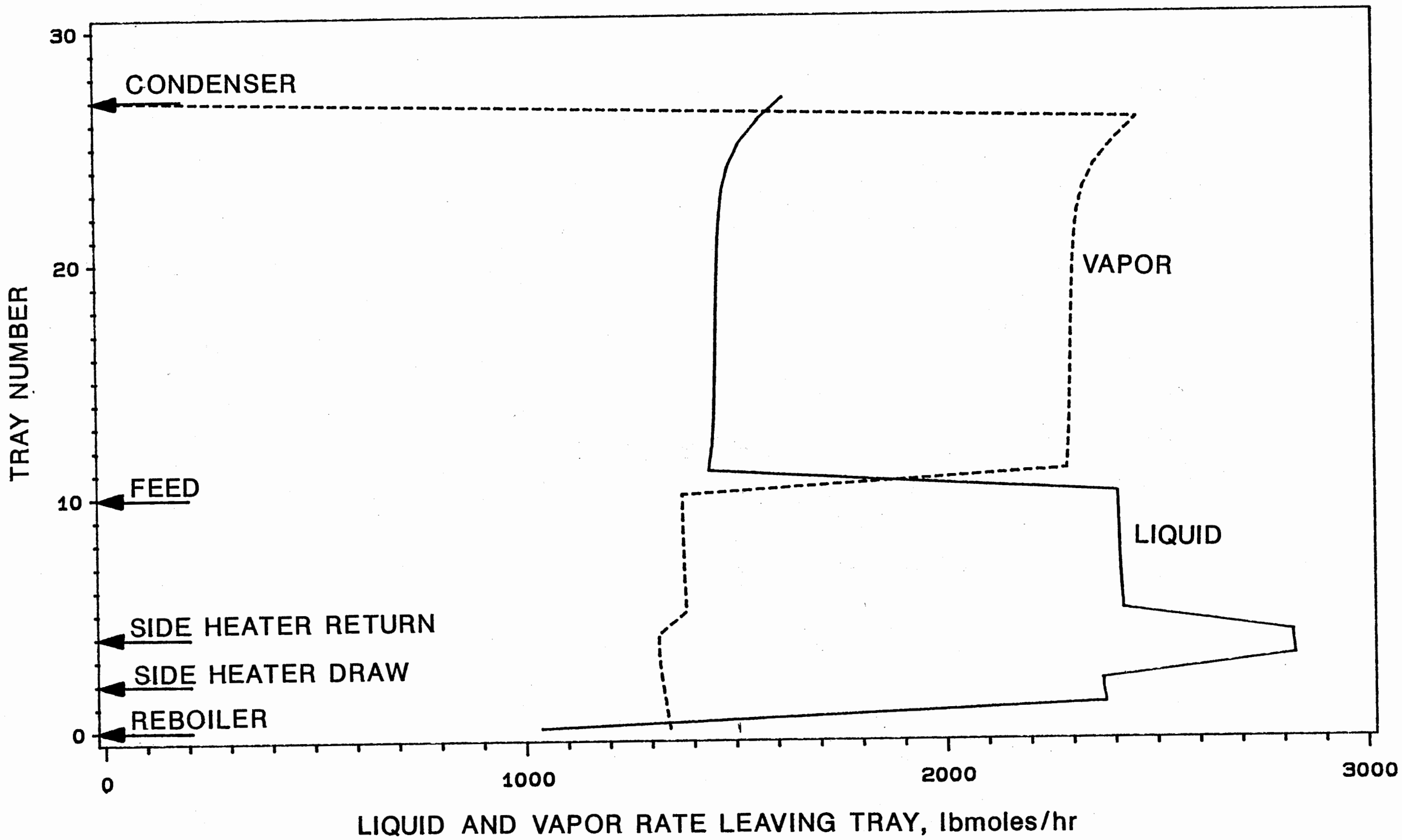


Figure 65. Steady State Simulation Results For Run 13

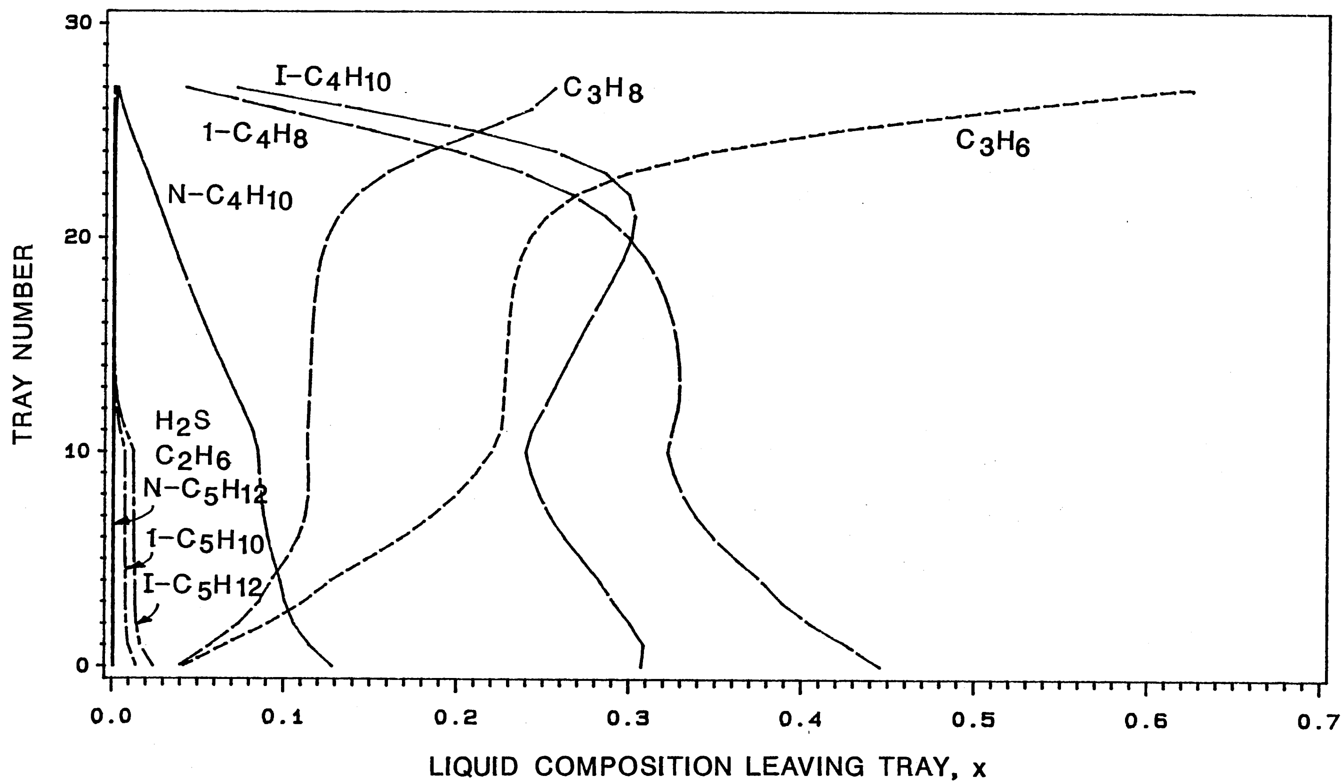


Figure 66. Steady State Simulation Results For Run 13

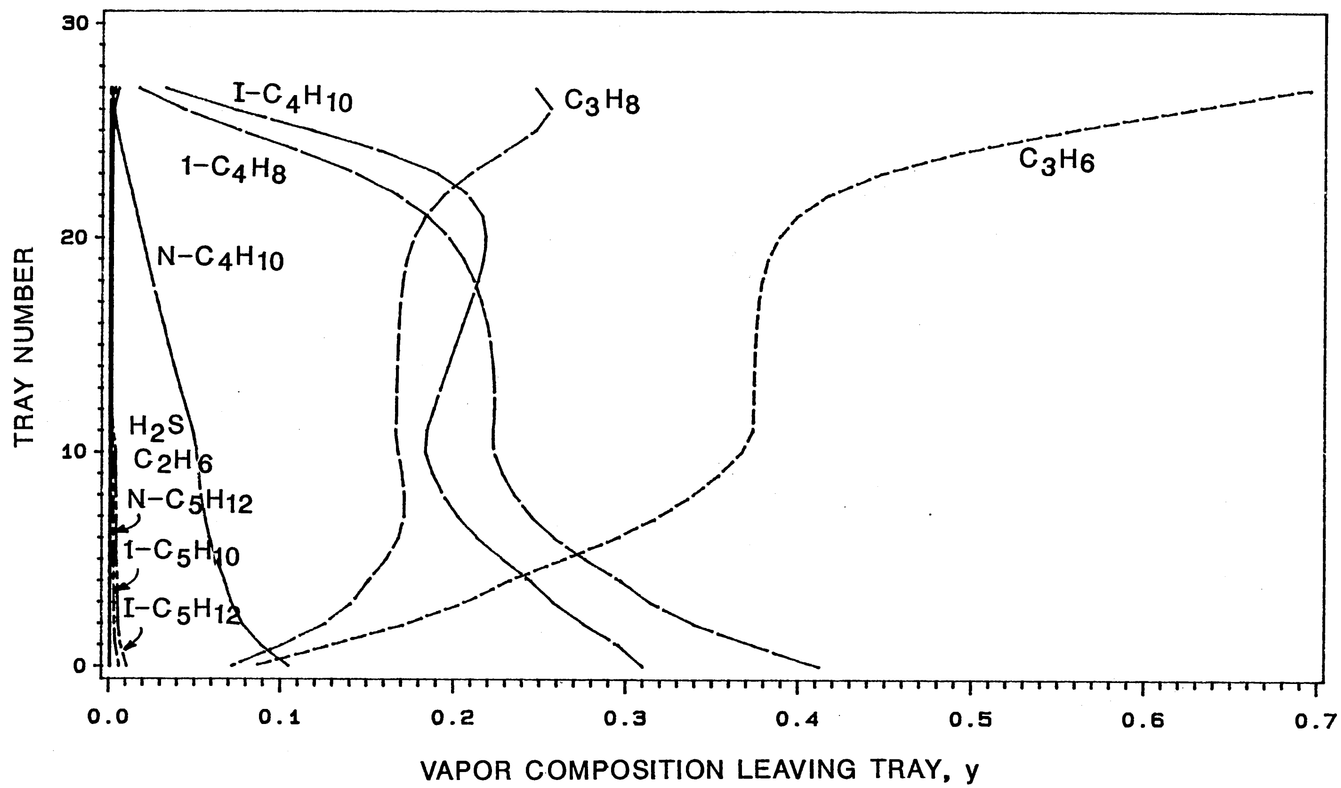


Figure 67. Steady State Simulation Results For Run 13

TABLE XLIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 14

FEED PLATE = 10, SIDE DRAW = 4, RETURN = 6

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	6

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	4	0.20000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE XLIV

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 14

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		504.00 KBTU
Specific Delta P		1.00 PSIA

TABLE XLV

STEADY STATE RESULTS FOR SIMULATION 14

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0029	1.5996	0.0029	0.0003
C2H6	0.90	0.0006	0.9000	0.0006	0.0000
C3H6	567.70	65.1828	523.8270	65.2423	43.8135
C3H8	254.40	45.9351	214.2701	45.5674	40.4975
1-C4H8	497.30	172.7839	35.1692	172.9795	461.9351
IC4H10	378.40	130.0949	59.8495	130.0223	318.6230
NC4H10	134.70	44.7394	1.7641	44.8733	132.8020
1-C5H10	14.80	3.6733	0.0000	3.7006	14.7727
IC5H12	25.10	6.2912	0.0000	6.3373	25.0539
NC5H12	0.90	0.2158	0.0000	0.2175	0.8983
Total lbmols/hr	1875.80	468.9199	837.3821	468.9440	1038.3961
T., Deg. F.	140.00	156.11	91.28	151.37	170.87
P., Psia	183.00	189.00	179.00	184.23	185.00
H, KBtu	7504.98	1144.27	-371.72	640.09	2177.78
S, KBtu/R	117.2065	28.6838	42.0275	27.8692	64.0250
Mol. Weight	51.0851	54.0633	44.3372	54.0742	56.5227
D, Lb/FT3	3.5280	10.0245	31.1203	31.1518	30.8961
L/F (Molar)	0.51764	0.85936	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15600.085
Reboiler, KBtu/hr	9396.703
Intermediate Reboiler, KBtu/hr	504.02
Intermediate Reboiler Side Draw	4
Intermediate Reboiler Return	6
Intermediate Reboiler Pumparound Rate, Lbmol/hr	468.9199
Feed Plate	10
Operating Cost, $/Year	$253,433.00
Column Thermodynamic Efficiency	10.7%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.60 Ft	7.00 Ft
Bottom Section	5.72 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE XLV

STEADY STATE RESULTS FOR SIMULATION 14
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0029	0.0029
C2H6	0.0006	0.0006
C3H6	65.2423	65.1828
C3H8	45.5674	45.9351
1-C4H8	172.9795	172.7839
IC4H10	130.0223	130.0949
NC5H10	44.8733	44.7394
1-C5H12	3.7006	3.6733
IC5H12	6.3373	6.2912
NC5H12	0.2175	0.2158
Total	468.9440	468.9199
T., Deg. F.	151.37	151.40
P., Psia	184.23	190.00
H. KBtu	640.09	640.24
S, KBtu/R	27.8692	27.8632
Mol. Weight	54.0742	54.0637
D, Lb/Ft3	31.1518	31.1514
L/F (Molar)	1.00000	1.00000

WORK = -0.48 HP at 75% Efficiency

TABLE XLVII

STEADY STATE RESULTS FOR SIMULATION 14
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0029	0.0029
C2H6	0.0006	0.0006
C3H6	65.1828	65.1828
C3H8	45.9351	45.9351
1-C4H8	172.7839	172.7839
IC4H10	130.0949	130.0949
NC5H10	44.7394	44.7394
1-C5H12	3.6733	3.6733
IC5H12	6.2912	6.2912
NC5H12	0.2158	0.2158
Total	468.9199	468.9199
T., Deg. F.	151.40	156.11
P., Psia	190.00	189.00
H. KBtu	640.24	1144.27
S, KBtu/R	27.8632	28.6838
Mol. Weight	54.0637	54.0633
D, Lb/Ft3	31.1514	10.0245
L/F (Molar)	1.00000	0.85936
Heat Transferred 504.02 KBTU		

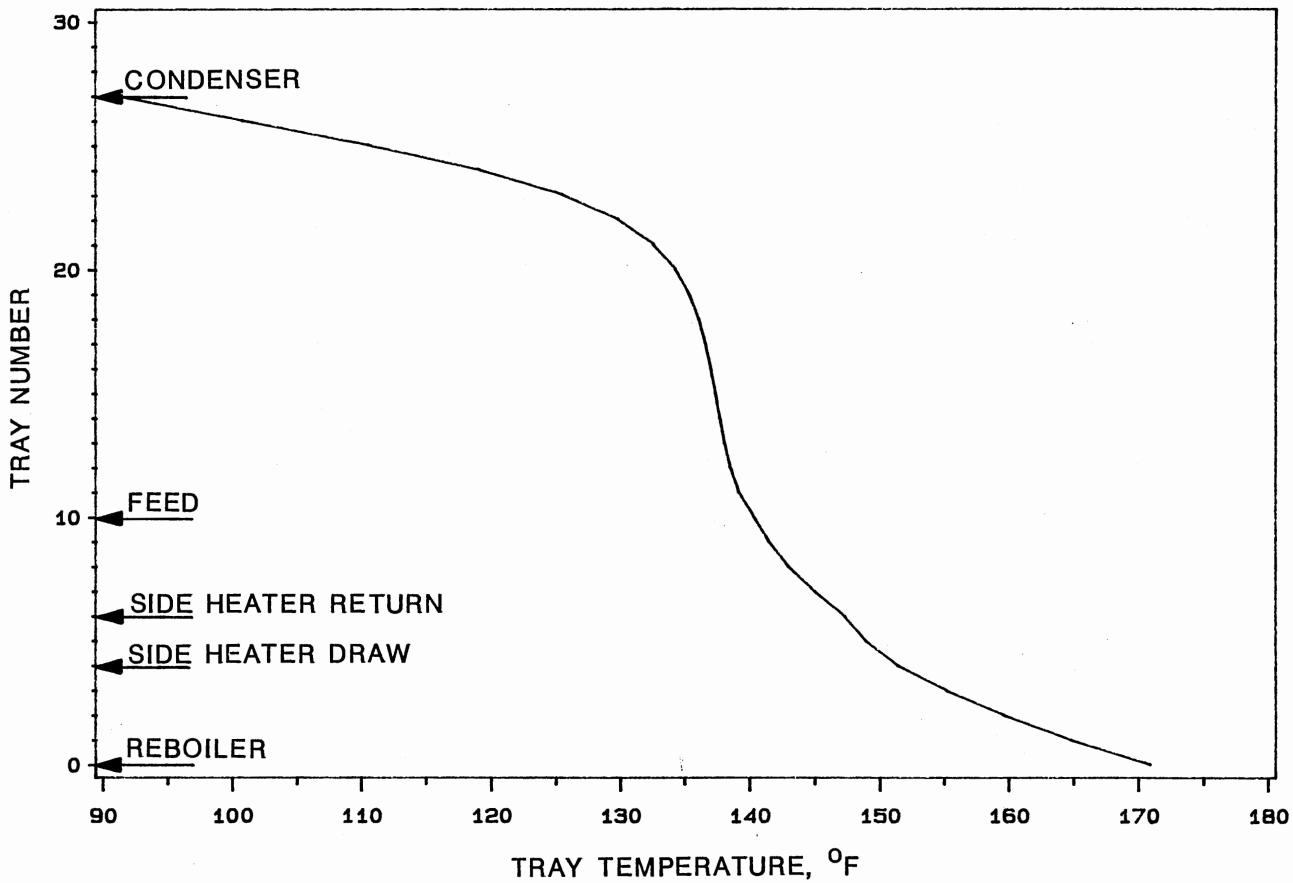


Figure 68. Steady State Simulation Results For Run 14

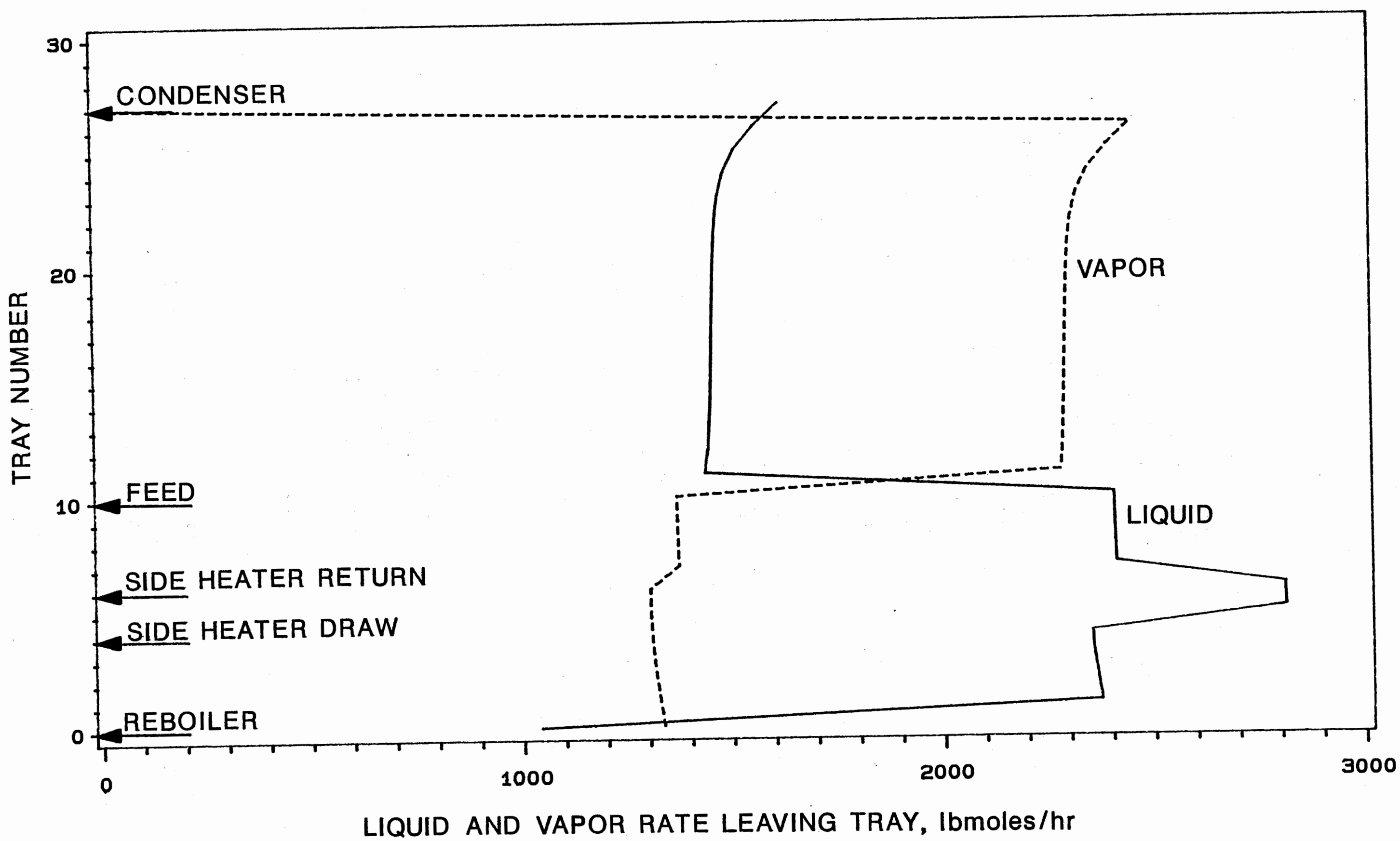


Figure 69. Steady State Simulation Results For Run 14

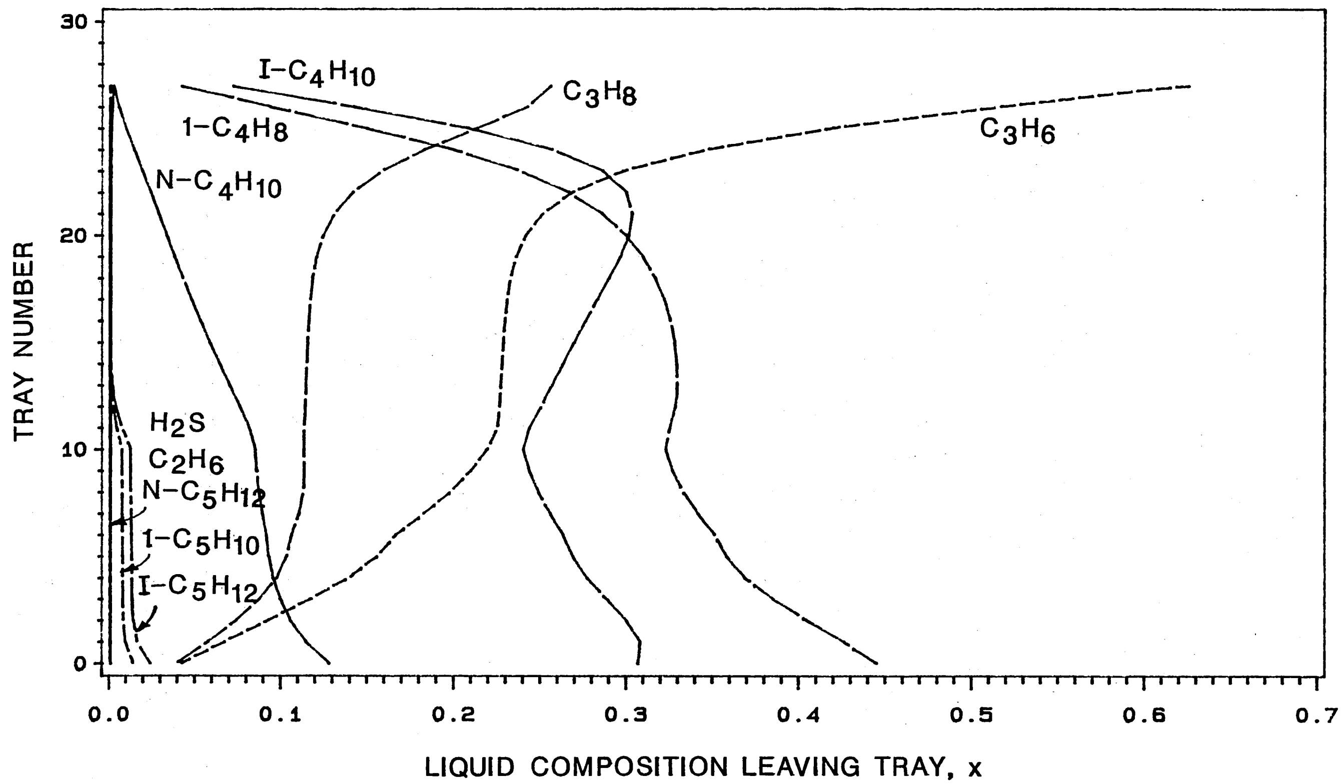


Figure 70. Steady State Simulation Results For Run 14

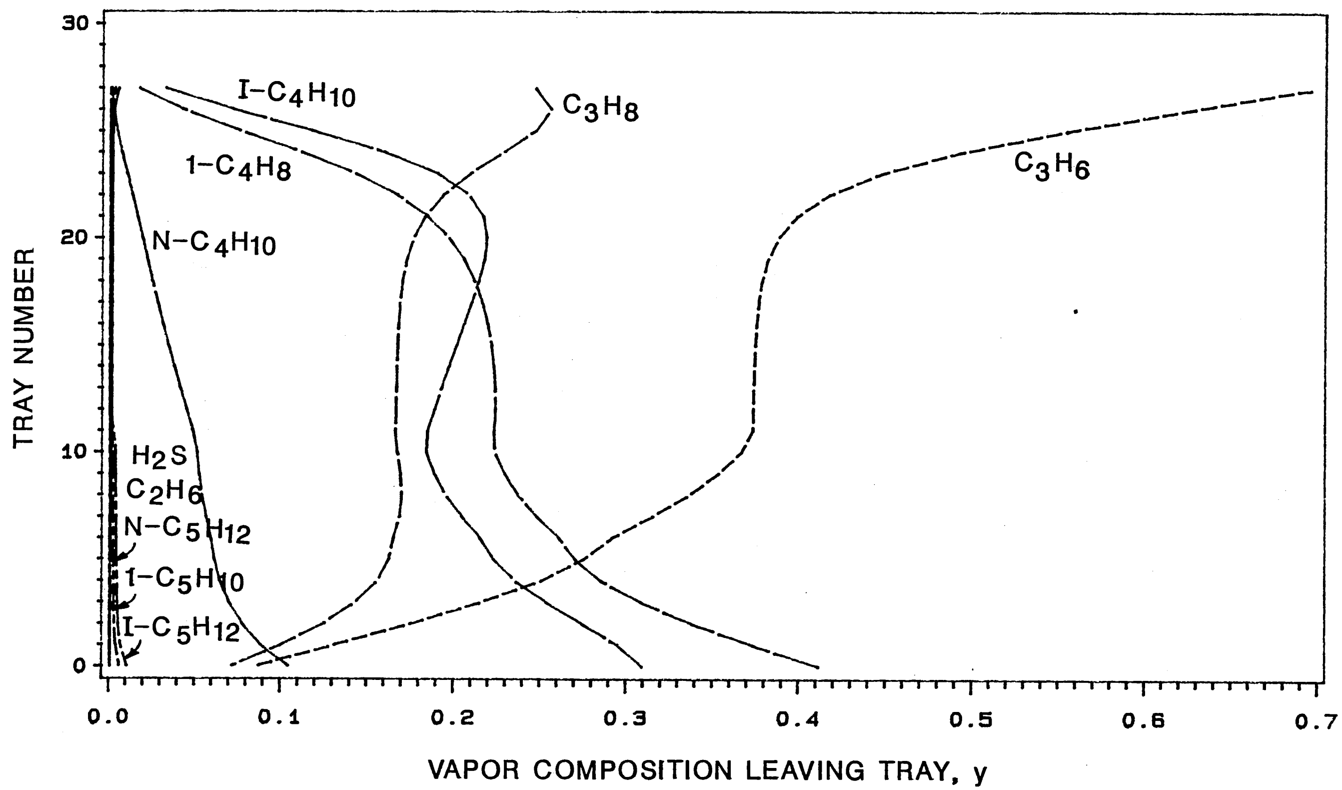


Figure 71. Steady State Simulation Results For Run 14

TABLE XLVIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 15

FEED PLATE = 10, SIDE DRAW = 6, RETURN = 8

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	8

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	6	0.20000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE XLIX

PUMP AND HEATER/COOLER SPECIFICATIONS
FOR SIMULATION 15

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		504.00 KBTU
Specific Delta P		1.00 PSIA

TABLE L

STEADY STATE RESULTS FOR SIMULATION 15

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0106	1.5996	0.0106	0.0004
C2H6	0.90	0.0027	0.9000	0.0027	0.0000
C3H6	567.70	78.5661	520.0547	81.7799	44.4316
C3H8	254.40	49.7007	212.9830	50.4078	40.7098
1-C4H8	497.30	164.3814	34.9413	162.5346	464.2055
IC4H10	378.40	123.3606	59.7089	121.6281	320.4236
NC4H10	134.70	42.8597	1.7423	42.5336	133.2838
1-C5H10	14.80	3.6234	0.0000	3.6267	14.7968
IC5H12	25.10	6.2007	0.0000	6.2051	25.0955
NC5H12	0.90	0.2135	0.0000	0.2139	0.8997
Total lbmols/hr	1875.80	468.9194	831.9285	468.9439	1043.8499
T., Deg. F.	140.00	152.24	91.30	146.18	170.81
P., Psia	183.00	189.00	179.00	183.85	185.00
H, KBtu	7504.98	1071.63	-368.81	551.42	2186.65
S, KBtu/R	117.2065	28.4669	41.7571	27.5939	64.3529
Mol. Weight	51.0851	53.5248	44.3419	53.4021	56.5151
D, Lb/FT3	3.5280	31.2180	31.1204	31.2280	30.8968
L/F (Molar)	0.51764	0.86011	1.00000	0.99998	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15586.867
Reboiler, KBtu/hr	9379.291
Intermediate Reboiler, KBtu/hr	503.68
Intermediate Reboiler Side Draw	6
Intermediate Reboiler Return	8
Intermediate Reboiler Pumparound Rate, Lbmol/hr	468.9439
Feed Plate	10
Operating Cost, $/Year	$253,035.00
Column Thermodynamic Efficiency	10.05%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.60 Ft	7.00 Ft
Bottom Section	5.72 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE LI

STEADY STATE RESULTS FOR SIMULATION 15
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0106	0.0106
C2H6	0.0027	0.0007
C3H6	81.7799	78.5661
C3H8	50.4078	49.7007
1-C4H8	162.5346	164.3814
IC4H10	121.6281	123.3606
NC5H10	42.5336	42.8597
1-C5H12	3.6267	3.6234
IC5H12	6.2051	6.2007
NC5H12	0.2139	0.2135
Total	468.9439	468.9194
T., Deg. F.	146.18	147.18
P., Psia	183.85	190.00
H. KBtu	551.42	567.95
S, KBtu/R	27.5939	27.6414
Mol. Weight	53.4021	53.5248
D, Lb/Ft3	31.2280	31.2180
L/F (Molar)	0.99998	1.00000

WORK = -0.48 HP at 75% Efficiency

TABLE LII

STEADY STATE RESULTS FOR SIMULATION 15
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0106	0.0106
C2H6	0.0027	0.0027
C3H6	78.5661	78.5661
C3H8	49.7007	49.7007
1-C4H8	164.3814	164.3814
IC4H10	123.3606	123.3606
NC5H10	42.8597	42.8597
1-C5H12	3.6234	3.6234
IC5H12	6.2007	6.2007
NC5H12	0.2135	0.2135
Total	468.9194	468.9194
T., Deg. F.	147.18	152.24
P., Psia	190.00	189.00
H. KBtu	567.95	1071.63
S, KBtu/R	27.6414	28.4669
Mol. Weight	53.5248	53.5248
D, Lb/Ft3	31.2180	31.2180
L/F (Molar)	1.00000	0.86011
Heat Transferred	503.68 KBTU	

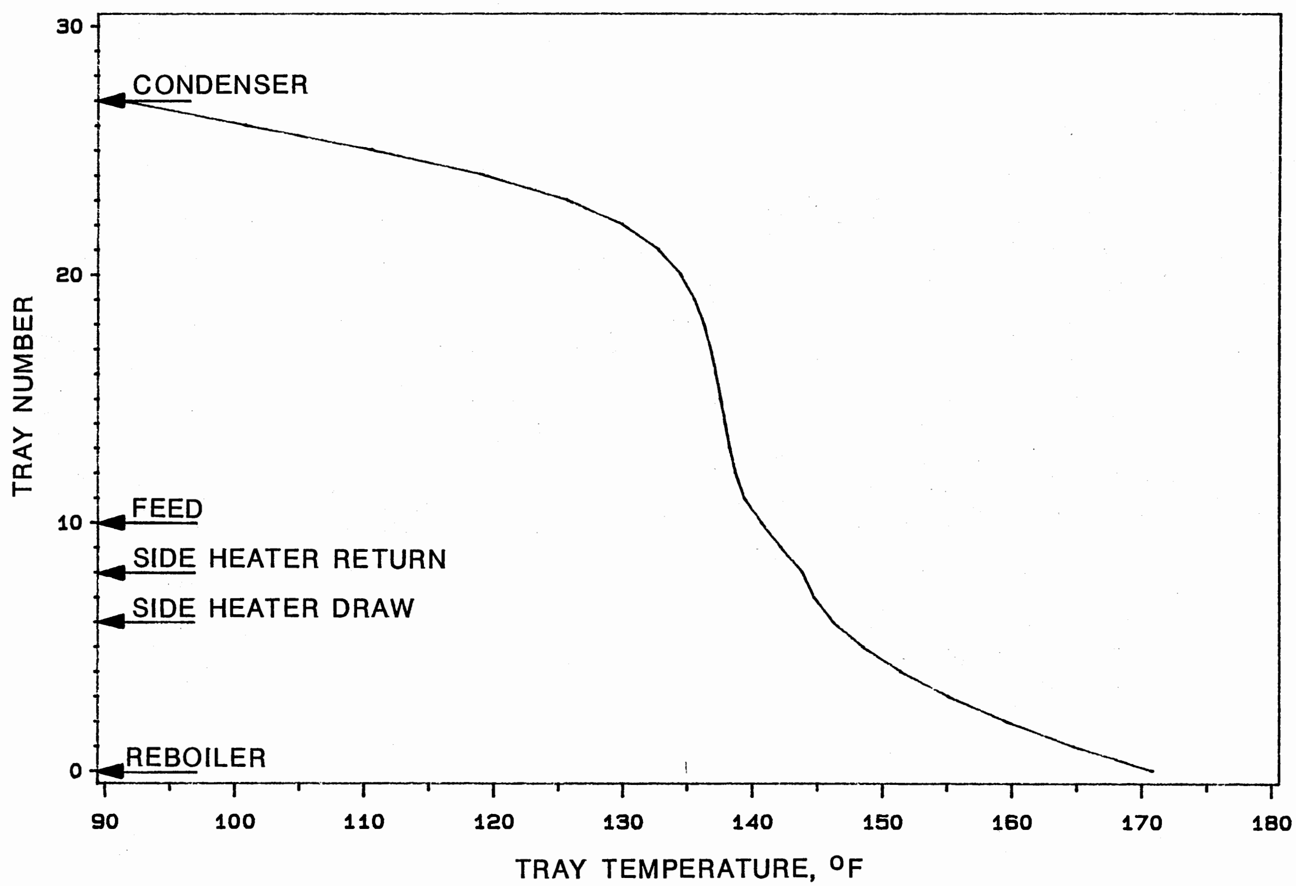


Figure 72. Steady State Simulation Results For Run 15

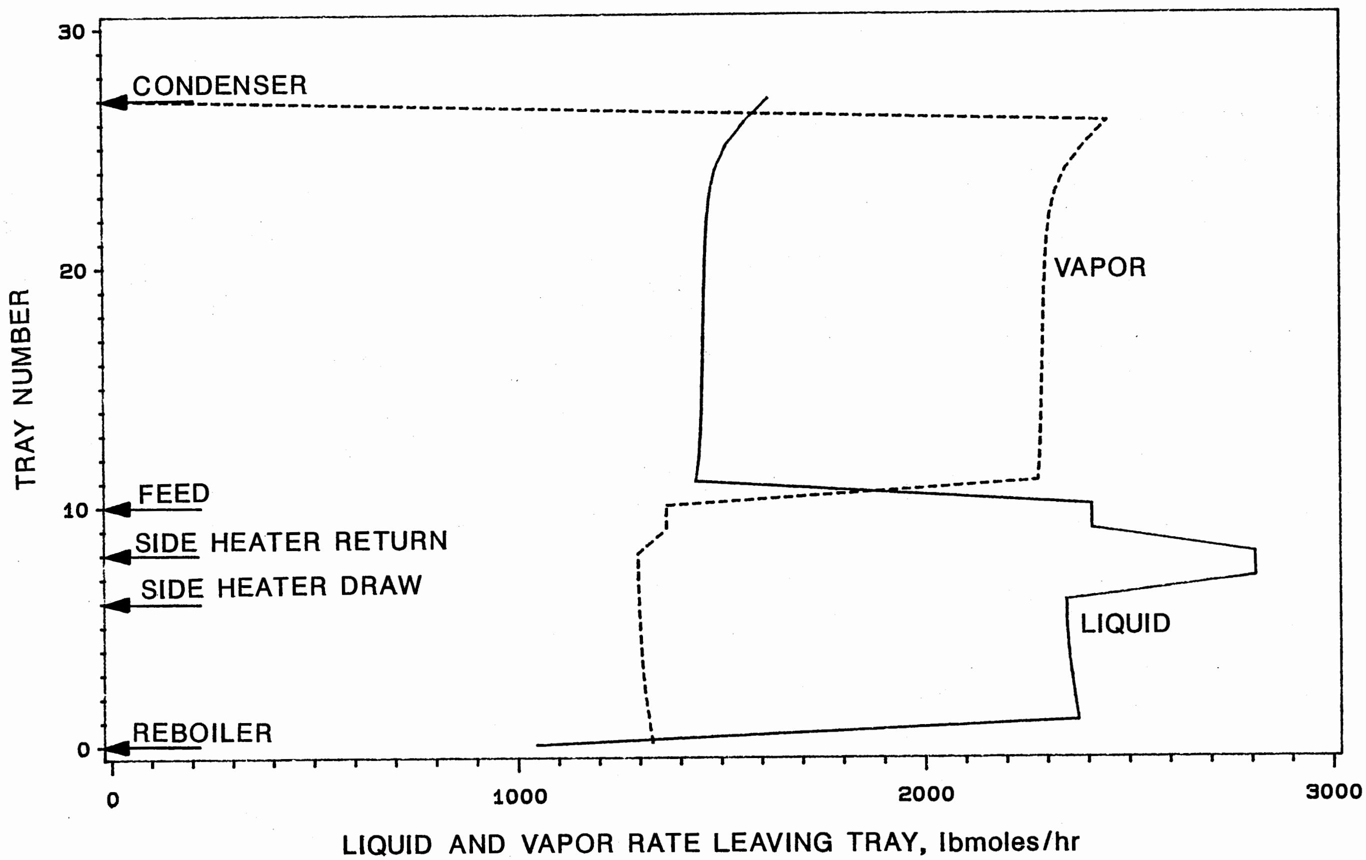


Figure 73. Steady State Simulation Results For Run 15

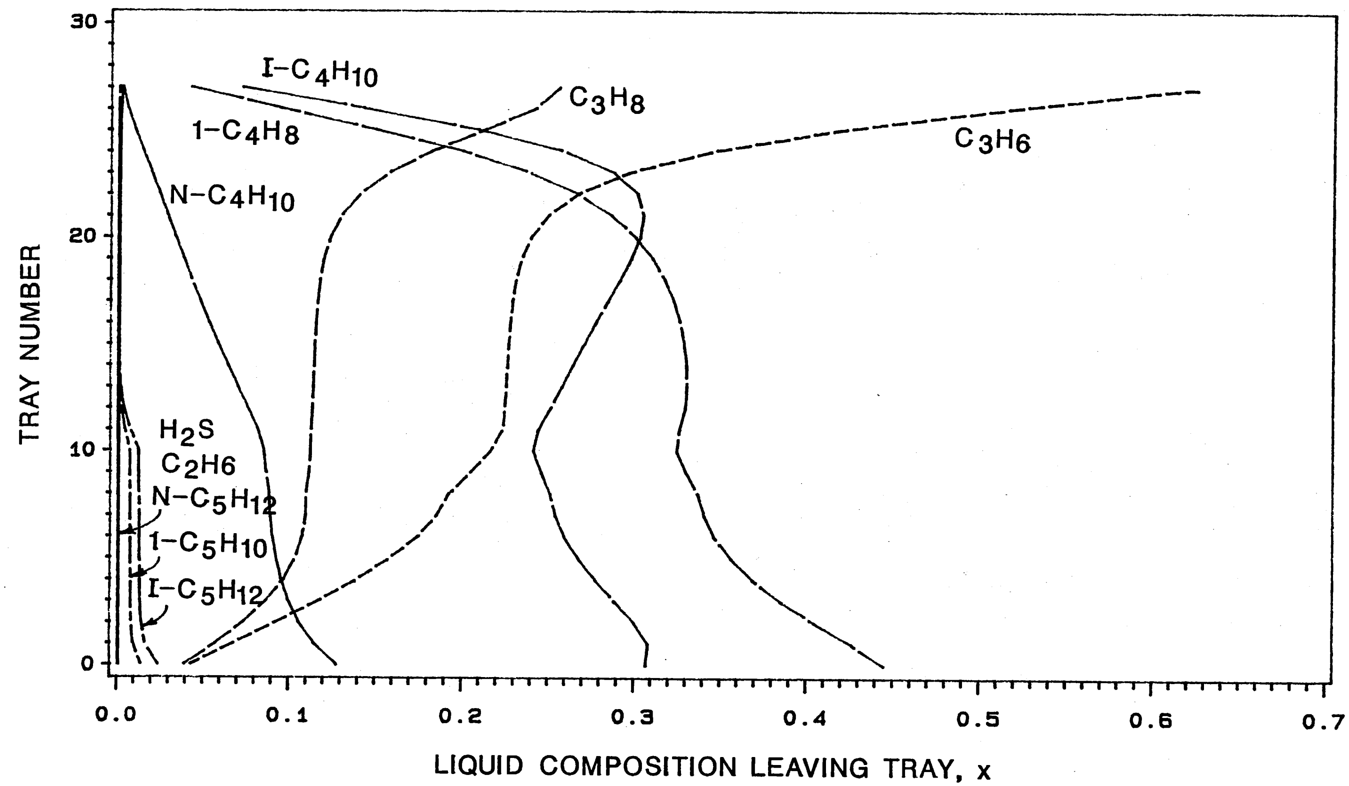


Figure 74. Steady State Simulation Results For Run 15

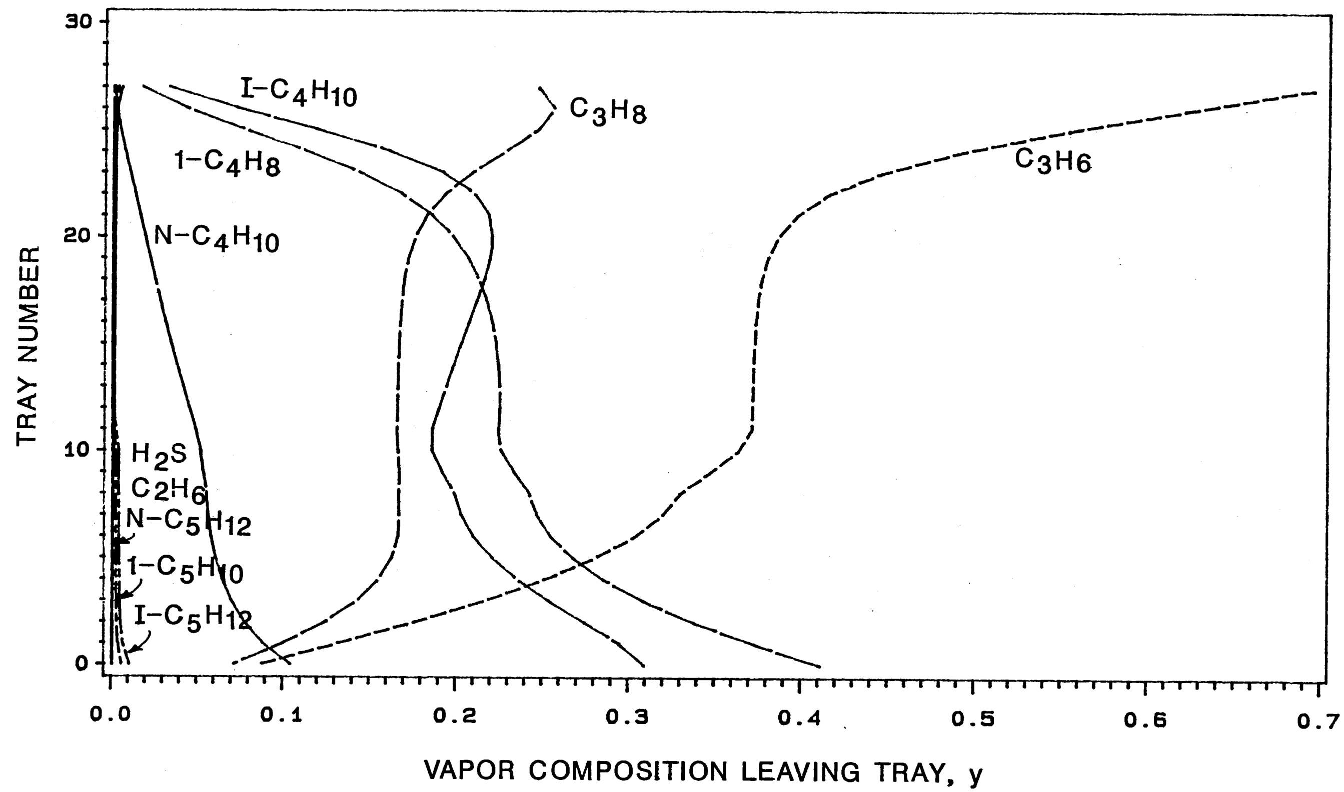


Figure 75. Steady State Simulation Results For Run 15

TABLE LIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 16

FEED PLATE = 10, SIDE DRAW = 10, RETURN = 8

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	8

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	10	0.20000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE LIV

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 16

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		504.00 KBTU
Specific Delta P		1.00 PSIA

TABLE LV

STEADY STATE RESULTS FOR SIMULATION 16

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0809	1.5934	0.0872	0.0003
C2H6	0.90	0.0351	0.8977	0.0373	0.0000
C3H6	567.70	97.1538	520.0793	101.5711	43.2034
C3H8	254.40	52.3080	213.3389	52.6736	40.6956
1-C4H8	497.30	154.1323	34.9568	151.9227	464.5529
IC4H10	378.40	114.8999	59.6753	112.8641	320.7606
NC4H10	134.70	40.5587	1.7455	40.1270	133.3863
1-C5H10	14.80	3.5211	0.0000	3.4884	14.8327
IC5H12	25.10	6.0218	0.0000	5.9665	25.1553
NC5H12	0.90	0.2080	0.0000	0.2060	0.9020
Total lbmols/hr	1875.80	468.9196	832.2910	468.9440	1043.4868
T., Deg. F.	140.00	147.37	91.30	140.62	170.96
P., Psia	183.00	189.00	179.00	183.08	185.00
H, KBtu	7504.98	981.26	-368.85	457.48	2192.76
S, KBtu/R	117.2065	28.1827	41.7756	27.2867	64.3469
Mol. Weight	51.0851	52.8412	44.3415	52.6860	56.5342
D, Lb/FT3	3.5280	10.0181	31.1197	31.3392	30.8931
L/F (Molar)	0.51764	0.86119	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15576.021
Reboiler, KBtu/hr	9370.926
Intermediate Reboiler, KBtu/hr	503.95
Intermediate Reboiler Side Draw	10
Intermediate Reboiler Return	8
Intermediate Reboiler Pumparound Rate, Lbmol/hr	468.9440
Feed Plate	10
Operating Cost, $/Year	$252,848.00
Column Thermodynamic Efficiency	10.0%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.60 Ft	7.00 Ft
Bottom Section	5.72 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE LVI

STEADY STATE RESULTS FOR SIMULATION 16
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0872	0.0809
C2H6	0.0373	0.0351
C3H6	101.5711	97.1538
C3H8	52.6736	52.3080
1-C4H8	151.9227	154.1323
IC4H10	112.8641	114.8999
NC5H10	40.1270	40.5587
1-C5H12	3.4884	3.5211
IC5H12	5.9665	6.0218
NC5H12	0.2060	0.2080
Total	468.9440	468.9196
T., Deg. F.	140.62	141.84
P., Psia	183.08	190.00
H. KBtu	457.48	477.30
S, KBtu/R	27.2867	27.3499
Mol. Weight	52.6860	52.8413
D, Lb/Ft3	31.3392	31.3161
L/F (Molar)	1.00000	1.00000

WORK = -0.53 HP at 75% Efficiency

TABLE LVII

STEADY STATE RESULTS FOR SIMULATION 16
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0809	0.0809
C2H6	0.0351	0.0351
C3H6	97.1538	97.1538
C3H8	52.3080	52.3080
1-C4H8	154.1323	154.1323
IC4H10	114.8999	114.8999
NC5H10	40.5587	40.5587
1-C5H12	3.5211	3.5211
IC5H12	6.0218	6.0218
NC5H12	0.2080	0.2080
Total	468.9196	468.9196
T., Deg. F.	141.84	147.37
P., Psia	190.00	189.00
H. KBtu	477.30	981.26
S, KBtu/R	27.3499	28.1827
Mol. Weight	52.8413	52.8412
D, Lb/Ft3	31.3161	10.0181
L/F (Molar)	1.00000	0.86119
Heat Transferred	503.95 KBTU	

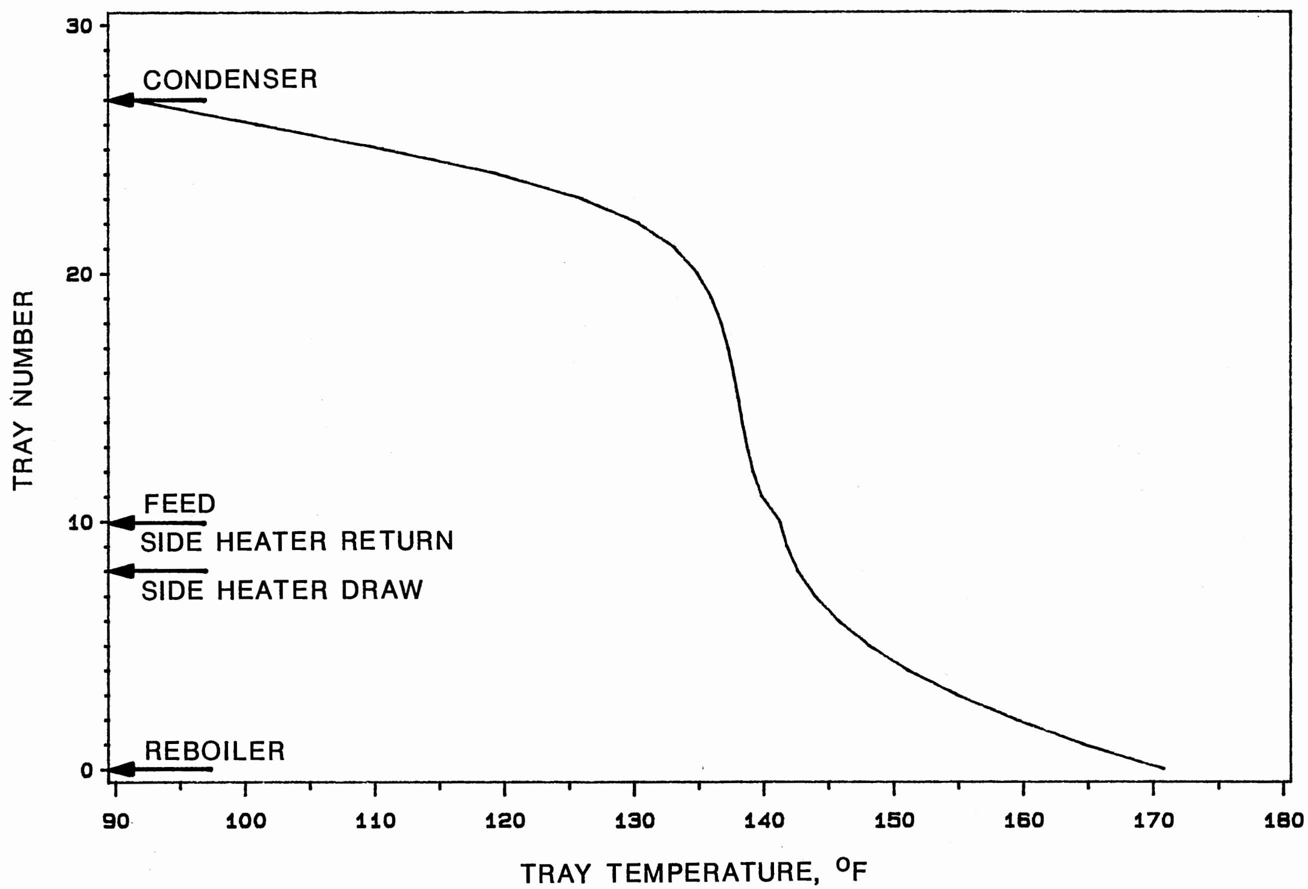


Figure 76. Steady State Simulation Results For Run 16

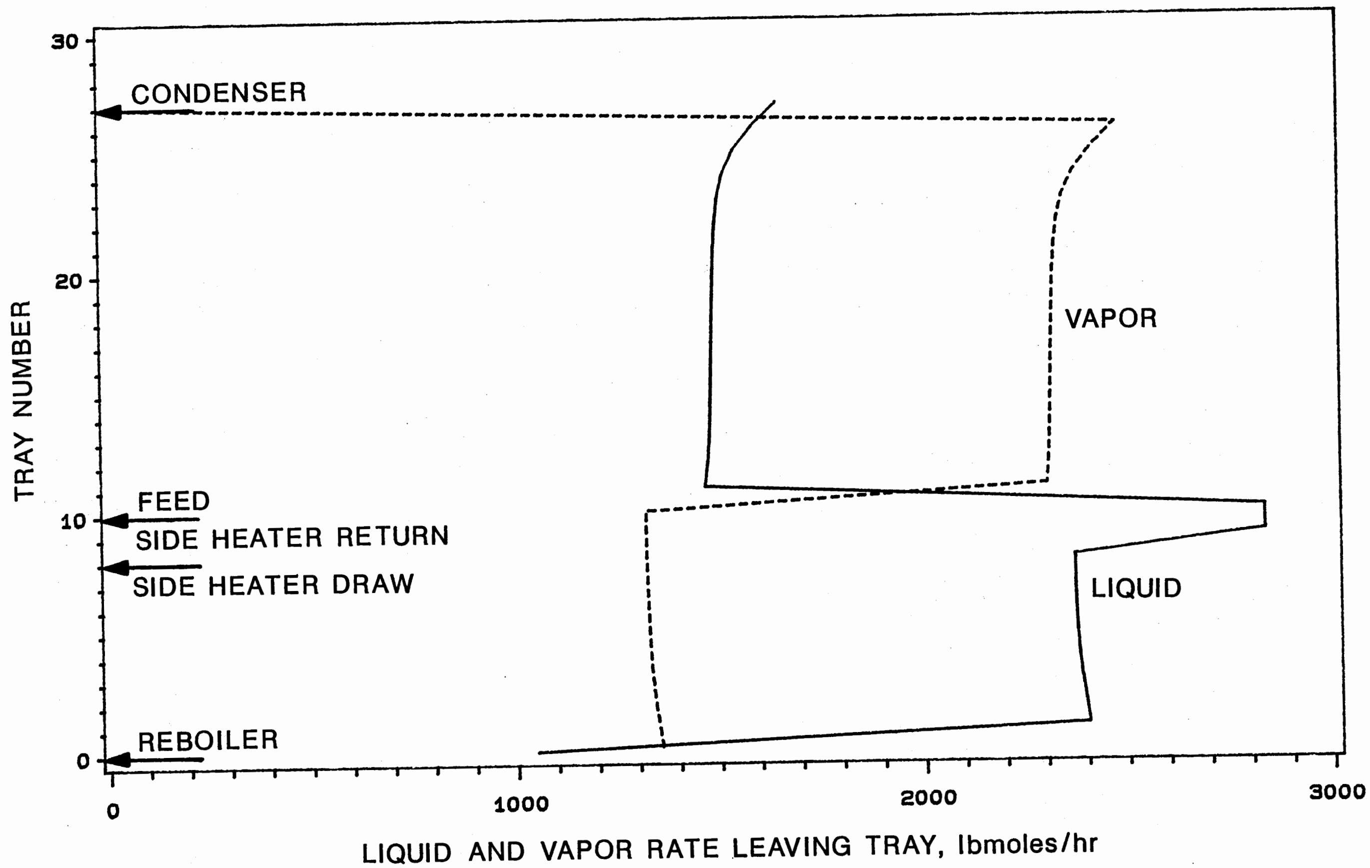


Figure 77. Steady State Simulation Results For Run 16

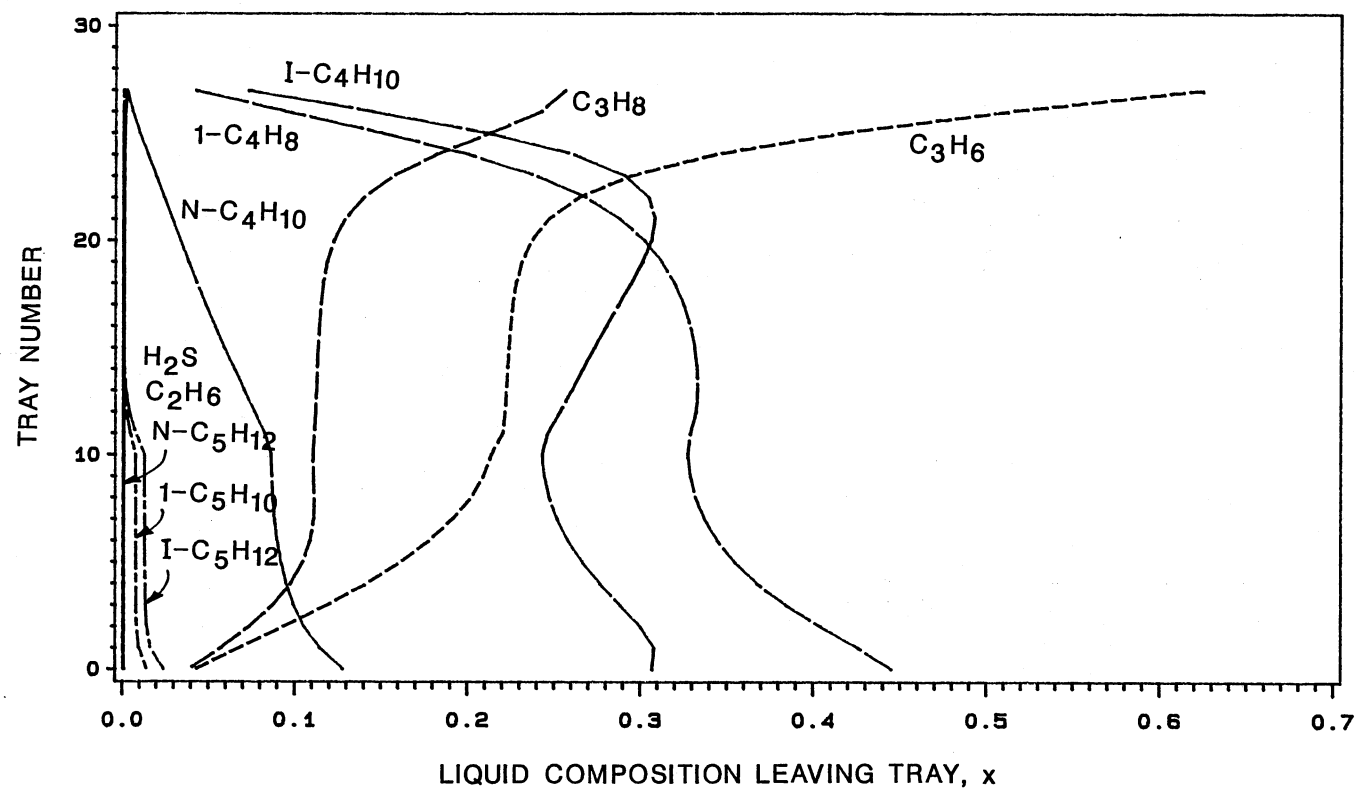


Figure 78. Steady State Simulation Results For Run 16

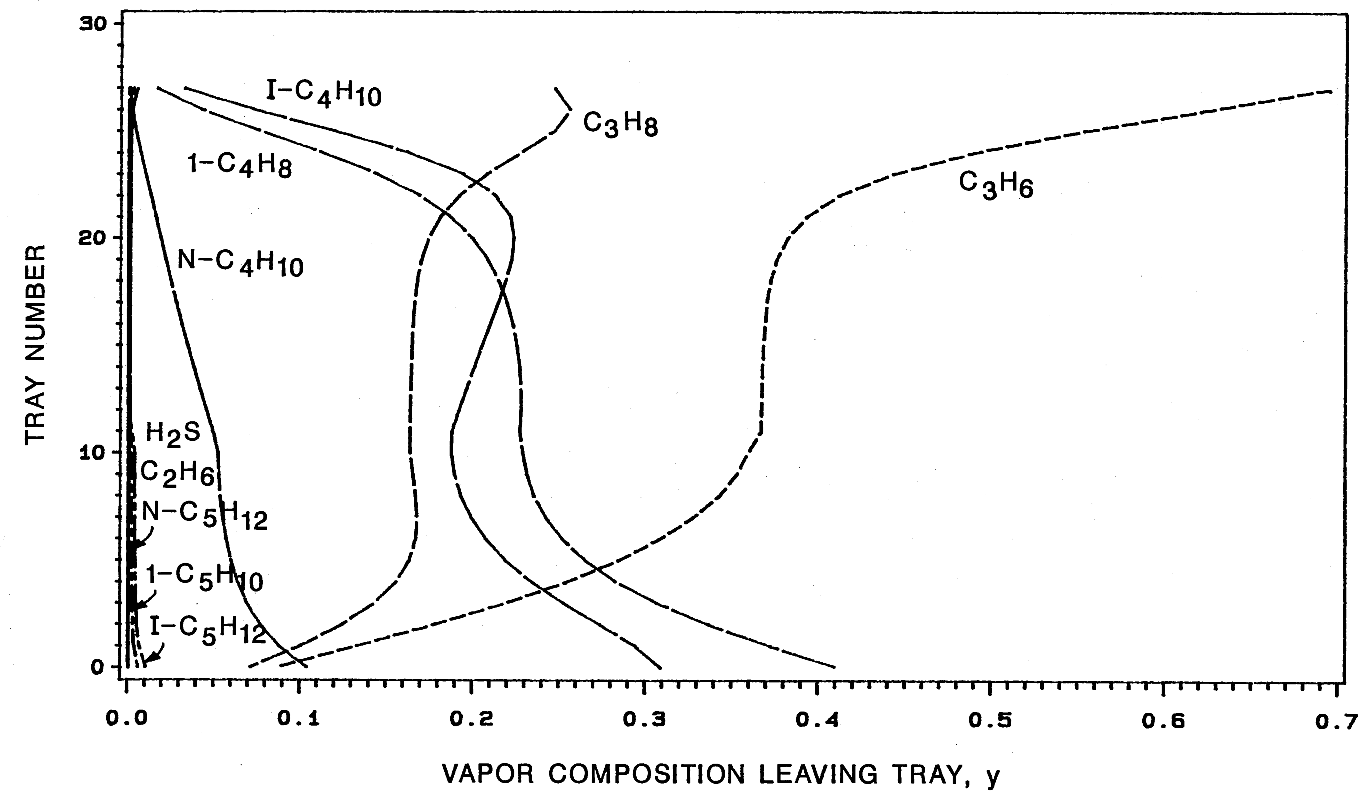


Figure 79. Steady State Simulation Results For Run 16

TABLE LVIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 17

FEED PLATE = 10, SIDE DRAW = 7, RETURN = 5

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	5

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	7	0.20000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE LIX

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 17

PUMP UNIT OPERATION

Discharge Pressure	=	190.00	PSIA
Efficiency	=	75.00	%
Work Bal Option	=	0.00	
From Unit	=	0.00	
or Spec	=	0.00	HP

HEATER/COOLER SPECIFICATION

Specific Duty	504.00	KBTU
Specific Delta P	1.00	PSIA

TABLE LX

STEADY STATE RESULTS FOR SIMULATION 17

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0145	1.5991	0.0151	0.0003
C2H6	0.90	0.0042	0.8999	0.0043	0.0000
C3H6	567.70	84.4093	521.7322	87.6301	42.7470
C3H8	254.40	52.2971	213.2252	52.8305	40.6414
1-C4H8	497.30	160.1915	35.0152	158.4881	463.9881
IC4H10	378.40	120.1390	59.4522	118.6205	320.4663
NC4H10	134.70	41.9257	1.7626	41.5324	133.3306
1-C5H10	14.80	3.5883	0.0000	3.5462	14.8421
IC5H12	25.10	6.1389	0.0000	6.0679	25.1710
NC5H12	0.90	0.2117	0.0000	0.2091	0.9026
Total lbmols/hr	1875.80	468.9201	833.6915	468.9441	1042.0867
T., Deg. F.	140.00	150.37	91.27	144.20	171.02
P., Psia	183.00	189.00	179.00	183.65	185.00
H, KBtu	7504.98	1038.53	-370.46	518.49	2192.30
S, KBtu/R	117.2065	28.3619	41.8403	27.4843	64.2671
Mol. Weight	51.0851	53.2619	44.3344	53.1402	56.5413
D, Lb/FT3	3.5280	10.0040	31.1207	31.2655	30.8919
L/F (Molar)	0.51764	0.86024	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15489.627
Reboiler, KBtu/hr	9286.169
Intermediate Reboiler, KBtu/hr	503.97
Intermediate Reboiler Side Draw	7
Intermediate Reboiler Return	5
Intermediate Reboiler Pumparound Rate, Lbmol/hr	468.9441
Feed Plate	10
Operating Cost, $/Year	$250,794.00
Column Thermodynamic Efficiency	10.3%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.58 Ft	7.00 Ft
Bottom Section	5.70 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE LXI

STEADY STATE RESULTS FOR SIMULATION 17
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0151	0.0145
C2H6	0.0043	0.0042
C3H6	87.6301	84.4093
C3H8	52.8305	52.2971
1-C4H8	158.4881	160.1915
IC4H10	118.6205	120.1390
NC5H10	41.5324	41.9257
1-C5H12	3.5462	3.5883
IC5H12	6.0679	6.1389
NC5H12	0.2091	0.2117
Total	468.9441	468.9201
T., Deg. F.	144.20	145.18
P., Psia	183.65	190.00
H. KBtu	518.49	534.56
S, KBtu/R	27.4843	27.5334
Mol. Weight	53.1402	53.2621
D, Lb/Ft3	31.2655	31.2468
L/F (Molar)	1.00000	1.00000

WORK = -0.49 HP at 75% Efficiency

TABLE LXII

STEADY STATE RESULTS FOR SIMULATION 17
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0145	0.0145
C2H6	0.0042	0.0042
C3H6	84.4093	84.4093
C3H8	52.2971	52.2971
1-C4H8	160.1915	160.1915
IC4H10	120.1390	120.1390
NC5H10	41.9257	41.9257
1-C5H12	3.5883	3.5883
IC5H12	6.1389	6.1389
NC5H12	0.2117	0.2117
Total	468.9201	468.9201
T., Deg. F.	145.18	150.37
P., Psia	190.00	189.00
H. KBtu	534.56	1038.53
S, KBtu/R	27.5334	28.3619
Mol. Weight	53.2621	53.2619
D, Lb/Ft3	31.2468	10.0040
L/F (Molar)	1.00000	0.86024
Heat Transferred 503.97 KBTU		

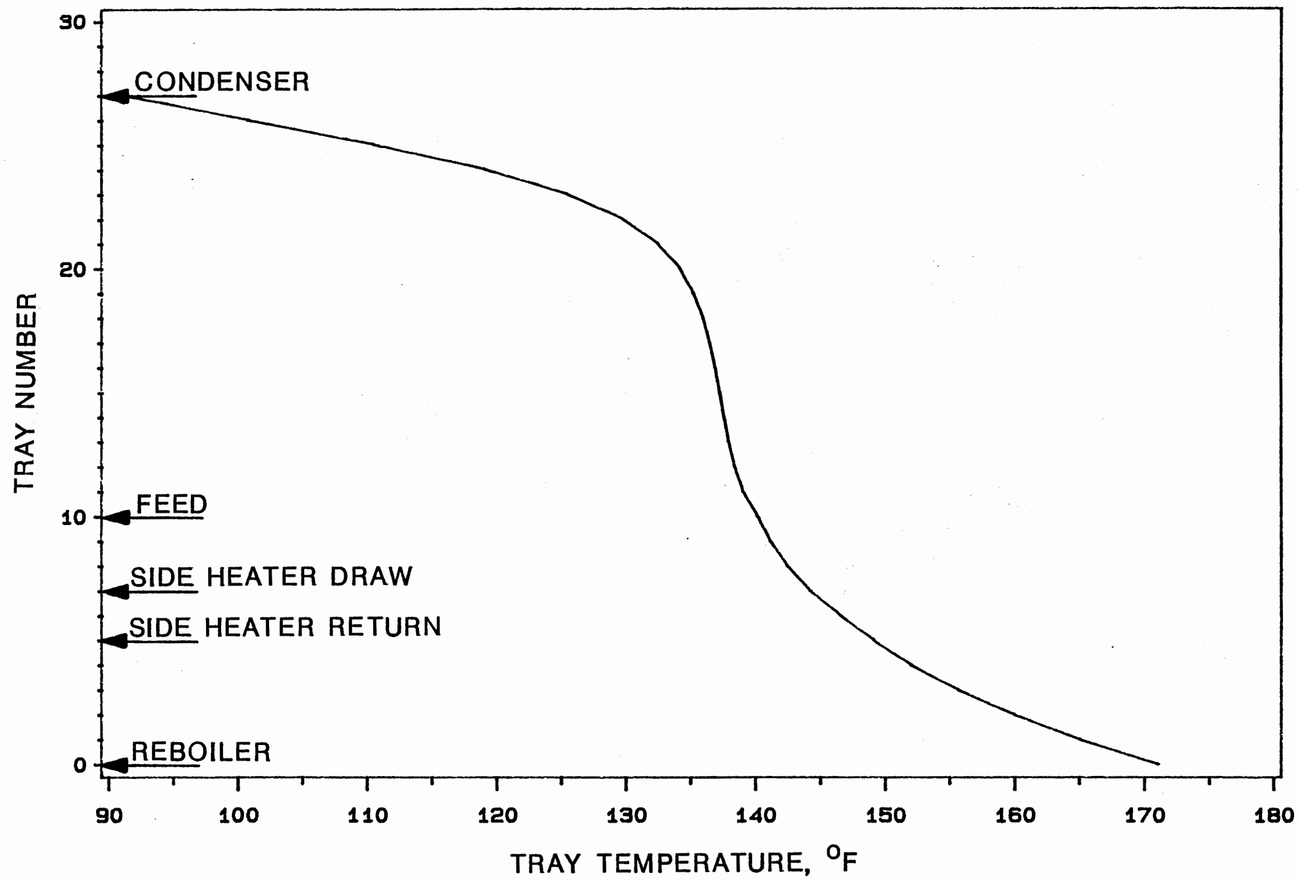


Figure 80. Steady State Simulation Results For Run 17

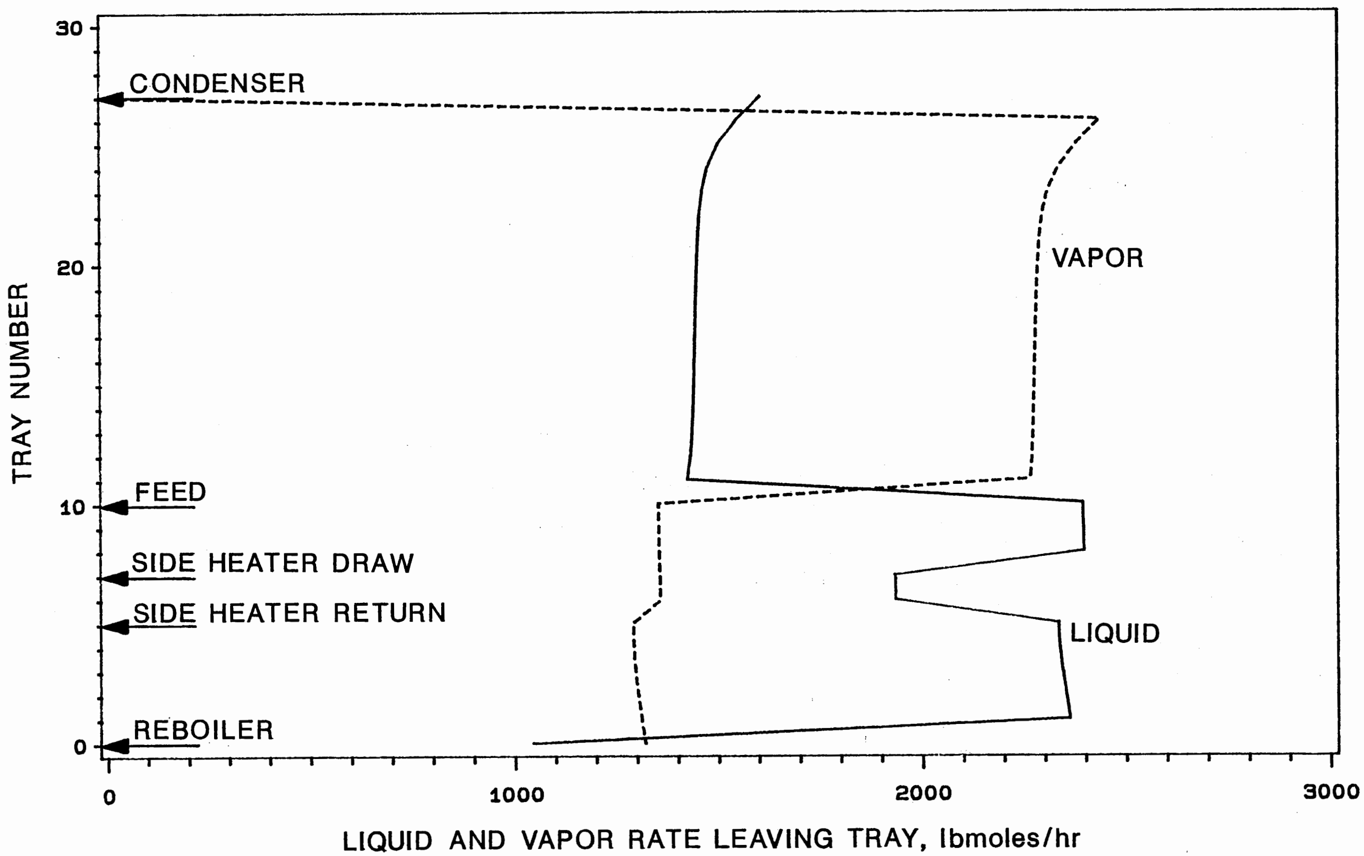


Figure 81. Steady State Simulation Results For Run 17

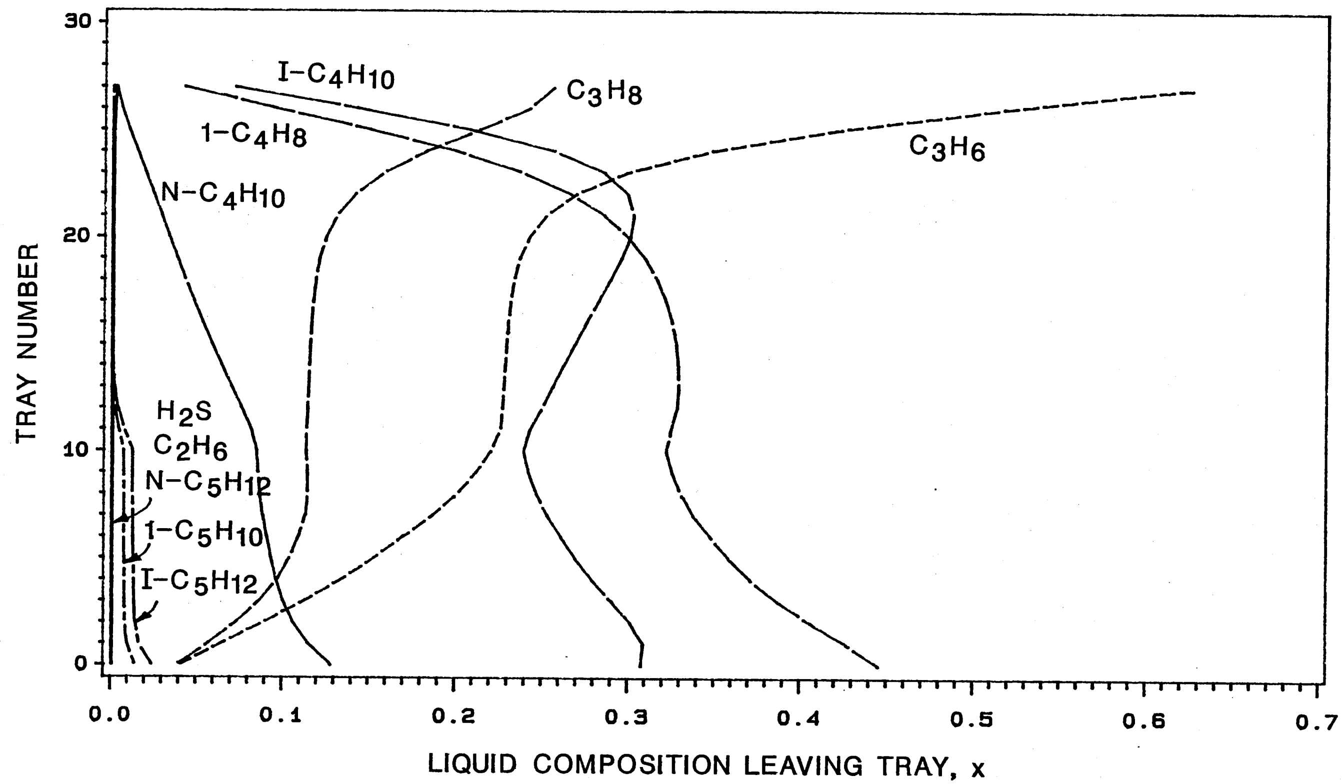


Figure 82. Steady State Simulation Results For Run 17

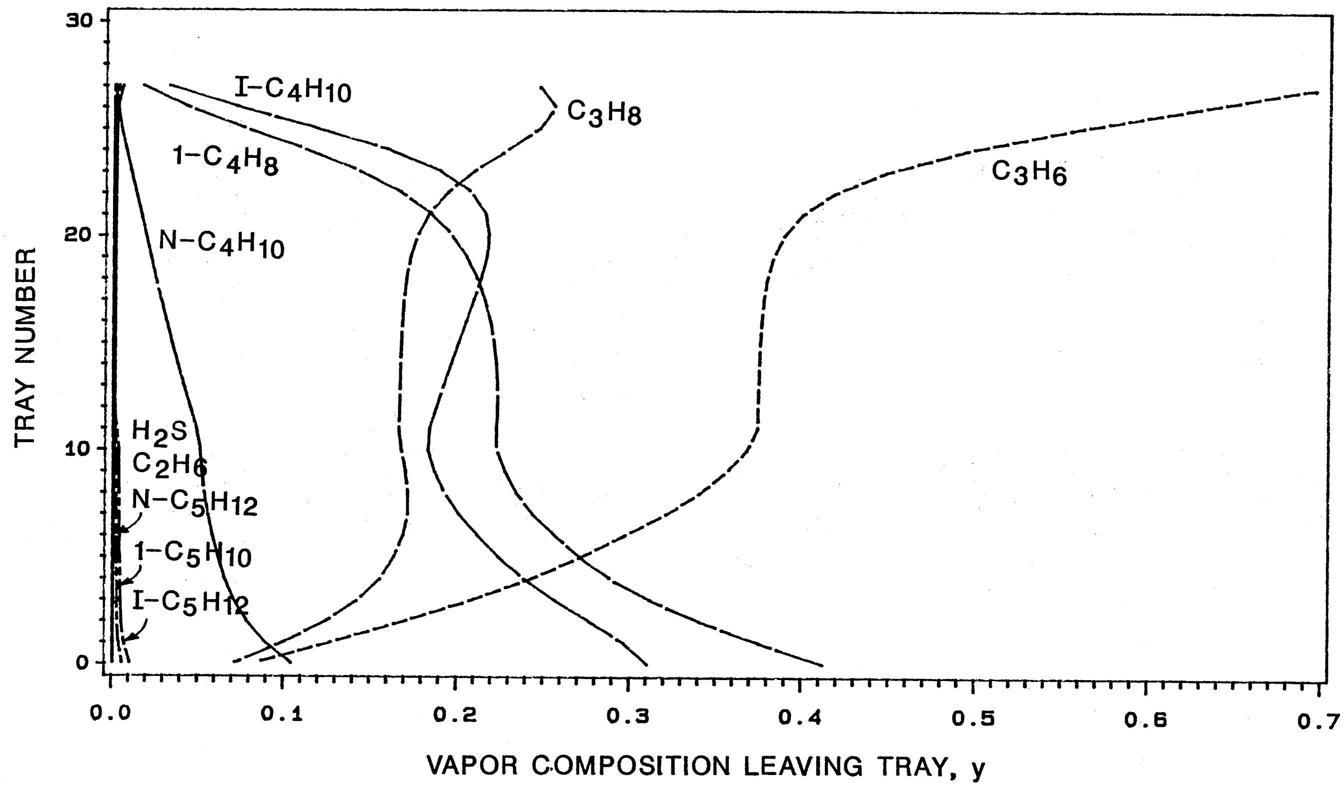


Figure 83. Steady State Simulation Results For Run 17

TABLE LXIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 18

FEED PLATE = 10, SIDE DRAW = 7, RETURN = 5

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	5

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	7	0.30000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C_4H_8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C_3H_8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE LXIV

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 18

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		858.00 KBTU
Specific Delta P		1.00 PSIA

TABLE LXV

STEADY STATE RESULTS FOR SIMULATION 18

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0284	1.6014	0.0267	0.0003
C2H6	0.90	0.0081	0.9006	0.0075	0.0000
C3H6	567.70	145.0181	520.8880	148.3749	43.4552
C3H8	254.40	85.9404	212.3190	88.1268	39.8945
1-C4H8	497.30	261.8672	34.9339	269.4767	454.7565
IC4H10	378.40	195.6976	59.3311	201.4930	313.2735
NC4H10	134.70	68.8140	1.7579	70.6634	131.0926
1-C5H10	14.80	5.9135	0.0000	6.0274	14.6861
IC5H12	25.10	10.1174	0.0000	10.3143	24.9032
NC5H12	0.90	0.3488	0.0000	0.3553	0.8935
Total lbmols/hr	1875.80	773.7535	831.7361	794.8662	1022.9540
T., Deg. F.	140.00	149.71	91.26	144.39	170.86
P., Psia	183.00	189.00	179.00	183.65	185.00
H, KBtu	7504.98	1717.50	-369.89	883.50	2144.97
S, KBtu/R	117.2065	46.7723	41.7409	46.6039	63.0781
Mol. Weight	51.0851	53.1553	44.3336	53.1672	56.5234
D, Lb/FT3	3.5280	9.7614	31.1216	31.2661	30.8980
L/F (Molar)	0.51764	0.85531	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15459.544
Reboiler, KBtu/hr	8895.474
Intermediate Reboiler, KBtu/hr	857.96
Intermediate Reboiler Side Draw	7
Intermediate Reboiler Return	5
Intermediate Reboiler Pumparound Rate, Lbmol/hr	794.8662
Feed Plate	10
Operating Cost, $/Year	$246,763.00
Column Thermodynamic Efficiency	32.4%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.57 Ft	7.00 Ft
Bottom Section	5.60 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE LXVI

STEADY STATE RESULTS FOR SIMULATION 18
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0267	0.0284
C2H6	0.0075	0.0081
C3H6	148.3749	145.0181
C3H8	88.1268	85.9404
1-C4H8	269.4767	261.8672
IC4H10	201.4930	195.6976
NC5H10	70.6634	68.8140
1-C5H12	6.0274	5.9135
IC5H12	10.3143	10.1174
NC5H12	0.3553	0.3488
Total	794.8662	773.7535
T., Deg. F.	144.39	144.40
P., Psia	183.65	190.00
H. KBtu	883.50	859.55
S, KBtu/R	46.6039	45.3602
Mol. Weight	53.1672	53.1555
D, Lb/Ft3	31.2661	31.2622
L/F (Molar)	1.00000	1.00000

WORK = -0.81 HP at 75% Efficiency

TABLE LXVII

STEADY STATE RESULTS FOR SIMULATION 18.0
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0284	0.0284
C2H6	0.0081	0.0081
C3H6	145.0181	145.0181
C3H8	85.9404	85.9404
1-C4H8	261.8672	261.8672
IC4H10	195.6976	195.6976
NC5H10	68.8140	68.8140
1-C5H12	5.9135	5.9135
IC5H12	10.1174	10.1174
NC5H12	0.3488	0.3488
Total	773.7535	773.7535
T., Deg. F.	144.40	149.71
P., Psia	190.00	189.00
H. KBtu	859.55	1717.50
S, KBtu/R	45.3602	46.7723
Mol. Weight	53.1555	53.1553
D, Lb/Ft3	31.2622	9.7614
L/F (Molar)	1.00000	0.85531
Heat Transferred 857.96 KBTU		

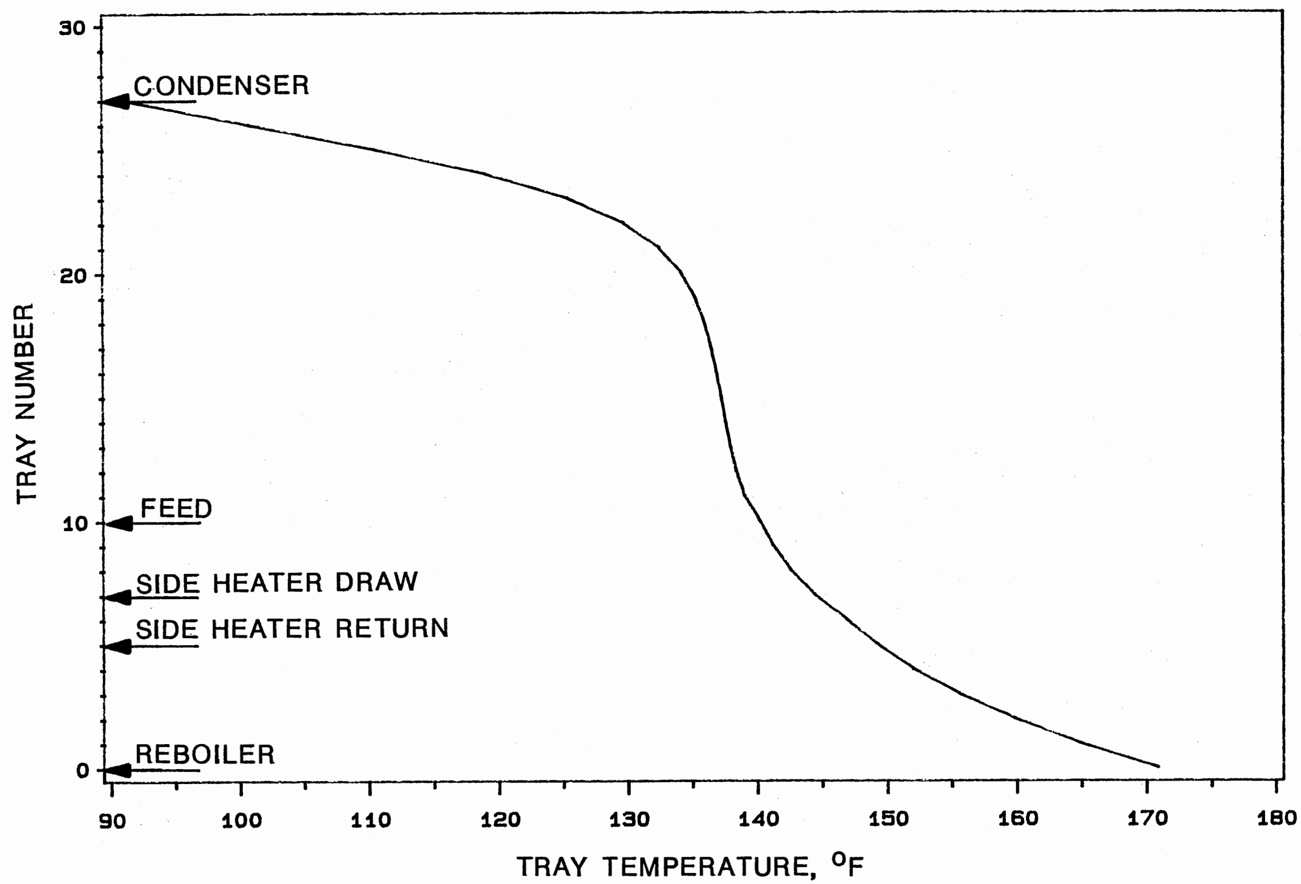


Figure 84. Steady State Simulation Results For Run 18

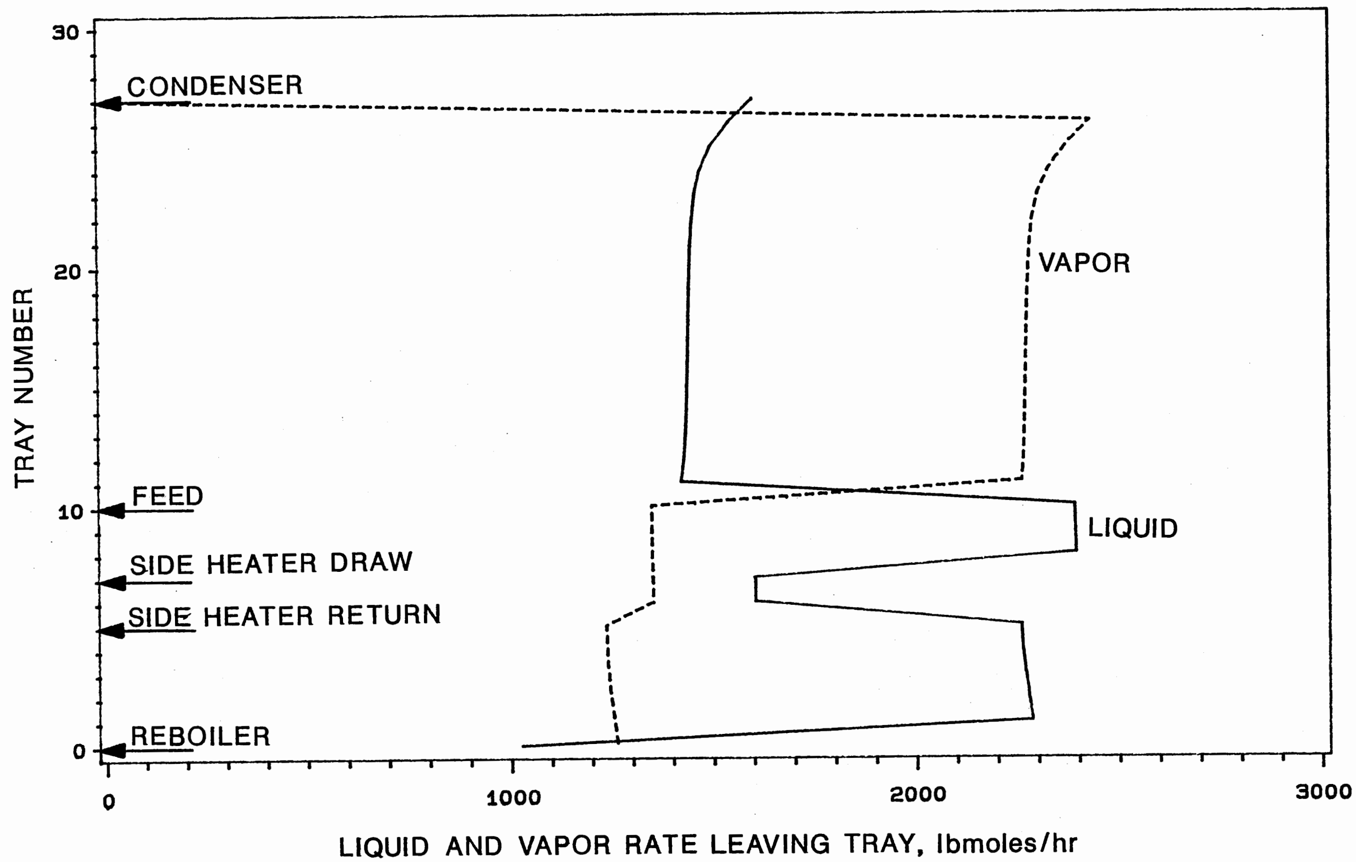


Figure 85. Steady State Simulation Results For Run 18

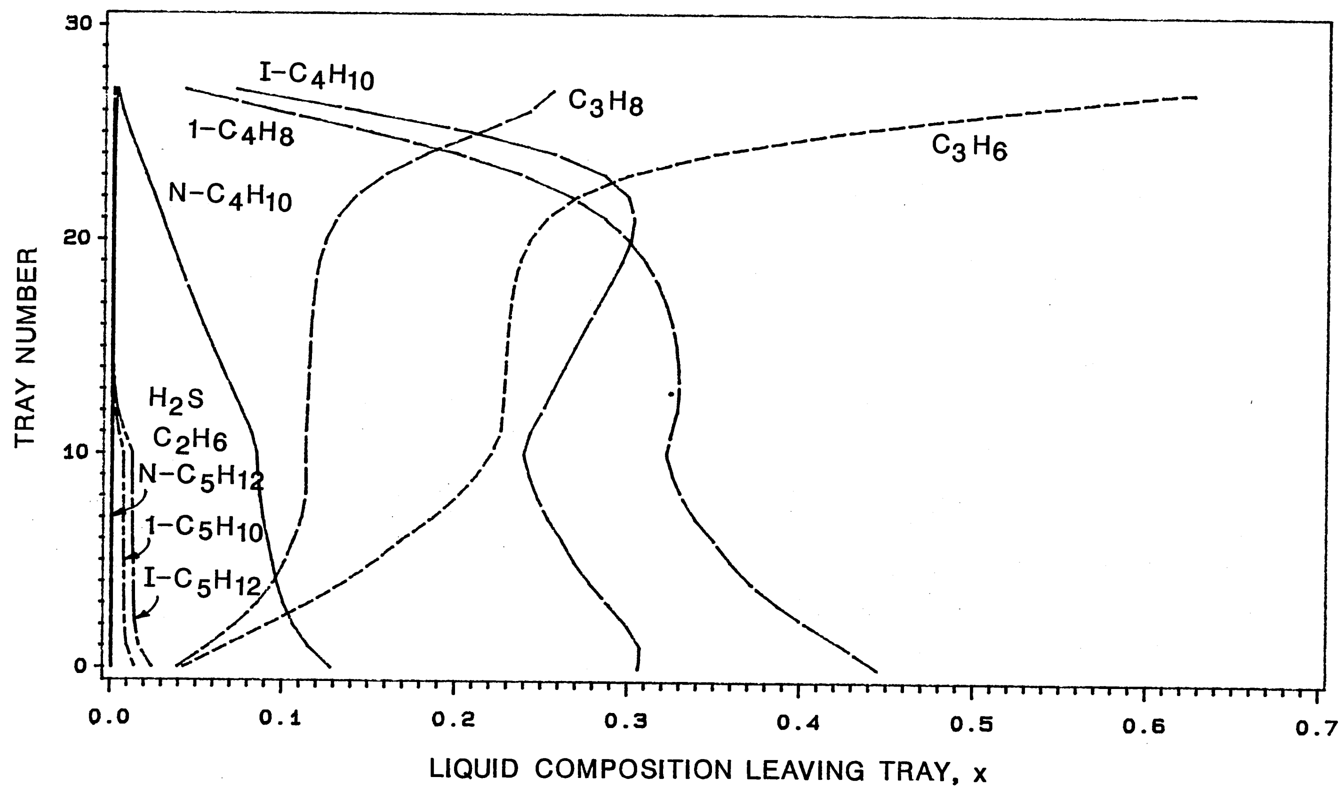


Figure 86. Steady State Simulation Results For Run 18

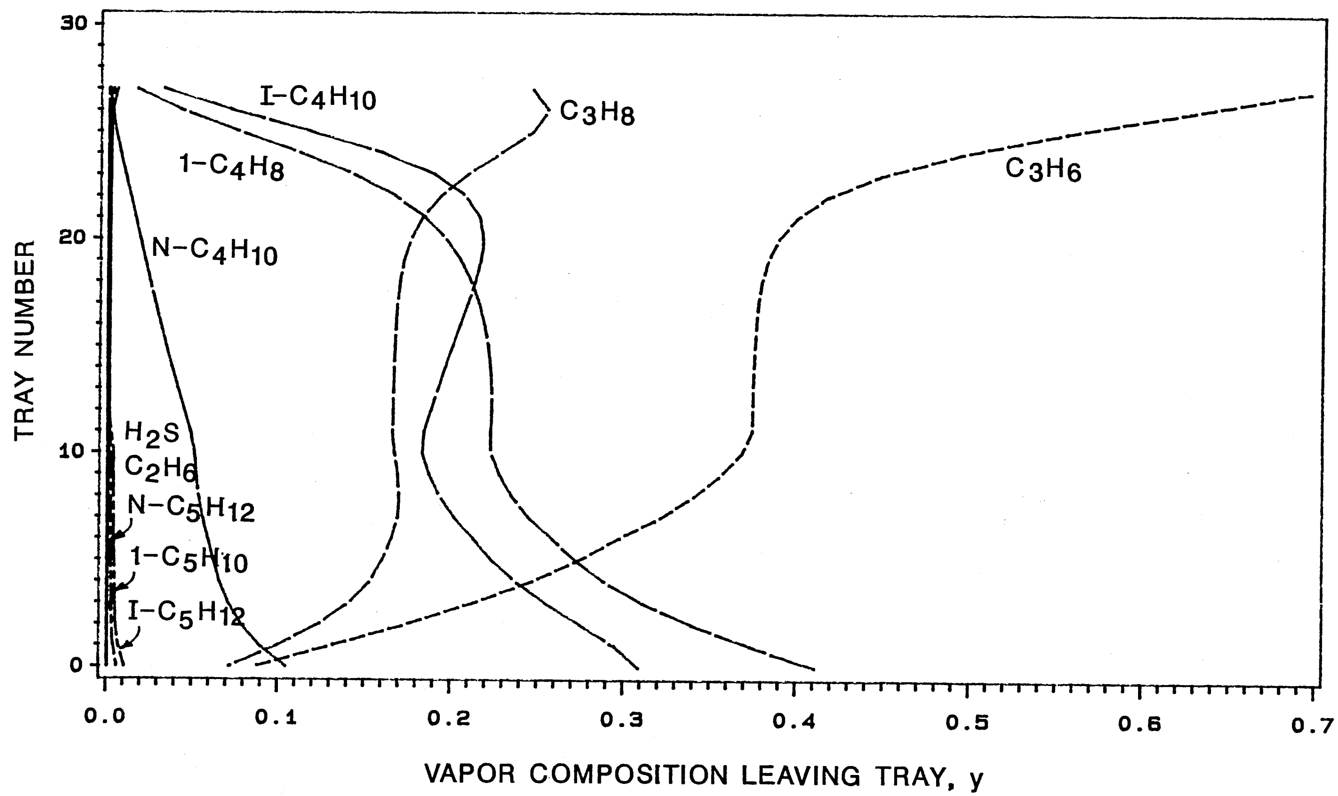


Figure 87. Steady State Simulation Results For Run 18

TABLE LXVIII

DISTILLATION COLUMN SPECIFICATIONS
FOR SIMULATION 19

FEED PLATE = 10, SIDE DRAW = 7, RETURN = 5

Number of Plates in Column	26
Number of Feed Plates	2
Number of Products	3
Number of Side Coolers/Heaters	0

Feed No	Stream No	Feed Plate
1	1	10
2	5	5

Product No	Stream No	Draw Plate	Draw Rate
1	2	27	******
2	3	7	0.40000
3	6	0	******

Condenser Type - Total
Reboiler Type - Partial

Condenser/Distillate Specifications
Mole Fractions 0.03900 for 1-C4H8

Reboiler/Bottoms Specifications
Mole Fraction 0.04200 for C3H8

Column Pressures and Estimated Temperatures

	P(PSIA)	T(Deg. F)
Condenser	179.00	96.15
Top Plate	180.00	
Reboiler	185.00	172.83

Convergence Parameters

No. of Allowable Constant Molal Overflow Iteration	0
Max Allowable Iterations	20
Max Delta T Per Plate	20.000
Max Fractional Liquid Change Per Plate	0.500

Plate Spacing

Top Section	21.00 In.
Bottom Section	21.00 In.

Estimated Liquid Rate Leaving Top Plate/Condenser
0.700 (L/F)

Estimated Bottoms Rate 0.433 (B/F)

TABLE LXIX

PUMP AND HEATER/COOLER SPECIFICATIONS FOR SIMULATION 19

PUMP UNIT OPERATION		
Discharge Pressure	=	190.00 PSIA
Efficiency	=	75.00 %
Work Bal Option	=	0.00
From Unit	=	0.00
or Spec	=	0.00 HP
HEATER/COOLER SPECIFICATION		
Specific Duty		1751.00 KBTU
Specific Delta P		1.00 PSIA

TABLE LXX

STEADY STATE RESULTS FOR SIMULATION 19

MOLE FRACTION PROPANE IN FEED, x=0.1356
DISTILLATION UNIT OPERATION

Component	Feed	Side Heater Return	Distillate	Side Heater Draw	Bottoms
H2S	1.60	0.0444	1.6028	0.0412	0.0004
C2H6	0.90	0.0125	0.9009	0.0116	0.0001
C3H6	567.70	218.5857	520.3605	221.2947	44.6305
C3H8	254.40	128.3929	212.1258	131.0953	39.5717
1-C4H8	497.30	412.1559	34.9071	424.1204	450.4285
IC4H10	378.40	307.5472	59.4655	316.7943	309.6874
NC4H10	134.70	108.2526	1.7488	111.1365	130.0673
1-C5H10	14.80	9.2075	0.0000	9.3931	14.6145
IC5H12	25.10	15.7602	0.0000	16.0801	24.7800
NC5H12	0.90	0.5422	0.0000	0.5528	0.8894
Total lbmols/hr	1875.80	1200.5011	831.1127	1230.5205	1014.6699
T., Deg. F.	140.00	151.61	91.27	145.55	170.68
P., Psia	183.00	189.00	179.00	183.65	185.00
H, KBtu	7504.98	3125.07	-369.31	1417.41	2119.72
S, KBtu/R	117.2065	73.3911	41.7116	72.3167	62.5531
Mol. Weight	51.0851	53.2899	44.3368	53.3281	56.5022
D, Lb/FT3	3.5280	7.9133	31.1218	31.2545	30.9037
L/F (Molar)	0.51764	0.80596	1.00000	1.00000	1.00000

Column Condenser, Reboiler and Intermediate Reboiler Duties

Condenser, KBtu/hr	-15505.755
Reboiler, KBtu/hr	8043.445
Intermediate Reboiler, KBtu/hr	1471.06
Intermediate Reboiler Side Draw	7
Intermediate Reboiler Return	5
Intermediate Reboiler Pumparound Rate, Lbmol/hr	1230.5205
Feed Plate	10
Operating Cost, $/Year	$239,618.00
Column Thermodynamic Efficiency	42.7%

Estimated Column Diameters*		Actual Column Diameters
Top Section	5.58 Ft	7.00 Ft
Bottom Section	5.38 Ft	7.00 Ft

*Based on a 75% Vapor Flood Velocity and 5 Second Liquid Residence in Downcomer.

TABLE LXXI

STEADY STATE RESULTS FOR SIMULATION 19
PUMP UNIT OPERATION

Component	Suction	Discharge
H2S	0.0412	0.0444
C2H6	0.0116	0.0125
C3H6	221.2947	218.5857
C3H8	131.0953	128.3929
1-C4H8	424.1204	412.1559
IC4H10	316.7943	307.5472
NC5H10	111.1365	108.2526
1-C5H12	9.3931	9.2075
IC5H12	16.0801	15.7602
NC5H12	0.5528	0.5422
Total	1230.5205	1200.5011
T., Deg. F.	145.55	145.37
P., Psia	183.65	190.00
H. KBtu	1417.41	1374.02
S, KBtu/R	72.3167	70.5162
Mol. Weight	53.3281	53.2902
D, Lb/Ft3	31.2545	31.2567
L/F (Molar)	1.00000	1.00000

WORK = -1.33 HP at 75% Efficiency

TABLE LXXII

STEADY STATE RESULTS FOR SIMULATION 19
HEATER COOLER UNIT OPERATION

Component	Inlet	Outlet
H2S	0.0444	0.0444
C2H6	0.0125	0.0125
C3H6	218.5857	218.5857
C3H8	128.3929	128.3929
1-C4H8	412.1559	412.1559
IC4H10	307.5472	307.5472
NC5H10	108.2526	108.2526
1-C5H12	9.2075	9.2075
IC5H12	15.7602	15.7602
NC5H12	0.5422	0.5422
Total	1200.5011	1200.5011
T., Deg. F.	145.37	151.62
P., Psia	190.00	189.00
H. KBtu	1374.02	3125.07
S, KBtu/R	70.5162	73.3911
Mol. Weight	53.2902	53.2899
D, Lb/Ft3	31.2567	7.9133
L/F (Molar)	1.00000	0.80596
Heat Transferred	1751.06 KBTU	

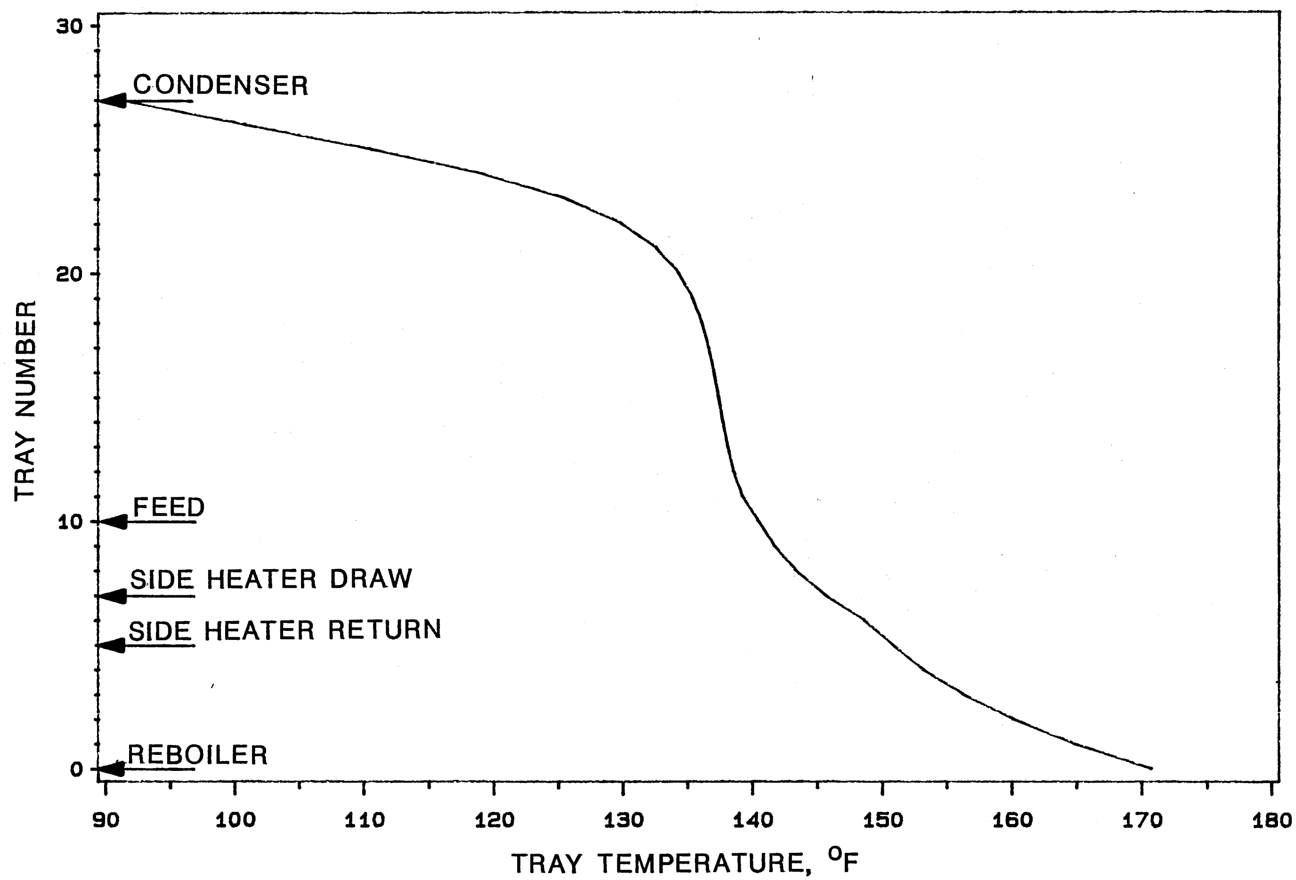


Figure 88. Steady State Simulation Results For Run 19

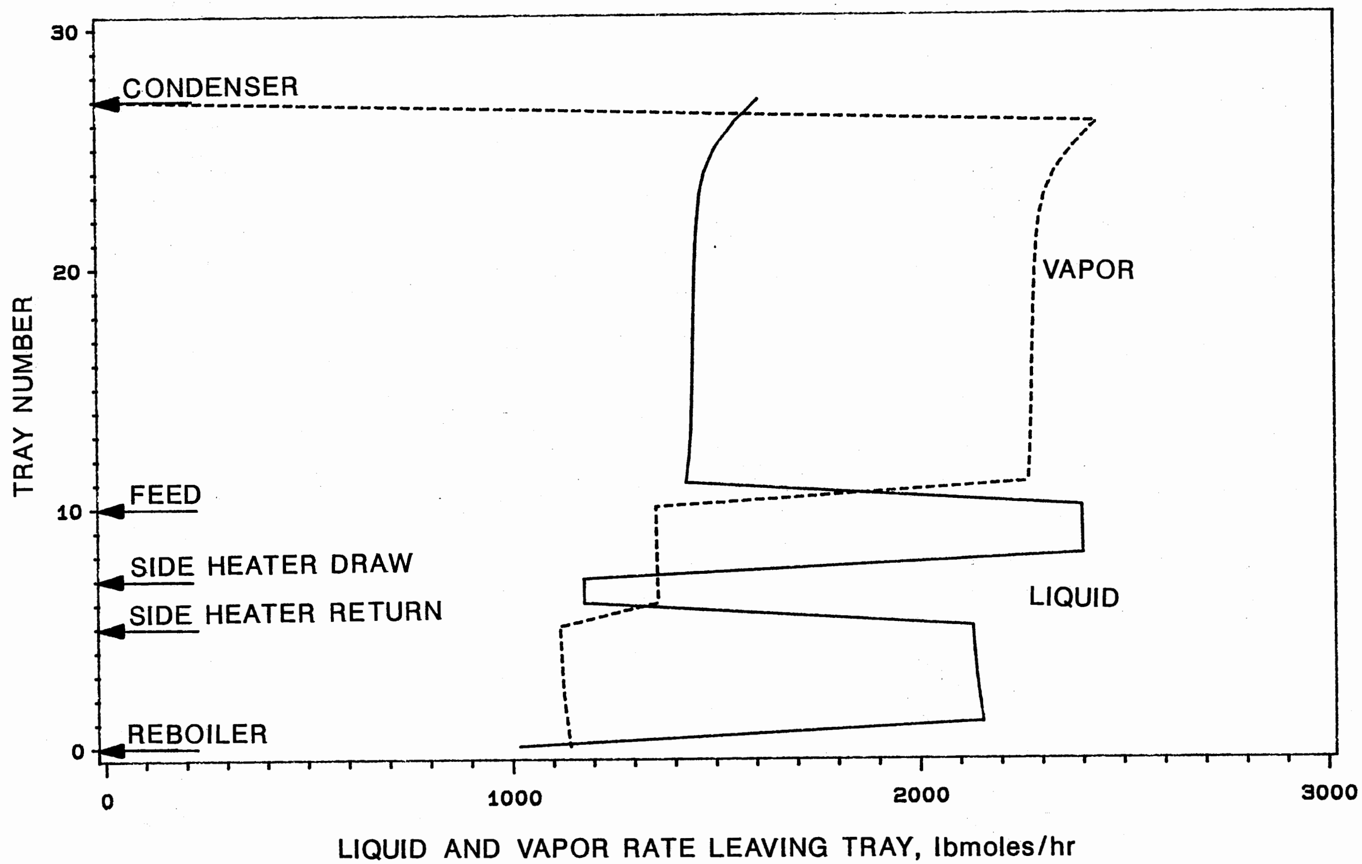


Figure 89. Steady State Simulation Results For Run 19

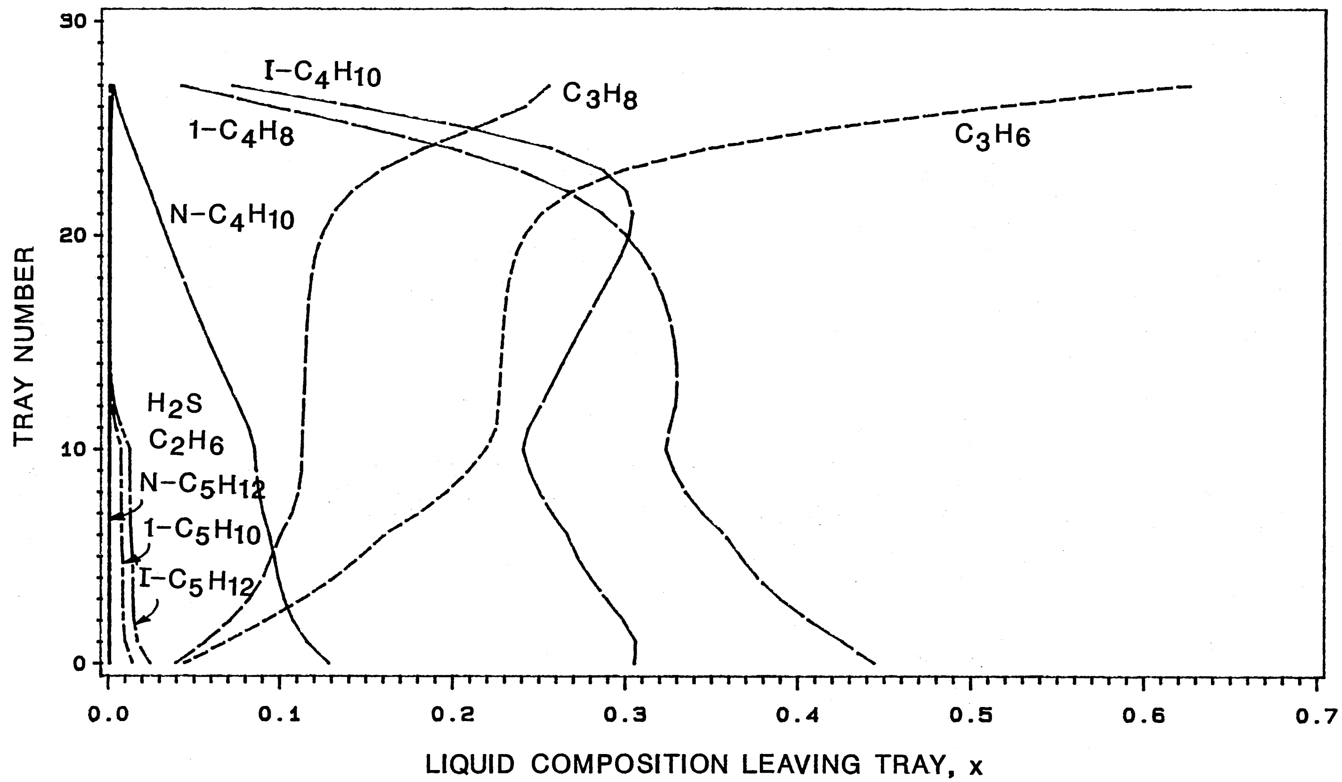


Figure 90. Steady State Simulation Results For Run 19

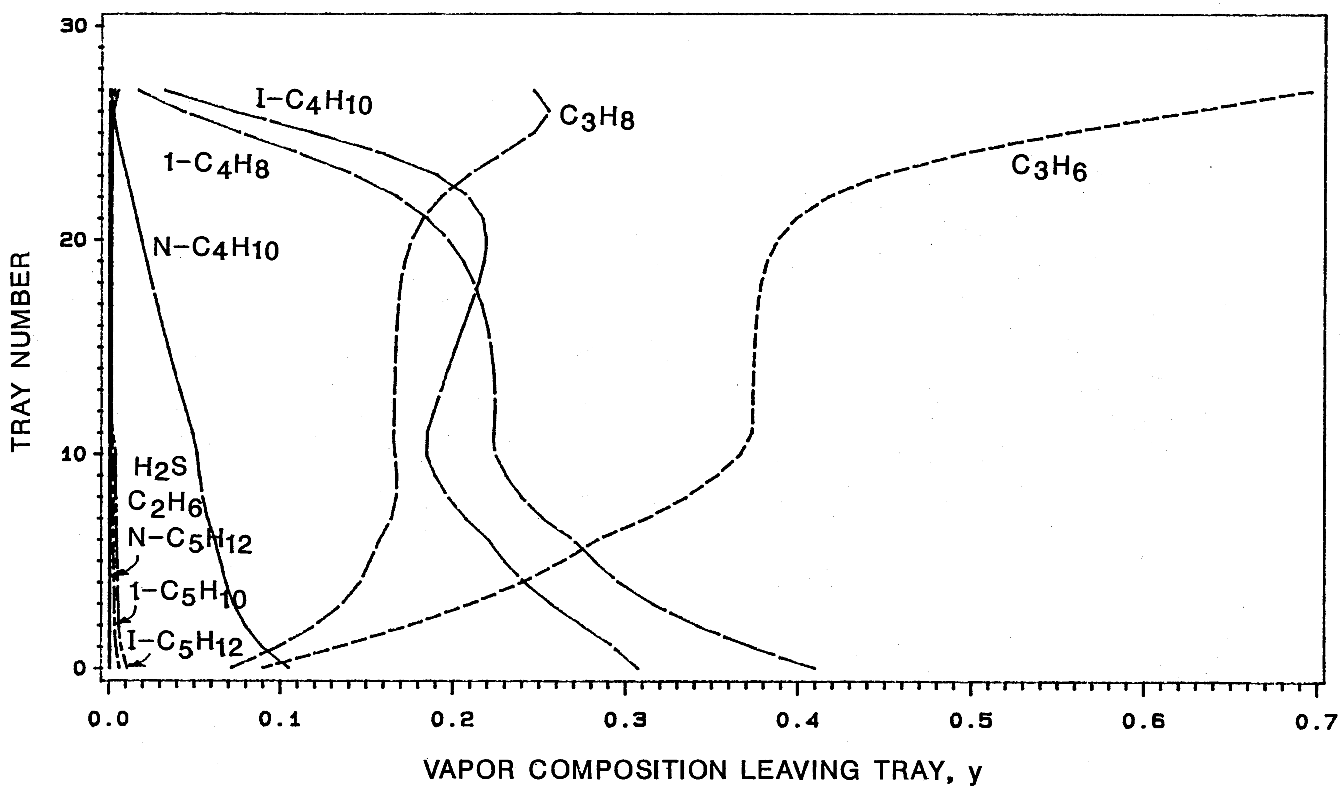
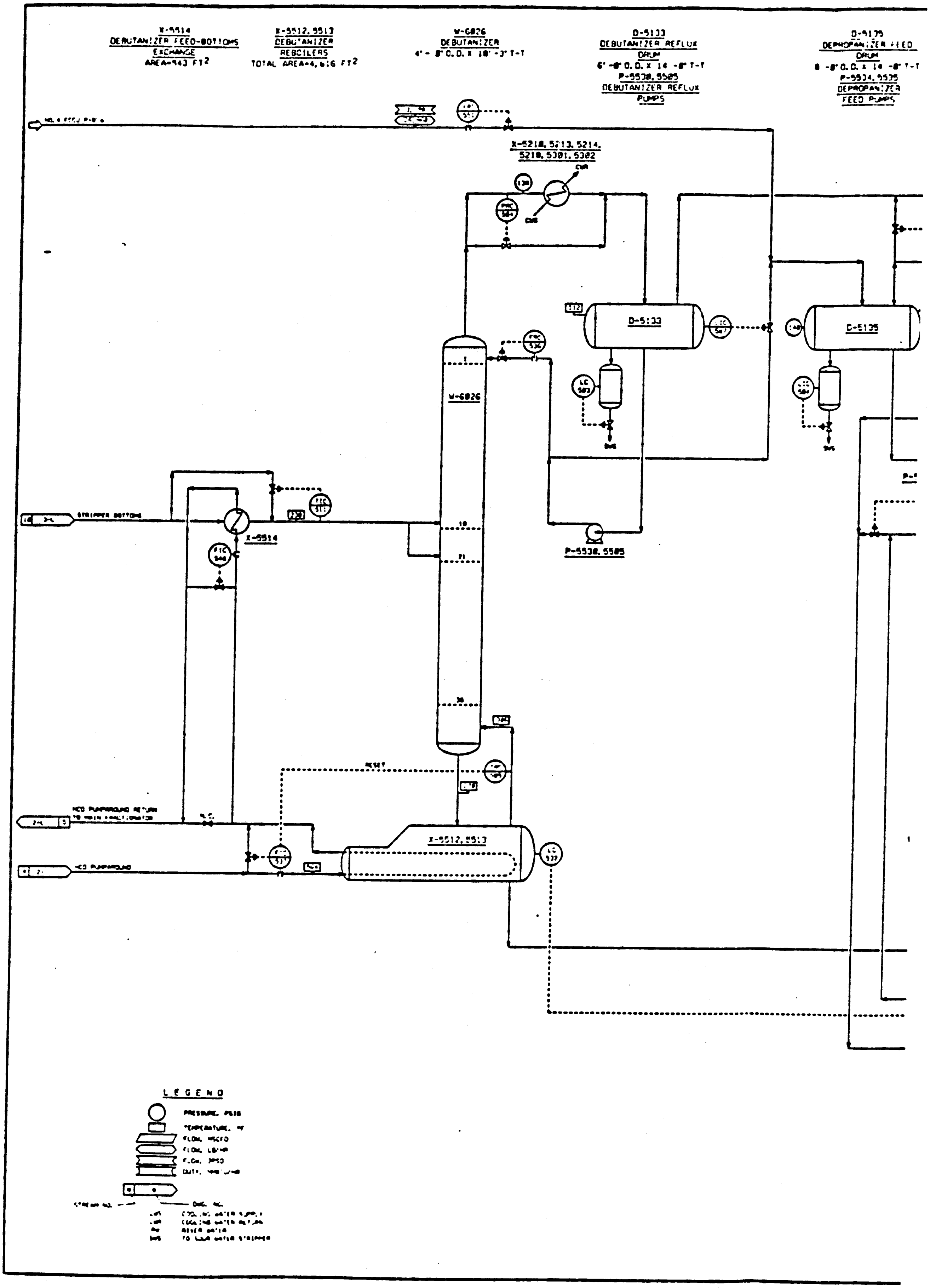
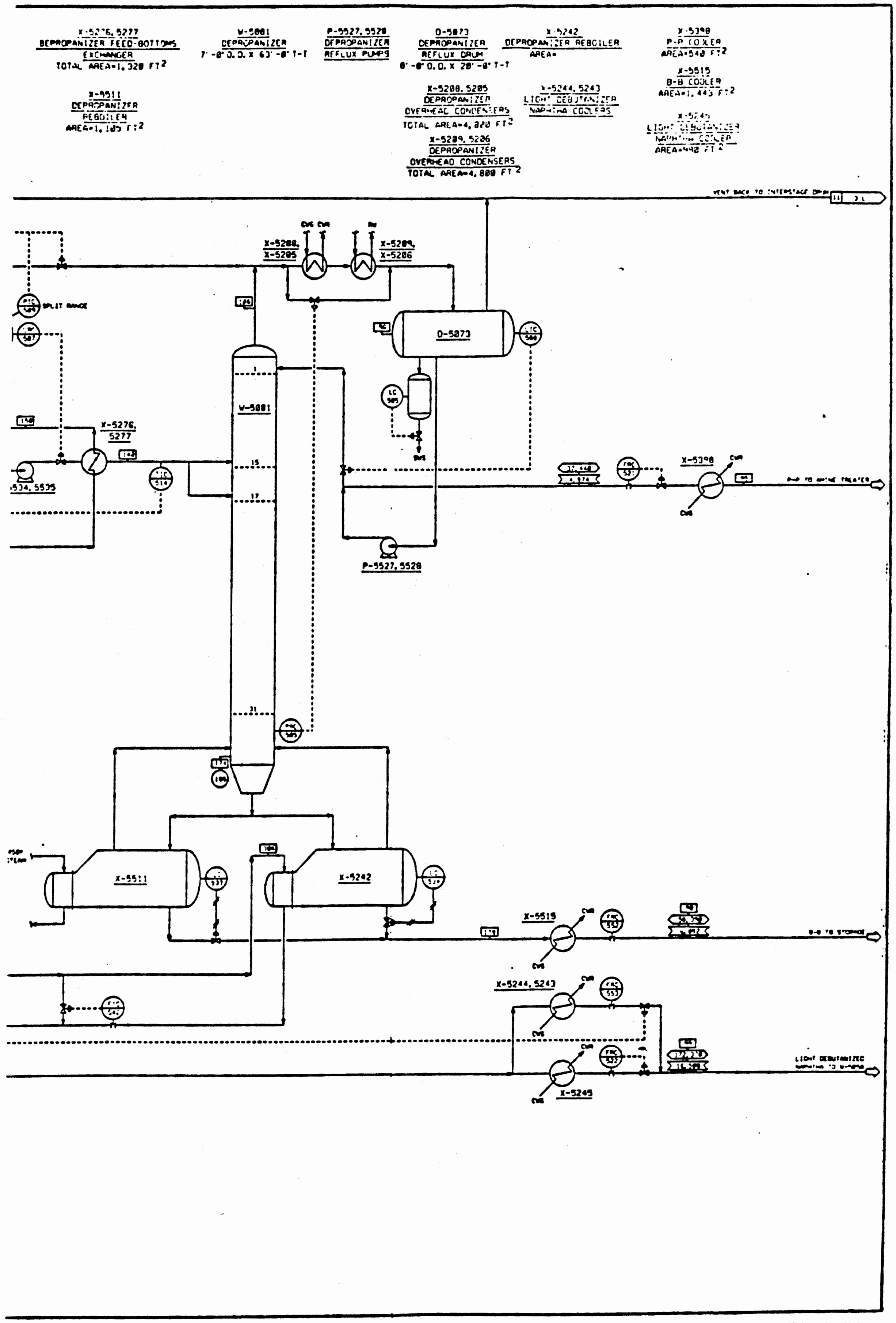


Figure 91. Steady State Simulation Results For Run 19

APPENDIX B

DEPROPANIZER PROCESS FLOW DIAGRAM


X-5514
DEBUTANIZER FEED-BOTTOMS
EXCHANGE
AREA=943 FT2
X-5512, 5513
DEBUTANIZER
REBOILERS
TOTAL AREA=4,616 FT2
W-6026
DEBUTANIZER
4' - 8" O.D. X 18' -3" T-T
D-5133
DEBUTANIZER REFLUX
DRUM
6' -8" O.D. X 14 -8" T-T
P-5530, 5505
DEBUTANIZER REFLUX
PUMPS
D-5135
DEPROPANIZER FEED
DRUM
P-5534, 5535
DEPROPANIZER
FEED PUMPS
X-5218, 5213, 5214,
5218, 5301, 5302
CWR
CWS
SWS
D-5133
D-5135
W-6026
STRIPPER BOTTOMS
X-5514
P-5530, 5505
RESET
HCO PUMPAROUND RETURN
TO MAIN FRACTIONATOR
HCO PUMPAROUND
X-5512, 5513
LEGEND

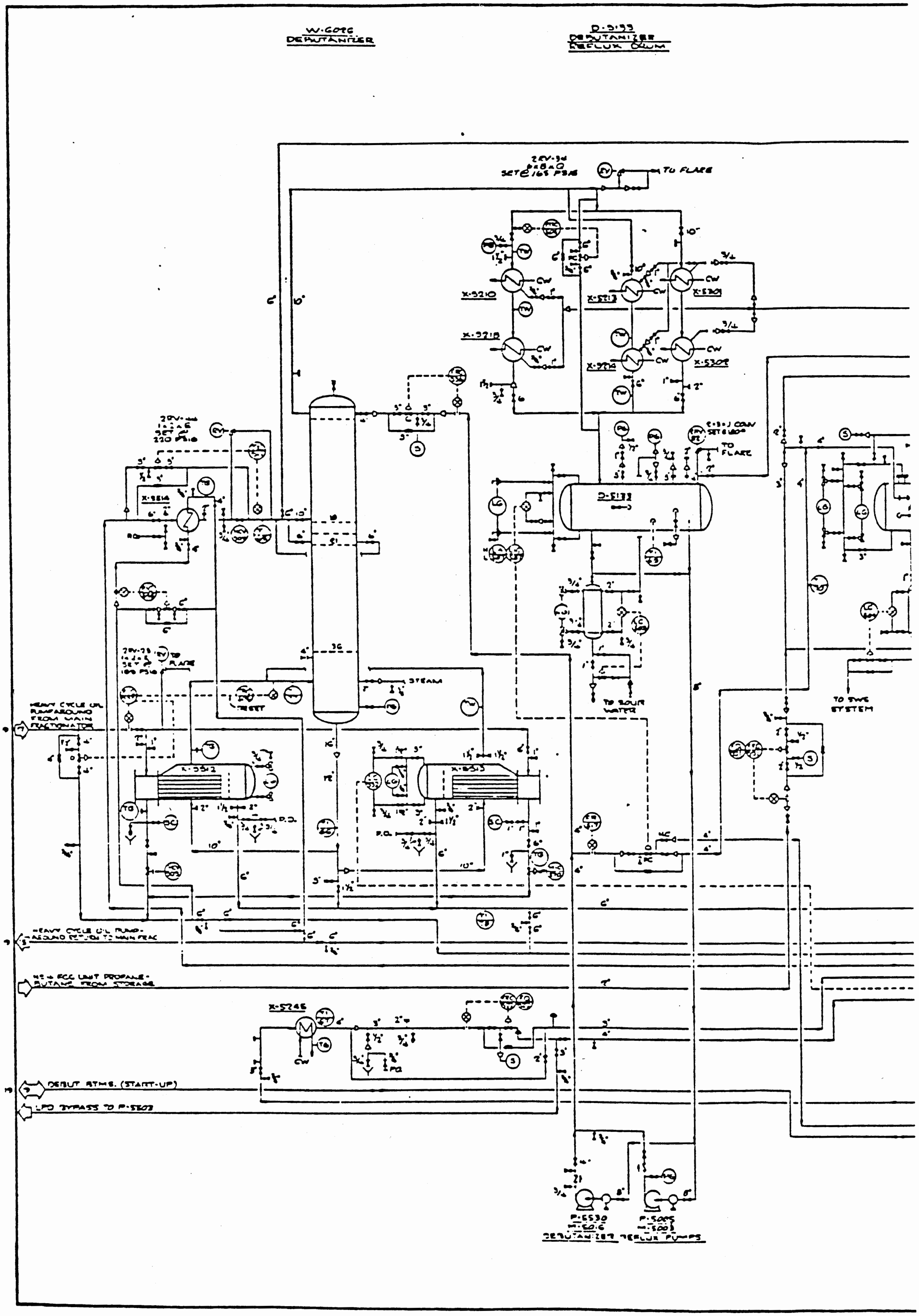


X-5276, 5277
DEPROPANIZER FEED-BOTTOMS EXCHANGER
TOTAL AREA=1,320 FT2
X-5511
DEPROPANIZER REBOILER
AREA=1,105 FT2
W-5001
DEPROPANIZER
7'-0" O.D. X 63'-0" T-T
P-5527, 5528
DEPROPANIZER REFLUX PUMPS
D-5073
DEPROPANIZER REFLUX DRUM
8'-0" O.D. X 20'-0" T-T
X-5208, 5205
DEPROPANIZER OVERHEAD CONDENSERS
TOTAL AREA=4,020 FT2
X-5209, 5206
DEPROPANIZER OVERHEAD CONDENSERS
TOTAL AREA=4,800 FT2
X-5242
DEPROPANIZER REBOILER
AREA=
X-5244, 5243
LIGHT DEBUTANIZER NAPHTHA COOLERS
X-5398
P-P COOLER
AREA=540 FT2
X-5515
B-B COOLER
AREA=1,443 FT2
X-5245
LIGHT DEBUTANIZER NAPHTHA COOLER
AREA=490 FT2
SPLIT RANGE
X-5208, X-5205
X-5209, X-5206
D-5073
W-5001
X-5276, 5277
P-5527, 5528
X-5398
X-5511
X-5242
X-5515
X-5244, 5243
X-5245

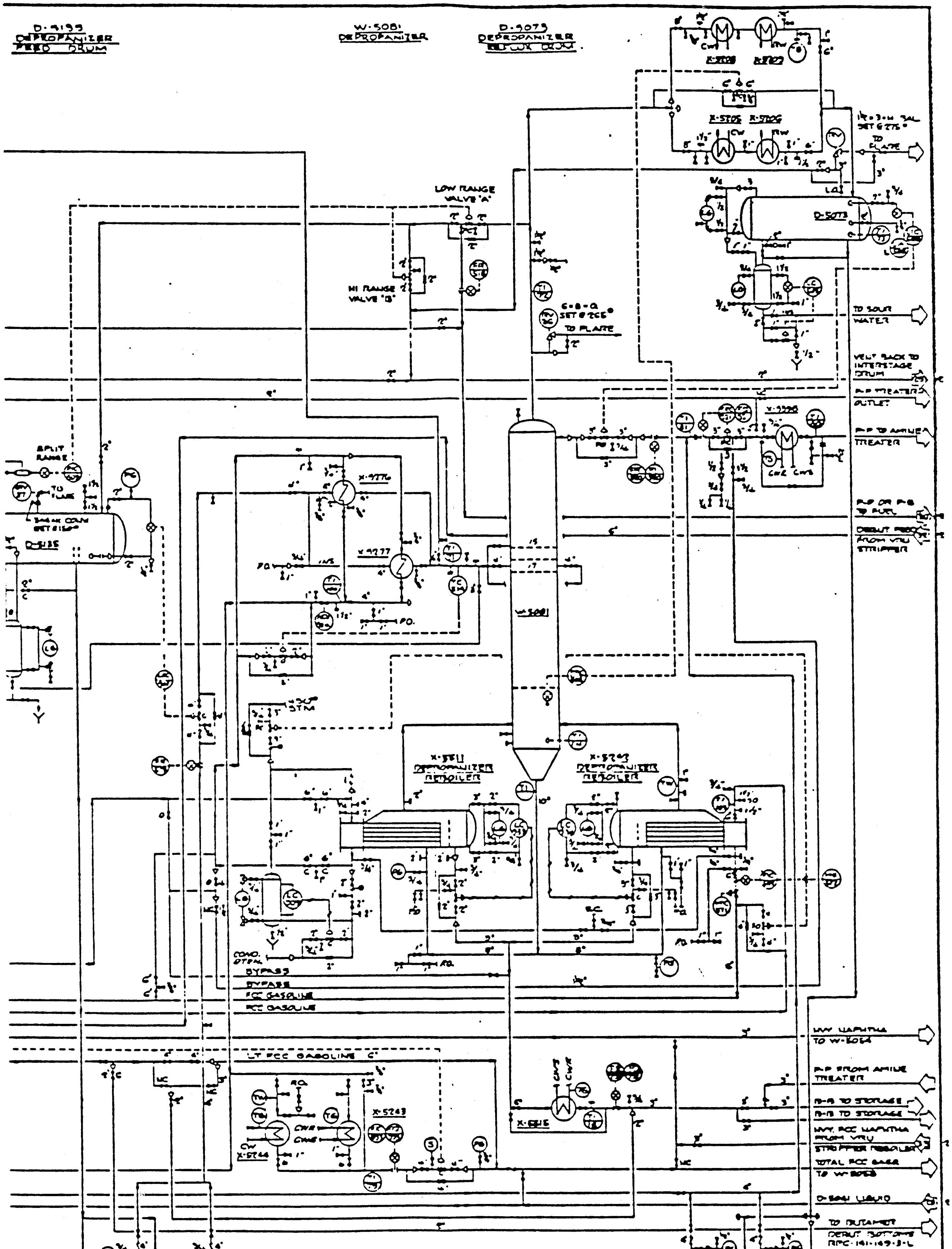
APPENDIX C

DEPROPANIZER PROCESS AND INSTRUMENTATION

DIAGRAM



W-5076
DEBUTANIZER
D-5133
DEBUTANIZER
REFLUX DRUM
TO FLARE
X-5210
X-5213
X-5301
X-5218
X-5302
D-5133
STEAM
HEAVY CYCLE OIL
PUMPAROUND
FROM MAIN
FRACTIONATOR
X-5512
X-5513
HEAVY CYCLE OIL PUMP-
AROUND RETURN TO MAIN FRAC
TO SOUR
WATER
TO SWS
SYSTEM
X-5245
DEBUT ATMS. (START-UP)
LPG BYPASS TO P-5503
P-5530
P-5005
DEBUTANIZER REFLUX PUMPS



D-5195
DEPROPANIZER FEED DRUM
W-5081
DEPROPANIZER
D-5073
DEPROPANIZER REFLUX DRUM
LOW RANGE VALVE "A"
HI RANGE VALVE "B"
TO FLARE
TO SOUR WATER
W-5081
DEPROPANIZER REBOILER
DEPROPANIZER REBOILER
BYPASS
BYPASS
FCC GASOLINE
FCC GASOLINE
HVY NAPHTHA TO W-5064
TO BUTAMER
DEPROPANIZER CHARGE PUMPS
DEPROPANIZER REFLUX PUMPS
P & I DIAGRAM
DEBUTANIZER & DEPROPANIZER
RPC-135-55-20-L

APPENDIX D

1983 DEPROPANIZER TEST RUN

RESULTS

TABLE LXXIII

1983 DEPROPANIZER TEST RUN RESULTS

STEAM	B-B PRODUCT					P-P-PRODUCT				
Component	LB/HR	WT. %	BPSD (BFOE)	L.V. %	MOLES/HR	LB/HR	WT. %	BPSD (BFOE)	L.V. %	MOLES/HR
H2O	-	-	-	-	-	-	-	-	-	-
N2	-	-	-	-	-	-	-	-	-	-
CO	-	-	-	-	-	-	-	-	-	-
CO2	-	-	-	-	-	-	-	-	-	-
H2	-	-	-	-	-	-	-	-	-	-
H25(1)	-	-	-	-	-	56	0.15	(2)	0.04	1.60
C1	-	-	-	-	-	-	-	-	-	-
C2-	-	-	-	-	-	-	-	-	-	-
C2	-	-	-	-	-	26	0.07	(2)	0.04	0.90
C3-	1676	2.87	220	3.20	39.80	22213	59.33	2920	5886	527.90
C3	1933	3.31	261	3.79	43.80	9285	24.80	1255	25.73	210.60
C4-	26060	44.63	2974	43.21	464.50	1842	4.92	210	4.31	32.80
iC4	18188	31.15	2216	32.20	312.90	3808	10.17	464	9.51	65.50
nC4	7620	13.05	895	13.00	131.10	210	0.56	25	0.51	3.60
C5-	1039	1.78	110	1.60	14.80	-	-	-	-	-
iC5	1810	3.10	199	2.89	25.10	-	-	-	-	-
nC5	64	0.11	7	0.10	0.90	-	-	-	-	-
100-125	-	-	-	-	-	-	-	-	-	-
125-150	-	-	-	-	-	-	-	-	-	-
150-175	-	-	-	-	-	-	-	-	-	-
175-200	-	-	-	-	-	-	-	-	-	-
200-225	-	-	-	-	-	-	-	-	-	-
225-250	-	-	-	-	-	-	-	-	-	-
250-275	-	-	-	-	-	-	-	-	-	-
275-300	-	-	-	-	-	-	-	-	-	-
300-325	-	-	-	-	-	-	-	-	-	-
325-350	-	-	-	-	-	-	-	-	-	-
350-375	-	-	-	-	-	-	-	-	-	-
375-400	-	-	-	-	-	-	-	-	-	-
400-425	-	-	-	-	-	-	-	-	-	-
425-450	-	-	-	-	-	-	-	-	-	-
450-475	-	-	-	-	-	-	-	-	-	-
475-500	-	-	-	-	-	-	-	-	-	-
500-525	-	-	-	-	-	-	-	-	-	-
525-550	-	-	-	-	-	-	-	-	-	-
550-575	-	-	-	-	-	-	-	-	-	-
575-600	-	-	-	-	-	-	-	-	-	-
600-625	-	-	-	-	-	-	-	-	-	-
625-650	-	-	-	-	-	-	-	-	-	-
650-675	-	-	-	-	-	-	-	-	-	-
675-700	-	-	-	-	-	-	-	-	-	-
700-725	-	-	-	-	-	-	-	-	-	-
725-750	-	-	-	-	-	-	-	-	-	-
750-775	-	-	-	-	-	-	-	-	-	-
775-800	-	-	-	-	-	-	-	-	-	-
800-850	-	-	-	-	-	-	-	-	-	-
850-900	-	-	-	-	-	-	-	-	-	-
900-950	-	-	-	-	-	-	-	-	-	-
950-1000	-	-	-	-	-	-	-	-	-	-
1000+	-	-	-	-	-	-	-	-	-	-
TOTAL	58390	100.00	6882	100.00	1032.90	37440	100.00	4878	100.00	842.90
BPSD					6883					4874
MSXFD										
API					111.60					137.50
K					13.42					14.22
MW					56.53					44.42

(1) By laboratory analyses. H25 is subject to loss in metal containers.

APPENDIX E

DEPROPANIZER (W-5081) EQUIPMENT SPECIFICATIONS

APPENDIX E

DEPROPANIZER (W-5081) EQUIPMENT SPECIFICATION

Top Section (Above Feed Stage Existing)

Tower Diameter	7 Ft
Tray Spacing	21 in.
Number of Flow Paths	1
Straight Downcomers	
Downcomer Top Area	4.88 Ft^2
Downcomer Bottom Area	4.88 Ft^2
Downcomer Clearance	2.5625 in.
Outlet Weir Height	3 in.
Outlet Weir Length	65.17 in.
Downcomer Bottom Length	65.17 in.
Number of Valves	192
Nutter Valves	14 gauge
10 Gauge Tray Thickness	0.134 in.
Stainless Steel Valves	

Bottom Section (Below Feed Stage Existing)

Tower Diameter	7 Ft.
Tray Spacing	21 in.
Number of Flow Paths	2
Straight Downcomers	9.76 Ft^2
Downcomer Top Area	9.76 Ft^2
Downcomer Bottom Area	1.8125 in.
Downcomer Clearance	3.625 in.
Outlet Weir Height	164.92 in.
Outlet Weir Length	164.92 in.
Hole Area % of Bubbling Area	32.65
Hole Diameter	0.1875 in.
Sharp Edge Faces Downward	
Tray Thickness 10 Gauge	0.134 in.

APPENDIX F

COMPUTER PROGRAM FOR ECONOMIC EVALUATION

OF DISTILLATION COLUMN OPERATING

AND EQUIPMENT COSTS

```
10    REM ***********************************************************
20    REM *      COMPUTER PROGRAM TO CALCULATE DISTILLATION          *
30    REM *      COLUMN OPERATING COSTS AND RETROFITTED EQUIPMENT    *
40    REM *      COSTS                                               *
50    REM ***********************************************************
60    REM *                     NOMENCLATURE                         *
70    REM ***********************************************************
80    REM *      EXTERNAL REFLUX RATE = RE, LBMOL/HR                 *
90    REM *      LIQUID MOLECULAR WEIGHT = MW, LB/LBMOL              *
100   REM *      LIQUID DENSITY = LD, LBM/FT^3                       *
110   REM *      CONDENSER DUTY = CD, BTU/HR                         *
120   REM *      REBOILER DUTY = RD, BTU/HR                          *
130   REM *      CONDENSER TEMPERATURE = CT, DEG. F                  *
140   REM *      REBOILER TEMPERATURE = RT, DEG. F                   *
150   REM *      INTERMEDIATE REBOILER TEMPERATURE = IRT, DEG. F     *
160   REM *      INTERMEDIATE REBOILER DUTY = IRD, BTU/HR            *
170   REM *      INTERMEDIATE REBOILER PUMP BHP = HPIR, HP           *
180   REM *      DENSITY OF LIQUID WATER = DW, LBM/FT^3              *
190   REM *      HYDROCARBON SPECIFIC GRAVITY = SG, DIMENSIONLESS    *
200   REM *      REFLUX PUMP DISCHARGE HEAD = H, FT                  *
210   REM *      MAIN REBOILER PUMP BHP = BHP, BHP                   *
220   REM *      ELECTRICAL INPUT MAIN REBOILER PUMP = KW, KW        *
230   REM *      MAIN REBOILER FUEL EQUIVALENT COST, $ HR/BTU YEAR   *
240   REM *      = 0.0201439                                         *
250   REM *      ELECTRICAL INPUT, INTERMEDIATE REBOILER PUMP        *
260   REM *      = KWIR, KW                                          *
270   REM *      TOTAL STEAM COSTS = CST, $/YR                       *
280   REM *      TOTAL COOLING WATER COSTS = CWT, $/YR               *
290   REM *      TOTAL ELECTRICAL COSTS = CET, $/YR                  *
300   REM *      TOTAL OPERATING COSTS = COT, $/YR                   *
310   REM ***********************************************************
320   REM *                INTERMEDIATE REBOILER DATA                *
330   REM *      INTERMEDIATE REBOILER 20# STEAM COSTS, $ HR/BTU YEAR *
340   REM *      = 0.0107672                                         *
350   REM *      (1988 COST/1968 COST) = 7.22, M&S EQUIPMENT COST    *
360   REM *      INTERMEDIATE REBOILER DRIVING FORCE, DEG. F = DT    *
370   REM *      INTERMEDIATE REBOILER OVERALL HEAT TRANSFER         *
345   REM *      COEFFICIENT = 243 BUT/FT^2 HR DEG. F                *
380   REM ***********************************************************
390   REM *      INTERMEDIATE REBOILER CIRCULATION PUMP DATA         *
400   REM *      INTERMEDIATE REBOILER CIRCULATION PUMP COST, $, CP  *
410   REM *      CONVERSION FACTOR = 2545 BTU/(HP*HR)                *
420   REM *      MOTOR AND PUMP EFFICIENCY = 0.75                    *
430   REM ***********************************************************
440   REM *      INTERMEDIATE REBOILER AND INTERMEDIATE              *
450   REM *      CIRCULATION PUMP COSTS WERE CALCULATED USING        *
460   REM *      GUTHRIE'S CAPITAL COST ESTIMATING TECHNIQUE         *
470   REM ***********************************************************
480   SCREEN 0,1:COLOR 14,1,1:KEY OFF
490   CLS
500   REM *      CALCULATE EXTERNAL REFLUX PUMP BHP                  *
510   PRINT:PRINT:PRINT:PRINT:PRINT
520   PRINT TAB(27):PRINT"COMPUTER PROGRAM TO CALCULATE DISTILLATION"
530   PRINT TAB(27):PRINT"COLUMN OPERATING COSTS AND RETROFITTED"
```

```
540   PRINT TAB(27):PRINT "INTERMEDIATE REBOILER AND CIRCULATION
550   PRINT TAB(27):PRINT "PUMP EQUIPMENT COSTS"
560   PRINT
570   PRINT TAB(27):PRINT"REFERENCE:GUTHRIE,K.M.,'CHEMICAL ENGINEERING'"*
580   PRINT TAB(27):PRINT"          16 (MARCH 1969), PG. 114."
590   PRINT:PRINT
600   PRINT TAB(27):PRINT"ENTER TRAY/TRAY DISTILLATION OUTPUT"
610   PRINT TAB(27):PRINT"***********************************"
620   PRINT
630   PRINT TAB(27): INPUT "EXTERNAL REFLUX RATE, LBMOL/HR",RE
640   PRINT TAB(27): INPUT "LIQUID MW";MW
650   PRINT TAB(27): INPUT "LIQUID DENSITY, LBM/FT^3";LD
660   PRINT TAB(27): INPUT "ABS. VALUE CONDENSER DUTY, DBTU/HR"; CD:CD=CD*1000
670   PRINT TAB(27): INPUT "REBOILER DUTY, KBTU/HR";RD:RD=RD*1000
680   PRINT TAB(27): INPUT "INTERMEDIATE REBOILER DRIVING FORCE, DEG. F."; DT
690   PRINT TAB(27): INPUT "INTERMEDIATE REBOILER DUTY, KBTU/HR";IRD:IRD=IRD*1000
700   PRINT TAB(27): INPUT "INTERMEDIATE REBOILER PUMP BHP"; HPIR
710   DW=62.16
720   SG=LD/DW
730   RE=(RE*MW*7.48)/(LD*60)
740   H=1440/LD
750   BHP=(RE*H*SG)/(3960*.75)
760   KW=(BHP*.7457)/.75
770   KWIR=(HPIR*.7457)/.75
780   CSMR=RD*.0201439
790   CSIR=IRD*.0107672
800   CSMR=INT(CSMR)
810   CSIR=INT(CSIR)
820   CST=CSMR+CSIR
830   CWT=CD*.0036884
840   CWT=INT(CWT)
850   KWT=KW+KWIR
860   CET=KWT*.05*24*365
870   CET=INT(CET)
880   COT=CST+CWT+CET
890   COT=INT(COT)
900   IF IRD=0 THEN GO TO 930
910   AREA=IRD/(243*DT)
920   CR=7.22*8826*(AREA/1000)^.65*1.602
930   IF IRD = 0 THEN CR=0
940   CP=7.22*380*(HPIR/10)^.52
950   WACT=RD*(1-540/784)+IRD*(1-540/688)+BHP*2545+HPIR*2545
960   TC=CP+CR
970   CLS
980   PRINT TAB(15):PRINT "*********************************************"
990   PRINT TAB(15):PRINT "                OPERATING COSTS              "
1000  PRINT TAB(15):PRINT "STEAM COSTS, $/YR = ";CST
1010  PRINT TAB(15):PRINT "COOLING WATER COSTS, $/YR = ";CWT
1020  PRINT TAB(15):PRINT "ELECTRICAL COSTS, $/YR = ";CET
1030  PRINT TAB(15):PRINT "OPERATING COSTS, $/YR = ";COT
1040  PRINT TAB(15):PRINT "*********************************************"
1050  PRINT TAB(15):PRINT "*********************************************"
1060  PRINT TAB(15):PRINT "ACTUAL PROCESS WORK, KBTU/HR = ";WACT/1000
1070  PRINT TAB(15):PRINT "*********************************************"
```

```
1080  PRINT TAB(15):PRINT "*********************************************"
1090  PRINT TAB(15):PRINT "                   EQUIPMENT COSTS            "
1100  PRINT TAB(15):PRINT "INTERMEDIATE REBOILER AREA, FT^2=";AREA:PRINT
1110  PRINT TAB(15):PRINT "INTERMEDIATE REBOILER COST, $ = ";CR
1120  PRINT TAB(15):PRINT "INTERMEDIATE REBOILER PUMP COST, $ = ";CP
1130  PRINT TAB(15):PRINT "TOTAL EQUIPMENT CAPITAL COST, $ = ";TC
1140  PRINT TAB(15):PRINT "**********************************************
1150  STOP
```

2

VITA

Paul Coulter Johnson

Candidate for the Degree of

Master of Science

Thesis: CASE STUDY ON THE INSTALLATION OF A RETROFITTED INTERMEDIATE REBOILER ON AN INDUSTRIAL DEPROPANIZER FOR MINIMUM ENERGY CONSUMPTION

Major Field: Chemical Engineering

Biographical:

Personal Data: Born in Henryetta, Oklahoma, March 6, 1958, the son of C. Eugene and Adeline Johnson.

Education: Graduated from Henryetta High School in 1976; received Bachelor of Arts degree in Chemistry from the University of Arkansas in 1980, received Bachelor of Science degree in Chemical Engineering from Oklahoma State University in 1983, completed requirements for the Master of Science degree May, 1988. Membership in scholarly or professional societies includes Omega Chi Epsilon and American Institute of Chemical Engineers.

Professional Experience: Employed as a chemical engineer at the Plastics Technical Center, Phillips Chemical Company, during the summers of 1981 and 1982. Employed as a process engineer with Diamond Shamrock Refining and Marketing Company at their Sunray, Texas refinery from January to October 1984.