



DESIGN PRACTICES

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EXXON EXXON ENGINEERING	FRACTIONATING TOWERS DIRECT CONTACT HEAT TRANSFER PROPRIETARY INFORMATION - For Authorized Company Use Only	DESIGN PRACTICES	
		Section III-F	Page 1 of 29
		Date December, 1998	

Changes shown by ↕

CONTENTS

Section	Page
SCOPE	3
REFERENCES	3
BACKGROUND	3
DEFINITIONS	3
EQUIPMENT TYPES AND APPLICATIONS	3
TRAYS	4
BAFFLE AND SHED SECTIONS	4
GRID	4
PACKING	4
BASIC DESIGN CONSIDERATIONS	4
BASIC INFORMATION REQUIRED	4
DEFINITIONS OF HEAT TRANSFER DUTIES	5
SIZING HEAT TRANSFER SECTIONS	6
DETERMINING PUMPAROUND DRAWOFF TEMPERATURES	6
OPTIMIZING HEAT TRANSFER SECTIONS	7
LIMITATIONS OF HEAT TRANSFER CORRELATIONS	7
SELECTION OF MATERIALS	8
TOWER SECTIONING	8
PURPOSE	8
HOW TO SECTION A TOWER	8
CALCULATION PROCEDURES	10
PART 1 - PRELIMINARY CALCULATIONS	10
PART 2 - SPECIFIC DEVICE CALCULATIONS	11
Trays	11
Baffle and Shed Sections	12
Packing and Grid	12
SAMPLE PROBLEM	14
FOR TRAYS (SIEVE, JET, BUBBLE CAP, VALVE)	16
FOR BAFFLE AND SHED SECTIONS	17
FOR PACKING	18
NOMENCLATURE	21
COMPUTER PROGRAMS	22
AVAILABLE PROGRAMS	22



DESIGN PRACTICES		FRACTIONATING TOWERS DIRECT CONTACT HEAT TRANSFER
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CONTENTS (Cont)

Section	Page
TABLE	
Table A	7
FIGURES	
Figure A Pumparound Streams and Temperatures	5
Figure B Method of Sectioning Tower for Heat Transfer Calculations	9
Figure 1A Heat Transfer Correlation for Sieve, Valve, Bubble Cap, and Jet Trays (Customary Units)	23
Figure 1B Heat Transfer Correlation for Sieve, Valve, Bubble Cap, and Jet Trays (Metric Units) ...	23
Figure 2A Heat Transfer Correlation for Baffle and Shed Sections (Customary Units)	24
Figure 2B Heat Transfer Correlation for Baffle and Shed Sections (Metric Units)	25
Figure 3A Heat Transfer Correlations for Countercurrent Contacting Devices (Customary Units) ..	26
Figure 3B Heat Transfer Correlations for Countercurrent Contacting Devices (Metric Units)	27
Figure 4 ΔT_{lm} Nomograph (Same for Customary and Metric Units)	28
Figure 5 Multicomponent Correction Factor, k_m (Same for Customary and Metric Units)	29

Revision Memo

- 12/98** Highlights of this revision are:
1. More definition provided for limitations to heat transfer correlations.
 2. Reference made to technology for estimating heat transfer at low vapor rates.
 3. Updated references to computer programs.
 4. Reference made to **Design Practices III-A** for hardware selection in heat transfer services.



 EXXON ENGINEERING	FRACTIONATING TOWERS DIRECT CONTACT HEAT TRANSFER PROPRIETARY INFORMATION - For Authorized Company Use Only		DESIGN PRACTICES	
			Section III-F	Page 3 of 29
			Date December, 1998	

SCOPE

This section provides methods for sizing direct contact heat transfer sections containing trays, baffle sections, grid or packing. It deals with the design of equipment for pumparound services only. For other types of direct contact heat transfer applications (such as condensable blowdown drums, barometric condensers, drying towers, and water cooling and condensing towers) consult your FRACTIONATION SPECIALIST for help.

The hydrodynamic performance characteristics of these devices are discussed in the following sections:

- III-B Sieve Trays
- III-C Bubble Cap Trays
- III-D Jet Trays
- III-E Valve Trays
- III-G Packing and Grid
- III-J Baffles and Sheds

REFERENCES

1. C. J. Colwell, *New Direct Contact Heat Transfer Correlations for Towers*, Report No. EE.98E.76 (September, 1976).
2. C. J. Colwell, *Direct Contact Heat Transfer Methods Enhanced*, 96CET190 (October 24, 1996).

BACKGROUND

In large towers, such as pipestills and catalytic cracking unit fractionators, one or more heat transfer or "pumparound" sections are often provided to recover heat effectively from the tower. The use of pumparounds results in a better distribution of tower loadings than would be the case if the entire cooling duty were assigned to the overhead condenser. This, in turn, permits the use of smaller tower diameters in the upper sections of these columns and recovery of high temperature level heat. The heat is removed from the tower by direct contact heat transfer between the hot, ascending vapor and the descending liquid, which is externally cooled and returned, i.e., "pumped around."

Specifying internals for heat transfer service requires calculations that account for simultaneous heat and mass transfer effects in which fundamental temperature driving forces are often difficult to evaluate. The Multi-component Correction Factor, k_m , described under **SIZING HEAT TRANSFER SECTIONS** introduces an easily applied term into the heat transfer procedure that accounts for condensation effects and corrects the log-mean temperature to a more realistic average driving force in hydrocarbon pumparounds.

For other, less frequently used types of direct contact heat transfer applications (such as condensable blowdown drums, barometric condensers, FCCU slurry sections, steam cracker fractionator overhead condensers, and water cooling and condensing towers) the heat transfer methods described here can be applied provided the designer formulates an appropriate sectioning technique. (See discussion under **TOWER SECTIONING**.) With this approach, **localized** log-mean temperatures that closely reflect true driving forces can then be determined for each section, whereas use of a log-mean temperature from **terminal** conditions could result in significantly undersizing the number of trays or the amount of packing required. In several water cooling and condensing towers, graphical or numerical integration techniques described in most Unit Operations texts for simultaneous heat and mass transfer may be required. Your FRACTIONATION SPECIALIST can provide assistance in setting up these calculations via a computerized procedure.

The sample calculation provided in this section addresses only the method needed to sizing pumparound sections of a tower.

DEFINITIONS

See **NOMENCLATURE**.

EQUIPMENT TYPES AND APPLICATIONS

In non-fouling fractionation services, heat transfer may be accomplished with trays, packing, or grid. Fouling services are encountered in several washing or scrubbing operations, where the fluids may contain solids such as coke, catalyst, or scale, and when polymer formation tends to plug the internals. For such services, baffle sections (sheds or discs-and-donuts) should be used. For non-fouling services where pressure drop is critical (e.g., vacuum pipestills), packing (random or structured types) should be used. [Design Practices Section III-A](#), [Table 5A](#) should be consulted for proper internal selection.

DESIGN PRACTICES		<i>FRACTIONATING TOWERS</i> DIRECT CONTACT HEAT TRANSFER PROPRIETARY INFORMATION - For Authorized Company Use Only	 EXXON ENGINEERING
Section	Page		
III-F	4 of 29		
Date			
December, 1998			

EQUIPMENT TYPES AND APPLICATIONS (Cont)

TRAYS (SEE SECTIONS III-A, B, C, D, E)

Since the factors affecting direct-contact, vapor-liquid heat transfer are similar to those affecting fractionation, it follows that fractionating trays are usually suitable for heat transfer service in nonfouling pumparound sections. Indeed, it is often convenient to use the same tower diameter in the pumparound section as in the fractionating section immediately above or below. While jet trays are frequently used in heavy hydrocarbon pumparound service, the proper tray choice also depends on considerations of capacity, turndown, hydraulics and maintenance.

BAFFLE AND SHED SECTIONS (SEE SECTION III-J)

Baffle or shed sections are normally used only in dirty or coking services. An important application is in the heat transfer section at the bottom of catalytic and fluid coker fractionators. In these cases, the tower bottoms are cooled and recirculated over the baffles to desuperheat the reactor vapors and to scrub out any entrained catalyst or coke.

GRID (SEE SECTION III-G)

The grid types available include Glitsch Grid, SNAPGRID by Nutter, Flexigrid by Koch, and Intalox Grid by Norton. The advantages of these grids are low-pressure drop at high capacity, good particulate removal efficiency and low susceptibility to fouling and coking (low liquid holdup). Grids should therefore be considered for washing or scrubbing services where: (a) low pressure drop is critical, (b) entrainment is serious and must be minimized, and/or (c) coking or fouling is likely to be a problem because of high liquid residence time. Examples are the wash sections of atmospheric and vacuum pipestills and cat fractionators. The disadvantage of grid compared to trays and packing is very low fractionation and heat transfer efficiency. Nevertheless, their efficiency is still better than baffle or shed sections. While grid has been used in some vacuum pipestill pumparounds, recent studies have shown that 2 in. (50 mm) size random packings (such as Pall rings, IMTP, or Nutter rings) are more economical for most cases.

PACKING (SEE SECTION III-G)

Packing is economically attractive in non-fouling services requiring low-pressure drop, good heat transfer or fractionation efficiency, and capacity. Their most common application is in pumparound sections of vacuum pipestills. Compared to grid, tower sections with lower packed heights can usually be designed with random or structured packing, because of their better efficiency. Therefore, packed beds may have a lower overall pressure drop and somewhat lower investment and operating costs than a grid bed.

For **revamps** of capacity-limited pumparound sections (atmospheric pipestills, cat fractionators, vacuum pipestills), packing may be an economical replacement for trays if higher vapor and liquid throughputs are required with no loss in heat transfer efficiency. If trays must be respaced to provide the desired capacity, an excessive amount of downtime may be required. Under these conditions, packing may be especially attractive because of the relative ease of installation.

For both packing and grid, the height required for heat transfer is proportional to the relative HETP for the various types and sizes. The bed height sizing procedure, therefore, uses the same relative HETP factor, f_p , that is used in [Section III-G](#) for mass transfer. In this way, the packing requirement for 2 in. (50 mm) Pall rings is extended to all packings and grids for which the f_p factor has been defined.

BASIC DESIGN CONSIDERATIONS

BASIC INFORMATION REQUIRED

The calculation method for designing or rating direct contact heat transfer sections is based on a "transfer unit" approach. This method is analogous to the mass transfer unit approach to fractionation efficiency. The number of trays (for tray or baffle internals) or the height of packing (for packing and grid) can be determined on the basis of heat duty, tower loadings, temperature driving forces and tower area. It is assumed that the designer already has heat and material balance information for the heat transfer section and has completed a tray or packed tower design. To obtain heat and material balance information, heat transfer sections can be included on plate-to-plate computer programs such as PRO/II or PROVISION.

EXXON EXXON ENGINEERING	FRACTIONATING TOWERS DIRECT CONTACT HEAT TRANSFER PROPRIETARY INFORMATION - For Authorized Company Use Only		DESIGN PRACTICES	
			Section III-F	Page 5 of 29
			Date December, 1998	

BASIC DESIGN CONSIDERATIONS (Cont)

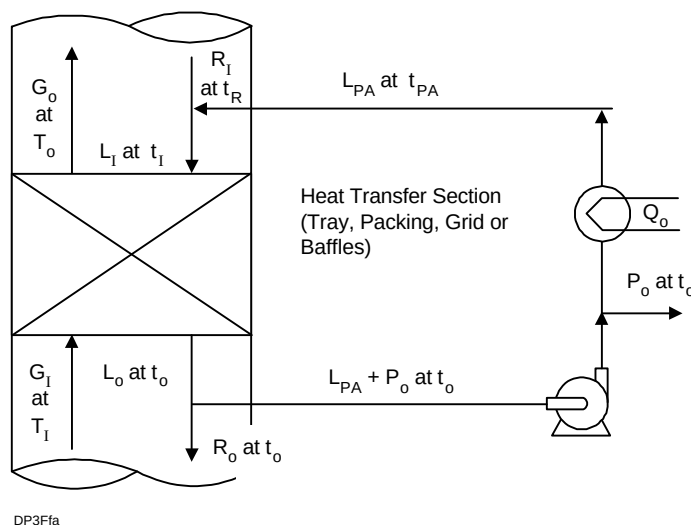
DEFINITIONS OF HEAT TRANSFER DUTIES

1. **Exchanger Duty Q_o** - The exchanger duty Q_o is the amount of heat that is removed in the external pumparound circuit of a heat transfer section in a column. The exchanger reduces the pumparound liquid temperature from the drawoff temperature t_o to the return temperature t_{PA} (see **Figure A**). In a normal design, Q_o and t_o are usually set by the heat and material balances and the designer must select appropriate values of t_{PA} and the pumparound rate L_{PA} . Methods for selecting these quantities are outlined in subsequent paragraphs. These variables are related by the following equation:

$$Q_o = L_{PA} C_{PL} (t_o - t_{PA}) \quad \text{Eq. (1)}$$

where: Q_o = Exchanger duty, Btu/hr (kW)
 L_{PA} = Pumparound liquid rate, lb/hr (kg/s)
 C_{PL} = Liquid specific heat at average liquid temperature, Btu/lb°F (kJ/kg°C)
 t_o = Pumparound liquid drawoff temperature, °F (°C)
 t_{PA} = Pumparound liquid return temperature, °F (°C)

FIGURE A
PUMPAROUND STREAMS AND TEMPERATURES



2. **Heat Transfer Required** - In general, the overall amount of heat transferred within the heat transfer section is not the same as the exchanger duty. The difference between the internal and external heat transfer requirements can be visualized for systems involving net condensation of vapor if one recognizes that the reflux entering the section, R_I , provides some cooling in addition to that of the pumparound liquid. Likewise, in systems with net vaporization, the latent heat required to vaporize the liquid provides cooling in addition to that of the pumparound.

For systems involving **net condensation** of vapor, the total number of heat transfer units required, N_{GH} , can be calculated by the following equation:

$$\overline{N_{GH}} = \frac{\Delta T}{\Delta T_{lm}} + \ln \left[\frac{G_I}{G_o} \right] \quad \text{Eq. (2)}$$

where: $\overline{N_{GH}}$ = Total number of heat transfer units required
 ΔT = Vapor phase temperature difference, $T_I - T_o$, °F (°C)
 ΔT_{lm} = Log mean temperature difference, (LMTD), °F (°C)
 G_I = Vapor rate entering heat transfer section, lb/hr (kg/s)
 G_o = Vapor rate leaving heat transfer section, lb/hr (kg/s)

DESIGN PRACTICES		<i>FRACTIONATING TOWERS</i> DIRECT CONTACT HEAT TRANSFER PROPRIETARY INFORMATION - For Authorized Company Use Only	 EXXON ENGINEERING
Section	Page		
III-F	6 of 29		
Date			
December, 1998			

BASIC DESIGN CONSIDERATIONS (Cont)

For systems involving **net vaporization** of liquid (such as pipestill wash zones and cat fractionator desuperheating sections) the total number of heat transfer units required is given by **Eq. (3)**.

$$\overline{N_{GH}} = \frac{\Delta T}{\Delta T_{lm}} \quad \text{Eq. (3)}$$

SIZING HEAT TRANSFER SECTIONS

The required number of trays, baffles, or the height of packing / grid required are calculated from the equations below:

- For trays and baffle sections:

$$N_A = \frac{\overline{N_{GH}} k_m}{N_{GH}} \quad \text{Eq. (4)}$$

where: N_A = Number of actual trays or baffle (shed) sections
 $\overline{N_{GH}}$ = Total number of heat transfer units required
 k_m = Multi-component correction factor (from **Figure 5**)
 N_{GH} = Number of heat transfer units per tray (from **Figure 1**) or per baffle (shed) section (from **Figure 2**)

Note: In FCCU and coker fractionator baffle sections, where the gas enters at high velocity through a flush side nozzle or the snout of a cyclone, a significant amount of contacting occurs in the "raining" section below the baffles. To account for this effect, subtract one heat transfer unit from the total number required. That is, replace $\overline{N_{GH}}$ with $(\overline{N_{GH}} - 1)$ in **Eq. (4)**.

- For packing or grid:

$$Z = H_{GHP} \left[k_m \overline{N_{GH}} - \frac{Z_S}{H_{GHS}} - \frac{Z_B}{H_{GHB}} \right] \quad \text{Eq. (5)}$$

where: Z = Height of packing required, ft (m)
 H_{GH} = Height of a gas phase heat transfer unit, ft (m) (from **Figure 3**)
subscripts - P for packing
- S for sprays
- B for accumulator tray space
 Z_S = Vertical distance between top of bed and bottom surface of spray nozzles, ft (m)
 Z_B = Vertical distance between the bottom of the bed and the high liquid level on the accumulator tray, ft (m)

For packed pumparound heat transfer sections, the heat transfer associated with the spray distributors and the open area below the bed is included in the packed height calculation [see **Eq. (5)** above]. This can reduce the required packed height by as much as 10 - 20%.

The methods for calculating $\overline{N_{GH}}$ for trays or baffles and H_{GH} for the various counter-current devices are given later under the subheading **CALCULATION PROCEDURES**.

DETERMINING PUMPAROUND DRAWOFF TEMPERATURES

The pumparound liquid drawoff temperature, t_o , is equal to the bubble point of the liquid leaving the pumparound section. This temperature is set by the rate and cut range of the product (if any) immediately below the pumparound, the amount of fractionation in the tower below the pumparound, and the amount of fractionation within the pumparound. Liquid drawoff temperatures are accurately predicted by the plate-to-plate computer programs used for definitive process design of all fractionation towers. Drawoff temperatures for heavy hydrocarbon towers such as atmospheric and vacuum pipestills and cat fractionators should be obtained from a PRO/II or PROVISION simulation.

 EXXON ENGINEERING	FRACTIONATING TOWERS DIRECT CONTACT HEAT TRANSFER PROPRIETARY INFORMATION - For Authorized Company Use Only		DESIGN PRACTICES	
			Section III-F	Page 7 of 29
			Date December, 1998	

BASIC DESIGN CONSIDERATIONS (Cont)

OPTIMIZING HEAT TRANSFER SECTIONS

The optimum number of heat transfer trays (or packed height) is based on an economic study involving tower height and diameter, external heat exchange surface, and pump and power costs. The variables involved in an optimization study are pumparound return temperature t_{PA} and pumparound rate L_{PA} .

Increasing the pumparound rate L_{PA} increases the temperature driving force in the exchanger and thus reduces heat exchanger costs. However, increasing L_{PA} also increases the return temperature t_{PA} . This effect reduces the temperature driving force in the tower which, in turn, may increase the amount of tray surface or packed volume required. In addition, increasing L_{PA} increases pumping costs and may cause tower hydraulics problems, especially in revamps.

LIMITATIONS OF HEAT TRANSFER CORRELATIONS

The following table lists the recommended ranges of applicability of the heat transfer correlations. These ranges were established based on the heat transfer data available to develop the correlations. It should be recognized that these data were taken under acceptable hydraulic conditions. Therefore, if a design falls outside the ranges shown in **Table A**, your FRACTIONATION SPECIALIST should be consulted.

TABLE A

	CUSTOMARY	METRIC
Packing or Grid Liquid Rate, Q_L / A_S Vapor Rate	1 to 50 gpm/ft ² $C_S = 0.05$ ft/s to 85% of flood	0.7 to 35 dm ³ /s/m ² $C_S = 0.015$ m/s to 85% of flood
Sieve, Valve, Bubble Cap, Jet Trays Liquid Rate, $Q_L / N_D I_0$	0.5 to 25 gpm/ in.	1.25 to 60 dm ³ /s/m
Baffle Tray (Sheds) Liquid Rate, Q_L / A_S Vapor Rate Horizontal Free Area	2 to 50 gpm/ft ² $C_S = 0.05$ ft/s to 90% of flood 30 to 60% of A_S	1.3 to 35 dm ³ /s/m ² $C_S = 0.015$ m/s to 90% of flood 30 to 60% of A_S
Sprays, Space Below Packing Liquid Rate, Q_L / A_S Vapor Rate	1 to 50 gpm/ft ² $C_S = 0.05$ to 0.3 ft/s	0.7 to 35 dm ³ /s/m ² $C_S = 0.015$ to 0.09 m/s

In addition to the above ranges, the following limitations should also be observed.

- A FRACTIONATION SPECIALIST should be consulted to determine the potential impact of liquid or vapor maldistribution if any of the following are true:
 - Approach temperature is less than 5°F (3°C).
 - Design number of theoretical stages is greater or equal to three.
 - The liquid rate is less than 110% of the minimum rate as determined as the liquid rate needed to meet the gas temperature specification using an infinite (large) number of theoretical stages.
 - A venturi scrubber or venturi scrubber separator is immediately upstream.
- At very low vapor loadings, the heat transfer coefficient asymptotes to a finite constant value and not zero as predicted. Thus, heat transfer rates may be significantly underpredicted when nearly total condensation of vapor occurs. To determine if fewer trays or packed bed heights are needed, consult your FRACTIONATION SPECIALIST and see **Reference 2** when vapor rates are below 100 lb/hr ft² (0.1 kg/s/m²).

DESIGN PRACTICES		FRACTIONATING TOWERS DIRECT CONTACT HEAT TRANSFER PROPRIETARY INFORMATION - For Authorized Company Use Only	EXXON EXXON ENGINEERING
Section	Page		
III-F	8 of 29		
Date December, 1998			

BASIC DESIGN CONSIDERATIONS (Cont)

3. For all types of cross-flow trays, check that the number of trays predicted is not less than 1.2 times the theoretical minimum. The predicted value can, at times, be too low due to the use of the LMTD driving force. This effect comes from the fact that the LMTD is really intended for true countercurrent contacting whereas these trays operate in a cascading crossflow mode. An estimate of the theoretical minimum number of trays is given by the following equation:

$$N_{A(\min)} = \frac{\ln \left[\frac{T_I - t_o}{T_o - t_I} \right]}{\ln \left[\frac{T_I - T_o}{t_o - t_I} \right]} \quad \text{Eq. (6)}$$

SELECTION OF MATERIALS

The materials of construction for tower internals must be appropriate for each fractionation service. Some considerations affecting the choice of materials are cost, required corrosion resistance, temperature operating range, and mechanical strength. The design engineer should consult with the MATERIALS SPECIALIST for the final selection.

For example, aluminum Pall rings have performed satisfactorily in several vacuum pipestill top pumparound sections. However, for new designs, corrosion and temperature considerations should still be checked with the MATERIALS SPECIALIST.

Additional information concerning the various types of packing and grid is given in [Section III-G](#).

TOWER SECTIONING

In some direct contact heat transfer applications, it is necessary to divide the tower into two or more sections for calculation purposes, depending on the relative amounts of latent and sensible heat transfer in each section. Separate heat transfer calculations are then made for each section. Typical situations which require tower sectioning are: (1) cooling of superheated vapor below its dew point, and (2) cooling a vapor containing hydrocarbon and steam below the water dew point. Pumparound sections of pipestills and primary fractionators usually do **not** require sectioning whereas FCCU and coker slurry pumparounds do.

PURPOSE

The reason for sectioning a tower is to obtain realistic temperature driving forces (ΔT_{lm}) for heat transfer. In general, different values of ΔT_{lm} are obtained for each tower section.

HOW TO SECTION A TOWER

Consider the vapor, as it is cooled in a heat transfer tower. Logical break points occur wherever hydrocarbon or water dew points are encountered and wherever condensables are depleted from the vapor. The best way to determine sectioning points is to construct a vapor condensation curve, in which the points appear as abrupt changes of slope in the curve. Data for constructing this plot can be generated from a series of successive flash calculations on the vapor passing through the heat transfer zone. Unlike conventional T-Q curves, however, the flash calculations must account for changes in vapor composition resulting from condensation or vaporization to and/or from the liquid cooling medium.

Figure B shows a vapor condensation curve with five general regions. Each has different heat transfer characteristics, as stated on the figure. In practice, most towers that require sectioning will exhibit only two or three of these regions. As an example, a direct contact condenser involving steam mixed with hydrocarbon vapor would have [Sections II, III, and IV](#).