DESIGN OF MULTIPASS FRACTIONATING TRAYS

BY

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ABSTRACT

Multipass fractionating trays are vapor-liquid contacting devices with high liquid handling capabilities which can be economically used in large fractionating towers. However, process design engineers in the chemical and petroleum industries seem to have an aversion to specifying multipass trays for their tower designs. This thesis presents the case for using multipass trays as well as methods for their design.

Because multipass trays are not symmetrical, as one and two pass trays are, the liquid and vapor need not split equally between the three or four passes. Equations are developed which enable the vapor and liquid flowrate for each pass to be determined. A computer program is presented which is capable of either rating existing multipass trays or designing multipass trays for new services. Also, techniques for the optimum design of multipass trays are suggested.

The present energy shortage has provided strong incentive to build larger refineries, which means larger capacity fractionation towers are required. This thesis demonstrates how the use of multipass trays can reduce investment costs for these large towers.

The use of the tools presented in this thesis enable process engineers to design multipass trays without relying on the proprietary techniques and programs of others, not readily available to them. It is hoped that this will enable multipass trays to be specified whenever they are economically justified.

APPROVAL OF THESIS

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The author wishes to dedicate this thesis to the late Dr. Erwin Amick, of Columbia University, whose instruction inspired the author's interest in the area of fractionation.

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INTRODUCTION

What is a Multipass Tray?

Fractionating columns in the chemical and petroleum industries generally utilize perforated metal trays as the contacting devices. These sieve trays facilitate the countercurrent contacting of vapor and liquid. Liquid flows across the tray and contacts the vapor which is bubbling through the perforations. The liquid passes downward from tray to tray via downcomers.

The most common and simplest type of crossflow tray is the single pass tray. On a single pass tray, the liquid travels in only one path, and there is only one contacting or bubble area on each tray. There is also only one downcomer leaving each tray.

Another common type of crossflow tray is the two pass tray. On this type of tray, there are two different paths in which liquid may flow, as well as two distinct bubble areas. Half of the trays have a single center downcomer while every other tray has two outboard downcomers.

Multipass trays, while not used very often, have distinct advantages over single or two pass trays. Multipass trays generally have three or four passes, although five pass trays have at least been considered (1). Three and four pass trays have three or four different liquid paths and distinct bubble areas on each tray. A three pass tray has two downcomers on each tray: one outboard and one off-center. Half of the four pass trays have two downcomers - both off-center. Every other tray has three downcomers: two outboard and one center.

The liquid and vapor flow patterns on all four types of trays are depicted in Figure 1.

Advantages of Multipass Tray Design

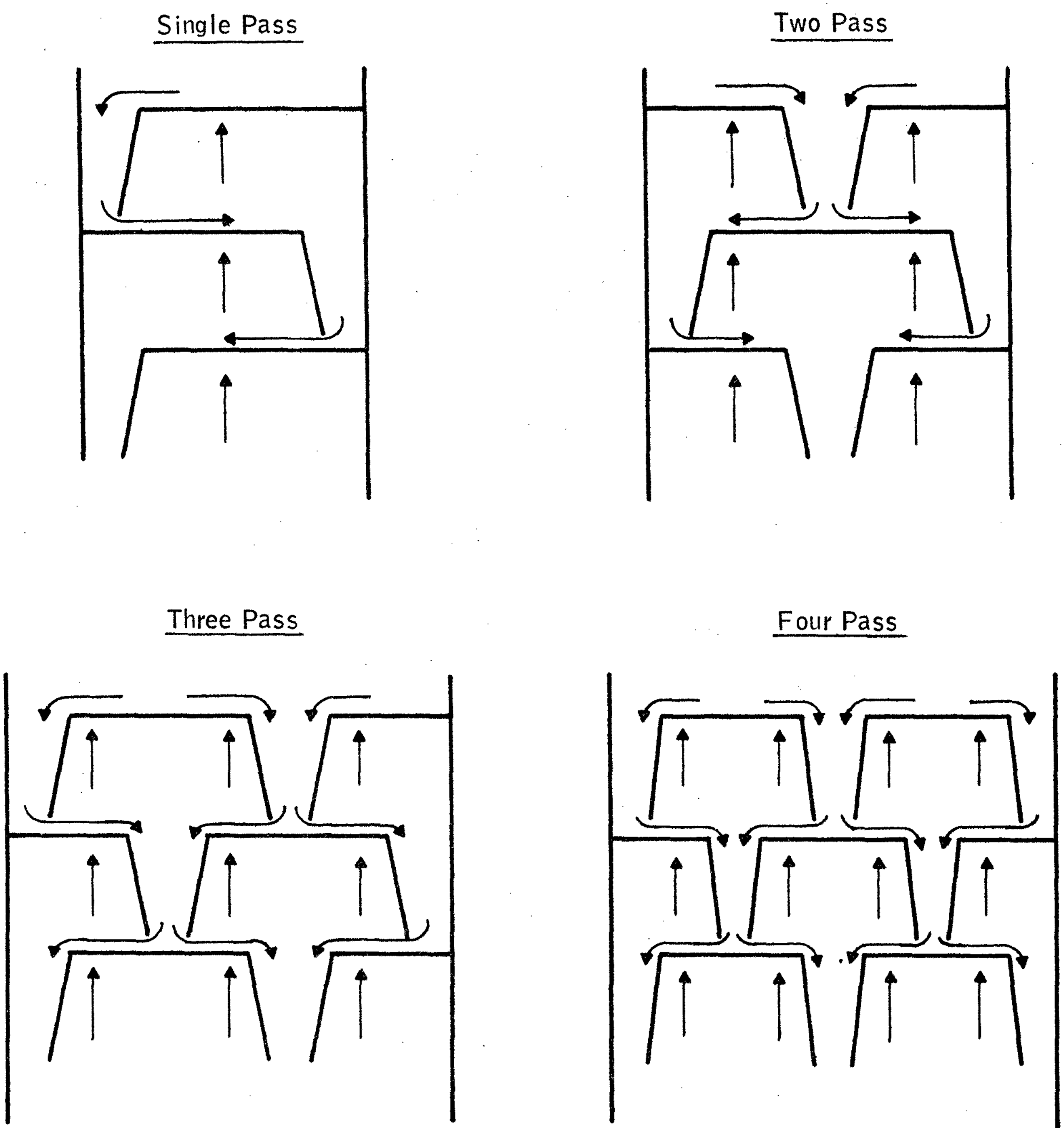
The use of multipass trays becomes economically attractive for large towers. A tower's vapor handling capacity increases proportionately to the tower cross sectional area. Therefore, vapor capacity is proportional to the square of the diameter. However, a tower's liquid handling capacity is proportional to the weir length over which the liquid flows on each tray. Therefore, for a one pass tray, the liquid handling capacity is linearly proportional to the tower diameter.

By increasing the number of passes, the weir length per tray is increased. Therefore, a two pass tray will have almost twice the liquid handling capacity of a one pass tray; a three pass tray will have almost three times the liquid handling capacity; and so on. Therefore, using multiple passes helps the liquid capacity increase as rapidly as the vapor capacity.

For example, a 20 foot diameter tower has roughly four times the vapor capacity of a 10 foot diameter tower. However, if both towers are single pass, the 20 foot diameter tower has only twice the liquid capacity. If the 20 foot tower is made two pass, then it will be able

Figure 1

LIQUID AND VAPOR FLOW PATTERNS ON TRAYS



to handle four times the liquid rate, and four times the vapor rate. If the 10 foot tower was already two pass, then the 20 foot tower would have to be four pass in order to handle four times the vapor and liquid. In such a case, if multipass trays are not used, tower diameter would have to be increased to handle the liquid loading, although it would not be necessary to handle the vapor loading.

Another reason for going to multipass trays is that several capacity correlations indicate that vapor capacity is also dependent on the weir length available for liquid flow (7). The explanation for this is that with a larger weir length, the froth height on a tray is lower. This permits more space for vapor disengaging above the tray, and therefore increased vapor capacity. Because increasing the number of liquid passes decreases the liquid height on each tray, it also decreases the tray pressure drop. This, in turn, decreases the liquid backup in the downcomer. Therefore, multipass trays also provide for designs with lower tray spacings.

The one disadvantage to a multipass tray is that it has a shorter flowpath in which the liquid travels on each tray. There is some evidence that shorter flowpaths reduce tray efficiency (4). But most tray efficiency correlations do not take liquid flowpath into account (8), and it is doubtful that this has much of an effect on large diameter towers, which have large flowpath lengths regardless of the number of liquid passes.

Why Multipass Trays Are Important

The previous section has demonstrated how multipass trays are economically attractive for large towers. With the present energy shortage and the world need for economic expansion of petroleum capacity, there is a strong incentive to build larger and larger refineries. Since single train plants are the most economical, larger capacity fractionating towers are required. For example, atmospheric crude distillation towers in large refineries can be over 30 feet in diameter. With the use of multipass trays, these towers can be designed with smaller diameters, and, therefore, at lower cost.

Another attractive use of multipass trays is in superfractionators. These are towers used to separate close boiling mixtures into high purity components. Some examples are propane/propylene splitters and ethane/ethylene splitters. These difficult separations require a high reflux rate, or liquid loading, and a large number of trays, and, therefore, a larger diameter and a high tower height. In fact, depending on the plant's location and local height restrictions (e.g. if it is near an airport), the tower may have to be split into two shells. Because, as mentioned in the previous section, multipass trays can decrease tower height and diameter, tower investment for superfractionators can be reduced.

Another reason the use of multipass trays is economically attractive is that it can eliminate the need for special, high cost fractionating devices in some cases. Proprietary devices have been developed for use especially in heavily liquid loaded services, such as high pressure light ends towers and absorbers and strippers. These devices are marketed at premium prices because they are patented. In some cases, conventional sieve trays designed for three or four liquid passes may have liquid handling capabilities comparable to such proprietary devices. Because the sieve tray is non-proprietary, no premiums need be paid for patented technology.

What Has Been Done So Far?

It has been noted that, "There seems to be an aversion in the industry to using multipass trays (4).". This is probably because engineers do not know how to design them. The main problem is that unlike one or two pass trays, multipass trays are not absolutely symmetrical. This makes engineers worry about the hydraulic performance of multipass trays, since the liquid and vapor will not necessarily split into three or four equal parts to travel through each of the passes. Therefore, the design of multipass trays requires a little more work (which may be the real reason engineers shy away from such designs).

Actually, engineers who do not work for a tray vendor have no instructional manual in the design of multipass trays. An investigation of the literature has shown no articles or texts which show how to design multipass trays, although Jamison (4) does make some suggestions, and some tray vendors' manuals do give methods of setting up designs (1). However, most tray vendors consider their detailed design techniques proprietary, and, therefore, do not make them publicly available.

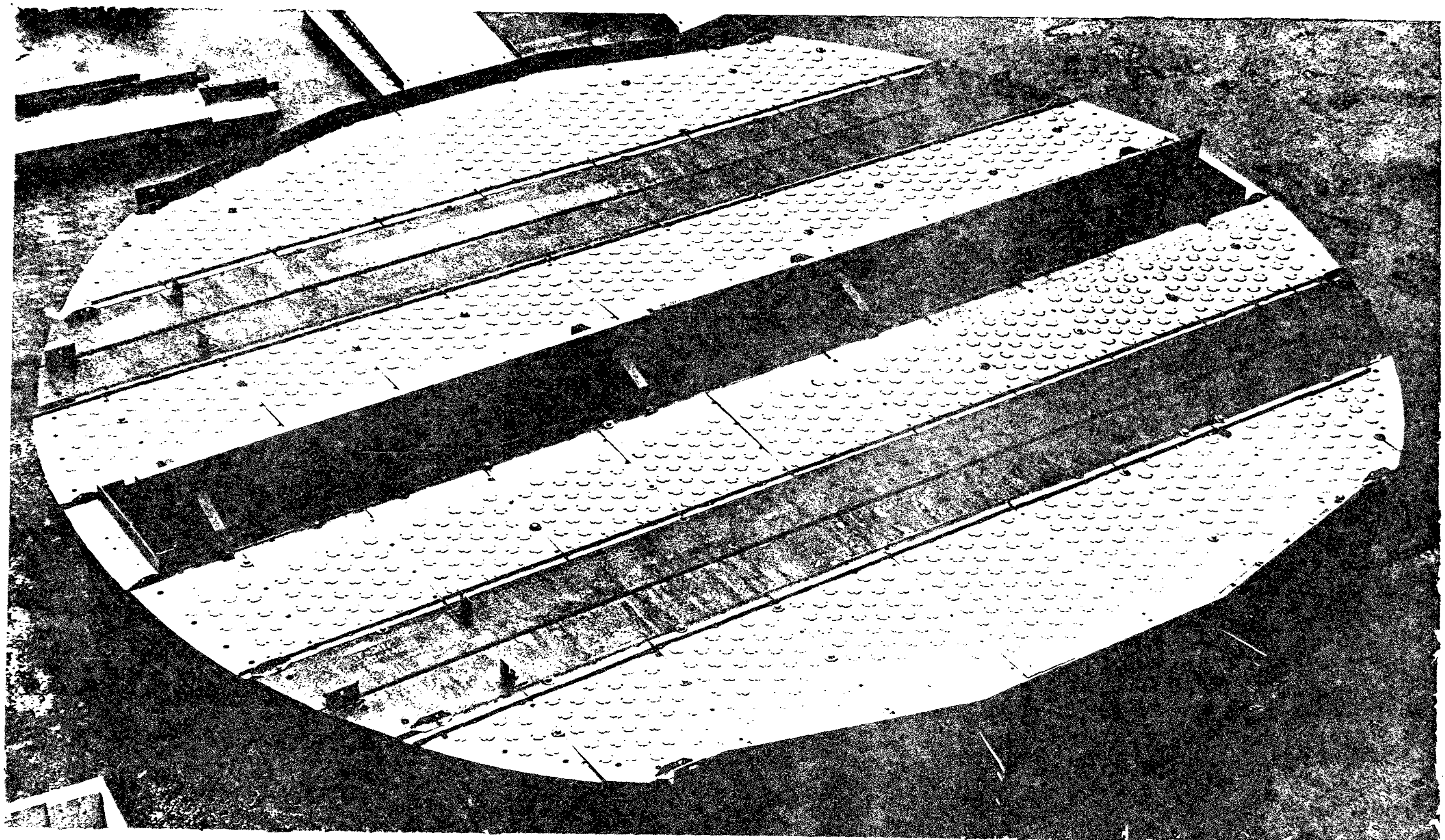
The main drawback to engineers designing multipass trays is that there is no publicly available program for either rating or designing multipass trays. Tray vendors do have their own proprietary programs which utilize their own special design techniques. But there are various methods of designing multipass trays, and, therefore, each vendor's program uses their own technique.

The purpose of this thesis is to present the various methods of designing three and four pass sieve trays, with the appropriate design equations required. In addition, a computer program is presented for the rating of existing multipass trays and for the design of new multipass trays. This program utilizes publicly available correlations for capacity and pressure drop. These equations can be replaced with the user's own proprietary correlations if he wishes. The remainder of this thesis describes the development of these design methods and the program.

A photograph of a four pass tray is shown in Figure 2.

Although the methodology presented in this thesis can be applied to single and double pass trays, their design is not elaborated on in this work. The design of such trays is common knowledge to most process engineers.

FIGURE 2



Photograph of Four Pass Tray.
Courtesy of F.W. Glitsch & Sons, Inc.

CHAPTER II

METHODS OF DESIGNING MULTIPASS TRAYS

Background: One and Two Pass Trays

The design of one and two pass trays for fractionating columns is relatively straightforward. Nearly every chemical process design engineer in the petroleum and chemical industries has done at least one such design. Figures 3 and 4 depict the liquid and vapor flow patterns and pressure drop equations for one and two pass trays, respectively.

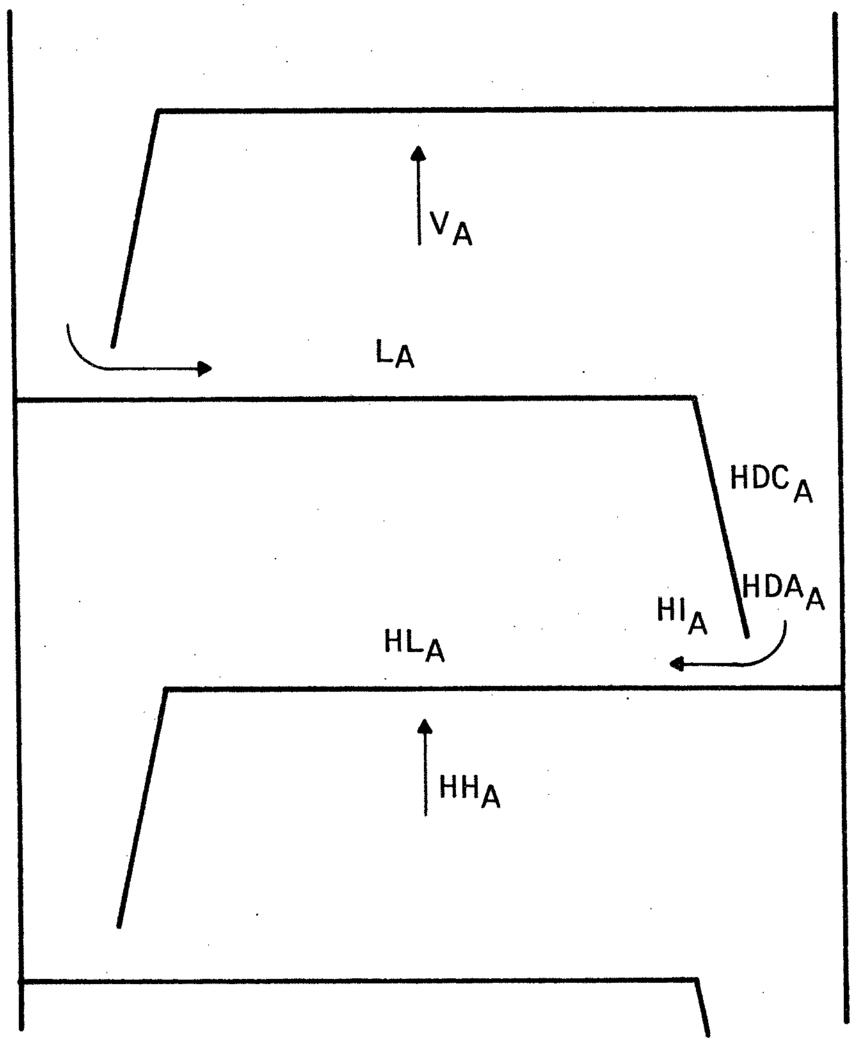
On a single pass tray, there is only one path or bubble area for the liquid and the vapor to travel from tray to tray. The vapor rate on the single pass obviously equals the total vapor rate, and the liquid rate on the single tray pass obviously equals the total liquid rate.

On a two pass tray, both the vapor and liquid have a choice of two paths to take in traveling from tray to tray. But as can be seen in Figure 4, a two pass tray is completely symmetrical. The vapor and liquid have no preference as to which path to travel and consequently split equally into the two paths.

The only way the fluids will not split equally is if something such as improper shop fabrication upsets the symmetry of the trays. For example, if there are more perforations on one side of the tray than the other, the vapor will preferentially travel through this side. Since the total tray pressure drop across each side of the tray must be equal, the liquid will preferentially travel across the other side. However,

Figure 3

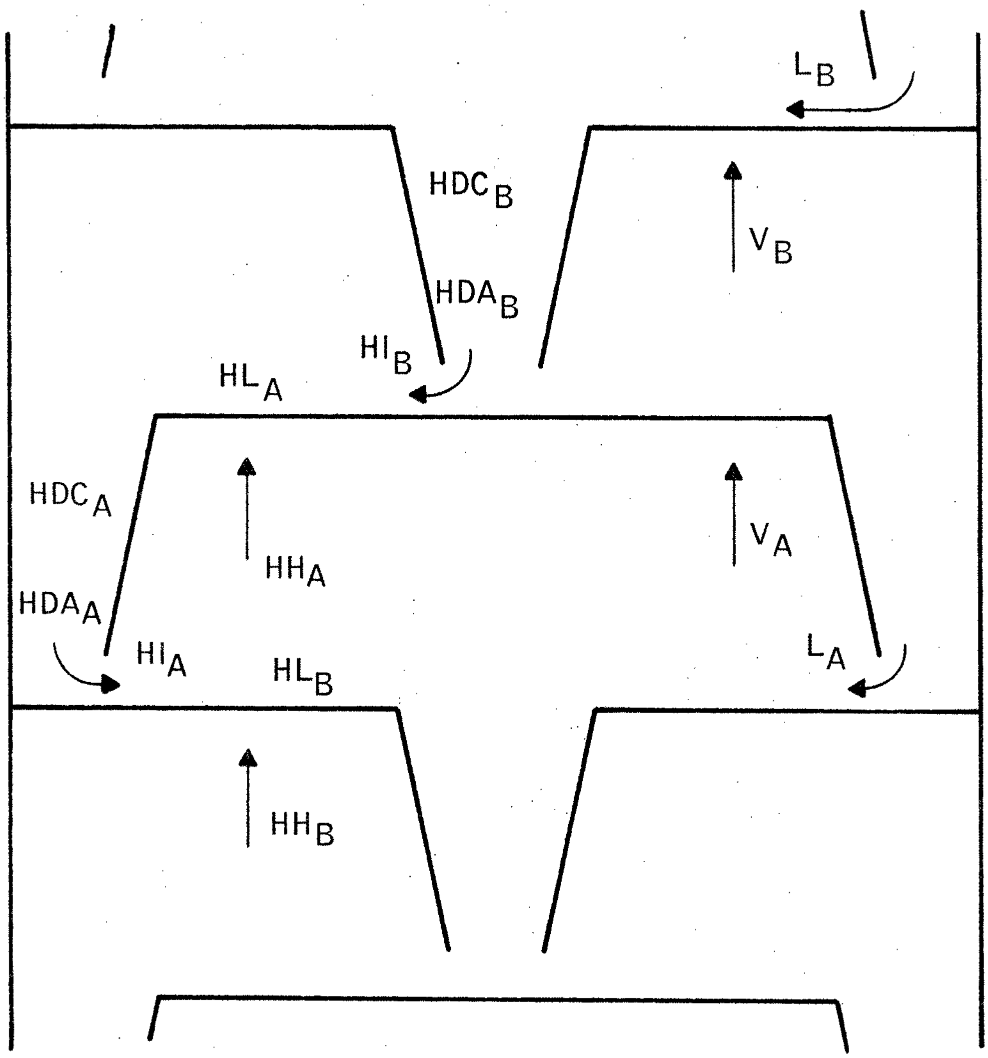
ONE-PASS TRAY FLOW PATTERNS
AND PRESSURE DROPS



Total Tray ΔP	Downcomer Backup
$HT_A = HH_A + HL_A$	$HDC_A = HT_A + HI_A + HDA_A$

Figure 4

TWO-PASS TRAY FLOW PATTERNS
AND PRESSURE DROPS



Total Tray ΔP

$$HT_A = HH_A + HL_A$$
$$HT_B = HH_B + HL_B$$

Downcomer Backup

$$HDC_A = HT_A + HI_A + HDA_A$$
$$HDC_B = HT_B + HI_B + HDA_B$$

because two pass trays are always designed symmetrically, an unequal split can only occur as a result of holes plugging or improper field construction or shop fabrication.

In determining the vapor and liquid splits on a two pass tray, the four unknowns (V_A, V_B, L_A, L_B) are determined by the following four simple equations:

(1) $V_A = V_B$

(2) $V_A + V_B = V_{total}$

(3) $L_A = L_B$

(4) $L_A + L_B = L_{total}$

Where V_X is the vapor rate in cubic feet per second for pass X, L_X is the liquid rate in gallons per minute for pass X. The subscript total refers to rates for the entire tray. Knowing V_{total} and L_{total}, it is obvious that the flowrate through any given pass is equal to one-half the total flowrate.

Three and Four Pass Trays

The design of three and four pass trays, however, is not as straightforward. Although multipass trays are not symmetrical, there are enough equations to solve for the six unknowns in a three pass design, and the eight unknowns in a four pass design. These equations are presented in the next chapter.

There are several methods of setting up multipass tray designs. Because the liquid and vapor do not necessarily have symmetrical paths to choose from, the liquid and vapor do not split equally. That is, unless great care is taken in the design, the liquid and vapor flowrate for each pass of a three or four pass tray is not equal to one-third or one-fourth the total flowrate. In order to prevent possible vapor maldistribution from propogating itself, trays are often designed with passageways for vapor to travel from one pass to another.

The most common method of providing for such vapor crossover is to design the inboard or off-center downcomers (those which are not segmental) as envelope or box downcomers. This is depicted in Figure 5. These downcomers are of almost rectangular shape and are fabricated as two separate downcomers. A space is left between them through which vapor can cross over from one pass to another. If no provision for vapor crossover is desired, the downcomer extends across the entire tray with no separation.

Another method of providing for vapor crossover is to place a horizontal pipe or duct running across the downcomer through which vapor can travel. Jamison (4) has suggested this technique.

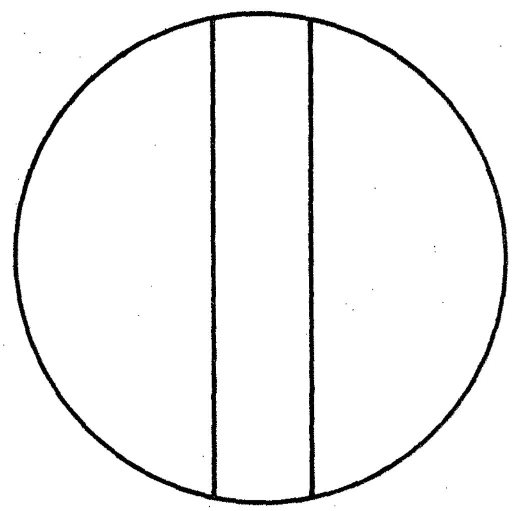
Through the use of vapor crossover, the pressure above any tray is equalized. Therefore, trays designed with vapor crossover have a different set of equations than trays designed without vapor crossover. Therefore, four sets of equations for determining liquid and vapor splits are presented in the next chapter: three and four pass trays, with and without vapor crossover.

There are two basic methods of laying out the plan view of three

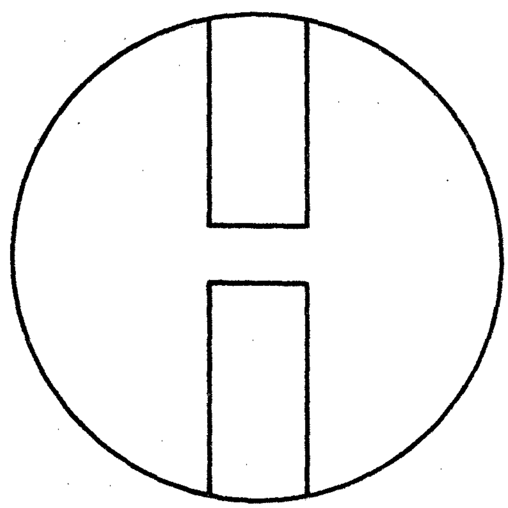
Figure 5

DESIGN OF CENTER AND OFF-CENTER DOWNCOMERS
WITH AND WITHOUT VAPOR CROSSOVER

Without Vapor Crossover



With Vapor Crossover



and four pass trays. The first method consists of designing for equal liquid flow path lengths. That is, equal distances the liquid must travel in its course from downcomer to downcomer. The other method is to design for equal bubbling areas. That is, the perforated area in which vapor-liquid contacting takes place should be the same for each pass. Each of these methods has its own advantages and disadvantages. Neither is generally accepted as the "proper" method because some tray vendors design for equal flowpath length, while others design for equal bubbling areas.

Some vendors probably prefer the equal flowpath length method because it is easy to fabricate. All tray panels can be made of equal widths. Some also claim that since tray efficiency is dependent on flowpath length, such a design provides for equal tray efficiencies. The equal bubble area method is preferred by some because they can then attempt to design for equal liquid and vapor flowrates for each pass. Chapter VI of this thesis describes how the equal bubble area method can be used in the optimum design of multipass trays.

CHAPTER III

EQUATIONS FOR THREE AND FOUR PASS TRAYS

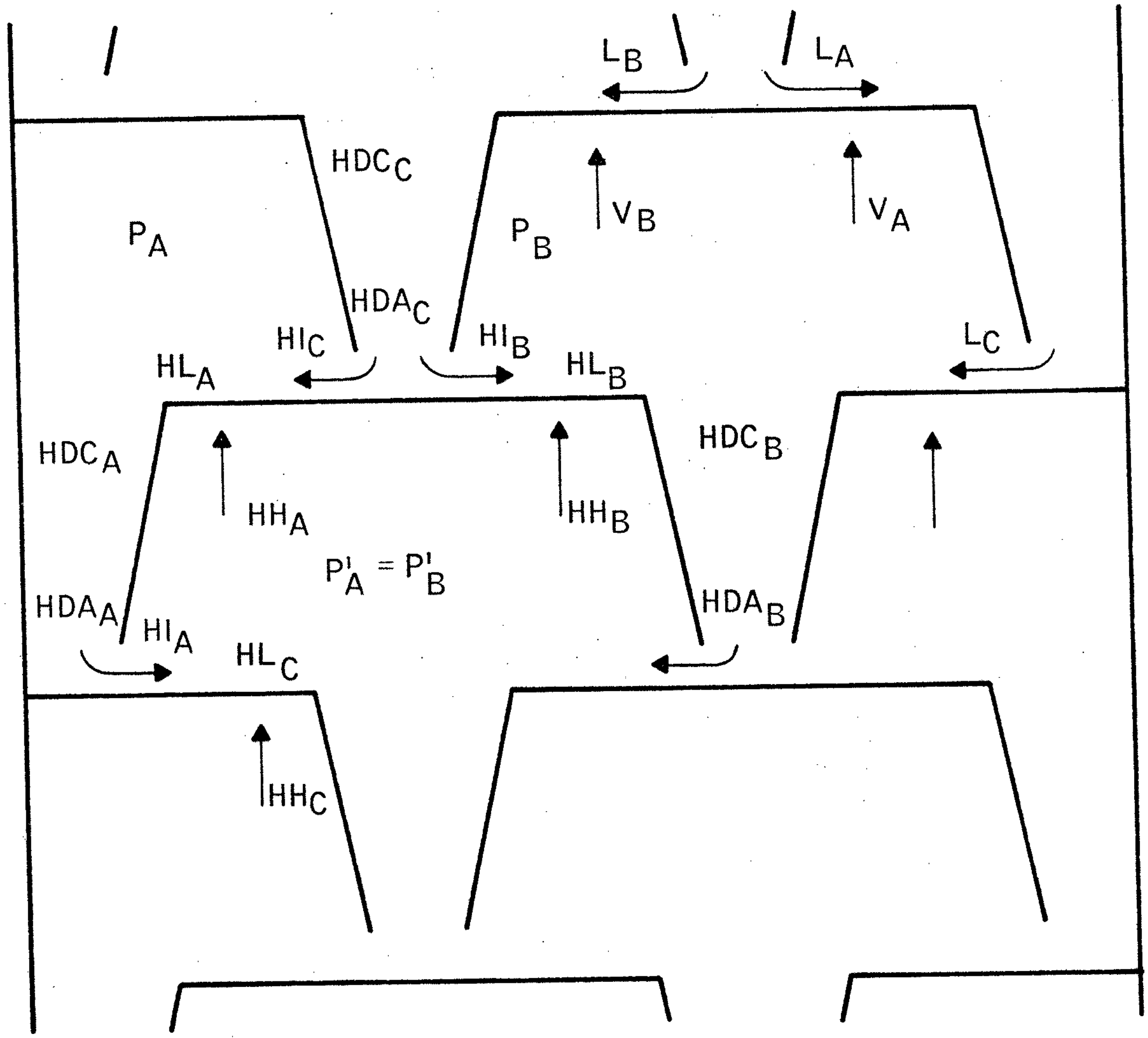
The liquid and vapor splits for a multipass tray are determined by various pressure drop equations. There are enough equations to solve for each of the unknown liquid and vapor flowrates on a multipass tray. Because vapor crossover affects the tray pressure drop relationships, a separate but related set of equations are necessary for tray designs with vapor crossover. The first section of this chapter presents the pressure drop equations for the four types of multipass tray designs (three and four pass, each with and without vapor crossover) which are necessary and sufficient to completely determine the liquid and vapor flowrates in each pass. The next section presents the derivation of the critical equations. Finally, it is shown that through the use of these equations, the calculated downcomer backup of a downcomer which is shared by two passes of a multipass tray, is indeed the same, regardless of which pass it is calculated for.

Equations For Determining Liquid and Vapor Splits

Three pass, no vapor crossover. The vapor and liquid flow patterns and pressure drops of a three pass tray are shown in Figure 6. The following six equations (A1 to A6) can be used to determine the three vapor and liquid rates, one for each pass. The first three equations determine the liquid split, and the last three equations determine the vapor split.

Figure 6

THREE-PASS TRAY FLOW PATTERNS
AND PRESSURE DROPS



Total Tray ΔP

$HT_A = HH_A + HL_A$
$HT_B = HH_B + HL_B$
$HT_C = HH_C + HL_C$

Downcomer Backup

$HDC_A = HT_A + HI_A + HDA_A$
$HDC_B = HT_B + HI_B + HDA_B$
$HDC_C = HT_C + HI_C + HDA_C$

(A1) $L_A = L_C$

(A2) $HI_C + HDA_C - HT_A = HI_B + HDA_B - HT_B$

(A3) $L_A + L_B + L_C = L_{total}$

(A4) $V_A = V_C$

(A5) $HT_A + HT_C = 2 \times HT_B$

(A6) $V_A + V_B + V_C = V_{total}$

Where HI_X is the inlet head on pass X, HDA_X is the head loss under the downcomer for pass X, and HT_X is the total tray pressure drop on pass X.

<u>Three pass with vapor crossover.</u> If provision is made for vapor to crossover through the off-center downcomer, equations (A4) and (A5) above can be replaced with the two equations below (B4 and B5). Note that equation (B5) is merely a simplification of equation (A5) knowing (B4) is true.

(B4) $HT_A = HT_B$

(B5) $HT_B = HT_C$ $(HT_A + HT_C = 2 \times HT_B)$

<u>Four pass, no vapor crossover.</u> The vapor and liquid flow patterns and pressure drops for a four pass tray are shown in Figure 7. The following eight equations (C1 to C8) can be used to determine the four liquid and vapor rates, one for each pass. The first four equations determine the liquid split, and the last four equations determine the vapor split.

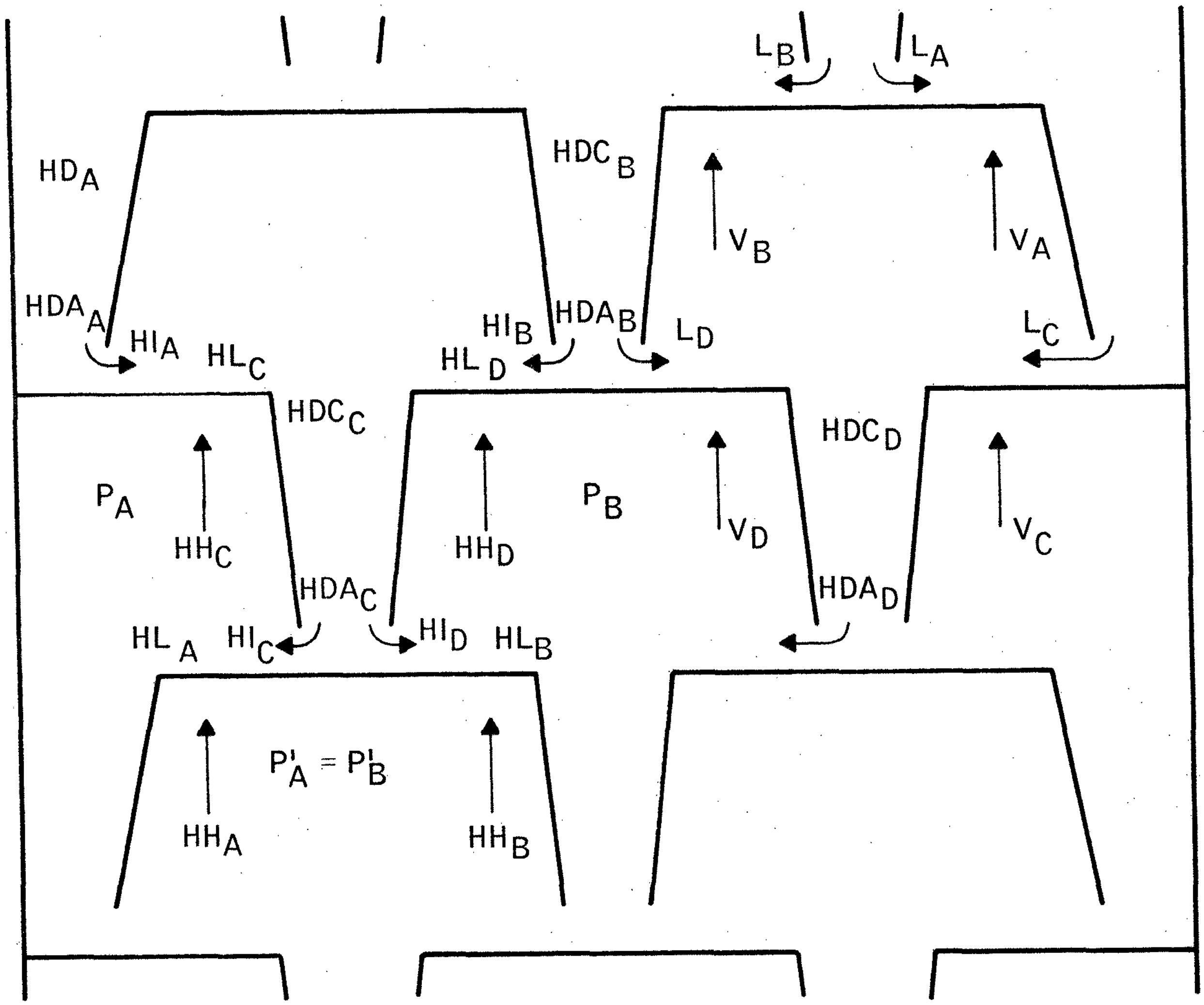
(C1) $L_A = L_C$

(C2) $L_B = L_D$

(C3) $HI_C + HDA_C - HT_A = HI_D + HDA_D - HT_B$

Figure 7

FOUR PASS TRAY FLOW PATTERNS AND PRESSURE DROPS



Total Tray ΔP

$HT_A = HL_A + HH_A$
$HT_B = HL_B + HH_B$
$HT_C = HL_C + HH_C$
$HT_D = HL_D + HH_D$

Downcomer Backup

$HDC_A = HT_A + HI_A + HDA_A$
$HDC_B = HT_B + HI_B + HDA_B$
$HDC_C = HT_C + HI_C + HDA_C$
$HDC_D = HT_D + HI_D + HDA_D$

(C4) $L_A + L_B + L_C = L_{total}$

(C5) $V_A = V_C$

(C6) $V_B = V_D$ $(2 \times V_A + 2 \times V_B = V_{total})$

(C7) $HT_A + HT_C = HT_B + HT_D$

(C8) $V_A + V_B + V_C + V_D = V_{total}$

Four pass with vapor crossover. If provision is made for vapor to crossover through the off-center and center downcomers, equations (D5) to (D8) below replace equations (C5) to (C8) above. Note that equation (D6) is merely a simplification of (C6) once (D5) is true. Also, note that (C6) is a simplification of (D6) once (C5) is true.

(D5) $HT_A = HT_B$

(D6) $HT_C = HT_D$ $(HT_A + HT_C = HT_B + HT_D)$

(D7) $2 \times V_A + 2 \times V_B = V_{total}$

(D8) $2 \times V_C + 2 \times V_D = V_{total}$

Derivation of Critical Pressure Drop Equations

Upon studying Figures 6 and 7, most of the equations presented above become obvious. However, the four pressure drop equations which determine the critical vapor and liquid splits (A2, A5, C3, C7) are derived below.

Equation (A2). The critical liquid split on a three pass tray occurs at the bottom of the off-center downcomer. The liquid will split such that the pressure drop it must overcome in each possible path is exactly equal. The pressure it must overcome is equal to the sum of the inlet head of liquid (HI) the head loss it undergoes in going through the area under the downcomer (HDA), and the pressure level in the chamber it is entering. Therefore,

$$(E1)\quad HI_C + HDA_C + P_A = HI_B + HDA_B + P_B$$

Where P_X is the pressure level above pass X.

The pressure level in the chamber (P_A, P_B) is equal to the pressure level below that chamber (P'_A, P'_B) minus the tray pressure drop through that pass (HT_A, HT_B). That is

$$(E2)\quad P_A = P'_A - HT_A$$

$$(E3)\quad P_B = P'_B - HT_B$$

Where P'_X is the pressure level below pass X. Substituting equations (E2) and (E3) into equation (E1),

$$(E4)\quad HI_C + HDA_C + P'_A - HT_A = HI_B + HDA_B + P'_B - HT_B$$

Since the pressures P'_A and P'_B are for the same chamber,

$$(E5)\quad P'_A = P'_B$$

Therefore, substituting (E5) into (E4) gives equation (A2).

$$(A2)\quad HI_C + HDA_C - HT_A = HI_B + HDA_B - HT_B$$

Equation (A5). For trays without vapor crossover, we must consider a pressure balance across two trays because for any one tray, one vapor flow chamber is completely closed off from the other chamber. The vapor from the chamber above pass C travels through the chamber above pass A before it returns to another chamber above another pass C. It cannot travel through the chamber above pass C, then through the chamber above pass B, because $V_A = V_C$ as defined by equation (A4). Therefore,

$$(F1)\quad HT_A + HT_C = HT_B + HT_B$$

(A5) $HT_A + HT_C = 2 \times HT_B$

Equation (C3). As with the three pass tray, the critical liquid split occurs at the bottom of the off-center downcomer, and the same type of pressure balance is required:

(G1) $HI_C + HDA_C + P_A = HI_D + HDA_D + P_B$

(G2) $P_A = P'_A - HT_A$

(G3) $P_B = P'_B - HT_B$

(G4) $HI_C + HDA_C + P'_A - HT_A = HI_D + HDA_D + P'_B - HT_B$

(G5) $P'_A = P'_B$

(C3) $HI_C + HDA_C - HT_A = HI_D + HDA_D - HT_B$

Equation (C7). As with the three pass tray, consider the pressure balance across two trays. Vapor from the chambers above passes C and D, must pass through the chambers above passes A and B respectively. Therefore,

(C7) $HT_A + HT_C = HT_B + HT_D$

Proofs That Shared Downcomers Have Equal Backups.

On multipass trays, liquid from two different passes can flow into a single shared downcomer. For example, liquid from passes B and C on a three pass tray share a common downcomer, as does liquid from passes C and D on a four pass tray. Because the liquid in these downcomers blend and actually form one column of liquid, the downcomer backup (the static head equal to the height of this column) must be the same regardless of which pass it is calculated for. That is, for a three pass tray, HD_C must equal HD_B; and for a four pass tray, HD_C must equal HD_D. This is proven below.

Three pass. By definition, the backup in a downcomer is equal to the sum of the total tray pressure drop (HT), plus the head loss under the downcomer (HDA), plus the inlet head (HI). Therefore,

(H1) $HDC_B = HT_B + HDA_B + HI_B$

(H2) $HDC_C = HT_C + HDA_C + HI_C$

Where HDC_X is the downcomer filling in the downcomer from pass X. For HDC_B to be equal to HDC_C, the following must hold,

(H3) $HDC_B - HDC_C = 0 = HT_B + HDA_B + HI_B - HT_C - HDA_C - HI_C$

Now from previous equations,

(A5) $HT_A + HT_C = 2 \times HT_B = HT_B + HT_B$

(H4) $HT_B - HT_C = HT_A - HT_B$

Substituting (H4) into (H3)

(H5) $0 = HT_A + HDA_B + HI_B - HT_B - HDA_C - HI_C$

Rearranging, this equation is the same as the identity of equation (A2),

(A2) $HI_C + HDA_C - HT_A = HI_C + HDA_B - HT_B$

Therefore, (H3) is true, and

(H6) $HDC_B = HDC_C$

Q.E.D.

Four pass. Following the logic used in the derivation for three passes above:

(I1) $HDC_C = HT_C + HDA_C + HI_C$

(I2) $HDC_D = HT_D + HDA_D + HI_D$

We will prove

$$\text{(I3)}\quad HDC_C - HDC_D = 0 = HT_C + HDA_C + HI_C - HI_D - HDA_D - HI_D$$

Using the following equations:

$$\text{(C7)}\quad HTA + HT_C = HT_B + HT_D$$

$$\text{(I4)}\quad HT_C - HT_D = HT_B - HTA$$

$$\text{(I5)}\quad 0 = HT_B - HT_A + HDA_C + HI_C - HDA_D - HI_D$$

Now (I5) is the same as the identity (C3) rearranged. Therefore, (I3) is true, and

$$\text{(I6)}\quad HDC_C = HDC_D$$

Q.E.D.

CHAPTER IV

COMPUTER PROGRAM FOR RATING AND DESIGNING MULTIPASS TRAYS

A computer program has been written to rate existing multipass trays and to design three and four pass trays for new services. This program uses the equations presented in the preceding chapter to determine the vapor and liquid loadings for each pass.

Equations Used to Rate Designs

In order to rate or design trays, equations are necessary for the various pressure drops required, as well as for tray capacity and efficiency. This section presents the equations used in this program. Most are published equations although the jet flood capacity equation is not from any single source but is contrived to represent known trends in tower capacity. The equations chosen are not intended to be recommended as the best possible equation available. It is expected that those interested in using this program will substitute some or all of these rating equations with their own proprietary rating equations.

Jet Flood. The jet flood point normally sets the maximum vapor capacity of a sieve tray. Jet flooding is the condition in which liquid entrained from one tray to the next by the vapor jets becomes excessive. Tower pressure drop increases significantly, and the tower may become filled with liquid. Tray efficiency decreases drastically.

Many tower capacity correlations predict the vapor velocity through the bubble area at which jet flooding occurs. This jet flood point decreases as the liquid rate across the weir increases. This program calculates the percentage of the flood point at which the tray is operating for each pass. A desirable design is generally at about 85 percent of the flood point. This maximizes tower capacity without debiting tower efficiency due to excessive entrainment.

The following equation used in this program to calculate the jet flood point is not taken from any one source. It is a contrived equation based on known trends in tower capacity.

$$(V_L/A_B) \text{ flood} = \text{HFACT1} \times 0.55 - 0.035 \text{ (GPHFTWEIR/1000)}$$

where $V_L = CFS_V \sqrt{\rho_V/(\rho_L - \rho_V)}$

and $\text{HFACT1} = \sqrt{H/24}$

Where V_L is the vapor load in cubic feet per second, A_B is the bubble area, CFS_V is the vapor flowrate in cubic feet per second, ρ_V is the vapor density in pounds per cubic foot, ρ_L is the liquid density in pounds per cubic foot, H the tray spacing in inches, HFACT1 is a tray spacing capacity factor, and GPHFTWEIR is the liquid weir loading in gallons per hour per foot of weir length.

Allowable downcomer inlet velocity. As the frothy liquid from the tray enters the downcomer, the froth disengages. The liquid goes down through the downcomer to the next lower tray while the vapor goes up through the vapor space to the next higher tray. There is an upper limit to the velocity at which the froth can enter the downcomer and successfully disengage without carrying vapor downward to be recycled to the tray below.

This allowable downcomer inlet velocity increases as the tray spacing increases. As the tray spacing or downcomer height increases, the disengaging residence time increases, and, therefore, the vapor and liquid separate more easily. The allowable velocity also increases as the difference between the liquid and vapor densities ($\rho_L - \rho_V$) increases. As the liquid and vapor densities come closer, the two phases are more difficult to separate, and, therefore, a lower downcomer inlet velocity is allowed.

ALLVEL = HFACT2 x RHOFAC

Where HFACT2 = H/24

and RHOFAC = f ($\rho_L - \rho_V$)

Where ALLVEL is the allowable downcomer inlet velocity, HFACT2 is a tray spacing downcomer design factor and RHOFAC is a function of the density difference.

Dry tray pressure drop. The dry tray pressure drop is the pressure drop the vapor would undergo in passing through the tray's perforations if there were no liquid on the tray. This is calculated from a typical velocity head equation. All pressure drop equations used are similar to those presented by Smith (9). To simplify the dry tray pressure drop equation, the constant C_{VO} was set at an average value of 0.70. The literature gives several methods of predicting C_{VO}, including correlating it with the ratio of hole to bubble area (A_O/A_B) and the ratio of hole diameter to tray thickness (D_O/TT).

$$HH = 0.186\ (1/C_{VO})^2\ V_O^2\ (\rho_V/\rho_L)$$

where $V_O = CFSV/A_O$

and $C_{VO} = 0.70$

where HH is the dry tray pressure drop, V_O is the vapor velocity through the open area to feet per second, A_O is the open area in square feet, and C_{VO} is a dry tray pressure drop coefficient.

Clear liquid height. The height of the froth on a tray is given as the sum of the weir height, plus the static head of the crest of liquid overflowing the weir (the Francis weir formula). The static head of this froth, as a clear liquid, is equal to the froth height multiplied by an aeration factor (β). Some texts give β as a function of the weir liquid loading and the ratio of weir length to diameter (9). This program uses average values of 0.70 and 1.00 for β and F_W, respectively.

$$HL = \beta\ (HOW + HWO)$$

Where $\beta = 0.70$

$$HOW = 0.48\ F_W\ (GPM/LWO)^{2/3}$$

and $F_W = 1.00$

Where HL is the clear liquid height on a tray, HOW is the crest over the weir, HWO is the outlet weir height in inches, β is an aeration factor and F_W is a weir factor, GPM is liquid flowrate in gallons per minute, and LWO is the weir length in inches.

Total tray pressure drop. The total pressure drop a vapor undergoes in passing from one tray to another (HT) is generally agreed to be equal to the sum of the dry tray pressure drop plus the clear liquid head on the tray.

$$HT = HH + HL$$

Inlet head. The static head of liquid at the tray inlet is used in calculating downcomer filling. It is usually equal to the clear liquid height on a sieve tray (a sieve tray is generally regarded to have no crossflow pressure gradrent) unless there is an inlet weir. If there is an inlet weir, the inlet head is equal to the inlet weir height plus the crest over the inlet weir. Since the liquid at this point is clarified, no aerator factor is necessary (i.e. $\beta = 1.00$).

Without an inlet weir $HI = HL$

With an inlet weir $HI = 0.48\ F_W\ (GPM/LWI)^{2/3} + HWI$

Where HI is the inlet head, LWI is the inlet weir length in inches and HWI is the inlet weir height in inches.

Head loss under downcomer. As the liquid passes through the area under each downcomer, it changes direction from vertical to horizontal. This requires a pressure loss (HDA) which is predicted by the submerged weir formula.

$$HDA = 0.06\ (GPM/A_{UD})^2$$

where $A_{UD} = C \times L_{UD}$

Where A_{UD} is the area under the downcomer in square inches, C is the downcomer clearance in inches, and L_{UD} is the length under the downcomer in inches.

By curving the outlet lip of the downcomer, this head loss is reduced. If a shaped lip downcomer is used, this program calculates the head loss to be one-half the value calculated by the above equation.

Downcomer filling. A static head of liquid builds up in the downcomer (HDC) to compensate for the pressure drop between trays plus enough head to overcome the tray inlet head and the head loss under the downcomer.

$$HDC = HT + HI + HDA$$

If a recessed box or inlet weir is used, HDA is doubled, because the liquid makes two turns in leaving the downcomer.

If downcomer filling is excessive, liquid may back up to the tray above and flood the column. Because the froth in the downcomer is not completely clarified, it is generally recommended that the downcomer clear liquid filling not exceed 50 percent of the tray spacing.

Tray efficiency. There are many tray efficiency equations. This program uses a simple correlation of overall tray efficiency with the liquid fluidity on the tray, as presented by Maxwell (8). The liquid fluidity is defined as the reciprocal of the liquid viscosity in centipoises.

Convergence Techniques.

The equations presented in Chapter III are solved simultaneously to determine the liquid and vapor flowrates in each pass. These convergence techniques are summarized in this section.

Three pass, no vapor crossover.

1. Guess $L_A = L_B = L_C = L_{total}/3$
   $V_A = V_B = V_C = V_{total}/3$

2. Calculate HL, HDA, and HI for each pass

3. Calculate HH and HT for each pass

4. Solve for V_A such that

   $HH_A = HT_B + HI_C + HDA_C - HL_A - HI_B - HDA_B$

   which is equivalent to equation (A2)

5. Recalculate $V_C = V_A$

   $V_B = V_{total} - V_A - V_C$

   Return to Step 3 until V_A is converged.

6. Once V_A is converged, solve for L_A such that

   $HL_A = 2 \times HT_B - HT_C - HH_A$

   which is equivalent to equation (A5)

7. Recalculate $L_C = L_A$

   $L_B = L_{total} - L_A - L_C$

   Return to Step 2 until L_A is converged.

<u>Three pass, with vapor crossover.</u>

1. Guess $L_A = L_B = L_C = L_{total}/3$

   $V_A = V_B = V_C = V_{total}/3$

2. Calculate HL, HDA, and HI for each pass

3. Solve for L_A such that

   $HI_C = HI_B + HDA_B + HDA_C$

   which is equivalent to equations (A2) and (B4)

4. Recalculate $L_C = L_A$

   $L_B = L_{total} - L_A - L_C$

   Return to Step 2 until L_A is converged

5. Solve for V_B such that

$HH_B = HT_C - HL_B$

6. Solve for V_A such that

$HH_A = HT_B - HL_A$

which is equivalent to equation (B4)

7. If $V_A + V_B + V_C$ does not equal V_{total}, recalculate $V_C = V_{total} - V_A - V_B$

Repeat, starting at Step 5, until $V_A + V_B + V_C$ does equal V_{total}

Four pass, no vapor crossover.

1. Guess $L_A = L_B = L_C = L_D = L_{total}/4$

$$V_A = V_B = V_C = V_C = V_{total}/4$$

2. Calculate HL, HDA, and HI for each pass

3. Solve for V_A such that

$HH_A = HT_B + HI_C + HDA_C - HL_A - HI_D - HDA_D$

which is equivalent to equation (C3)

4. Recalculate $V_C = V_A$

$$V_B = V_D = 0.5\ V_{total} - V_A$$

Return to Step 3 until V_A is converged

5. Solve for L_A such that

$HL_A = HT_B + HT_D - HT_C - HH_A$

which is equivalent to equation (C7)

6. Recalculate $L_C = L_A$

$$L_B = L_D = 0.5\ L_{total} - L_A$$

Return to Step 2 until L_A is converged

Four pass, with vapor crossover.

1. Guess $L_A = L_B = L_C = L_D = L_{total}/4$

   $V_A = V_C = V_{total}/4$

2. Calculate HL, HDA, and HI for each pass

3. Solve for L_C such that

   $HI_C = HI_D + HDA_D - HDA_C$

   which is equivalent to equations (C3) and (D5)

4. Recalculate $L_A = L_C$

   $L_B = L_D = 0.5\ L_{total} - L_A$

   Return to Step 2 until L_A is converged

5. Recalculate $V_B = 0.5\ V_{total} - V_A$

6. Solve for V_A such that

   $HH_A = HT_B - HL_A$

   which is equivalent to equation (D5)

   Return to Step 5 until V_A is converged

7. Recalculate $V_D = 0.5\ V_{total} - V_C$

8. Solve for V_C such that

   $HH_C = HT_D - HL_C$

   which is equivalent to equation (D6)

   Return to Step 5 until V_C is converged

How to Use the Program

This section describes how to fill out the input form for the eight possible options this program is capable of evaluating. These are three and four pass trays, each with or without vapor crossover, and each as either a rating or a design case.

The input form for this program is presented on the next page. The input form is, for the most part, self-explanatory. The following are notes describing the use of this input form, as referenced by the numbers in parentheses on the form. Note that all 14 cards must be submitted for each case. Even if there is no input on a card for a given case, a blank card must still be submitted in its place.

1. Any alphanumeric titles may be placed on these three cards. They will be printed out exactly as submitted.

2. At the present time, this information is not used by the program. It is simply read and printed out as submitted.

3. Omit for a design case. Submit a blank card if entire information on a card is to be omitted.

4. Enter geometry values as described in Figure 8 and Figure 9. All geometry values are in inches.

5. Enter 0.0 or a blank card if another case follows. Enter 1.0 if this is the last case.

Design Logic.

This section describes the logic that this computer program uses to design three and four pass trays. Given the liquid and vapor loadings and the number of tray passes, the program proceeds to develop a tray design in the manner described below.

Tray spacing is set at 24 inches. This is a typical tray spacing

MULTIPASS TRAY DESIGN PROGRAM

	1–80	
CARD #1		TITLE 1 (1)
CARD #2		TITLE 2 (1)
CARD #3		TITLE 3 (1)

	VAPOR RATE MLBS/HR	MIN. VAPOR RATE MLBS/HR (2)	VAPOR DENSITY LB/CU FT	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER
	1–10	11–20	21–30	31–50
CARD #4	•	•	•	•

	LIQUID RATE MLBS/HR	MIN. LIQ. RATE MLBS/HR (2)	LIQUID DENSITY LB/CU FT	LIQUID VISCOSITY CP	SURFACE TENSION DYNES/CM (2)
	1–10	11–20	21–30	31–40	41–50
CARD #5	•	•	•	•	•

	TEMPERATURE DEG F (2)	PRESSURE PSIA (2)
	1–10	11–20
CARD #6	•	•

	NO. OF PASSES 3 OR 4	HOLE DIAMETER INCHES (2)	TOWER DIAMETER FEET (3)	TRAY SPACING INCHES (3)
	1–10	11–20	21–30	31–40
CARD #7	•	•	•	•

	WIDTH #1 / WIDTH #6	WIDTH #2 / WIDTH #7	WIDTH #3 / WIDTH #8	WIDTH #4 / WIDTH #9	WIDTH #5 / WIDTH #10
	1–10	11–20	21–30	31–40	41–50
CARD #8 (3,4)	•	•	•	•	•
CARD #9 (3,4)	•	•	•	•	•

	OUTLET WEIR HT HWO	INLET WEIR HT HWI	DC CLEARANCE C	HOLE AREA AO - SQ FT	SHAPED LIP = 1.0	RECESSED BOX = 1.0	
	1–10	11–20	21–30	31–40	41–50	51–60	
CARD #10 (3,4)	•	•	•	•	•	•	PASS A
CARD #11 (3,4)	•	•	•	•	•	•	PASS B
CARD #12 (3,4)	•	•	•	•	•	•	PASS C
CARD #13 (3,4)	•	•	•	•	•	•	PASS D

	1–10
CARD #14 (5)	•

Figure 8

THREE-PASS TRAY GEOMETRY

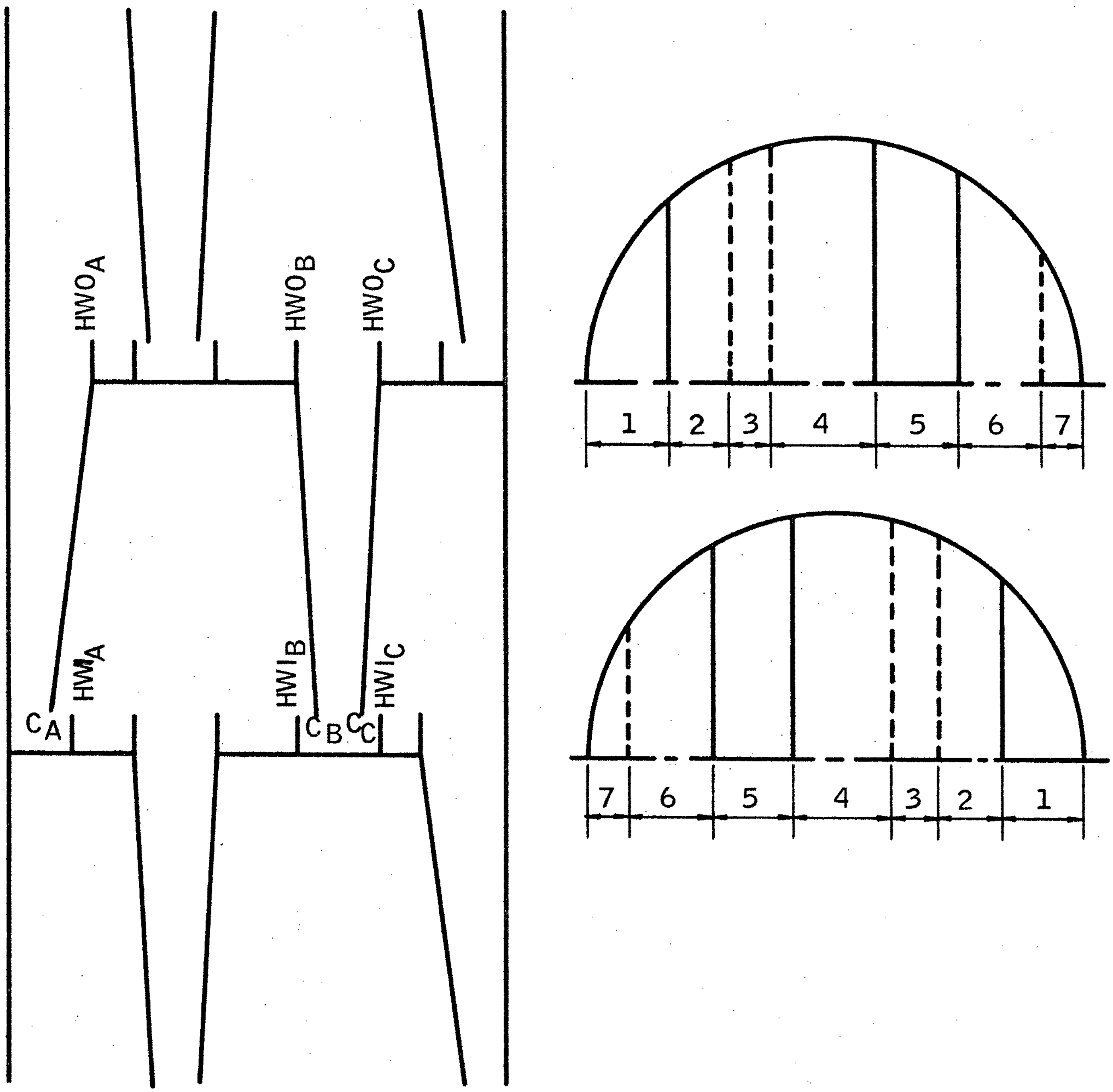
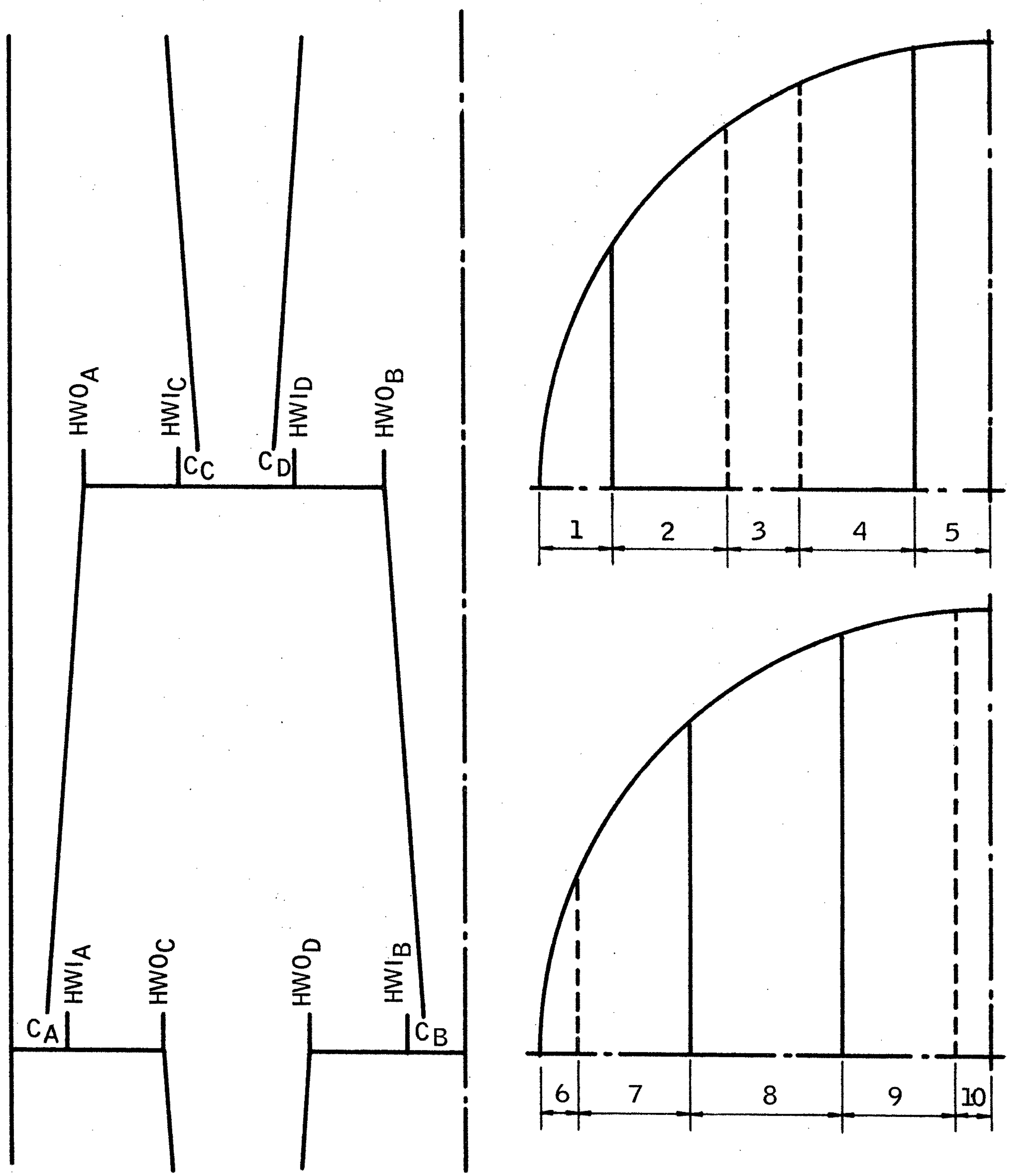


Figure 9

FOUR-PASS TRAY GEOMETRY



used in commercial fractionation towers.

A diameter is then selected using double table lookups (see Table 2 and Table 3 in the Fortran computer program presented in the appendix) with vapor load and volumetric liquid rate as parameters. These tables were not developed from any single source, but are based on the data presented by a tray vendor (6). They follow the general trends that vapor capacity increases with tower diameter and decreases with liquid rate.

The minimum diameter for three pass trays is 7 feet, for four pass trays it is 10 feet. This program is incapable of designing three pass trays for liquid rates greater than 5000 GPM, four pass trays for liquid rates greater than 6000 GPM, and all trays for vapor loads (V_L) greater than 100 CFS. These are the limits of the prediction methods used (7).

The program determines the allowable downcomer inlet velocity as described in a previous section (see Table 1 of the program in the appendix). The total downcomer area is then calculated as the area required to maintain the total downcomer inlet velocity exactly at the allowable level. This total downcomer area is then divided into parts for each pass as proposed by a tray vendor (1). All downcomers are straight. That is, the inlet area is equal to the outlet area.

Now the program has a tower cross-sectional area and a total downcomer area. It then splits the remaining bubble area into three or four segments with equal flow path length. Although this thesis does not propose that equal flow path length designs are the most desirable, it is a common method of designing multipass trays, and is therefore the only method used by this program.

At this point, the program has the entire plan layout (top view) of the tray. Now the program sets the outlet weir height (HWO) so that the average clear liquid height (HL) is 3 inches. It sets the hole area (A_O) so that the average dry tray pressure drop (HH) is 2 inches. These are typical design values which should give good operability and efficiency. It then sets the downcomer clearance (C) so that the average head loss under the downcomer (HDA) is 1 inch. The maximum downcomer clearance is 3 inches, and the program will design a shaped lip downcomer if HDA is greater than 1 inch with a 3 inch straight lip downcomer. This yields an average tray pressure drop (HT) of 5 inches and an average downcomer filling of 9 inches, or 37.5 percent of the 24 inch tray spacing.

The following section describes how these suggested values can be adjusted to obtain a more desirable design than is printed out by the program. For example, if the particular circumstances require a low pressure drop (e.g. a low pressure service), low weir heights and higher open areas will reduce both the clear liquid height and the dry tray pressure drop, which, in turn, reduces the total tray pressure drop.

The program does not design for recessed inlet boxes or inlet weirs. A recessed inlet box is a sump below the downcomer to assure that no vapor can enter the downcomer through the clearance. That is, it is a method of providing a positive seal on the downcomer.

Use of the Program To Improve Initial Design.

It is not proposed that this program will give an optimum design the first time it is run. In fact, the first design the program picks can have several deficiencies. In order to make optimum use of this program as a design tool, the original design case should be altered as necessary and rerun as a rating case. This may have to be done several times until a final optimum design is reached. Several possible deficiencies of a design case are described below.

The program only designs for 24 inch tray spacing. Greater or smaller tray spacings may be chosen to increase tower capacity, reduce downcomer filling or reduce tower height.

The program chooses a tower diameter which can have any value. Very often a company prefers to order tower shells on one foot or half foot diameter increments. Therefore, the diameter chosen by the program should be changed to conform to the specific standard procedures of the user.

Similarly, flow path lengths, downcomer widths, weir heights, and downcomer clearances are often preferred to be specified on some standard increment (say one quarter inch). Since the program chooses any value it needs to meet its design logic, these values should be changed to conform with specific standard procedures of the user.

The program also sets all weir heights and clearances equal. Therefore, clear liquid heights and other pressure drop values can vary greatly for different passes even though the average value conforms with the design logic of the program. Therefore, it is suggested that the original values be altered to equalize pressure drops somewhat. In particular, the outboard downcomer (the shortest downcomer) clearance should usually be increased and the outboard downcomer weir height should usually be decreased.

Also, although the average downcomer velocity is at the allowable limit, the velocity for any one downcomer may exceed this limit. The suggestions in the preceding paragraph should help in balancing the downcomer inlet velocities.

Although this program may not give an optimum design on the first trial, good engineering judgment can be used to obtain an economic and well-balanced design with one or two additional trials.

CHAPTER V

SAMPLE PROBLEMS

This chapter presents sample problems run on the Multipass Tray Design computer program. Included are input forms and two pages of printout for each of the following eight cases:

1. Four pass rating case, no vapor crossover.
2. Four pass rating case, with vapor crossover.
3. Three pass rating case, no vapor crossover.
4. Three pass rating case, with vapor crossover.
5. Four pass design case, no vapor crossover.
6. Four pass design case, with vapor crossover.
7. Three pass design case, no vapor crossover.
8. Three pass design case, with vapor crossover.

The printouts include all inputted information, tray geometry information, vapor and liquid loadings per pass, pressure drops and downcomer backup in inches of hot liquid, percent of jet flood, downcomer inlet velocity, and overall tray efficiency.

Note that for four pass trays, the downcomer for passes C and D are shared, and, for three pass trays the downcomer for passes B and C are shared. Also, for four pass trays, a single downcomer is used for liquid from two individual passes B. On the program printout, these downcomers are split in half, and downcomer inlet velocities per pass are calculated by dividing the liquid flowrate per pass by the area of the "half" downcomer.

CARD #1	NCE TEST CASE: FØUR PASS RATING	TITLE 1 (1)
CARD #2	DESIGNER: P.W. BECKER	TITLE 2 (1)
CARD #3	NØ VAPØR CRØSSØVER	TITLE 3 (1)

	VAPOR RATE MLBS/HR	MIN. VAPOR RATE MLBS/HR (2)	VAPOR DENSITY LB/CU FT	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER
CARD #4	618.	309.	1.403	0.

	LIQUID RATE MLBS/HR	MIN. LIQ. RATE MLBS/HR (2)	LIQUID DENSITY LB/CU FT	LIQUID VISCOSITY CP	SURFACE TENSION DYNES/CM (2)
CARD #5	554.6	272.3	31.55	0.113	6.16

	TEMPERATURE DEG F (2)	PRESSURE PSIA (2)
CARD #6	140.	125.

	NO. OF PASSES 3 OR 4	HOLE DIAMETER INCHES (2)	TOWER DIAMETER FEET (3)	TRAY SPACING INCHES (3)
CARD #7	4.	0.38	13.5	21.

	WIDTH #1 / WIDTH #6	WIDTH #2 / WIDTH #7	WIDTH #3 / WIDTH #8	WIDTH #4 / WIDTH #9	WIDTH #5 / WIDTH #10
CARD #8 (3,4)	19.4375	26.5625	9.25	21.75	4.0
CARD #9 (3,4)	19.4375	26.5625	9.25	21.75	4.0

	OUTLET WEIR HT HWO	INLET WEIR HT HWI	DC CLEARANCE C	HOLE AREA AO - SQ FT	SHAPED LIP = 1.0	RECESSED BOX = 1.0	
CARD #10 (3,4)	1.25	.	1.54	2.39	.	.	PASS A
CARD #11 (3,4)	2.13	.	1.0	2.39	.	.	PASS B
CARD #12 (3,4)	2.0	.	1.0	2.39	.	.	PASS C
CARD #13 (3,4)	2.0	.	1.0	2.39	.	.	PASS D

	1–10
CARD #14 (5)	.

NCE TEST CASE: FOUR PASS RATING

DESIGNER: P.W.BECKER

NO VAPOR CROSSOVER

OPERATING CONDITIONS

MLBS/HR VAPOR MAX		619.000	MLBS/HR LIQUID MAX		544.600
MLBS/HR VAPOR MIN		309.000	MLBS/HR LIQUID MIN		272.300
LBS/CU FT VAPOR AT COND		1.403	LBS/CU FT LIQUID AT COND		31.550
TRAY LIQUID TEMPERATURE	DEG F	140.000	SURFACE TENSION AT COND	DYNES/CM	6.160
OPERATING PRESSURE	PSIA	125.000	VISCOSITY AT COND	CP	0.113
CFS VAPOR AT COND		122.357	LIQUID FLOW RATE	GPM	2151.932
VAPOR LOAD	CFS	26.396			

TRAY GEOMETRY

DIAMETER	FT	13.50
TRAY SPACING	IN	21.00
NUMBER OF PASSES		4.00
HOLE DIAMETER	IN	0.38
CROSS SECT AREA	SQ FT	143.14
BUBBLE/CROSS SECT AREA	PCT	66.86
VAPOR CROSSOVER (YES OR NO)		NO

		PASS A	PASS B	PASS C	PASS D
DOWNCOMER INLET WIDTH **	IN	19.438	4.000	4.625	4.625
DOWNCOMER OUTLET WIDTH **	IN	19.438	4.000	4.625	4.625
FLOW PATH LENGTH	IN	26.563	21.750	26.563	21.750
CHORD LENGTH AT TOP OF DC	IN	105.285	162.018	145.884	153.568
CHORD LENGTH AT BTM OF DC	IN	105.285	162.018	145.884	153.568
DC INLET AREA	SQ FT	9.708	4.390	4.742	4.879
DC OUTLET AREA	SQ FT	9.708	4.390	4.742	4.879
OUTLET WEIR HEIGHT	IN	1.250	2.130	2.000	2.000
INLET WEIR HEIGHT ON TRAY BELOW	IN	0.0	0.0	0.0	0.0
DC CLEARANCE TO TRAY BELOW	IN	1.540	1.000	1.000	1.000
SHAPED LIP (YES OR NO)		NO	NO	NO	NO
RECESSED BOX (YES OR NO)		NO	NO	NO	NO
BUBBLE AREA	SQ FT	23.601	24.250	23.601	24.250
FREE AREA	SQ FT	33.308	28.640	29.343	29.128
HOLE AREA	SQ FT	2.390	2.390	2.390	2.390
HOLE/BUBBLE AREA	PCT	10.127	9.856	10.127	9.856

** HALF WIDTH FOR PASSES B,C,D

LOADINGS PER PASS			PASS A	PASS B	PASS C	PASS D
GPM LIQUID			549.469	526.497	549.469	526.497
GPH/FT WEIR			3757.569	2339.732	2711.951	2468.471
CFS VAPOR			30.994	30.184	30.994	30.184
VAPOR LOAD		CFS	6.686	6.512	6.686	6.512
VLOAD/BUBBLE AREA		FPS	0.283	0.269	0.283	0.269
VLOAD/CFS LIQUID			5.461	5.551	5.461	5.551
DOWNCOMER FILLING CALCULATIONS						
DRY TRAY PRESSURE DROP	(HH)	IN	2.839	2.692	2.839	2.692
CLEAR LIQUID HEIGHT	(HL)	IN	1.886	2.228	2.214	2.164
TOTAL TRAY PRESSURE DROP	(HT)	IN	4.725	4.921	5.053	4.857
INLET HEAD	(HI)	IN	2.214	2.164	1.886	2.228
DC HEAD LOSS	(HDA)	IN	0.699	0.634	0.851	0.705
DC FILLING	(HDC)	IN	7.628	7.719	7.790	7.790
DC FILLING		PCT	36.325	36.756	37.097	37.097
ADDITIONAL CALCULATIONS						
PERCENT JET FLOOD			73.979	62.073	67.525	62.727
DC INLET VELOCITY		FPS	0.126	0.267	0.258	0.240

ALLOWABLE DC INLET VELOCITY FPS 0.341

OVERALL TRAY EFFICIENCY PCT 98.833

MULTIPASS TRAY DESIGN PROGRAM

	1–80	
CARD #1	NCE TEST CASE: FØUR PASS RATING	TITLE 1 (1)
CARD #2	DESIGNER: P. W. BECKER	TITLE 2 (1)
CARD #3	WITH VAPØR CRØSSØVER	TITLE 3 (1)

	VAPOR RATE MLBS/HR (1–10)	MIN. VAPOR RATE MLBS/HR (2) (11–20)	VAPOR DENSITY LB/CU FT (21–30)	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER (31–50)
CARD #4	618.	309.	1.403	1.

	LIQUID RATE MLBS/HR (1–10)	MIN. LIQ. RATE MLBS/HR (2) (11–20)	LIQUID DENSITY LB/CU FT (21–30)	LIQUID VISCOSITY CP (31–40)	SURFACE TENSION DYNES/CM (2) (41–50)
CARD #5	554.6	272.3	31.55	0.113	6.16

	TEMPERATURE DEG F (2) (1–10)	PRESSURE PSIA (2) (11–20)
CARD #6	140.	125.

	NO. OF PASSES 3 OR 4 (1–10)	HOLE DIAMETER INCHES (2) (11–20)	TOWER DIAMETER FEET (3) (21–30)	TRAY SPACING INCHES (3) (31–40)
CARD #7	4.	0.38	13.5	21.

	WIDTH #1 / WIDTH #6 (1–10)	WIDTH #2 / WIDTH #7 (11–20)	WIDTH #3 / WIDTH #8 (21–30)	WIDTH #4 / WIDTH #9 (31–40)	WIDTH #5 / WIDTH #10 (41–50)
CARD #8 (3,4)	19.4375	26.5625	9.25	21.75	4.0
CARD #9 (3,4)	19.4375	26.5625	9.25	21.75	4.0

	OUTLET WEIR HT HWO (1–10)	INLET WEIR HT HWI (11–20)	DC CLEARANCE C (21–30)	HOLE AREA AO - SQ FT (31–40)	SHAPED LIP = 1.0 (41–50)	RECESSED BOX = 1.0 (51–60)	
CARD #10 (3,4)	1.25	.	1.54	2.39	.	.	PASS A
CARD #11 (3,4)	2.13	.	1.0	2.39	.	.	PASS B
CARD #12 (3,4)	2.0	.	1.0	2.39	.	.	PASS C
CARD #13 (3,4)	2.0	.	1.0	2.39	.	.	PASS D

	1–10
CARD #14 (5)	.

DESIGN AND RATING PROGRAM FOR THREE AND FOUR PASS SIEVE TRAYS

NCE TEST CASE: FOUR PASS RATING

DESIGNER: P.W.BECKER

WITH VAPOR CROSSOVER

OPERATING CONDITIONS

MLBS/HR VAPOR MAX		618.000	MLBS/HR LIQUID MAX		544.600
MLBS/HR VAPOR MIN		309.000	MLBS/HR LIQUID MIN		272.300
LBS/CU FT VAPOR AT COND		1.403	LBS/CU FT LIQUID AT COND		31.550
TRAY LIQUID TEMPERATURE	DEG F	140.000	SURFACE TENSION AT COND	DYNES/CM	6.160
OPERATING PRESSURE	PSIA	125.000	VISCOSITY AT COND	CP	0.113
CFS VAPOR AT COND		122.357	LIQUID FLOW RATE	GPM	2151.932
VAPOR LOAD	CFS	26.396			

TRAY GEOMETRY

DIAMETER	FT	13.50
TRAY SPACING	IN	21.00
NUMBER OF PASSES		4.00
HOLE DIAMETER	IN	0.38
CROSS SECT AREA	SQ FT	143.14
BUBBLE/CROSS SECT AREA	PCT	66.86
VAPOR CROSSOVER (YES OR NO)		YES

		PASS A	PASS B	PASS C	PASS D
DOWNCOMER INLET WIDTH **	IN	19.438	4.000	4.625	4.625
DOWNCOMER OUTLET WIDTH **	IN	19.438	4.000	4.625	4.625
FLOW PATH LENGTH	IN	26.563	21.750	26.563	21.750
CHORD LENGTH AT TOP OF DC	IN	105.285	162.018	145.884	153.568
CHORD LENGTH AT BTM OF DC	IN	105.235	162.018	145.884	153.568
DC INLET AREA	SQ FT	9.708	4.390	4.742	4.879
DC OUTLET AREA	SQ FT	9.708	4.390	4.742	4.879
OUTLET WEIR HEIGHT	IN	1.250	2.130	2.000	2.000
INLET WEIR HEIGHT ON TRAY BELOW	IN	0.0	0.0	0.0	0.0
DC CLEARANCE TO TRAY BELOW	IN	1.540	1.000	1.000	1.000
SHAPED LIP (YES OR NO)		NO	NO	NO	NO
RECESSED BOX (YES OR NO)		NO	NO	NO	NO
BUBBLE AREA	SQ FT	23.601	24.250	23.601	24.250
FREE AREA	SQ FT	33.308	28.640	28.343	29.128
HOLE AREA	SQ FT	2.390	2.390	2.390	2.390
HOLE/BUBBLE AREA	PCT	10.127	9.856	10.127	9.856

** HALF WIDTH FOR PASSES B,C,D

LOADINGS PER PASS			PASS A	PASS B	PASS C	PASS D
GPM LIQUID			574.216	501.750	574.216	501.750
GPH/FT WEIR			3926.804	2229.756	2533.999	2352.444
CFS VAPOR			31.387	29.792	30.316	30.862
VAPOR LOAD		CFS	6.771	6.427	6.540	6.658
VLOAD/BUBBLE AREA		FPS	0.287	0.265	0.277	0.275
VLOAD/CFS LIQUID			5.292	5.749	5.112	5.955
DOWNCOMER FILLING CALCULATIONS						
DRY TRAY PRESSURE DROP	(HH)	IN	2.911	2.623	2.716	2.815
CLEAR LIQUID HEIGHT	(HL)	IN	1.917	2.205	2.238	2.140
TOTAL TRAY PRESSURE DROP	(HT)	IN	4.828	4.828	4.954	4.955
INLET HEAD	(HI)	IN	2.238	2.140	1.917	2.205
DC HEAD LOSS	(HDA)	IN	0.753	0.575	0.930	0.641
DC FILLING	(HDC)	IN	7.818	7.544	7.800	7.801
DC FILLING		PCT	37.230	35.922	37.144	37.145
ADDITIONAL CALCULATIONS						
PERCENT JET FLOOD			76.091	60.727	66.727	63.534
DC INLET VELOCITY		FPS	0.132	0.255	0.270	0.229

ALLOWABLE DC INLET VELOCITY	FPS	0.341
OVERALL TRAY EFFICIENCY	PCT	98.833

	1–80	
CARD #1	NCE TEST CASE: THREE PASS RATING	TITLE 1 (1)
CARD #2	DESIGNER: P. W. BECKER	TITLE 2 (1)
CARD #3	NØ VAPØR CRØSSØVER	TITLE 3 (1)

	VAPOR RATE MLBS/HR (1–10)	MIN. VAPOR RATE MLBS/HR (2) (11–20)	VAPOR DENSITY LB/CU FT (21–30)	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER (31–50)
CARD #4	618.	309.	1.403	0.

	LIQUID RATE MLBS/HR (1–10)	MIN. LIQ. RATE MLBS/HR (2) (11–20)	LIQUID DENSITY LB/CU FT (21–30)	LIQUID VISCOSITY CP (31–40)	SURFACE TENSION DYNES/CM (2) (41–50)
CARD #5	554.6	272.3	31.55	0.113	6.16

	TEMPERATURE DEG F (2) (1–10)	PRESSURE PSIA (2) (11–20)
CARD #6	140.	125.

	NO. OF PASSES 3 OR 4 (1–10)	HOLE DIAMETER INCHES (2) (11–20)	TOWER DIAMETER FEET (3) (21–30)	TRAY SPACING INCHES (3) (31–40)
CARD #7	3.	0.38	13.5	21.

	WIDTH #1 / WIDTH #6 (1–10)	WIDTH #2 / WIDTH #7 (11–20)	WIDTH #3 / WIDTH #8 (21–30)	WIDTH #4 / WIDTH #9 (31–40)	WIDTH #5 / WIDTH #10 (41–50)
CARD #8 (3,4)	24.	24.	21.	24.	24.
CARD #9 (3,4)	24.	21.	.	.	.

	OUTLET WEIR HT HWO (1–10)	INLET WEIR HT HWI (11–20)	DC CLEARANCE C (21–30)	HOLE AREA AO - SQ FT (31–40)	SHAPED LIP = 1.0 (41–50)	RECESSED BOX = 1.0 (51–60)	
CARD #10 (3,4)	1.25	.	1.54	2.39	.	.	PASS A
CARD #11 (3,4)	2.13	.	1.0	2.66	.	.	PASS B
CARD #12 (3,4)	2.0	.	1.0	2.39	.	.	PASS C
CARD #13 (3,4)	.	.	.	.	.	.	PASS D

	1–10
CARD #14 (5)	.

NCE TEST CASE: THREE PASS RATING

DESIGNER: P.W.BECKER

NO VAPOR CROSSOVER

OPERATING CONDITIONS

MLBS/HR VAPOR MAX		618.000	MLBS/HR LIQUID MAX		544.600
MLBS/HR VAPOR MIN		309.000	MLBS/HR LIQUID MIN		272.300
LBS/CU FT VAPOR AT COND		1.403	LBS/CU FT LIQUID AT COND		31.550
TRAY LIQUID TEMPERATURE	DEG F	140.000	SURFACE TENSION AT COND	DYNES/CM	6.160
OPERATING PRESSURE	PSIA	125.000	VISCOSITY AT COND	CP	0.113
CFS VAPOR AT COND		122.357	LIQUID FLOW RATE	GPM	2151.932
VAPOR LOAD	CFS	26.396			

TRAY GEOMETRY

DIAMETER	FT	13.50
TRAY SPACING	IN	21.00
NUMBER OF PASSES		3.00
HOLE DIAMETER	IN	0.38
CROSS SECT AREA	SQ FT	143.14
BUBBLE/CROSS SECT AREA	PCT	49.30
VAPOR CROSSOVER (YES OR NO)		NO

		PASS A	PASS B	PASS C	PASS D
DOWNCOMER INLET WIDTH **	IN	24.000	12.000	12.000	0.0
DOWNCOMER OUTLET WIDTH **	IN	21.000	10.500	10.500	0.0
FLOW PATH LENGTH	IN	24.000	24.000	24.000	0.0
CHORD LENGTH AT TOP OF DC	IN	115.332	160.273	144.924	0.0
CHORD LENGTH AT BTM OF DC	IN	109.019	160.273	147.734	0.0
DC INLET AREA	SQ FT	13.163	13.286	12.506	0.0
DC OUTLET AREA	SQ FT	10.854	11.662	11.091	0.0
OUTLET WEIR HEIGHT	IN	1.250	2.130	2.000	0.0
INLET WEIR HEIGHT ON TRAY BELOW	IN	0.0	0.0	0.0	0.0
DC CLEARANCE TO TRAY BELOW	IN	1.540	1.000	1.000	0.0
SHAPED LIP (YES OR NO)		NO	NO	NO	NO
RECESSED BOX (YES OR NO)		NO	NO	NO	NO
BUBBLE AREA	SQ FT	22.174	26.949	21.449	0.0
FREE AREA	SQ FT	32.302	38.612	33.265	0.0
HOLE AREA	SQ FT	2.390	2.660	2.390	0.0
HOLE/BUBBLE AREA	PCT	10.778	9.870	11.143	0.0

** HALF WIDTH FOR PASSES B,C,D

LOADINGS PER PASS			PASS A	PASS B	PASS C	PASS D
GPM LIQUID			716.954	718.024	716.954	0.0
GPH/FT WEIR			4475.820	3225.595	3561.914	0.0
CFS VAPOR			39.631	43.094	39.631	0.0
VAPOR LOAD		CFS	8.550	9.297	8.550	0.0
VLOAD/BUBBLE AREA		FPS	0.386	0.345	0.399	0.0
VLOAD/CFS LIQUID			5.352	5.811	5.352	0.0
DOWNCOMER FILLING CALCULATIONS						
DRY TRAY PRESSURE DROP	(HH)	IN	4.641	4.430	4.641	0.0
CLEAR LIQUID HEIGHT	(HL)	IN	2.012	2.405	2.376	0.0
TOTAL TRAY PRESSURE DROP	(HT)	IN	6.653	6.835	7.018	0.0
INLET HEAD	(HI)	IN	2.376	2.405	2.012	0.0
DC HEAD LOSS	(HDA)	IN	1.094	1.204	1.413	0.0
DC FILLING	(HDC)	IN	10.123	10.444	10.442	0.0
DC FILLING		PCT	48.207	49.732	49.725	0.0
ADDITIONAL CALCULATIONS						
PERCENT JET FLOOD			107.753	85.901	102.258	0.0
DC INLET VELOCITY		FPS	0.121	0.120	0.128	0.0

ALLOWABLE DC INLET VELOCITY	FPS	0.341
OVERALL TRAY EFFICIENCY	PCT	98.833

51

	1–80	
CARD #1	NCE TEST CASE: THREE PASS RATING	TITLE 1 (1)
CARD #2	DESIGNER: P.W. BECKER	TITLE 2 (1)
CARD #3	WITH VAPØR CRØSSØVER	TITLE 3 (1)

	VAPOR RATE MLBS/HR (1–10)	MIN. VAPOR RATE MLBS/HR (2) (11–20)	VAPOR DENSITY LB/CU FT (21–30)	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER (31–50)
CARD #4	618.	309.	1.403	1.

	LIQUID RATE MLBS/HR (1–10)	MIN. LIQ. RATE MLBS/HR (2) (11–20)	LIQUID DENSITY LB/CU FT (21–30)	LIQUID VISCOSITY CP (31–40)	SURFACE TENSION DYNES/CM (2) (41–50)
CARD #5	554.6	272.3	31.55	0.113	6.16

	TEMPERATURE DEG F (2) (1–10)	PRESSURE PSIA (2) (11–20)
CARD #6	140.	125.

	NO. OF PASSES 3 OR 4 (1–10)	HOLE DIAMETER INCHES (2) (11–20)	TOWER DIAMETER FEET (3) (21–30)	TRAY SPACING INCHES (3) (31–40)
CARD #7	3.	0.38	13.5	21.

Card	WIDTH #1 / WIDTH #6 (1–10)	WIDTH #2 / WIDTH #7 (11–20)	WIDTH #3 / WIDTH #8 (21–30)	WIDTH #4 / WIDTH #9 (31–40)	WIDTH #5 / WIDTH #10 (41–50)
CARD #8 (3,4)	24.	24.	21.	24.	24.
CARD #9 (3,4)	24.	21.	.	.	.

Card	OUTLET WEIR HT HWO (1–10)	INLET WEIR HT HWI (11–20)	DC CLEARANCE C (21–30)	HOLE AREA AO - SQ FT (31–40)	SHAPED LIP = 1.0 (41–50)	RECESSED BOX = 1.0 (51–60)	
CARD #10 (3,4)	1.25	.	1.54	.	2.39	.	PASS A
CARD #11 (3,4)	2.13	.	1.0	.	2.66	.	PASS B
CARD #12 (3,4)	2.0	.	1.0	.	2.39	.	PASS C
CARD #13 (3,4)	.	.	.	.	.	.	PASS D

	1–10
CARD #14 (5)	.

NCE TEST CASE: THREE PASS RATING

DESIGNER: P.W.BECKER

WITH VAPOR CROSSOVER

OPERATING CONDITIONS

MLBS/HR VAPOR MAX		618.000	MLBS/HR LIQUID MAX		544.600
MLBS/HR VAPOR MIN		309.000	MLBS/HR LIQUID MIN		272.300
LBS/CU FT VAPOR AT COND		1.403	LBS/CU FT LIQUID AT COND		31.550
TRAY LIQUID TEMPERATURE	DEG F	140.000	SURFACE TENSION AT COND	DYNES/CM	6.160
OPERATING PRESSURE	PSIA	125.000	VISCOSITY AT COND	CP	0.113
CFS VAPOR AT COND		122.357	LIQUID FLOW RATE	GPM	2151.932
VAPOR LOAD	CFS	26.396			

TRAY GEOMETRY

DIAMETER	FT	13.50
TRAY SPACING	IN	21.00
NUMBER OF PASSES		3.00
HOLE DIAMETER	IN	0.38
CROSS SECT AREA	SQ FT	143.14
BUBBLE/CROSS SECT AREA	PCT	49.30
VAPOR CROSSOVER (YES OR NO)		YES

		PASS A	PASS B	PASS C	PASS D
DOWNCOMER INLET WIDTH **	IN	24.000	12.000	12.000	0.0
DOWNCOMER OUTLET WIDTH **	IN	21.000	10.500	10.500	0.0
FLOW PATH LENGTH	IN	24.000	24.000	24.000	0.0
CHORD LENGTH AT TOP OF DC	IN	115.332	160.273	144.924	0.0
CHORD LENGTH AT BTM OF DC	IN	109.019	160.273	147.734	0.0
DC INLET AREA	SQ FT	13.168	13.286	12.506	0.0
DC OUTLET AREA	SQ FT	10.854	11.662	11.091	0.0
OUTLET WEIR HEIGHT	IN	1.250	2.130	2.000	0.0
INLET WEIR HEIGHT ON TRAY BELOW	IN	0.0	0.0	0.0	0.0
DC CLEARANCE TO TRAY BELOW	IN	1.540	1.000	1.000	0.0
SHAPED LIP (YES OR NO)		NO	NO	NO	NO
RECESSED BOX (YES OR NO)		NO	NO	NO	NO
BUBBLE AREA	SQ FT	22.174	26.949	21.448	0.0
FREE AREA	SQ FT	32.302	38.612	33.265	0.0
HOLE AREA	SQ FT	2.390	2.660	2.390	0.0
HOLE/BUBBLE AREA	PCT	10.778	9.870	11.143	0.0

** HALF WIDTH FOR PASSES B,C,D

LOADINGS PER PASS			PASS A	PASS B	PASS C	PASS D
GPM LIQUID			730.821	690.290	730.821	0.0
GPH/FT WEIR			4562.391	3101.006	3630.806	0.0
CFS VAPOR			40.347	43.209	38.792	0.0
VAPOR LOAD		CFS	6.704	9.321	8.369	0.0
VLOAD/BUBBLE AREA		FPS	0.393	0.346	0.390	0.0
VLOAD/CFS LIQUID			5.345	6.060	5.139	0.0

DOWNCOMER FILLING CALCULATIONS

DRY TRAY PRESSURE DROP	(HH)	IN	4.811	4.454	4.447	0.0
CLEAR LIQUID HEIGHT	(HL)	IN	2.026	2.331	2.389	0.0
TOTAL TRAY PRESSURE DROP	(HT)	IN	6.837	6.835	6.836	0.0
INLET HEAD	(HI)	IN	2.339	2.381	2.026	0.0
DC HEAD LOSS	(HDA)	IN	1.137	1.113	1.468	0.0
DC FILLING	(HDC)	IN	10.362	10.329	10.330	0.0
DC FILLING		PCT	49.345	49.185	49.191	0.0

ADDITIONAL CALCULATIONS

PERCENT JET FLOOD		110.636	85.206	100.716	0.0
DC INLET VELOCITY	FPS	0.124	0.116	0.130	0.0

ALLOWABLE DC INLET VELOCITY	FPS	0.341
OVERALL TRAY EFFICIENCY	PCT	93.833

MULTIPASS TRAY DESIGN PROGRAM

	1–80	
CARD #1	NCE TEST CASE: FØUR PASS DESIGN	TITLE 1 (1)
CARD #2	DESIGNER. P. W. BECKER	TITLE 2 (1)
CARD #3	NØ VAPØR CRØSSØVER	TITLE 3 (1)

	VAPOR RATE MLBS/HR (1–10)	MIN. VAPOR RATE MLBS/HR (2) (11–20)	VAPOR DENSITY LB/CU FT (21–30)	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER (31–50)
CARD #4	618.	309.	1.403	0.

	LIQUID RATE MLBS/HR (1–10)	MIN. LIQ. RATE MLBS/HR (2) (11–20)	LIQUID DENSITY LB/CU FT (21–30)	LIQUID VISCOSITY CP (31–40)	SURFACE TENSION DYNES/CM (2) (41–50)
CARD #5	554.6	272.3	31.55	0.113	6.16

	TEMPERATURE DEG F (2) (1–10)	PRESSURE PSIA (2) (11–20)
CARD #6	140.	125.

	NO. OF PASSES 3 OR 4 (1–10)	HOLE DIAMETER INCHES (2) (11–20)	TOWER DIAMETER FEET (3) (21–30)	TRAY SPACING INCHES (3) (31–40)
CARD #7	4.	0.38	.	.

	WIDTH #1 / WIDTH #6 (1–10)	WIDTH #2 / WIDTH #7 (11–20)	WIDTH #3 / WIDTH #8 (21–30)	WIDTH #4 / WIDTH #9 (31–40)	WIDTH #5 / WIDTH #10 (41–50)
CARD #8 (3,4)	.	.	.	.	.
CARD #9 (3,4)	.	.	.	.	.

	OUTLET WEIR HT HWO (1–10)	INLET WEIR HT HWI (11–20)	DC CLEARANCE C (21–30)	HOLE AREA AO - SQ FT (31–40)	SHAPED LIP = 1.0 (41–50)	RECESSED BOX = 1.0 (51–60)	
CARD #10 (3,4)	.	.	.	.	.	.	PASS A
CARD #11 (3,4)	.	.	.	.	.	.	PASS B
CARD #12 (3,4)	.	.	.	.	.	.	PASS C
CARD #13 (3,4)	.	.	.	.	.	.	PASS D

	(1–10)
CARD #14 (5)	.

DESIGN AND RATING PROGRAM FOR THREE AND FOUR PASS SIEVE TRAYS

NO3 TEST CASE: FOUR PASS DESIGN

DESIGNER: P.W.BECKER

NO VAPOR CROSSOVER

OPERATING CONDITIONS

MLBS/HR VAPOR MAX		618.000	MLBS/HR LIQUID MAX		544.600
MLBS/HR VAPOR MIN		309.000	MLBS/HR LIQUID MIN		272.300
LBS/CU FT VAPOR AT COND		1.403	LBS/CU FT LIQUID AT COND		31.550
TRAY LIQUID TEMPERATURE	DEG F	140.000	SURFACE TENSION AT COND	DYNES/CM	6.160
OPERATING PRESSURE	PSIA	125.000	VISCOSITY AT COND	CP	0.113
CFS VAPOR AT COND		122.357	LIQUID FLOW RATE	GPM	2151.932
VAPOR LOAD	CFS	25.396			

TRAY GEOMETRY

DIAMETER	FT	11.80
TRAY SPACING	IN	24.00
NUMBER OF PASSES		4.00
HOLE DIAMETER	IN	0.38
CROSS SECT AREA	SQ FT	109.45
BUBBLE/CROSS SECT AREA	PCT	77.40
VAPOR CROSSOVER (YES OR NO)		NO

		PASS A	PASS B	PASS C	PASS D
DOWNCOMER INLET WIDTH **	IN	8.396	3.593	3.531	3.531
DOWNCOMER OUTLET WIDTH **	IN	8.396	3.593	3.531	3.531
FLOW PATH LENGTH	IN	25.889	25.889	25.889	25.889
CHORD LENGTH AT TOP OF DC	IN	69.072	141.665	121.320	128.612
CHORD LENGTH AT BTM OF DC	IN	69.072	141.665	121.320	128.612
DC INLET AREA	SQ FT	2.804	3.452	3.009	3.101
DC OUTLET AREA	SQ FT	2.804	3.452	3.009	3.101
OUTLET WEIR HEIGHT	IN	2.944	2.944	2.944	2.944
INLET WEIR HEIGHT ON TRAY BELOW	IN	0.0	0.0	0.0	0.0
DC CLEARANCE TO TRAY BELOW	IN	1.144	1.144	1.144	1.144
SHAPED LIP (YES OR NO)		NO	NO	NO	NO
RECESSED BOX (YES OR NO)		NO	NO	NO	NO
BUBBLE AREA	SQ FT	17.549	24.807	17.549	24.807
FREE AREA	SQ FT	20.553	28.259	20.558	27.909
HOLE AREA	SQ FT	2.361	3.260	2.361	3.260
HOLE/BUBBLE AREA	PCT	13.451	13.141	13.451	13.141

** HALF WIDTH FOR PASSES B,C,D

LOADINGS PER PASS			PASS A	PASS B	PASS C	PASS D
GPM LIQUID			495.924	580.042	495.924	580.042
GPH/FT WEIR			5169.500	2948.019	2943.169	3247.218
CFS VAPOR			25.075	36.104	25.075	36.104
VAPOR LOAD		CFS	5.409	7.789	5.409	7.789
VLOAD/BUBBLE AREA		FPS	0.308	0.314	0.308	0.314
VLOAD/CFS LIQUID			4.895	6.026	4.895	6.026
DOWNCOMER FILLING CALCULATIONS						
DRY TRAY PRESSURE DROP	(HH)	IN	1.905	2.071	1.905	2.071
CLEAR LIQUID HEIGHT	(HL)	IN	3.312	2.921	2.920	2.978
TOTAL TRAY PRESSURE DROP	(HT)	IN	5.216	4.991	4.825	5.049
INLET HEAD	(HI)	IN	2.920	2.978	3.312	2.921
DC HEAD LOSS	(HDA)	IN	2.363	0.769	0.766	0.933
DC FILLING	(HDC)	IN	10.500	8.738	8.903	8.902
DC FILLING		PCT	43.749	36.410	37.094	37.093
ADDITIONAL CALCULATIONS						
PERCENT JET FLOOD			83.518	70.266	68.959	71.953
DC INLET VELOCITY		FPS	0.394	0.374	0.367	0.417

ALLOWABLE DC INLET VELOCITY	FPS	0.390
OVERALL TRAY EFFICIENCY	PCT	98.833

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	1–80	
CARD #1	NCE TEST CASE: FØUR PASS DESIGN	TITLE 1 (1)
CARD #2	DESIGNER: P.W. BECKER	TITLE 2 (1)
CARD #3	WITH VAPØR CRØSSØVER	TITLE 3 (1)

	VAPOR RATE MLBS/HR (1–10)	MIN. VAPOR RATE MLBS/HR (2) (11–20)	VAPOR DENSITY LB/CU FT (21–30)	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER (31–50)
CARD #4	618.	309.	1.403	1.

	LIQUID RATE MLBS/HR (1–10)	MIN. LIQ. RATE MLBS/HR (2) (11–20)	LIQUID DENSITY LB/CU FT (21–30)	LIQUID VISCOSITY CP (31–40)	SURFACE TENSION DYNES/CM (2) (41–50)
CARD #5	554.6	272.3	31.55	0.113	6.16

	TEMPERATURE DEG F (2) (1–10)	PRESSURE PSIA (2) (11–20)
CARD #6	140.	125.

	NO. OF PASSES 3 OR 4 (1–10)	HOLE DIAMETER INCHES (2) (11–20)	TOWER DIAMETER FEET (3) (21–30)	TRAY SPACING INCHES (3) (31–40)
CARD #7	4.	0.38	.	.

	WIDTH #1 / WIDTH #6 (1–10)	WIDTH #2 / WIDTH #7 (11–20)	WIDTH #3 / WIDTH #8 (21–30)	WIDTH #4 / WIDTH #9 (31–40)	WIDTH #5 / WIDTH #10 (41–50)
CARD #8 (3,4)	.	.	.	.	.
CARD #9 (3,4)	.	.	.	.	.

	OUTLET WEIR HT HWO (1–10)	INLET WEIR HT HWI (11–20)	DC CLEARANCE C (21–30)	HOLE AREA AO - SQ FT (31–40)	SHAPED LIP = 1.0 (41–50)	RECESSED BOX = 1.0 (51–60)	
CARD #10 (3,4)	.	.	.	.	.	.	PASS A
CARD #11 (3,4)	.	.	.	.	.	.	PASS B
CARD #12 (3,4)	.	.	.	.	.	.	PASS C
CARD #13 (3,4)	.	.	.	.	.	.	PASS D

	(1–10)
CARD #14 (5)	.

DESIGN AND RATING PROGRAM FOR THREE AND FOUR PASS SIEVE TRAYS

NCF TEST CASE: FOUR PASS DESIGN

DESIGNER: P.W.BECKER

WITH VAPOR CROSSOVER

OPERATING CONDITIONS

MLBS/HR VAPOR MAX		618.000	MLBS/HR LIQUID MAX		544.600
MLBS/HR VAPOR MIN		309.000	MLBS/HR LIQUID MIN		272.300
LBS/CU FT VAPOR AT COND		1.403	LBS/CU FT LIQUID AT COND		31.550
TRAY LIQUID TEMPERATURE	DEG F	140.000	SURFACE TENSION AT COND	DYNES/CM	6.160
OPERATING PRESSURE	PSIA	125.000	VISCOSITY AT COND	CP	0.113
CFS VAPOR AT COND		122.357	LIQUID FLOW RATE	GPM	2151.932
VAPOR LOAD	CFS	26.396			

TRAY GEOMETRY

DIAMETER	FT	11.80
TRAY SPACING	IN	24.00
NUMBER OF PASSES		4.00
HOLE DIAMETER	IN	0.38
CROSS SECT AREA	SQ FT	109.45
BUBBLE/CROSS SECT AREA	PCT	77.40
VAPOR CROSSOVER (YES OR NO)		YES

		PASS A	PASS B	PASS C	PASS D
DOWNCOMER INLET WIDTH **	IN	8.396	3.593	3.531	3.531
DOWNCOMER OUTLET WIDTH **	IN	8.396	3.593	3.531	3.531
FLOW PATH LENGTH	IN	25.889	25.889	25.889	25.889
CHORD LENGTH AT TOP OF DC	IN	69.072	141.665	121.320	128.612
CHORD LENGTH AT BTM OF DC	IN	69.072	141.665	121.320	128.612
DC INLET AREA	SQ FT	2.804	3.452	3.009	3.101
DC OUTLET AREA	SQ FT	2.804	3.452	3.009	3.101
OUTLET WEIR HEIGHT	IN	2.944	2.944	2.944	2.944
INLET WEIR HEIGHT ON TRAY BELOW	IN	0.0	0.0	0.0	0.0
DC CLEARANCE TO TRAY BELOW	IN	1.144	1.144	1.144	1.144
SHAPED LIP (YES OR NO)		NO	NO	NO	NO
RECESSED BOX (YES OR NO)		NO	NO	NO	NO
BUBBLE AREA	SQ FT	17.549	24.807	17.549	24.807
FREE AREA	SQ FT	20.353	28.259	20.558	27.909
HOLE AREA	SQ FT	2.361	3.260	2.361	3.260
HOLE/BUBBLE AREA	PCT	13.451	13.141	13.451	13.141

** HALF WIDTH FOR PASSES B,C,D

LOADINGS PER PASS			PASS A	PASS B	PASS C	PASS D
GPM LIQUID			470.998	604.968	470.998	604.968
GPH/FT WEIR			4909.668	3074.705	2795.239	3386.761
CFS VAPOR			24.480	36.698	26.119	35.060
VAPOR LOAD		CFS	5.281	7.917	5.635	7.563
VLOAD/BUBBLE AREA		FPS	0.301	0.319	0.321	0.305
VLOAD/CFS LIQUID			5.032	5.873	5.369	5.611
DOWNCOMER FILLING CALCULATIONS						
DRY TRAY PRESSURE DROP	(HH)	IN	1.315	2.139	2.067	1.953
CLEAR LIQUID HEIGHT	(HL)	IN	3.270	2.945	2.891	3.004
TOTAL TRAY PRESSURE DROP	(HT)	IN	5.085	5.085	4.957	4.957
INLET HEAD	(HI)	IN	2.891	3.004	3.270	2.945
DC HEAD LOSS	(HDA)	IN	2.132	0.836	0.691	1.014
DC FILLING	(HDC)	IN	10.108	8.925	8.918	8.917
DC FILLING		PCT	42.115	37.188	37.158	37.153
ADDITIONAL CALCULATIONS						
PERCENT JET FLOOD			79.577	72.139	71.008	70.663
DC INLET VELOCITY		FPS	0.374	0.391	0.349	0.435

ALLOWABLE DC INLET VELOCITY	FPS	0.390
OVERALL TRAY EFFICIENCY	PCT	98.833

CARD #1	NCE TEST CASE: THREE PASS DESIGN	TITLE 1 (1)
CARD #2	DESIGNER: P. W. BECKER	TITLE 2 (1)
CARD #3	NØ VAPØR CRØSSØVER	TITLE 3 (1)

	VAPOR RATE MLBS/HR	MIN. VAPOR RATE MLBS/HR (2)	VAPOR DENSITY LB/CU FT	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER
CARD #4	618.	309.	1.403	0.

	LIQUID RATE MLBS/HR	MIN. LIQ. RATE MLBS/HR (2)	LIQUID DENSITY LB/CU FT	LIQUID VISCOSITY CP	SURFACE TENSION DYNES/CM (2)
CARD #5	554.6	272.3	31.55	0.113	6.16

	TEMPERATURE DEG F (2)	PRESSURE PSIA (2)
CARD #6	140.	125.

	NO. OF PASSES 3 OR 4	HOLE DIAMETER INCHES (2)	TOWER DIAMETER FEET (3)	TRAY SPACING INCHES (3)
CARD #7	3.	0.38	.	.

	WIDTH #1 / WIDTH #6	WIDTH #2 / WIDTH #7	WIDTH #3 / WIDTH #8	WIDTH #4 / WIDTH #9	WIDTH #5 / WIDTH #10
CARD #8 (3,4)	.	.	.	.	.
CARD #9 (3,4)	.	.	.	.	.

	OUTLET WEIR HT HWO	INLET WEIR HT HWI	DC CLEARANCE C	HOLE AREA AO - SQ FT	SHAPED LIP = 1.0	RECESSED BOX = 1.0	
CARD #10 (3,4)	.	.	.	.	.	.	PASS A
CARD #11 (3,4)	.	.	.	.	.	.	PASS B
CARD #12 (3,4)	.	.	.	.	.	.	PASS C
CARD #13 (3,4)	.	.	.	.	.	.	PASS D

CARD #14 (5)	.

DESIGN AND RATING PROGRAM FOR THREE AND FOUR PASS SIEVE TRAYS

NCE TEST CASE: THREE PASS DESIGN

DESIGNER: P.W.BECKER

NO VAPOR CROSSOVER

OPERATING CONDITIONS

MLBS/HR VAPOR MAX		618.000	MLBS/HR LIQUID MAX		544.600
MLBS/HR VAPOR MIN		309.000	MLBS/HR LIQUID MIN		272.300
LBS/CU FT VAPOR AT COND		1.403	LBS/CU FT LIQUID AT COND		31.550
TRAY LIQUID TEMPERATURE	DEG F	140.000	SURFACE TENSION AT COND	DYNES/CM	6.160
OPERATING PRESSURE	PSIA	125.000	VISCOSITY AT COND	CP	0.113
CFS VAPOR AT COND		122.357	LIQUID FLOW RATE	GPM	2151.932
VAPOR LOAD	CFS	26.395			

TRAY GEOMETRY

DIAMETER	FT	11.94
TRAY SPACING	IN	24.00
NUMBER OF PASSES		3.00
HOLE DIAMETER	IN	0.38
CROSS SECT AREA	SQ FT	111.89
BUBBLE/CROSS SECT AREA	PCT	77.71
VAPOR CROSSOVER (YES OR NO)		NO

		PASS A	PASS B	PASS C	PASS D
DOWNCOMER INLET WIDTH **	IN	10.686	4.445	4.445	0.0
DOWNCOMER OUTLET WIDTH **	IN	10.686	4.445	4.445	0.0
FLOW PATH LENGTH	IN	37.655	37.655	37.655	0.0
CHORD LENGTH AT TOP OF DC	IN	75.693	140.414	135.412	0.0
CHORD LENGTH AT BTM OF DC	IN	75.693	140.414	135.412	0.0
DC INLET AREA	SQ FT	3.887	4.342	4.242	0.0
DC OUTLET AREA	SQ FT	3.887	4.342	4.242	0.0
OUTLET WEIR HEIGHT	IN	2.678	2.678	2.678	0.0
INLET WEIR HEIGHT ON TRAY BELOW	IN	0.0	0.0	0.0	0.0
DC CLEARANCE TO TRAY BELOW	IN	1.499	1.499	1.499	0.0
SHAPED LIP (YES OR NO)		NO	NO	NO	NO
RECESSED BOX (YES OR NO)		NO	NO	NO	NO
BUBBLE AREA	SQ FT	29.192	28.561	29.192	0.0
FREE AREA	SQ FT	33.079	32.903	33.434	0.0
HOLE AREA	SQ FT	3.485	4.272	3.485	0.0
HOLE/BUBBLE AREA	PCT	11.937	14.956	11.937	0.0

** HALF WIDTH FOR PASSES B,C,D

LOADINGS PER PASS			PASS A	PASS B	PASS C	PASS D
GPM LIQUID			682.473	786.937	632.473	0.0
GPH/FT WEIR			6491.785	4035.438	3628.785	0.0
CFS VAPOR			37.353	47.651	37.353	0.0
VAPOR LOAD		CFS	8.058	10.280	8.058	0.0
VLOAD/BUBBLE AREA		FPS	0.276	0.360	0.276	0.0
VLOAD/CFS LIQUID			5.299	5.862	5.299	0.0
DOWNCOMER FILLING CALCULATIONS						
DRY TRAY PRESSURE DROP	(HH)	IN	1.940	2.101	1.940	0.0
CLEAR LIQUID HEIGHT	(HL)	IN	3.332	2.936	2.863	0.0
TOTAL TRAY PRESSURE DROP	(HT)	IN	5.271	5.036	4.803	0.0
INLET HEAD	(HI)	IN	2.863	2.936	3.332	0.0
DC HEAD LOSS	(HDA)	IN	2.170	0.839	0.678	0.0
DC FILLING	(HDC)	IN	10.304	8.811	8.812	0.0
DC FILLING		PCT	42.934	36.711	36.718	0.0
ADDITIONAL CALCULATIONS						
PERCENT JET FLOOD			85.516	88.051	65.258	0.0
DC INLET VELOCITY		FPS	0.391	0.404	0.358	0.0

ALLOWABLE DC INLET VELOCITY	FPS	0.390
OVERALL TRAY EFFICIENCY	PCT	98.833

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	1–80	
CARD #1	NCE TEST CASE: THREE PASS DESIGN	TITLE 1 (1)
CARD #2	DESIGNER: P. W. BECKER	TITLE 2 (1)
CARD #3	WITH VAPØR CRØSSØVER	TITLE 3 (1)

Card	VAPOR RATE MLBS/HR (1–10)	MIN. VAPOR RATE MLBS/HR (2) (11–20)	VAPOR DENSITY LB/CU FT (21–30)	0. = NO VAPOR CROSSOVER 1. = VAPOR CROSSOVER (31–50)
CARD #4	618.	309.	1.403	1.

Card	LIQUID RATE MLBS/HR (1–10)	MIN. LIQ. RATE MLBS/HR (2) (11–20)	LIQUID DENSITY LB/CU FT (21–30)	LIQUID VISCOSITY CP (31–40)	SURFACE TENSION DYNES/CM (2) (41–50)
CARD #5	554.6	272.3	31.55	0.113	6.16

Card	TEMPERATURE DEG F (2) (1–10)	PRESSURE PSIA (2) (11–20)
CARD #6	140.	125.

Card	NO. OF PASSES 3 OR 4 (1–10)	HOLE DIAMETER INCHES (2) (11–20)	TOWER DIAMETER FEET (3) (21–30)	TRAY SPACING INCHES (3) (31–40)
CARD #7	3.	0.38	.	.

Card	WIDTH #1 / WIDTH #6 (1–10)	WIDTH #2 / WIDTH #7 (11–20)	WIDTH #3 / WIDTH #8 (21–30)	WIDTH #4 / WIDTH #9 (31–40)	WIDTH #5 / WIDTH #10 (41–50)
CARD #8 (3,4)	.	.	.	.	.
CARD #9 (3,4)	.	.	.	.	.

Card	OUTLET WEIR HT HWO (1–10)	INLET WEIR HT HWI (11–20)	DC CLEARANCE C (21–30)	HOLE AREA AO - SQ FT (31–40)	SHAPED LIP = 1.0 (41–50)	RECESSED BOX = 1.0 (51–60)	
CARD #10 (3,4)	.	.	.	.	.	.	PASS A
CARD #11 (3,4)	.	.	.	.	.	.	PASS B
CARD #12 (3,4)	.	.	.	.	.	.	PASS C
CARD #13 (3,4)	.	.	.	.	.	.	PASS D

	1–10
CARD #14 (5)	1.0

DESIGN AND RATING PROGRAM FOR THREE AND FOUR PASS SIEVE TRAYS

NCE TEST CASE: THREE PASS DESIGN

DESIGNER: P.W.BECKER

WITH VAPOR CROSSOVER

OPERATING CONDITIONS

MLBS/HR VAPOR MAX		618.000	MLBS/HR LIQUID MAX		544.600
MLBS/HR VAPOR MIN		309.000	MLBS/HR LIQUID MIN		272.300
LBS/CU FT VAPOR AT COND		1.403	LBS/CU FT LIQUID AT COND		31.550
TRAY LIQUID TEMPERATURE	DEG F	140.000	SURFACE TENSION AT COND	DYNES/CM	6.160
OPERATING PRESSURE	PSIA	125.000	VISCOSITY AT COND	CP	0.113
CFS VAPOR AT COND		122.357	LIQUID FLOW RATE	GPM	2151.932
VAPOR LOAD	CFS	26.395			

TRAY GEOMETRY

DIAMETER	FT	11.94
TRAY SPACING	IN	24.00
NUMBER OF PASSES		3.00
HOLE DIAMETER	IN	0.38
CROSS SECT AREA	SQ FT	111.89
BUBBLE/CROSS SECT AREA	PCT	77.71
VAPOR CROSSOVER (YES OR NO)		YES

		PASS A	PASS B	PASS C	PASS D
DOWNCOMER INLET WIDTH **	IN	10.686	4.445	4.445	0.0
DOWNCOMER OUTLET WIDTH **	IN	10.686	4.445	4.445	0.0
FLOW PATH LENGTH	IN	37.655	37.655	37.655	0.0
CHORD LENGTH AT TOP OF DC	IN	75.693	140.414	135.412	0.0
CHORD LENGTH AT BTM OF DC	IN	75.693	140.414	135.412	0.0
DC INLET AREA	SQ FT	3.887	4.342	4.242	0.0
DC OUTLET AREA	SQ FT	3.887	4.342	4.242	0.0
OUTLET WEIR HEIGHT	IN	2.678	2.678	2.678	0.0
INLET WEIR HEIGHT ON TRAY BELOW	IN	0.0	0.0	0.0	0.0
DC CLEARANCE TO TRAY BELOW	IN	1.499	1.499	1.499	0.0
SHAPED LIP (YES OR NO)		NO	NO	NO	NO
RECESSED BOX (YES OR NO)		NO	NO	NO	NO
BUBBLE AREA	SQ FT	29.192	28.561	29.192	0.0
FREE AREA	SQ FT	33.079	32.903	33.434	0.0
HOLE AREA	SQ FT	3.485	4.272	3.485	0.0
HOLE/BUBBLE AREA	PCT	11.937	14.956	11.937	0.0

** HALF WIDTH FOR PASSES B,C,D

LOADINGS PER PASS		PASS A	PASS B	PASS C	PASS D
GPM LIQUID		657.958	836.015	657.958	0.0
GPH/FT WEIR		6253.598	4286.844	3498.439	0.0
CFS VAPOR		35.404	47.176	39.776	0.0
VAPOR LOAD	CFS	7.638	10.177	8.581	0.0
VLOAD/BUBBLE AREA	FPS	0.262	0.356	0.294	0.0
VLOAD/CFS LIQUID		5.210	5.463	5.853	0.0

DOWNCOMER FILLING CALCULATIONS

DRY TRAY PRESSURE DROP	(HH)	IN	1.742	2.059	2.199	0.0
CLEAR LIQUID HEIGHT	(HL)	IN	3.296	2.979	2.839	0.0
TOTAL TRAY PRESSURE DROP	(HT)	IN	5.039	5.038	5.039	0.0
INLET HEAD	(HI)	IN	2.839	2.979	3.296	0.0
DC HEAD LOSS	(HDA)	IN	2.017	0.946	0.630	0.0
DC FILLING	(HDC)	IN	9.895	8.964	8.965	0.0
DC FILLING		PCT	41.230	37.350	37.356	0.0

ADDITIONAL CALCULATIONS

PERCENT JET FLOOD		79.056	89.091	68.751	0.0
DC INLET VELOCITY	FPS	0.377	0.429	0.346	0.0

ALLOWABLE DC INLET VELOCITY FPS 0.390

OVERALL TRAY EFFICIENCY PCT 98.833

Discussion of Sample Problem Output

The output for the first two sample problems (four pass rating cases) show that these trays should have no problems operating under the conditions inputted. The highest downcomer filling is about 37 percent, the highest percentage of jet flood is about 76, and the downcomer velocity for each downcomer is below the allowable value of 0.341 feet per second.

The three pass rating cases do show some potential problems, For both cases, the vapor velocities for passes A and C exceed 100 percent jet flood. This indicates that if the tower were run under these conditions, it is likely to flood. Note, however, that the downcomer velocities are well below the allowable level. Therefore, this tower could be made operable by changing the tray geometry so that the downcomers are smaller (this will increase the downcomer inlet velocities) and the bubbling areas greater. (This will reduce the percentages of jet flood.)

The three and four pass designs are, of course, workable, although downcomer velocities for some individual downcomers are slightly higher than allowable. Methods of balancing and improving such designs are discussed in Chapter IV.

CHAPTER VI

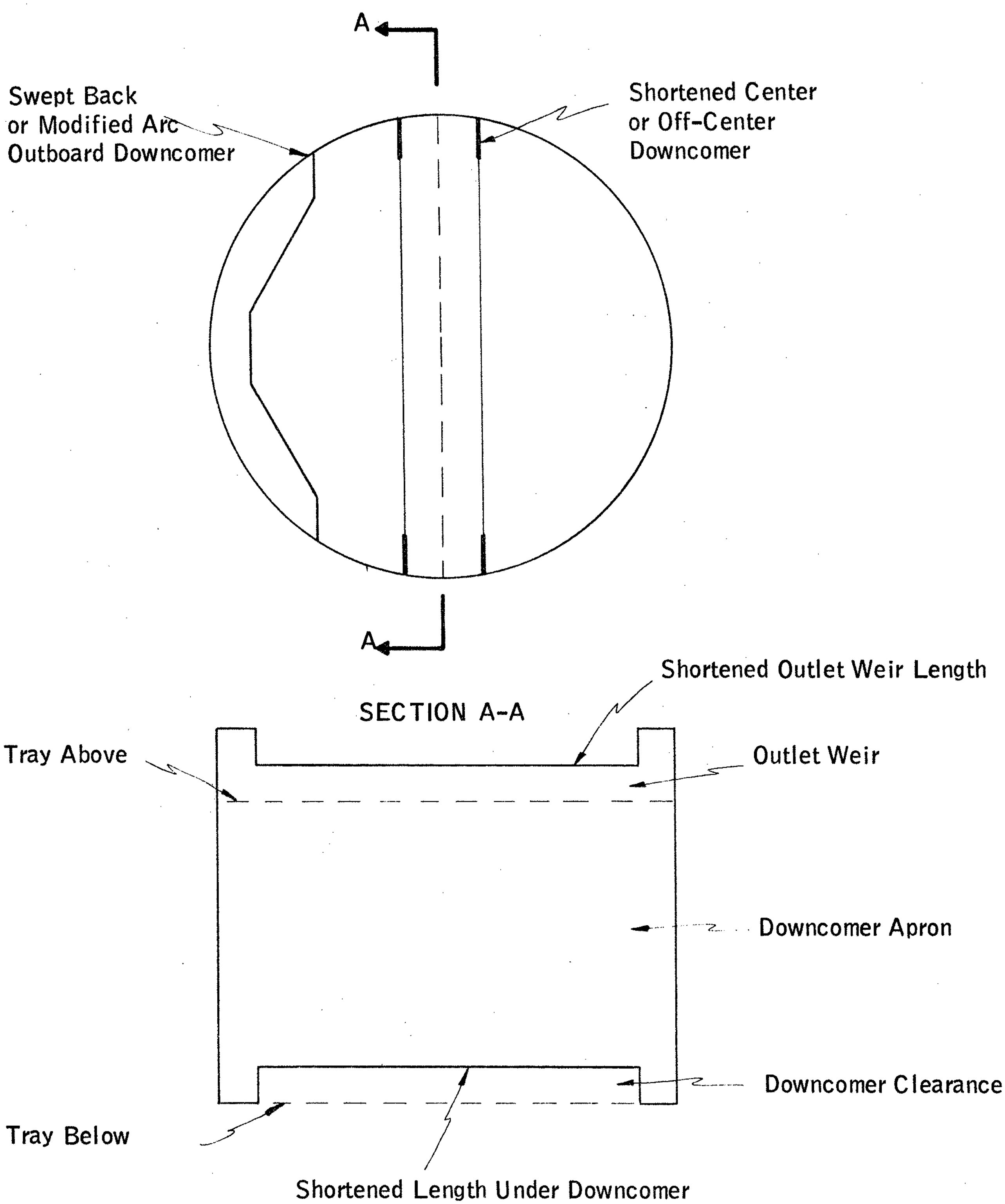
RECOMMENDATIONS FOR THE OPTIMUM DESIGN OF MULTIPASS TRAYS

This chapter presents the techniques recommended for the optimum design of multipass trays. The use of these techniques should provide designs with maximum flexibility and should eliminate those potential problems which have made engineers apprehensive about specifying multipass trays. In summary, the following rules are proposed for the design of multipass trays. They guarantee equal vapor and liquid flow rates for each pass.

1. Design for equal bubble areas and equal hole areas for each tray pass. This will enable each pass to accommodate equal vapor loadings. Equal downcomer areas are not necessary, and downcomers should be designed to meet the other criteria recommended.
2. Equalize weir lengths and lengths under downcomers for each pass, using the techniques depicted in Figure 10. Also, specify equal downcomer clearances and weir lengths for each pass. This will make the resistance to liquid flow the same for each pass.
3. Provide for vapor crossover through the downcomers using either pipes, ducts, or box-type downcomers, depicted in Figure 5. The box-type downcomer may be preferred by tray vendors as it is easier to fabricate. Also, the box-type downcomer provides another means of reducing downcomer weir

Figure 10

METHODS OF PROVIDING FOR EQUAL DOWNCOMER LENGTHS



length, as in recommendation 2. Vapor crossover will make the total tray pressure drop across each pass equal, and will provide a means of any vapor maldistribution (e.g. due to poor distribution at vapor inlet nozzles) to be corrected.

The first recommendation provides for equal dry tray pressure drops (HH) for each pass. The second recommendation provides for equal clear liquid heights (HL) and equal downcomer head losses (HDA) for each pass. If no inlet weirs or equal inlet weir heights and lengths are used, the tray inlet head (HI) will also be equal for each pass. Therefore, the total tray pressure drop (HT) will be equal for each pass. This is guaranteed by the third recommendation. Based on the equations presented in Chapters III and IV, these three recommendations guarantee equal vapor and liquid flowrates for each pass.

Although such a design may be slightly more difficult to fabricate than an equal flowpath length design (which can utilize tray panels of the same width), it has distinct advantages. An equal flowpath design, or, for that matter, any design, <u>can</u> be specified to provide any desired vapor and liquid split between the three or four passes. However, the desired split will <u>only</u> occur at the design vapor and liquid loadings. If the total vapor and liquid rates vary at all from the design values, the split will vary.

This variation is due to the fact that the clear liquid height equation is dependent on a term which includes the liquid rate, plus a constant term dependent on the weir height:

$$HL = \beta(HOW + HWO)$$

Where $HWO = 0.48 \times F_W (GPM/LWO)^{2/3}$

The head over the weir (HOW) depends on the liquid rate (GPM), but the weir height (HWO) is a constant.

For example, suppose the total liquid flowrate is 4000 GPM on a four pass tray. If the tray is designed for equal weir length and height, the clear liquid height for each pass will be equal. With weir height set at 2 inches and every weir length set at 200 inches, the clear liquid height for each pass with 1000 GPM is 2.38 inches ($F_W = 1.0$, $\beta = 0.7$).

$$HL = 0.7 \left[0.48 \times 1.0 \times (1000/200)^{2/3} + 2.0\right]$$

$$= 2.38 \text{ inches}$$

If one weir length is 240 inches, and another 120 inches, the two clear liquid heights can still be made equal for an equal liquid split by making the longer weir 2.16 inches high and the shorter weir only 1.43 inches high.

$$HL_A = 0.7 \left[0.48 \times 1.0 \times (1000/240)^{2/3} + 2.16\right]$$

$$= 2.38 \text{ inches}$$

$$HL_B = 0.7 \left[0.48 \times 1.0 \times (1000/120)^{2/3} + 1.43\right]$$

$$= 2.38 \text{ inches}$$

This example shows how even designs with unequal weir lengths <u>can</u> be made to have equal clear liquid heights for any given set of loadings. Only the weir height need be varied.

Suppose, however, that during the course of a tower's life, it must be operated at less than design rates. Suppose half rates, or a total liquid rate of 2000 GPM, were run through the tower. The equal weir length design would still have equal clear liquid heights for each pass.

$$HL = 0.7 \left[0.48 \times 1.0 \times (500/200)^{2/3} + 2.0\right]$$
$$= 2.02 \text{ inches}$$

However, the unequal weir length design, which gave equal clear liquid heights for the design rates, does not give equal clear liquid heights for half rates.

$$HL_A = 0.7 \left[0.48 \times 1.0 \times (500/240)^{2/3} + 2.16\right]$$
$$= 2.06 \text{ inches}$$
$$HL_B = 0.7 \left[0.48 \times 1.0 \times (500/120)^{2/3} + 1.43\right]$$
$$= 1.87 \text{ inches}$$

For this reason, if both designs were specified to provide for equal vapor and liquid rates to each pass for the design conditions, only the equal weir length design would have equal splits under all conditions. Only the equal weir length design provides for equal clear liquid heights for all conditions, which, combined with the other recommendations, guarantees equal vapor and liquid splits for each pass. Tray vendors have revealed that equal flowpath length designs have had operability problems due to imbalanced flowrates at other than design conditions (2).

The procedures presented in this chapter guarantee symmetrical multipass tray designs. Therefore, using these recommendations, engineers should have no "aversion" to specifying multipass trays in fractionating towers.

CHAPTER VII

CONCLUSIONS

This thesis has presented the case for the usefulness of multipass trays for large fractionating towers. An example will demonstrate how multipass trays are economically attractive.

Holland, et al (3) have stated that the cost of a tower of constant height increases linearly with capacity.

$$C_2/C_1 = Q_2/Q_1$$

Where C_2 and C_1 are costs for 2 towers and Q_1 and Q_2 are their respective capacities. Because capacity increases linearly with tower cross sectional area, it increases proportionately to the square of the diameter.

$$Q_2/Q_1 = (D_2/D_1)^2$$

Where D_2 and D_1 are the required tower diameters for the two towers. Therefore, tower cost increases with the square of tower diameter.

$$C_2/C_1 = (D_2/D_1)^2$$

Using this relationship we can compare the costs of towers using trays of varying number of liquid passes for a given service. For a system with a liquid load of 2000 GPM and a vapor load (V_L) of 37 cubic feet per second, one tray vendor (7) suggests the diameters given below for a typical column with 24 inch tray spacing. If the cost of the four pass design is set at 100, the relative costs of each of the other designs is given below.

No. of passes	Diameter (ft)	Relative Cost
1	18	192
2	14.5	124
3	13.5	108
4	13.0	100 (Base)

As shown in the table above, one, two and three pass designs are 92, 24 and 8 percent more costly than a four pass design. With the cost of large towers running in the six and seven figure range, substantial savings can be realized if multipass trays are used.

Through the use of the equations, recommendations, and computer program presented in this thesis, multipass fractionating tray design should be made easier to those engineers in the chemical and petroleum industries who do not have access to proprietary procedures. Although multipass trays sometimes have slightly lower tray efficiencies than trays with longer flowpath lengths, this effect becomes negligible for large size towers. Therefore, multipass trays are economical for many large tower designs, and should be specified more frequently by process design engineers.

A P P E N D I X

Fortran IV Computer Program for Rating and Designing Three and Four Pass Sieve Trays

```
                    C
                    C       FOUR PASS SIEVE TRAY RATING PROGRAM
                    C
0001                      REAL LFP, LTOT, L, LIQDES, LIQMIN, LBGAL,LWO,LWI,LUD,LFP,LIQCON,
                         1     NP
0002                      REAL LWOTOT,LUDTOT
0003                      DIMENSION W(14),HWO(4),HWI(4),C(4),AD(4),TITLE(60),ADCI(4),ADCO(4)
                         1          ,LWO(4),LWI(4),LUD(4),LFP(4),AB(4),AF(4),HED(4),HC(4),
                         2           HI(4),HUD(4),HD(4),SHAPE(4),RECBOX(4),ADAB(4)
                         3     ,L(4),XKHP(4),XKOP(4),V(4),VO(4),HT(4),PCTHD(4),VL(4),
                         4VLAB(4),S(4),GPHFTW(4),A(4),B(4),ALPHA(2),TABLE1(11)
0004                      DIMENSION HCKHL(4),VBJET(4),PCTJET(4),CFSL(4),DCVEL(4),GPHFTD(4)
0005                      DIMENSION TABLE2(72), TABLE3 (72) , TABLE4 (18)
0006                      DATA  ALPHA/' NO','YES'/
0007                      DATA TABLE1 / 8.0, 16.0, 2.0,
                         1              0.156, 0.232, 0.285, 0.314,
                         2              0.339, 0.359, 0.375, 0.390   /
0008                      DATA TABLE2 / 11.0, 0.0, 10.0,
                         1               4.0, 0.0, 2000.,
                         2    10.0,10.0,10.0,10.5,12.0,13.3,14.4,15.7,16.9,18.2,19.4,
                         3    10.0,10.0,10.5,12.3,13.5,14.9,16.2,17.5,18.9,20.2,21.5,
                         4    10.0,10.6,12.5,14.0,15.4,16.7,18.0,19.4,20.7,22.0,23.3,
                         5    10.5,12.8,14.4,15.2,16.7,18.2,19.7,21.2,22.7,24.2,25.7  /
0009                      DATA TABLE3 / 11.0, 0.0, 10.0,
                         1               6.0, 0.0, 1000.,
                         2     7.0, 7.0, 8.5,10.2,11.5,12.7,13.7,14.7,15.7,16.7,17.7,
                         3     7.0, 7.4, 9.4,11.1,12.6,13.8,14.8,15.8,17.0,18.1,19.2,
                         4     7.0, 8.6,10.6,12.3,13.7,14.9,16.2,17.4,18.6,19.8,21.0,
                         5     7.4, 9.9,12.2,13.8,15.3,16.5,17.9,19.2,20.5,21.8,23.0,
                         6     8.7,11.8,13.9,15.4,16.8,18.2,19.5,20.8,22.1,23.4,24.7,
                         7    11.4,14.0,15.7,17.3,18.9,19.5,21.1,22.7,24.3,25.9,27.5  /
0010                      DATA TABLE4 / 15.0,0.0,1.0,
                         1             10.0,36.2,50.0,60.4,68.6,76.0,82.4,
                         2             88.5,94.3,99.6,104.5,109.3,113.4,117.0,120.0   /
0011                      CALL RELOC
0012                 1000 VAPCON = 0.0
0013                      LIQCON = 0.0
                    C
                    C     USES FOLLOWING TYPICAL VALUES FOR 'FW' AND 'BETA'
                    C
0014                      FW = 1.00
0015                      BETA = 0.70
                    C
                    C     USES FOLLOWING TYPICAL VALUE OF CVO
                    C
0016                      CVO = 0.70
0017                      XCVO = 0.186*(1./CVO)**2.
                    C
                    C     READ INPUT DATA
                    C
0018                      READ 1001, TITLE
0019                 1001 FORMAT(20A4)
0020                      READ 1002, VAPDES, VAPMIN, RHOV,CROSS,
                         1           LIQDES, LIQMIN, RHOL, VISC, SURF,
```

```
                    2          TEMP, PSIA,
                    3          NP, DHOLE, DT , TS           ,
                    4          (W(I),I=1,5),
                    5          (W(K),K=6,10),
                    6          HWO(1), HWI(1), C(1), AO(1),SHAPE(1),RECBOX(1),
                    7          HWO(2), HWI(2), C(2), AO(2),SHAPE(2),RECBOX(2),
                    8          HWO(3), HWI(3), C(3), AO(3),SHAPE(3),RECBOX(3),
                    9          HWO(4), HWI(4), C(4), AO(4),SHAPE(4),RECBOX(4)    ,
                    A          AGAIN
0021          1002 FORMAT (2F10.3,F10.5,10X,F10.4,/,
                    1       2F10.3,F10.5,2F10.4,/,
                    2       2F10.3,/,
                    3       F10.3,3F10.5,/,
                    4       2(5F10.4,/),
                    5       4(6F10.4,/) ,
                    6       F10.4)
                 C
                 C      INTERMEDIATE CALCULATIONS: LOADINGS AND GEOMETRY
                 C
0022                    ZERO = 0.0
0023                    DRHOL = RHOL / (RHOL - RHOV)
0024                    VTOT = VAPDES /(RHOV * 3.6)
0025                    CFSLL= LIQDES /(RHOL * 3.6)
0026                    LTOT = CFSLL* 448.8
0027                    DRHOV = RHOV / (RHOL - RHOV)
0028                    VLTOT = VTOT * SQRT(DRHOV)
0029                    IF (TS.EQ.0.0) TS = 24.
                 C
                 C      DOWNCOMER INLET VELOCITY: A TYPICAL EQUATION
                 C
0030                    HFACT2 = TS/24.
0031                    RHOFAC = (RHOL - RHOV)
0032                    IF (RHOFAC.LT.16.)RHOFAC = 16.
0033                    IF (RHOFAC.GT.30.)RHOFAC = 30.
0034                    ALLVEL = STLU(RHOFAC,TABLE1)
0035                    ALLVEL = ALLVEL * HFACT2
0036                    TOTDCA = CFSLL/ALLVEL
0037                    IF (DT.GT.0.0) GO TO 1003
0038                    IF(VLTOT.GT.100. ) GO TO 2164
0039                    IF (NP.EQ.3.0) GO TO 1004
                 C
                 C      DESIGN - FOUR PASS
                 C
0040                    IF(LTOT.GT.6000.) GO TO 2162
0041                    DT = DTLU(VLTOT,LTOT,TABLE2)
0042                    ACS = .785 * (DT**2.)
                 C
                 C      4-PASS DC DESIGN
                 C
0043                    ADCI(1) = .21 * TOTDCA
0044                    ADCO(1) = ADCI(1)
0045                    W(1)     = RISE(100.*ADCI(1)/ACS) * 0.12 * DT
0046                    W(6)     = W(1)
0047                    W(8)     = 5.78 * TOTDCA/DT
```

```
0048                W(3)     = W(8)
0049                W25   = 6.9 *TOTDCA/DT
0050                W(6)  = W25  /2.
0051                W(10) = W(5)
0052                XFPL  = (12.*DT-(2.*W(1)+2.*W(8)+W25)) / NP
0053                W(2)  = XFPL
0054                W(4)  = XFPL
0055                W(7)  = XFPL
0056                W(9)  = XFPL
0057                GO TO 1003
              C
              C     DESIGN - THREE PASS
              C
0058           1004 IF(LTOT.GT.5000.) GO TO 2165
0059                DT = DTLU(VLTOT,LTOT,TABLE3)
0060                ACS = .785 * (DT**2.)
              C
              C     3-PASS DC DESIGN
              C
0061                ADCI(1) = .31 * TOTDCA
0062                ADCO(1) = ADCI(1)
0063                W(1)     = RISE (100.*ADCI(1)/ACS) * 0.12 * DT
0064                W(7)     = W(1)
0065                W(5)     = 8.63 * TOTDCA / DT
0066                W(3)     = W(5)
0067                XFPL     = (12.*DT-(2.*W(1)+W(5)))/NP
0068                W(2)     = XFPL
0069                W(4)     = XFPL
0070                W(6)     = XFPL
0071           1003 CONTINUE
0072                ACS = 0.7854 *(DT**2.)
0073                ADCI(1) = REA((100.*W(1))/(12.*DT))*ACS * 0.01
0074                LWD(1)  =CHRD (100.*ADCI(1)/ACS) * DT * 0.12
0075                XW1= W(1) + W(2)
0076                XA1      = REA((100.*XW1) /(12.*DT))*ACS * 0.01
0077                AB(1)    = XA1    - ADCI(1)
0078                LUD(3)   = CHRD (100.*XA1 /ACS)    * DT * 0.12
0079                LWI(3)   = LUD(3)
0080                LFP(1)   = W(2)
0081                XW2 = XW1 + W(3)/2.
0082                XA2 = REA((100.*XW2) / (12.*DT)) *ACS  * 0.01
0083                ADCO(3) = XA2 - XA1
0084                XW3 = XW2 + W(3)/2.
0085                XA3 = REA((100.*XW3) / (12.*DT)) *ACS  * 0.01
0086                IF(NP.EQ.3.) GO TO 500
0087                ADCO(4) = XA3 - XA2
0088                LUD(4)   = CHRD (100.*XA3 / ACS)   * DT * 0.12
0089                LWI(4)   = LUD(4)
0090                XW4 = XW3 + W(4)
0091                XA4 = REA((100.*XW4)/(12.*DT)) * ACS * 0.01
0092                AB(2)    =XA4 - XA3
0093                LFP(2)   = W(4)
0094                LWD(2)   = CHRD((100.*XA4/ACS)) * DT * 0.12
0095                ADCI(2) =(ACS/2.) - XA4
```

74

```
      ADCO(1) =REA((100.*W(6)) /(12.*DT)) *  ACS * 0.01
      LWI(1)  =CHRD (100.*ADCO(1)/ACS)    *   DT * 0.12
      LUD(1)  = LWI(1)
      XW5 = W(6) + W(7)
      XA5 =    REA((100.*XW5)/(12.*DT))   *  ACS * 0.01
      AB(3)   =XA5 - ADCO(1)
      LFP(3) = W(7)
      LWO(3) = CHRD (100.*XA5/ACS)        *   DT * 0.12
      XW6 = XW5 + W(8)/2.
      XA6 = REA((100.*XW6)/(12.*DT))      *  ACS * 0.01
      ADCI(3) = XA6 - XA5
      XW7 = XW6 + W(8)/2.
      XA7 = REA((100.*XW7)/(12.*DT))      *  ACS * 0.01
      ADCI(4) = XA7 - XA6
      LWO(4)  = CHRD(100.*XA7/ACS)        *   DT * 0.12
      XW8 = XW7 + W(9)
      XA8 = REA((100.*XW8)/(12.*DT))      *  ACS * 0.01
      AB(4) = XA8 - XA7
      LFP(4) = W(9)
      LWI(2) =  CHRD(100.*XA8/ACS)        *   DT * 0.12
      LUD(2) = LWI(2)
      ADCO(2) =(ACS/2.)-XA8
      WW3 = W(3)/2.
      WW8 = W(8)/2.
      GO TO 501
  500 ADCO(2) = XA3 - XA2
      LUD(2)  = CHRD (100.*XA3 / ACS) * DT * 0.12
      LWI(2)  = LUD(2)
      ADCO(1) = REA((100.*W(7))/(12.*DT))*ACS * 0.01
      LUD(1)  = CHRD(100.*ADCO(1)/ACS) * DT * 0.12
      LWI(1)  = LUD(1)
      XW4 = W(7) + W(6)
      XA4 = REA((100.*XW4)/(12.*DT))*ACS * 0.01
      AB(3) = XA4 - ADCO(1)
      LWO(3)  = CHRD (100.*XA4 / ACS) * DT * 0.12
      LFP(3)  = W(6)
      XW5 = XW4  + W(5)/2.
      XA5 = REA((100.*XW5)/(12.*DT))*ACS * 0.01
      ADCI(3) = XA5 - XA4
      XW6 = XW5  + W(5)/2.
      XA6 = REA((100.*XW6)/(12.*DT))*ACS * 0.01
      ADCI(2) = XA6 - XA5
      LWO(2)  =CHRD(100.*XA6 / ACS) * DT * 0.12
      AB(2) = ACS - XA6 - XA3
      LFP(2) = W(4)
      LFP(4) = 0.0
      AB(4)  = 0.0
      LUD(4) = 0.0
      LWI(4) = 0.0
      LWO(4) = 0.0
      ADCI(4)= 0.0
      ADCO(4)= 0.0
      WW3= W(3)/2.
      WW5= W(5)/2.
```

```
  501 CONTINUE
C
C     CALCULATING MINIMUM FREE AREAS
C
      AF(1) =                         AB(3) + ADCO(1)
      IF(NP.EQ.3.)GO TO 502
      AF(2) =                         AB(4) + ADCO(2)
      AF(3) =                         AB(1) + ADCO(3)
      AF(4) =                         AB(2) + ADCO(4)
      ABAS  =AMIN1((2*AB(1) + 2*AB(2))/ACS ,(2*AB(3)+2*AB(4))/ACS)*100.
      GO TO 503
  502 AF(2) = AB(2) + ADCO(2)
      AF(3) = AB(1) + ADCO(3)
      AF(4) = 0.0
      ABAS= ((AB(1)+AB(2)+AB(3))/ACS)*100.
  503 CONTINUE
      IF(C(1).NE.0.0) GO TO 5503
C
C     DESIGN OF CLEARANCE,WEIR HEIGHT, AND HOLE AREA
C
C     SET HWO SUCH THAT HC = 3 INCHES
      LWOTOT = LWO(1)+LWO(2)+LWO(3)+LWO(4)
      HWOX= (3.-.48*BETA*FW*((LTOT/LWOTOT)**0.667))/BETA
      DO 901 I=1,4
  901 HWO(I) = HWOX
      IF(NP.EQ.3.0) HWO(4)=0.0
C     SET C SUCH THAT HUD = 1 INCH
C     CMAX = 3 INCHES
C     CMIN = 1 INCH
      LUDTOT=LUD(1)+LUD(2)+LUD(3)+LUD(4)
      DO 902 I=1,4
      SHAPE(I) = 0.0
  902 C(I)=.2449* LTOT/LUDTOT
      IF(C(1).LE.3.0) GO TO 903
      DO 904 I=1,4
      SHAPE(I) = 1.0
      C(I)=.1732* LTOT/LUDTOT
  904 C(I)=AMIN1(C(I),3.0)
  903 DO 906 I=1,4
  906 C(I) = AMAX1 (C(I),1.0)
       IF (NP.EQ.3.0)  C(4) = 0.0
C     SET AO SUCH THAT HED = 2 INCHES
      AOTOT =(SQRT ((XCVO*RHOV)/(2.*RHOL))   ) * VTOT
      IF(NP.EQ.4.0)GO TO 905
      AO(1) = 0.31 * AOTOT
      AO(2) = 0.38 * AOTOT
      AO(3) = 0.31 * AOTOT
      AO(4) = 0.0
      GO TO 5503
  905 AO(1) = 0.21 *AOTOT
      AO(2) = 0.29 *AOTOT
      AO(3) = 0.21 *AOTOT
      AO(4) = 0.29 *AOTOT
 5503 CONTINUE
```

```
              M=NP
              DO 2  I=1,M
            2 ADAB(I) =(AD(I)/AB(I))*100.
              IF(NP.EQ.3.) ADAB(4)=0.0
C
C             DOUBLE TRIAL AND ERROR TO DETERMINE LIQUID AND VAPOR FLOW SPLITS
C             PER  PASS. FOUR PASS - NO VAPOR CROSSOVER.
C             FIRST GUESS: ASSUME FLOW PER PASS IS 1/4 TOTAL FLOW.
C             DO LOOP FOR VAPOR SPLIT(50) WITHIN DO LOOP FOR LIQUID SPLIT(100).
C
              IF(NP.EQ.3.) GO TO 504
              L(1) = LTOT/4.
              DELTAL = .03 * LTOT
              DO 100 JL=1,40
              L(2)  = 0.50 * LTOT - L(1)
              L(3)  = L(1)
              L(4)  = L(2)
              DO 16 I=1,4
              HC(I) = 0.48*BETA*FW*(L(I)/LWO(I))**0.667 + BETA*HWO(I)
              IF(SHAPE(I)) 11,11,12
           11 HUD(I) = 0.06 * ( L(I) / (C(I)*LUD(I))) ** 2.
              GO TO 13
           12 HUD(I) = 0.03 * ( L(I) / (C(I)*LUD(I))) ** 2.
           13 HI(I)  =0.48*( L(I)/LWI(I) )**0.667 + HWI(I)
              IF(HWI(I).GE.C(I).OR.RECBOX(I).GT.0.0) HUD(I) = 2*HUD(I)
           16 CONTINUE
              IF(HWI(I).GT.0.0) GO TO 14
              HI(1)=HC(3)
              HI(2)=HC(4)
              HI(3)=HC(1)
              HI(4)=HC(2)
           14 CONTINUE
              IF(CROSS.NE.1.0)GO TO 15
C
C             TRIAL AND ERROR TO DETERMINE LOADINGS. FOUR PASS - WITH VAPOR CROSSOVER
C             SOLVE FOR L'S AND V1/V2, V3/V4 INDEPENDENTLY
C
              HI3 = HI(4) + HUD(4) - HUD(3)
              IF(HWI(3).LE.0.0) GO TO 303
              QLTERM =(HI3-HWI(3))/0.48
              QLT = QLTERM**1.5
              QL1 = QLT*LWI(3)
              IF(ABS(QL1-L(1)).LT.0.01) GO TO 107
              IF(QL1.GT.L(1).AND.DELTAL.LE.0.0) DELTAL = -0.4*DELTAL
              IF(QL1.LT.L(1).AND.DELTAL.GE.0.0) DELTAL = -0.4*DELTAL
              L(1) = L(1) + DELTAL
              GO TO 100
          303 QLTERM =(HI3-BETA*HWO(1))/(0.48*FW*BETA)
              QLT= QLTERM**1.5
              QL1= QLT*LWO(1)
              IF(ABS(QL1-L(1)).LT.0.01) GO TO 107
              IF(QL1.GT.L(1).AND.DELTAL.LE.0.0) DELTAL = -0.4*DELTAL
              IF(QL1.LT.L(1).AND.DELTAL.GE.0.0) DELTAL = -0.4*DELTAL
              L(1) = L(1) + DELTAL
```

```
             GO TO 100
       C
       C     TRIAL AND ERROR FOR VAPOR SPLIT
       C
          15 V(1) = VTOT/4.
             DO 50 IV =1,50
             V(2) = 0.5*VTOT - V(1)
             V(3) = V(1)
             V(4) = V(2)
             DO 20 I=1,4
             VO(I) = V(I) / AO(I)
             HED(I)= XCVO              *((VO(I))**2.)* RHOV / RHOL
             HT(I) = HC(I) + HED(I)
          20 CONTINUE
             HED3 = HT(4) +HUD(4) + HI(4)        -HC(3) -HJD(3) -HI(3)
             VO3  = SQRT((HED3*RHOL)/(RHOV*XCVO))
             V3   = VO3 * AO(3)
             IF (ABS(V3 - V(3)).LT.0.01) GO TO 55
          50 V(1) = AMIN1( (V(3)+V3)/2. , 0.49*VTOT )
             VAPCON=1.0
          55 HC1 = HT(2) +HT(4) - HT(3) - HED(1)
             QLTERM = (HC1-BETA*HWO(1)) / (0.48*FW*BETA)
             QLT    = QLTERM ** 1.5
             QL1    = QLT * LWO(1)
         101 IF(ABS(QL1-L(1)).LT.0.01) GO TO 107
             IF(QL1.GT.L(1).AND.DELTAL.GE.0.0) DELTAL = -0.4*DELTAL
             IF(QL1.LT.L(1).AND.DELTAL.LE.0.0) DELTAL = -0.4*DELTAL
             L(1) = L(1) + DELTAL
         100 L(1) = AMIN1(L(1),0.49*LTOT)
             LIQCON=1.0
         107 IF(CROSS.NE.1.0)GO TO 105
       C
       C     VAPOR SPLIT - FOUR PASS - WITH VAPOR CROSSOVER
       C
             V(1)=VTOT/4.
             DO 400 I1=1,50
             V(2) = 0.50 * VTOT - V(1)
             VO(2)= V(2)/AO(2)
             HED(2)= XCVO * ((VO(2))**2.) * RHOV / RHOL
             HT(2) = HC(2)+HED(2)
             HED1  = HT(2) - HC(1)
             VO1   = SQRT((HED1*RHOL)/(RHOV*XCVO))
             V1    = VO1 * AO(1)
             IF (ABS(V1-V(1)).LT.0.01) GO TO 401
         400 V(1) = AMIN1((V(1)+V1)/2.,0.49*VTOT)
             VAPCON = 1.0
         401 V(3) = VTOT/4.
             DO 402 I2=1,50
             V(4) = 0.50*VTOT-V(3)
             VO(4)= V(4)/AO(4)
             HED(4)=XCVO*((VO(4))**2.) * RHOV/RHOL
             HT(4) =HC(4) +HED(4)
             HED3  = HT(4) - HC(3)
             VO3   = SQRT((HED3*RHOL)/(RHOV*XCVO))
```

```
          V3     = V03 * AO(3)
          IF(ABS(V3-V(3)).LT.0.01) GO TO 403
      402 V(3)=AMIN1((V(3)+V3)/2.,0.49*VTOT)
          VAPCON =1.0
      403 CONTINUE
          GO TO 505
C
C         THREE PASS
C
      504 L(4)=0.0
          V(4)=0.0
          L(1)=LTOT/3.
          DELTAL=.03*LTOT
          DO 600 JL=1,40
          L(3)=L(1)
          L(2)=LTOT -L(3) -L(1)
          DO 616 I=1,3
          HC(I) = 0.48*BETA*FW*(L(I)/LWO(I))**0.667 + BETA*HWO(I)
          IF(SHAPE(I))611,611,612
      611 HUD(I) = 0.06 * ( L(I) / (C(I)*LUD(I))) ** 2.
          GO TO 613
      612 HUD(I) = 0.03 * ( L(I) / (C(I)*LUD(I))) ** 2.
      613 HI(I)  =0.48*( L(I)/LWI(I) )**0.667 + HWI(I)
          IF(HWI(I).GE.C(I).OR.RECBOX(I).GT.0.0) HUD(I) = 2*HUD(I)
      616 CONTINUE
          IF(HWI(I).GT.0.0) GO TO 614
          HI(1) = HC(3)
          HI(2) = HC(2)
          HI(3) = HC(1)
      614 CONTINUE
          IF(CROSS.NE.1.0) GO TO 615
C
C         THREE PASS -  L/V SPLIT  - WITH VAPOR CROSSOVER
C
          HI3    = HI(2) + HUD(2) - HUD(3)
          IF(HWI(3).LE.0.0) GO TO 703
          QLTERM = (HI3-HWI(3))/0.48
          QLT    = QLTERM**1.5
          QL1    = QLT*LWI(3)
          IF(ABS(QL1-L(1)).LT.0.01) GO TO 607
          IF(QL1.GT.L(1).AND.DELTAL.LE.0.0) DELTAL = -0.4*DELTAL
          IF(QL1.LT.L(1).AND.DELTAL.GE.0.0) DELTAL = -0.4*DELTAL
          L(1) = L(1) + DELTAL
          GO TO 600
      703 QLTERM =(HI3-BETA*HWO(1))/(0.48*FW*BETA)
          QLT    =QLTERM**1.5
          QL1    =QLT * LWO(1)
          IF(ABS(QL1-L(1)).LT.0.01) GO TO 607
          IF(QL1.GT.L(1).AND.DELTAL.LE.0.0) DELTAL = -0.4*DELTAL
          IF(QL1.LT.L(1).AND.DELTAL.GT.0.0) DELTAL = -0.4*DELTAL
          L(1) = L(1) + DELTAL
          GO TO 600
C
C         VAPOR SPLIT
```

```
C
  615 V(1) = VTOT/3.
      DO 650 IV=1,50
      V(3)= V(1)
      V(2)= VTOT -V(1) -V(3)
      DO 620 I=1,3
      VO(I)=V(I)/AO(I)
      HED(I)=XCVO * ((VO(I))**2.)*RHOV/RHOL
      HT(I) =HC(I)+HED(I)
  620 CONTINUE
      HED1 = HT(2) + HI(3) + HUD(3) - HC(1) - HI(2) - HUD(2)
      VO1  = SQRT((HED1*RHOL)/(RHOV*XCVO))
      V1   = VO1* AO(1)
      IF  (ABS(V1 - V(1)).LT.0.01) GO TO 655
  650 V(1) = AMIN1((V(1)+V1)/2. , 0.49*VTOT )
      VAPCON = 1.0
  655 HC1 =2.*HT(2) - HT(3) - HED(1)
      QLTERM = (HC1-BETA*HWO(1)) / (0.48*FW*BETA)
      QLT    = QLTERM ** 1.5
      QL1    = QLT * LWO(1)
  601 IF(ABS(QL1-L(1)).LT.0.01) GO TO 607
      IF(QL1.LT.L(1).AND.DELTAL.GE.0.0) DELTAL=-0.4*DELTAL
      IF(QL1.GT.L(1).AND.DELTAL.LE.0.0) DELTAL=-0.4*DELTAL
      L(1) = L(1) +DELTAL
  600 L(1) = AMIN1(L(1),0.49*LTOT)
      LIQCON = 1.0
  607 IF(CROSS.NE.1.0)GO TO 105
C
C     VAPOR SPLIT - THREE PASS - WITH VAPOR CROSSOVER
C
      V(1) = VTOT/3.
      V(2) = V(1)
  799 DO 800 I3 = 1,50
      V(3) = VTOT - V(1) - V(2)
      DO 801 I=2,3
      VO(I) = V(I) / AO(I)
      HED(I) = XCVO*((VO(I))**2.)*RHOV/RHOL
  801 HT(I)  = HED(I) + HC(I)
      HED2 = HT(3) - HC(2)
      VO2  = SQRT((HED2*RHOL)/(RHOV*XCVO))
      V2   = VO2 * AO(2)
      IF (ABS(V2-V(2)).LT.0.01) GO TO 802
  800 V(2) =AMIN1((V(2)+V2)/2.,0.67*VTOT)
      VAPCON = 1.0
  802 CONTINUE
      DO 803 I4=1,50
      VO(1) = V(1)/AO(1)
      HED(1)= XCVO*((VO(1))**2.)*RHOV/RHOL
      HT(1) = HED(1) + HC(1)
      HED1  = HT(2) - HC(1)
      VO1   = SQRT((HED1*RHOL)/(RHOV*XCVO))
      V1 = VO1 * AO(1)
      IF (ABS(V1-V(1)).LT.0.01) GO TO 804
  803 V(1) =AMIN1((V(1) + V1)/2.,0.67*VTOT)
```

```
0381            VAPCON = 1.0
0382        804 TRYVT = V(1)+V(2)+V(3)
0383            IF (ABS(TRYVT - VTOT) .GT. 0.01 )  GO TO 799
0384        505 CONTINUE
0385            DO 404 I =1,M
0386            VD(I)=V(I) / AD(I)
0387            HED(I)= XCVD * ((VD(I))**2.) * RHOV / RHOL
0388        404 HT(I) = HED(I) + HC(I)
          C
          C     DOWNCOMER FILLING CALCULATIONS
          C
0389        105 DO 106 I=1,M
          C
          C     ASSUME NO LIQUID GRADIENT ACROSS TRAY
          C
0390            GRAD = 0.0
0391            HD(I) =(HT(I)+HUD(I))        + HI(I) + GRAD
0392        106 CONTINUE
0393            DO 3 I=1,M
0394            PCTHD(I) =(HD(I)/TS)*100.
0395            VL(I) = V(I) * SQRT(DRHOV )
0396            VL(I) = V(I) * SQRT(DRHOV )
0397            VLAB(I) = VL(I) / AB(I)
0398            S(I)    = VL(I) /(L(I)/448.8)
0399            GPHFTW(I) =(L(I)*60.)/(LWD(I)/12.)
0400          3 CONTINUE
          C
          C     ADDITIONAL CALCULATIONS
          C
          C
          C     JET FLOOD: A TYPICAL EQUATION
          C
0401            HFACT1 = SQRT(TS/24.)
0402            DO 203 I=1,M
0403            VBJET(I) = HFACT1 * 0.55 - 0.035 * ( GPHFTW(I)/1000. )
0404        203 PCTJET(I)=(VLAB(I)/VBJET(I)) * 100.
0405            DO 204 I=1,M
0406            CFSL(I) = L(I)/448.8
0407        204 DCVEL(I) = CFSL(I)/ADCI(I)
          C
          C
          C     TRAY EFFICIENCY
          C
0408            FLUID = 1./VISC
0409            IF(FLUID.GT.14.  ) FLUID=14.
0410            EFFCY = STLU(FLUID,TABLE4)
          C     PRINTING RESULTS
          C
0411            DO 1 I=1,4
0412            A(I)=ALPHA(1)
0413            IF(SHAPE(I).GT.0.0) A(I)=ALPHA(2)
0414            B(I)=ALPHA(1)
0415            IF(RECBOX(I).GT.0.0) B(I)=ALPHA(2)
0416          1 CONTINUE
```

```
                CROSSI = ALPHA(1)
                IF (CROSS .GT.0.0) CROSSI = ALPHA(2)
                PRINT 2001
          2001 FORMAT(1H1,//,34X,'DESIGN AND RATING PROGRAM FOR THREE AND FOUR PA
              1SS SIEVE TRAYS',25X,'PAGE1',//)
                PRINT 2002, TITLE
          2002 FORMAT(2(24X,20A4,//),24X ,20A4,/)
                PRINT 2003
          2003 FORMAT(1X,'OPERATING CONDITIONS')
                PRINT 2004
          2004 FORMAT(1X,'--------------------',/)
                PRINT 2005,VAPDES, LIQDES
          2005 FORMAT(1X,'MLBS/HR VAPOR MAX',22X,F10.3,10X,'MLBS/HR LIQUID MAX',
              122X,F10.3)
                PRINT 2006,VAPMIN, LIQMIN
          2006 FORMAT(1X,'MLBS/HR VAPOR MIN',22X,F10.3,10X,'MLBS/HR LIQUID MIN',
              122X,F10.3)
                PRINT 2007,RHOV, RHOL
          2007 FORMAT(1X,'LBS/CU FT VAPOR AT COND',16X,F10.3,10X,
              1          'LBS/CU FT LIQUID AT COND',16X,F10.3)
                PRINT 2008,TEMP,SURF
          2008 FORMAT(1X,'TRAY LIQUID TEMPERATURE',6X,'DEG F',5X,F10.3,10X,
              1'SURFACE TENSION AT COND',7X,'DYNES/CM',2X,F10.3)
                PRINT 2009,PSIA,VISC
          2009 FORMAT(1X,'OPERATING PRESSURE',11X,'PSIA',6X,F10.3,10X,
              1'VISCOSITY AT COND',13X,'CP',8X,F10.3)
                PRINT 2010,VTOT,LTOT
          2010 FORMAT(1X,'CFS VAPOR AT COND',22X,F10.3,10X,
              1'LIQUID FLOW RATE',14X,'GPM',7X,F10.3 )
                PRINT 2011,VLTOT
          2011 FORMAT(1X,'VAPOR LOAD',19X,'CFS',7X,F10.3,/)
                PRINT 2012
          2012 FORMAT(1X,'TRAY GEOMETRY')
                PRINT 2013
          2013 FORMAT(1X,'-------------',/)
                PRINT 2014,DT
          2014 FORMAT(1X,'DIAMETER',21X,'FT',5X,F6.2)
                PRINT 2015,TS
          2015 FORMAT(1X,'TRAY SPACING',17X,'IN',5X,F6.2)
                PRINT 2016,NP
          2016 FORMAT(1X,'NUMBER OF PASSES',20X,F6.2)
                PRINT 2017,DHOLE
          2017 FORMAT(1X,'HOLE DIAMETER',16X,'IN',5X,F6.2)
                PRINT 2018,ACS
          2018 FORMAT(1X,'CROSS SECT AREA',14X,'SQ FT',2X,F6.2)
                PRINT 2019,ABAS
          2019 FORMAT(1X,'BUBBLE/CROSS SECT AREA',7X,'PCT',4X,F6.2)
                PRINT 2120, CROSSI
          2120 FORMAT(1X,'VAPOR CROSSOVER (YES OR NO)',12X,A3,/)
                PRINT 2020
          2020 FORMAT(42X,'  PASS A  ',10X,'  PASS B  ',10X,'  PASS C  ',10X,
              1'  PASS D  ')
                PRINT 2021
          2021 FORMAT(42X,'----------',10X,'----------',10X,'----------',10X,
```

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                    1'-----------',/)
0463                 IF(NP.EQ.4) GO TO 2122
0464                 PRINT 2022,W(1),WW5,WW5,ZERO
0465                 PRINT 2023,W(7),WW3,WW3,ZERO
0466                 GO TO 2124
0467           2122 PRINT 2022,W(1),W(5),WW8,WW8
0468           2022 FORMAT(1X,'DOWNCOMER INLET WIDTH **',8X,'IN',5X,4(F10.3,10X))
0469                 PRINT 2023,W(6),W(10),WW3,WW3
0470           2023 FORMAT(1X,'DOWNCOMER OUTLET WIDTH **',7X,'IN',5X,4(F10.3,10X))
0471           2124 PRINT 2024,(LFP(I),I=1,4)
0472           2024 FORMAT(1X,'FLOW PATH LENGTH',16X,'IN',5X,4(F10.3,10X))
0473                 PRINT 2025,(LWO(I),I=1,4)
0474           2025 FORMAT(1X,'CHORD LENGTH AT TOP OF DC',7X,'IN',5X,4(F10.3,10X))
0475                 PRINT 2026,(LUD(I),I=1,4)
0476           2026 FORMAT(1X,'CHORD LENGTH AT BTM OF DC',7X,'IN',5X,4(F10.3,10X))
0477                 PRINT 2027,(ADCI(I),I=1,4)
0478           2027 FORMAT(1X,'DC INLET AREA',19X,'SQ FT',2X,4(F10.3,10X))
0479                 PRINT 2028,(ADCO(I),I=1,4)
0480           2028 FORMAT(1X,'DC OUTLET AREA',18X,'SQ FT',2X,4(F10.3,10X))
0481                 PRINT 2029,(HWO(I),I=1,4)
0482           2029 FORMAT(1X,'OUTLET WEIR HEIGHT',14X,'IN',5X,4(F10.3,10X))
0483                 PRINT 2030,(HWI(I),I=1,4)
0484           2030 FORMAT(1X,'INLET WEIR HEIGHT ON TRAY BELOW IN',5X,4(F10.3,10X))
0485                 PRINT 2031,(C(I),I=1,4)
0486           2031 FORMAT(1X,'DC CLEARANCE TO TRAY BELOW',6X,'IN',5X,4(F10.3,10X) )
0487                 PRINT 2032,(A(I),I=1,4)
0488           2032 FORMAT(1X,'SHAPED LIP (YES OR NO)',21X,4(A3,17X))
0489                 PRINT 2033,(B(I),I=1,4)
0490           2033 FORMAT(1X,'RECESSED BOX (YES OR NO)',19X,4(A3,17X),/)
0491                 PRINT 2034,(AB(I),I=1,4)
0492           2034 FORMAT(1X,'BUBBLE AREA',21X,'SQ FT',2X,4(F10.3,10X))
0493                 PRINT 2035,(AF(I),I=1,4)
0494           2035 FORMAT(1X,'FREE AREA',23X,'SQ FT',2X,4(F10.3,10X))
0495                 PRINT 2036,(AO(I),I=1,4)
0496           2036 FORMAT(1X,'HOLE AREA',23X,'SQ FT',2X,4(F10.3,10X))
0497                 PRINT 2037,(AOAB(I),I=1,4)
0498           2037 FORMAT(1X,'HOLE/BUBBLE AREA',16X,'PCT',4X,4(F10.3,10X),//)
0499                 PRINT 2038
0500           2038 FORMAT(1X,'** HALF WIDTH FOR PASSES B,C,D')
0501                 PRINT 2135
0502           2135 FORMAT(1H1,90X,'PAGE 2')
0503                 IF(VAPCON.GT.0.0)GO TO 3001
0504                 PRINT 2136
0505           2136 FORMAT(//)
0506                 GO TO 3002
0507           3001 PRINT 2137
0508           2137 FORMAT('NOTE: VAPOR SPLIT DID NOT CONVERGE IN 50 TRIALS - VAPOR SP
                    1LIT OF 50TH TRIAL IS USED',/)
0509           3002 IF(LIQCON.GT.0.0)GO TO 3003
0510                 PRINT 2136
0511                 GO TO 3004
0512           3003 PRINT 2138
0513           2138 FORMAT('NOTE: LIQUID SPLIT DID NOT CONVERGE IN 40 TRIALS - LIQUID
                    1SPLIT OF 40TH TRIAL IS USED',/)
```

```
 3004 CONTINUE
      PRINT 2039
 2039 FORMAT(1X,'LOADINGS PER PASS',            22X,'  PASS A  ',10X,
     1'  PASS B  ',10X,'  PASS C  ',10X,'  PASS D  ')
      PRINT 2040
 2040 FORMAT(1X,'-----------------',            22X,'----------',10X,
     1'----------',10X,'----------',10X,'----------')
      IF(NP.EQ.4.) GO TO 2141
      GPHFTW(4) = 0.0
      VL(4) = 0.0
      VLAB(4)=0.0
      S(4)   =0.0
      HED(4) =0.0
      HC(4)  =0.0
      HT(4)  =0.0
      HI(4)  =0.0
      HUD(4) =0.0
      HD(4)  =0.0
      PCTHD(4) = 0.0
      PCTJET(4)= 0.0
      DCVEL(4) = 0.0
 2141 PRINT 2041,(L(I),I=1,4)
 2041 FORMAT(1X,'GPM LIQUID',29X,4(F10.3,10X))
      PRINT 2042,(GPHFTW(I),I=1,4)
 2042 FORMAT(1X,'GPH/FT WEIR',28X,4(F10.3,10X))
      PRINT 2043,(V(I),I=1,4)
 2043 FORMAT(1X,'CFS VAPOR',30X,4(F10.3,10X))
      PRINT 2044,(VL(I),I=1,4)
 2044 FORMAT(1X,'VAPOR LOAD',22X,'CFS',4X,4(F10.3,10X) )
      PRINT 2045,(VLAB(I),I=1,4)
 2045 FORMAT(1X,'VLOAD/BUBBLE AREA',15X,'FPS',4X,4(F10.3, 10X))
      PRINT 2046,(S(I),I=1,4)
 2046 FORMAT(1X,'VLOAD/CFS LIQUID',23X,4(F10.3,10X),/)
      PRINT 2047
 2047 FORMAT(1X,'DOWNCOMER FILLING CALCULATIONS')
      PRINT 2048
 2048 FORMAT(1X,'------------------------------',/)
      PRINT 2049,(HED(I),I=1,4)
 2049 FORMAT(1X,'DRY TRAY PRESSURE DROP',4X,'(HH)  IN',5X,4(F10.3,10X))
      PRINT 2050,(HC(I),I=1,4)
 2050 FORMAT(1X,'CLEAR LIQUID HEIGHT',7X,'(HL)  IN',5X,4(F10.3,10X))
      PRINT 2051,(HT(I),I=1,4)
 2051 FORMAT(1X,'TOTAL TRAY PRESSURE DROP  (HT)  IN',5X,4(F10.3,10X))
      PRINT 2052,(HI (I),I=1,4)
 2052 FORMAT(1X,'INLET HEAD',16X,'(HI)  IN',5X,4(F10.3,10X))
      PRINT 2053,(HUD(I),I=1,4)
 2053 FORMAT(1X,'DC HEAD LOSS',14X,'(HDA) IN',5X,4(F10.3,10X))
      PRINT 2054,(   HD(I),I=1,4)
 2054 FORMAT(1X,'DC FILLING',16X,'(HDC) IN',5X,4(F10.3,10X))
      PRINT 2055,(PCTHD(I),I=1,4)
 2055 FORMAT(1X,'DC FILLING',22X,'PCT',4X,4(F10.3,10X),/)
      PRINT 2056
 2056 FORMAT(1X,'ADDITIONAL CALCULATIONS')
      PRINT 2057
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0566        2057 FORMAT(1X,'------------------------',/)
0567             PRINT 2058,(PCTJET(I),I=1,4)
0568        2058 FORMAT(1X,'PERCENT JET FLOOD',22X,4(F10.3,10X))
0569             PRINT 2059,(DCVEL(I),I=1,4)
0570        2059 FORMAT(1X,'DC INLET VELOCITY',15X,'FPS',4X,4(F10.3,10X))
0571             PRINT 2161,ALLVEL
0572        2161 FORMAT(/////,1X,'ALLOWABLE DC INLET VELOCITY',5X,'FPS',4X,F10.3)
0573             PRINT 2261,EFFCY
0574        2261 FORMAT(//,1X,'OVERALL TRAY EFFICIENCY',9X,'PCT',4X,F10.3)
0575             GO TO 2200
0576        2162 PRINT 2163
0577        2163 FORMAT(1H1,'THIS PROGRAM CANNOT DESIGN 4-PASS TRAYS FOR LIQUID RAT
                1ES GREATER THAN 6000 GPM.')
0578             GO TO 2200
0579        2164 PRINT 2165
0580        2165 FORMAT(1H1,'THIS PROGRAM CANNOT DESIGN TRAYS FOR VAPOR LOADS GREAT
                1ER THAN 100 CFS.')
0581             GO TO 2200
0582        2166 PRINT 2167
0583        2167 FORMAT(1H1,'THIS PROGRAM CANNOT DESIGN 3-PASS TRAYS FOR LIQUID RAT
                1ES GREATER THAN 5000 GPM.')
0584             GO TO 2200
0585        2200 CONTINUE
0586             IF (AGAIN.EQ.0.0) GO TO 1000
0587             STOP
0588             END
```

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VITA

Paul Becker was born in New York City in 1948. He attended public schools and the Bronx High School of Science. In 1970, he obtained a Bachelor of Science in Chemical Engineering from Columbia University School of Engineering and Applied Science in New York. At Columbia, Paul was student chapter president of the American Institute of Chemical Engineers, Editor of the Columbia Engineering Quarterly, an officer of Tau Beta Pi (national engineering honor society), and a member of Phi Upsilon Lambda (national chemistry honor society). As an undergraduate he was the recipient of the AICHE Scholarship award and the George Vincent Wendell medal for scholarship, character, and service.

Since 1970 Paul has been employed by Esso Research and Engineering Company in Florham Park, New Jersey. Until 1974 he worked in the Technology Department conducting R & D projects in the area of fractionation, and served as tower design consultant for engineers in the company. He is currently working in the Special Projects Design Division as a process design engineer.

Paul entered Newark College of Engineering in the Fall of 1971 as a part-time evening student and began working on this thesis in the Spring of 1973. The computer program presented in this thesis was developed through the use of the IBM 370 computer facilities of the Exxon Corporation Mathematics Computing and Systems Department in Florham Park.

NOMENCLATURE

A_B	Bubbling area, square feet. Perforated area in which vapor and liquid contact each other.
ALLVEL	Allowable downcomer inlet velocity, feet per second.
A_O	Open area or hole area, square feet.
A_{UD}	Area under downcomer, square inches.
C	Downcomer clearance, inches.
CFS_V	Vapor rate, cubic feet per second at conditions.
C_{VO}	Dry tray pressure drop coefficient, dimensionless.
D_O	Hole diameter, inches.
F_W	Weir factor used in clear liquid height equation, dimensionless.
GPHFTWEIR	Liquid weir loading, gallons per hour per foot of weir length.
GPM	Liquid rate, gallons per minute.
H	Tray spacing, inches.
HDA	Head loss under the downcomer, inches of liquid at conditions.
HDC = HD	Downcomer static backup, inches of liquid at conditions.
HFACT1	Tray spacing capacity factor used in jet flood equation, dimensionless.
HFACT2	Tray spacing capacity factor used in allowable downcomer inlet velocity equation, dimensionless.
HH	Dry tray pressure drop, inches of liquid at conditions.
HI	Inlet head, inches of liquid at conditions.
HL	Clear liquid height, inches of liquid at conditions.
HOW	Head of crest over weir, inches of liquid at conditions.
HT	Total tray pressure drop, inches of liquid at conditions.
HWI	Inlet weir height, inches.

HWO	Outlet weir height, inches.
L	Liquid rate, gallons per minute
L_{UD}	Length of chord at bottom of downcomer, inches.
LWI	Length of inlet weir, inches
LWO	Length of outlet weir, inches.
P	Pressure level in chamber above pass, any pressure dimension.
P'	Pressure level in chamber below pass, any pressure dimension.
RHOFAC	Density difference capacity factor used in calculating allowable downcomer inlet velocity. A function of $(\rho_L - \rho_V)$, dimensionless.
TT	Tray thickness, inches
V	Vapor rate, cubic feet per second.
V_L	Vapor load = $CFS_V \sqrt{\rho_V/\rho_L - \rho_V}$, cubic feet per second.
V_O	Vapor velocity through the perforations = CFS_V/A_O, feet per second.
β	Aeration faction used in clear liquid height equation, dimensionless.
ρ_V	Vapor density at conditions, pounds per cubic foot.
ρ_L	Liquid density at conditions, pounds per cubic foot.

Subscripts

A,B,C,D	Identify variable with one of the tray passes.
total	Identifies variable as total value for all passes.