KLM Technology Group

Solutions, Standards and Software
DESIGN GUIDELINES FOR PROPYLENE SPLITTERS EFFICIENCIES

Karl Kolmetz
KLM Technology Group
Based in USA since 1995, KLM is a technical consultancy group, providing specialized training, services and equipment to improve process plant operational efficiency, profitability and safety.
KLM Core Business

Training Classes
Kolmetz Handbook of Process Equipment Design
Engineering Software
Process Optimization Studies
HAZOP Facilitation
Engineering Support
KLM Technology Group has developed; 1) Process Engineering Equipment Design Guidelines, 2) Equipment Design Software, 3) Project Engineering Standards and Specifications, and 4) Unit Operations Manuals. Each has many hours of engineering development.

KLM is providing the introduction to this guideline for free on the internet. Please go to our website to order the complete document.

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1. Introduction

Actual field tray efficiencies are affected by many factors, these include:

a. tower pressure

b. geometry and design of contacting equipment,

c. flow rates and flow paths of the liquid and vapor streams,

d. composition and properties of the vapor and liquid streams,
1. Introduction

All these items may affect tray efficiencies and there are field examples were some have greatly impacted tray efficiencies.

This paper will review some case studies and develop some design best practices.
There is data – and then there is Folklore and Myths
General Estimates of Field Tray Efficiency  (We published this data in a paper in 2005)

Demethanizer 65%  Air Separation 90%
Deethanizer 70%  C2 & C3 Splitter 85%
Depropanizer 75%  Stabilizer 80%
Debutanizer 80%  Hydrocarbon/Water 15%
Depentanizer 80%  EB/Styrene 90%
Low alpha Aromatics 80%  Alcohol - Water 75%
High alpha Aromatics 70%  Amine Contactor 33%

1. Typical Cross Flowing Sieve Deck Trays
2. General Field Tray Efficiency

There is observed data that close boiling ideal binary pairs require many stages of vapor/liquid contacting to separate, but each stage has relatively high efficiency in the field.

And the converse – that non-ideal binary pairs that have a large boiling point difference require only a few stages to separate in a process simulator, but each stage has relatively low efficiency in the field.

<table>
<thead>
<tr>
<th>Binary Pair</th>
<th>ΔB.P.</th>
<th>Equilibrium Stages</th>
<th>Field Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane / Propylene</td>
<td>5.6 °C (11.2 °F)</td>
<td>120 Stages</td>
<td>85%</td>
</tr>
<tr>
<td>Benzene / Water</td>
<td>19.9 °C (37.8 °F)</td>
<td>5 Stages</td>
<td>20%</td>
</tr>
</tbody>
</table>
O’Connell Type Correlations can be used to predict the overall column efficiencies. (1958)
2. General Tray Efficiency

Overall Tray Efficiency
O’Connell Equation (1946)

\[ E_o = 49.2 \left( \alpha \mu \right)^{-0.245} \]

\( \mu \) is viscosity of feed
\( \alpha \) is relative volatility both at average tower temperature.

when viscosity and/or relative volatility are increased tray efficiency is decreased
2. General Tray Efficiency

Figure 2.2: O’Connell correlation (Adapted from: O’Connell, H. E. (1946). Plate efficiency of fractionating columns and absorbers. Transactions of the American Institute of Chemical Engineers, 42(4), 741-755)
For a fixed system (e.g. C3 splitter), efficiency might go up with increase of operation pressure. This is true for many systems.
This pressure effect can be seen in C3 Splitters from the O’Connell Equation and Field Data

<table>
<thead>
<tr>
<th>PSIG</th>
<th>O’Connell</th>
<th>Field Tray Efficiency</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>88</td>
<td>75-85+%</td>
<td>Numerous Papers</td>
</tr>
<tr>
<td>150</td>
<td>84</td>
<td>70-80%</td>
<td>Observed data</td>
</tr>
<tr>
<td>100</td>
<td>81</td>
<td>65-75%</td>
<td>Observed data</td>
</tr>
<tr>
<td>57</td>
<td></td>
<td>66%</td>
<td>AIChE 2011</td>
</tr>
<tr>
<td>50</td>
<td>75</td>
<td>60-70%</td>
<td>Observed data</td>
</tr>
</tbody>
</table>

Data for Cross Flowing Trays
The end result is what counts – does the tower meet capacity and product purities.

Each good vendor utilizes a tuned model that gives the proper end result.

There are over 200 C3 Splitter’s in operation.

O’Connell correlation works well for predicting the effect of pressure on efficiency.
Folklore and Myths can proclaim that lower pressure gives higher efficiencies – you need to review your system data – may not be true.
Effect of Pressure

This myth may have been developed from packing data, where HETP is much higher at lower pressures.

![World Myths And Folktales](image)
Effect of Pressure on Packing

The field data for trays confirms that as pressure increases the efficiency increases.

This is not the case for packing. There are two ideas of why this might be happening.
Effect of Pressure on Packing

The first idea - some studies have showed that at higher pressures there appeared more liquid hold up on the packing, creating a larger boundary layer – leading to lower efficiency.
The second idea - there is a relationship between the vapor density / the liquid density and packing efficiency. At higher pressure the densities become closer together, leading to backing mixing effect of the liquid by the vapor - leading to lower efficiency.
Device

Trays

Cross Flowing Trays

Multiple Down Comer Trays

High Capacity / Efficiency Trays

Packing

Random

Structured
Device

Trays

Best for High Pressure
High Flows
Fouling Service

Packing

Best for Low Pressure
Lower Flows
Tray Efficiency

Point Efficiency

\[ E_{\text{pq}} = \frac{(y_n - y_{n-1})}{(y^0_n - y_{n-1})} \]

Tray Efficiency

\[ E_{\text{MV}} = \frac{y_j - y_{j+1}}{y^*_j - y_{j+1}} \]

\[ y_j^* = K x_j, \]

\[ x_j \text{ is liquid composition at DC outlet.} \]
Effect of Path Flow Length on Trays

Cross Flowing Trays

V1 meets L1 – about 60% Efficiency

L1 becomes L2

V1 meets L3 – about 65% Efficiency

Cross Flow Tray Efficiency

>=

Point Efficiency
Good Practices in Sieve Tray Designs

From Data Published by FRI at AIChE in 2007;

1. The best range of hole size for efficiency is 12.7 mm (1/2 inch) to 25 mm (1 inch).

2. The capacity of sieve trays decreases as hole diameter becomes larger. This loss in capacity is due to higher entrainment.

The best choice might be 12.7 mm.
From Data Published by FRI at AIChE in 2007;

1. The efficiency of the 8% open area sieve tray is consistently higher than that of 14% open area sieve tray.

2. Open area should be in a range of ~6 - 16%.
Multiple Down Corner

Has less Path Flow Length and lower efficiency.

One rule is to keep the Path Flow Length above 450 mm (18 inches) to maintain good efficiency.
Effect of Path Flow Length on Trays

TWO PASS CROSSFLOW SLOTTED SIEVE TRAYS
And the question everyone ask - How much less efficient? You can hear numbers from 2% to 20%

Folklore and Myths
There is some published data on Multiple Down Comer Trays.

<table>
<thead>
<tr>
<th>Date</th>
<th>Aug 92</th>
<th>June 95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower</td>
<td>C2 Splitter</td>
<td>C3 Splitter</td>
</tr>
<tr>
<td>Pressure</td>
<td>290 PSI</td>
<td>250 PSI</td>
</tr>
<tr>
<td>Reflux</td>
<td>237,834 kg</td>
<td>1,400,000 lb/hr</td>
</tr>
<tr>
<td>Trays</td>
<td>155</td>
<td>325</td>
</tr>
<tr>
<td>Capacity Gain</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td>Efficiency</td>
<td>74%</td>
<td>74%</td>
</tr>
</tbody>
</table>
Multiple Down Comer Trays – Best Practices

1. Understand there is a loss in tray efficiency – but because they may be installed on 18” trays spacing or less, you can install more trays and possibility increase overall tower efficiency – based on the reflux to stages curves.

2. For the same tower shell diameter, capacity increase can be greater than 35%.

3. If designed properly there can be an efficiency and capacity increase.
Propylene Splitters

The types of internals that have been used in propylene splitter columns are:

1. Conventional Cross Flowing Trays
2. Dual Flow Ripple Trays
3. Structured Packing
4. Multiple Downcomer Trays
5. High Capacity / Efficiency Trays
Propylene Splitters

The types of internals that have been used in propylene splitter columns are;

1. Conventional Cross Flowing Trays
   They work very well – about 85% efficiency in High Pressure Propylene Splitter Service.

![Image of a tray](image-url)
The types of internals that have been used in propylene splitter columns are;

2. Dual Flow Ripple Trays

Dual Flow Ripple Tray were installed in several Propylene Splitters. There are two challenges of dual flow trays.

a. Point Efficiency
b. Maldistribution – vapor will travel up one side and the liquid will travel down the other side.
Propylene Splitters

To counter the Maldistribution one vendor installed the I-Beams on top the tray.
Propylene Splitters

The actual field efficiency was about 42%.

The vendor accounted for the low efficiency by installing 248 trays.
The types of internals that have been used in propylene splitter columns are;

3. Structured Packing

Structured Packing was installed in two high pressure Propylene Splitter with limited success. The packing was removed and trays reinstalled.
Propylene Splitters

The types of internals that have been used in propylene splitter columns are;

4. Multiple Downcomer Trays

There are many successful applications of Multiple Downcomer Trays in Propylene Splitter Service
Propylene Splitters

The types of internals that have been used in propylene splitter columns are;

5. High Capacity / Efficiency Trays

Many studies have shown that High Capacity / Efficiency Trays can improve capacity up to 25% and efficiency 7 to 10%. There is some published data in Propylene Splitters of greater than 10% efficiency increases.
High Pressure Verses Low Pressure Splitters

There is a wide range of pressure choices for Propylene Splitters – 50 PSIG to 300 PSIG

What might be guidelines to choose the best pressure?

Folklore Verse Myths
Propylene Splitters

High Pressure Splitters
Propylene Splitters

High Pressure Splitters

Advantages
a. Ability to utilize cooling water for overhead condenser
b. Ability to utilize medium level heat – there is a surplus in an Olefin Plant

Disadvantages
a. Capital Cost – thicker tower shell and foundation
Propylene Splitters

Low Pressure Splitters

[Diagram of process flow]
Low Pressure Splitters

Advantages
a. Capital Cost – thinner tower shell and foundation
b. Energy – if there is not a surplus of medium level heat – the compressor can utilize the energy needed for compression

Disadvantages
a. Capital and Maintenance Cost of a compressor
Propylene Splitters

Low Pressure Splitters

May need a study to determine best pressure for your Splitter - one vendor recommends 90 PSIG and a second vendor recommends 110 PSIG.

a. 90 PSIG is lower capital but higher energy cost
b. 110 PSIG is high capital but lower energy cost.
Conclusions

1. Field efficiency of trayed towers, may increase with operational pressure, as shown in the O’Connell correlation.

2. Field efficiency of packed towers, from the data appears to going down with increasing operational pressure.

3. Proper design and selection of trays, packings and internals are critical for success of distillation towers.
Thank You