Two Phase Flow Feed Pipes to Distillation Columns (Flashing Feed Piping)

2021 AIChE Spring Meeting

Kister Distillation Symposium
Troubleshooting: The Lessons Learned Applied to Better Operation

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Performance* **of distillation towers can be adversely affected by**

the piping sizing and layout upstream of a column, something

- **Often overlooked**
- **Receives minimal attention**

And contrary to popular belief

- **Distorted flow profiles cannot be "reconditioned" by the inlet feed distributor.**

* Capacity & Separation Efficiency

Purpose

To share some experiences on piping sizing and layout that will help in Minimizing / Avoiding:

Unstable flow/Slug conditions in the pipe (sizing)

And

Flow maldistribution in the Feed Section (layout)

What to expect:

Basic principles that when followed, will end up with a well performing system.

What not to expect:

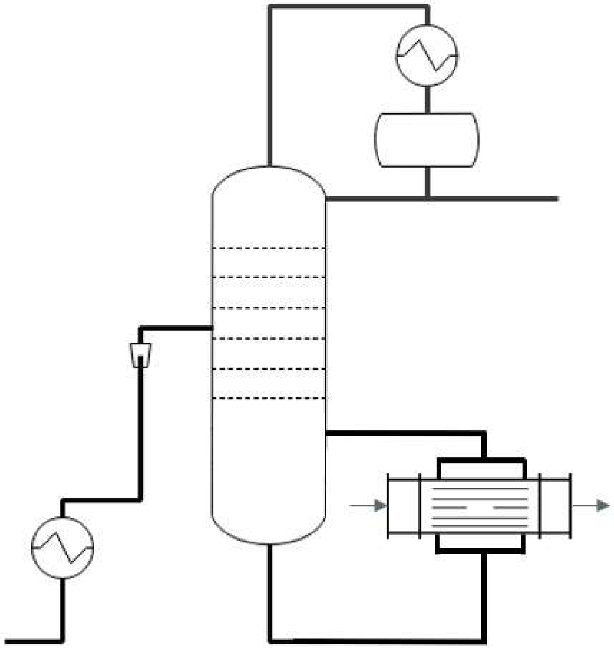
Answers to all questions regarding a specific installation.

Let's start …

Engineering Procurement & Construction Stage:

Everything is completed OK!

BUT…



At Start Up / Operation:

Unstable System Operation

despite:

- no change in process design conditions.
- Columns Hydraulics checks are OK.

Hydraulic Assessment

Typical Checks

ρv^2 <= limit guidelines

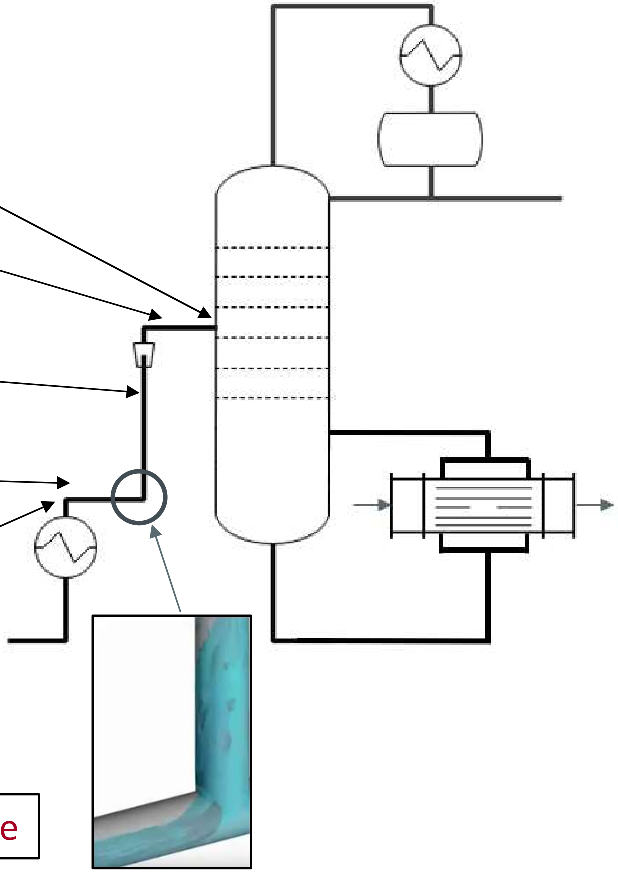
Horiz. Flow Regimes
Design= Stratified
Turndown = Stratified

Vert. Flow Regimes
Design=Slug/Churn*
Turndown = Slug*

Horiz. Flow Regimes
Design= Stratified
Turndown = Stratified

ρv^2 <= limit guidelines

* Slug not always avoidable but manageable



Generally done via "Flow Maps"

Horizontal:
1954: Baker
1974: Mandhane-Gregory-Aziz
1976: Taitel & Dukler
Vertical:
1959: Griffith & Wallis
1969: Hewitt & Roberts
1969: Golan & Stenning
1974: Oshimoto & Charles
Horizontal /Vertical:
1985: Pots-Oliemans (Froude #)

- Which Flow Map to select?
- Anything else to check?

What About?:

1.- Reboiler Return
2.- Flow Rates fluctuations (Amp. & Freq.)*
3.- Even phase distribution @Inlet Device

Hydraulic Assessment

Flow Maps & Reboiler Return

Horizontal:
1954: Baker
1974: Mandhane-Gregory-Aziz
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Vertical:
1959: Griffith & Wallis
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➡

Drawbacks

1.- Different methods ⬄ different results.

2.- Inconsistent extrapolation to field conditions, due to:

- L/D differences between Lab & Field (min. 10 L/D for a “fair” approximation)
- Regime Transitions are not sharp.
  - subjectivity involved in dentification of transition boundaries
  - difficulties in measuring dynamic / fluctuating 2phase flow conditions like flow rates & void fraction

3. No quantification of frequency & amplitude of Flowrate / liquid holdup fluctuations

Note: maps based on Froude numbers and mechanistic models are considered to offer improved range of application.

HTRI – Vertical Upflow (2016)
Report TPF-15 “New Flow Regime Map for Vertical Upflow Large Diameter Pipes”

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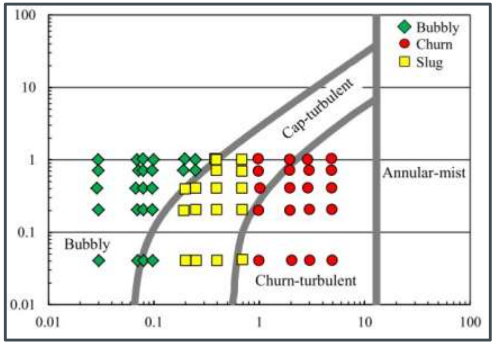
Advantage

Offers the best option for thermosiphon reboiler vertical piping. Experimental data shown in graphs provides excellent reference. Report provide detailed guidance on application and comparison with other flow maps.



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Hydraulic Assessment

Flow Rates Fluctuations (Amplitude and Frequency)

Multiphase Flow Simulators

Steady State:

Since 2-phase flow is a dynamic process => static/equilibrium models do not provide full picture
- but generally used to:
  - initial selection of steady state operating conditions based on software's generated flow maps
  - generate improved static flow maps (including pipe inclination, additional transport properties)

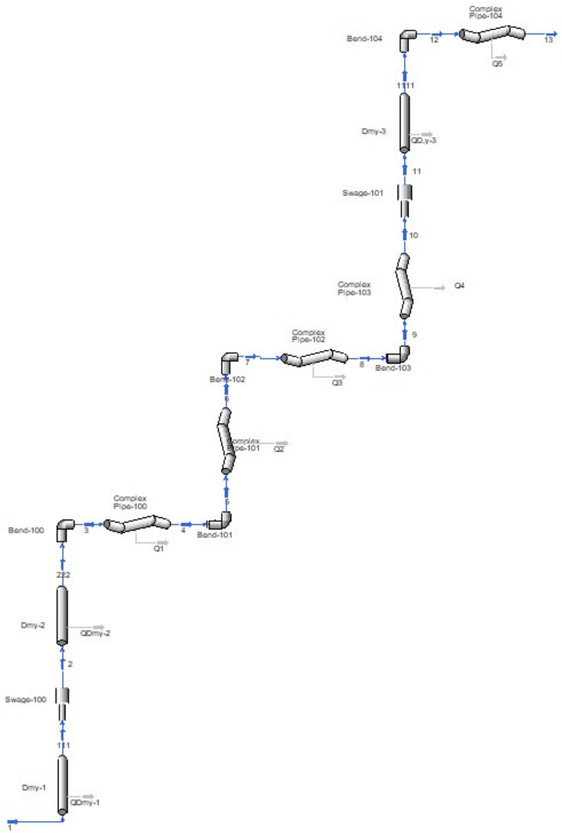
Dynamic Mode:

1.- Assess amplitude and frequency of fluctuations in liquid holdup => pressures => flowrates*
2.- Easy conversion from the initial steady state model
3.- Easy integration with downstream equipment for improved design, control and operating strategies*
4.- Examples: Olga (slug tracker mode), Leda, Aspen Hydraulics, Unisim

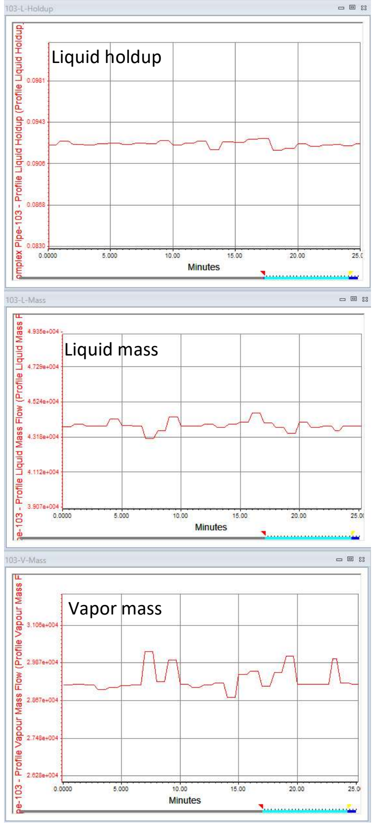
* To include mitigation options (design & operation) to minimize or prevent impact of unstable/slug flow conditions

Hydraulic Assessment

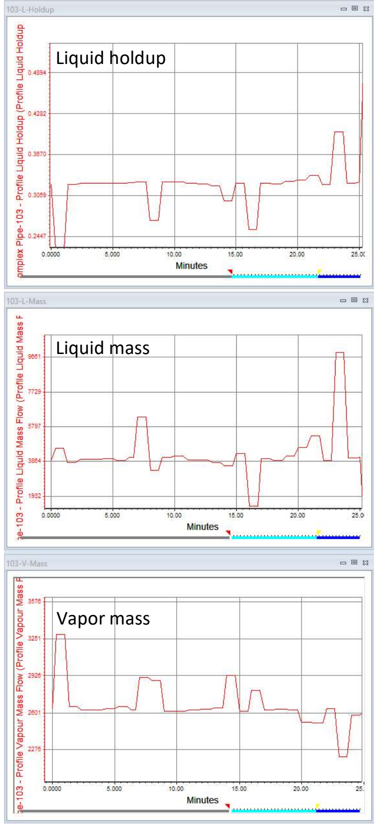
Flow Rates Fluctuations (Amplitude and Frequency by Dynamic Simulation)



Expected Operating Range



Reduced Rates



- Flow Maps do not allow to assess dynamic fluctuations that could affect system performance.

- Additionally, even the most stable 2-phase flow regime can be distorted by the pipe geometry…

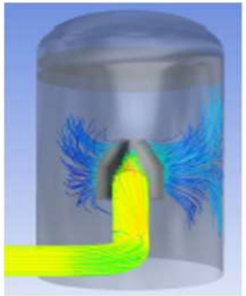
Hydraulic Assessment

Phase distribution @ Inlet Device / Effect of Pipe Geometry

Vertical (Out of Plane)
(not recommended)

2 L/D

10 L/D

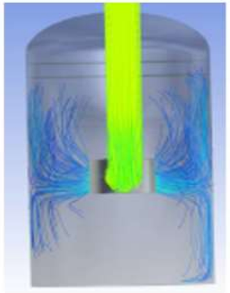


Vessel Diameter = 11.75 ft = 141.7”
Inlet Pipe Diam = 2.3 ft = 28”

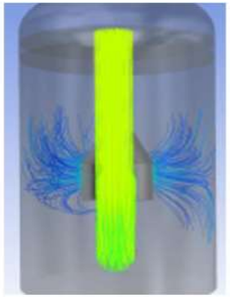
Elbows:
In Plane vs Out of Plane

Out of plane negative effect still persists even after 10 L/D

Vertical (In Plane)



2 L/D



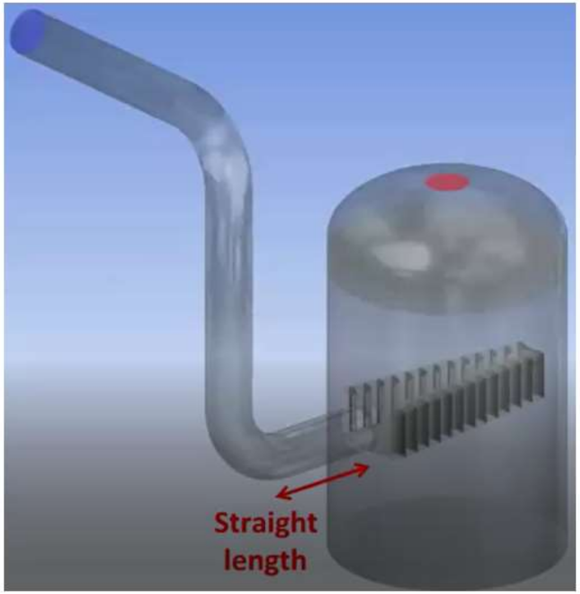
10 L/D

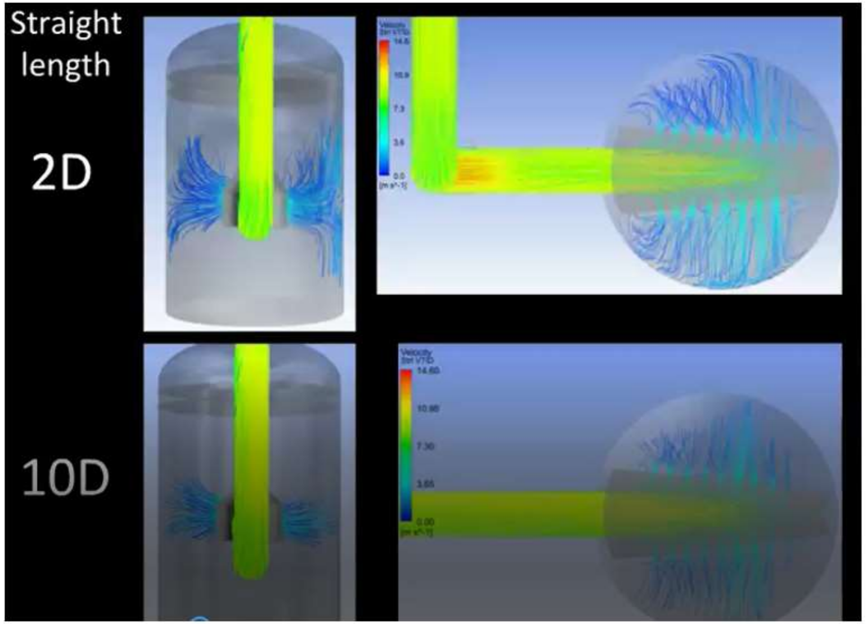
CFD Images courtesy of Kranji Solutions

Hydraulic Assessment

Phase distribution @ Inlet Device / Effect of Pipe Geometry

Two Vertical Bends





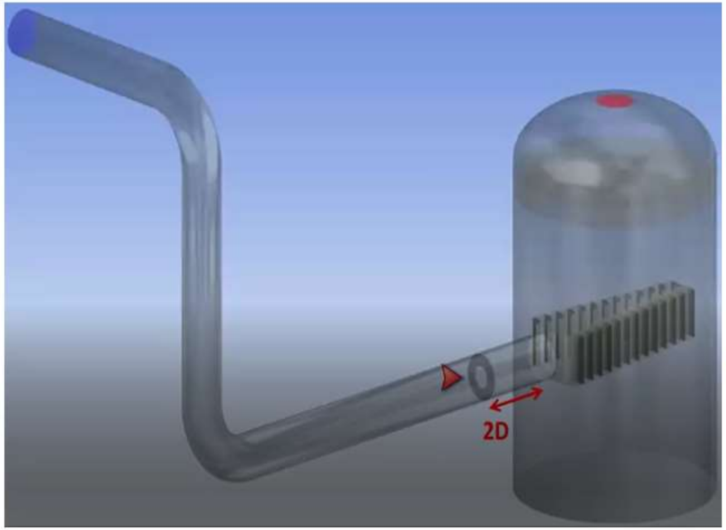
CFD Images courtesy of Kranji Solutions

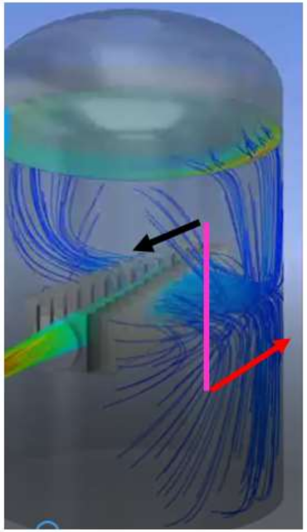
"In Plane" Feed Lines should be the preferred option to connect out of the plane piping, but…

Hydraulic Assessment

Phase distribution @ Inlet Device / Effect of Pipe Geometry

Two Vertical Bends + Valve





1.- Jet is created by valve, causing maldistribution in vessel even after inlet device

2.- liquid droplet decrease size, Increasing entrainment and contamination:

d_{100} – NO VALVE = 500 microns

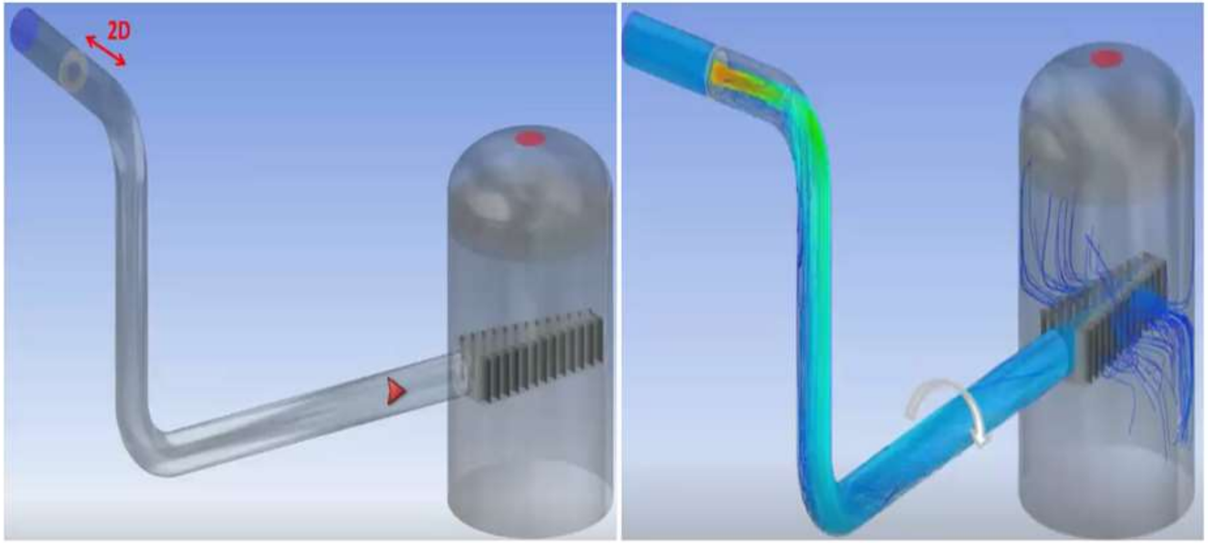
d_{100} – VALVE = 80 microns

CFD Images courtesy of Kranji Solutions

Hydraulic Assessment

Phase distribution @ Inlet Device / Effect of Pipe Geometry

Two Vertical Bends + Valve

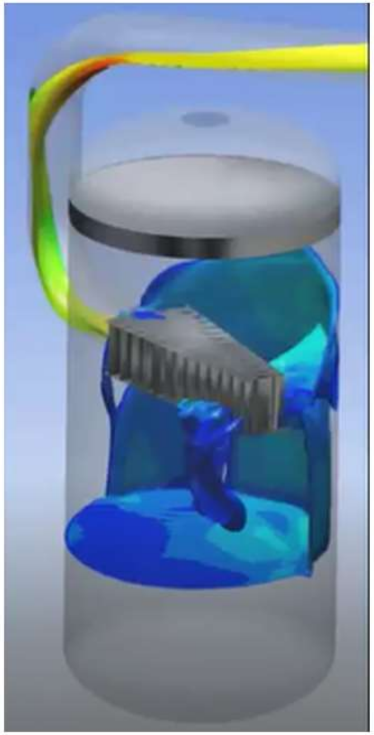


… swirl created by the valve travels long L/Ds and still creates flow maldistribution

CFD Images courtesy of Kranji Solutions

Hydraulic Assessment

Phase distribution @ Inlet Device / Effect of Pipe Geometry



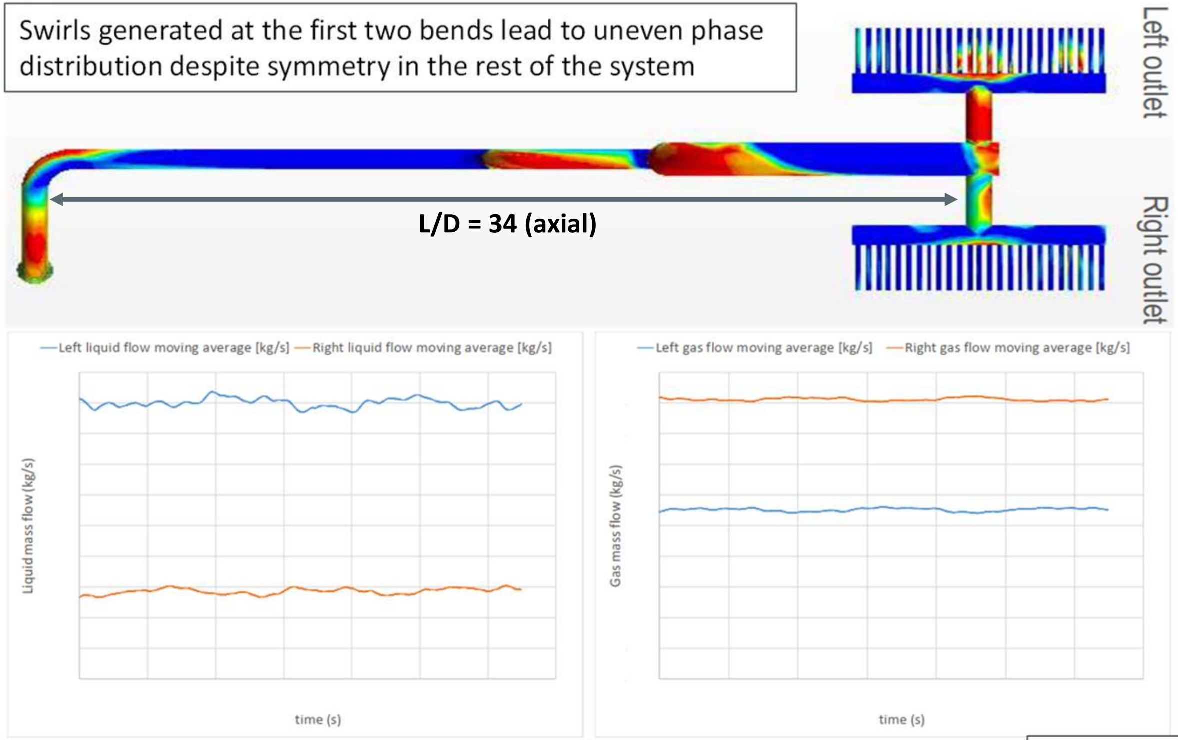
Two Phase Segregated Flow
can generate asymmetrical liquid
inflow pushing liquid along vessel wall

CFD Images courtesy of Kranji Solutions

Hydraulic Assessment

Phase distribution @ Inlet Device / Effect of Pipe Geometry

Swirls generated at the first two bends lead to uneven phase distribution despite symmetry in the rest of the system



CFD images Courtesy of Bechtel Corporation

Distance to re-establish uniform flow patter as function of pipe complexity

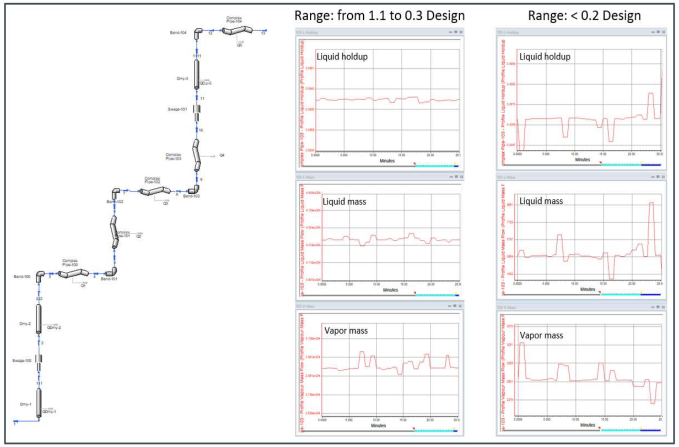
Pipe Arrangement	Reference L/D
One 90º elbow	**15 to 25 ideal** **Most Industrial Applications** **3 to 10 (the larger the better)** **< 3 (not recommended)**
Two 90º elbows same plane	20 to 36, elbows within 3D
Two 90º elbows diff. plane	40 to 62, elbows within 3D Same for orifices
4 to 1 Contraction	15 to 18
4 to 1 Expansion	30 to 84

Note: values for single phase flow

Hydraulic Assessment

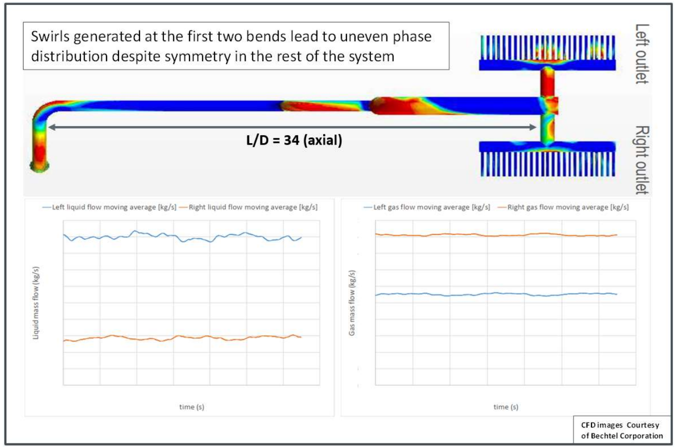
In Short

It is not only about Flow Regime (Pipe Diameter)



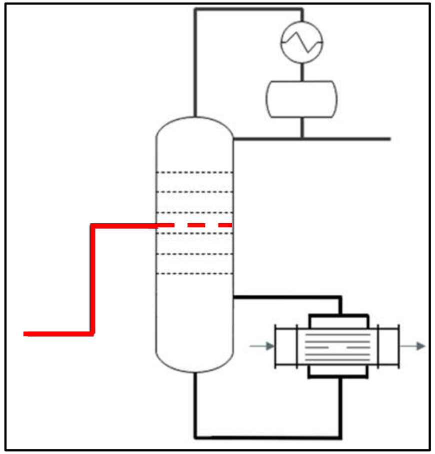
&

It is also about Phase Distribution (Pipe Geometry)



=>

Keep the feed line simple !



…. and in case of doubt… do not gamble…. Consider a CFD analysis

Feed Pipe Considerations (1/4)

- Two-Phase Flow oscillations and maldistribution can be minimized by:
  - Integrating feed pipe and feed distributor design as one piece of equipment
    - Pipe sizing and geometry (layout) should go hand by hand
    - Keep layout as simple as possible. Minimize bends and fittings
    - Avoid sizing by only checking nozzle ρv^2 limits

- Multiphase flow simulators (dynamic mode) offer a more accurate assessment than:
  - Steady state simulators or traditional flow maps
  - Conversion from steady state to dynamic mode requires minimum effort (for pipe segments)

- HTR TPF-15 report should be used to check thermosiphon reboiler circuits

Feed Pipe Considerations (2/4)

- Since:
  A) Two phase flow patterns are distorted by any change in geometry or flow conditions,
  B) Feed Inlet Devices are not Flow Conditioners, therefore Garbage In = Garbage Out

Consequently… Minimizing sources of flow disturbance is the best approach. Here are some strategies:

- All legs of the feed line should be assessed, starting from the connecting flange of the previous equipment
- Stratified flow in horizontal lines feeding vertical lines must be avoided whenever possible, since they can induce vertical slug flow, creating instabilities in the column and associated equipment.
- Dispersed /annular flow is preferred in "Tees" of "H" distributors over stratified flow regime due to a better distribution
- "Out of the plane elbows" should be avoided in the feed line
  - This minimizes the promotion of swirls that lead to uneven split of phases in the feed distributor
- However, feed maldistribution can still be generated by momentum-based flow oscillations between the branches of a feed distributor due to typical two-phase flow pressure drop fluctuations …….

THEREFORE…… =>

Feed Pipe Considerations (3/4)

Consider Chimney Trays when:

- Adequate phase distribution cannot be provided to the feed section
  Liquid maldistribution tend propagate and persist thought several the trays below the feed tray, severely affecting the performance and stability of the column
- Large temperature differentials exist between flashing feeds and tray above (see "How Flooding can affect tower operation", D.C. Hausch, Chemical Engineering Progress, Oct. 1964, page 55)

For Packed Towers, consider the use of flashing galleries

Caution must be used when considering a vapor/liquid (V/L) separator upstream of a Distillation Column

- If a V/L separator is included only to recombine the vapor and liquid streams <u>at the same feed tray location</u>, more problems than benefits may be created due to inadequate residence time and improper instrumentation, among other problems.
- A V/L separator routing the respective vapor and liquid streams to <u>different feed tray locations</u> for column efficiency reasons is of course understood.

Feed Pipe Considerations (4/4)

Additional Guidance:

3a) Henry Z. Kister, “Distillation Operations” , Chapter 2, Mc-Graw-Hill

3b) Kister, Grich, Yeley, “Better feed entry ups debutanizer capacity”, PTQ Revamp and Operations, p31, 2003.

3c) Lee,S.H., Binkley, M.J., “Optimize design for distillation feed”, Hydrocarbon Processing, June 2011.

3d) Fractionation Design Inc. (FRI) Design Practices Handbook