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13th December 2023

2023 EPSC – Third European Conference On Plant & Process Safety – Maastricht, Netherlands

Dynamic Vapor Breakthrough: Avoiding Pitfalls for ERS Design

Daniel Wilkes, Consultant
wilkes.d.uk@iomosaic.com

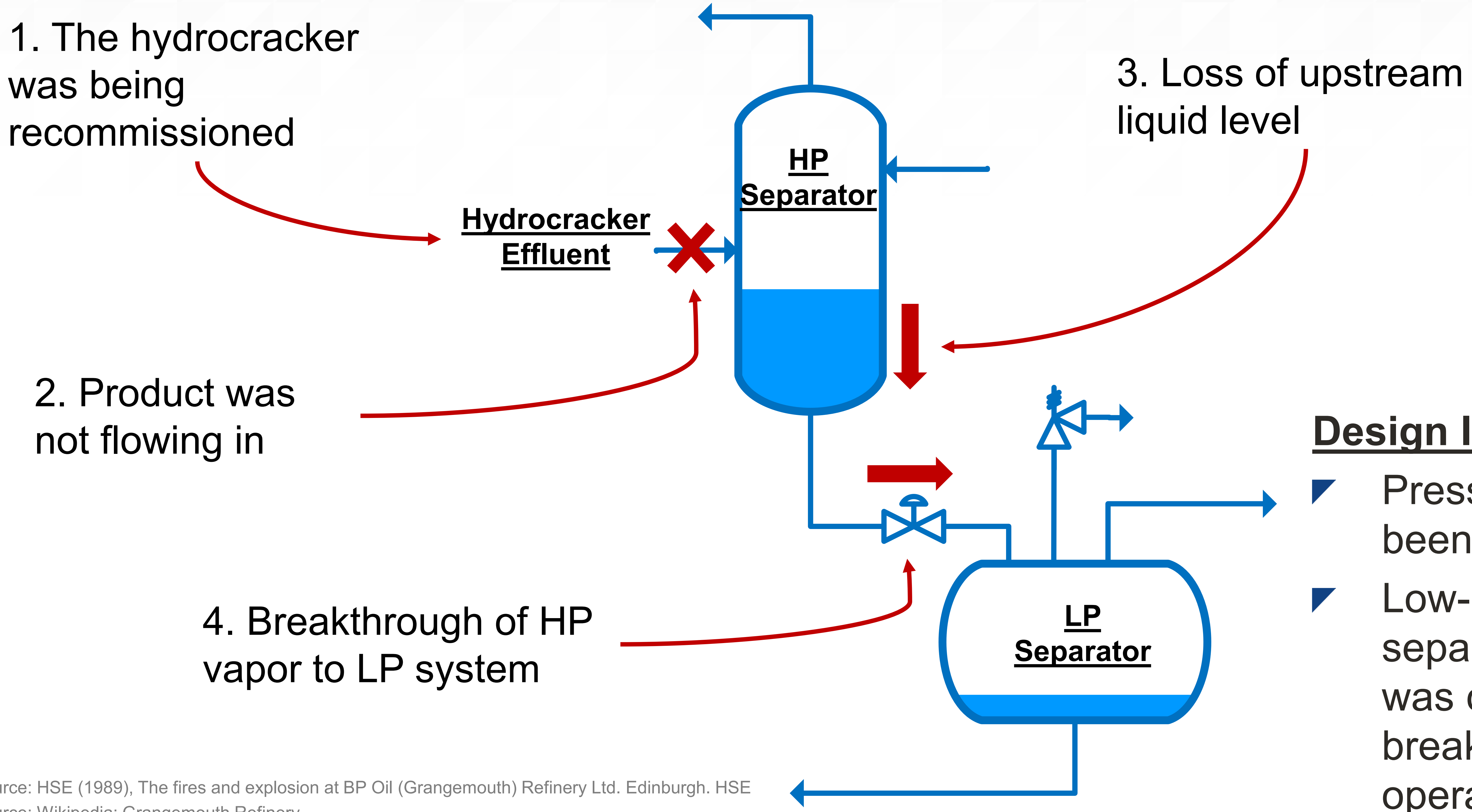
QMS_7.3_7.4.F13 Rev.3

Daniel Wilkes, AMIChemE – Consultant
ioMosaic Corporation UK Office

- Masters in Chemical Engineering (University of Bath, UK)
  - Molecular dynamics research for drug molecule characterization
- Industrial experience
  - Process dynamics, fluid mechanics and mathematical modelling
  - Reaction engineering and modeling runaway reactions
  - Relief systems design for reactive systems
  - Relief device stability analysis
  - Deflagration modelling
  - Guest lecturing 'Pressure Relief Engineering' at the University of Bath, UK
  - Management of capital engineering projects
- Contact info: wilkes.d.uk@iomosaic.com

Table of Contents

Case Study: Grangemouth Hydrocracker Explosion and Fire (22nd March 1987)

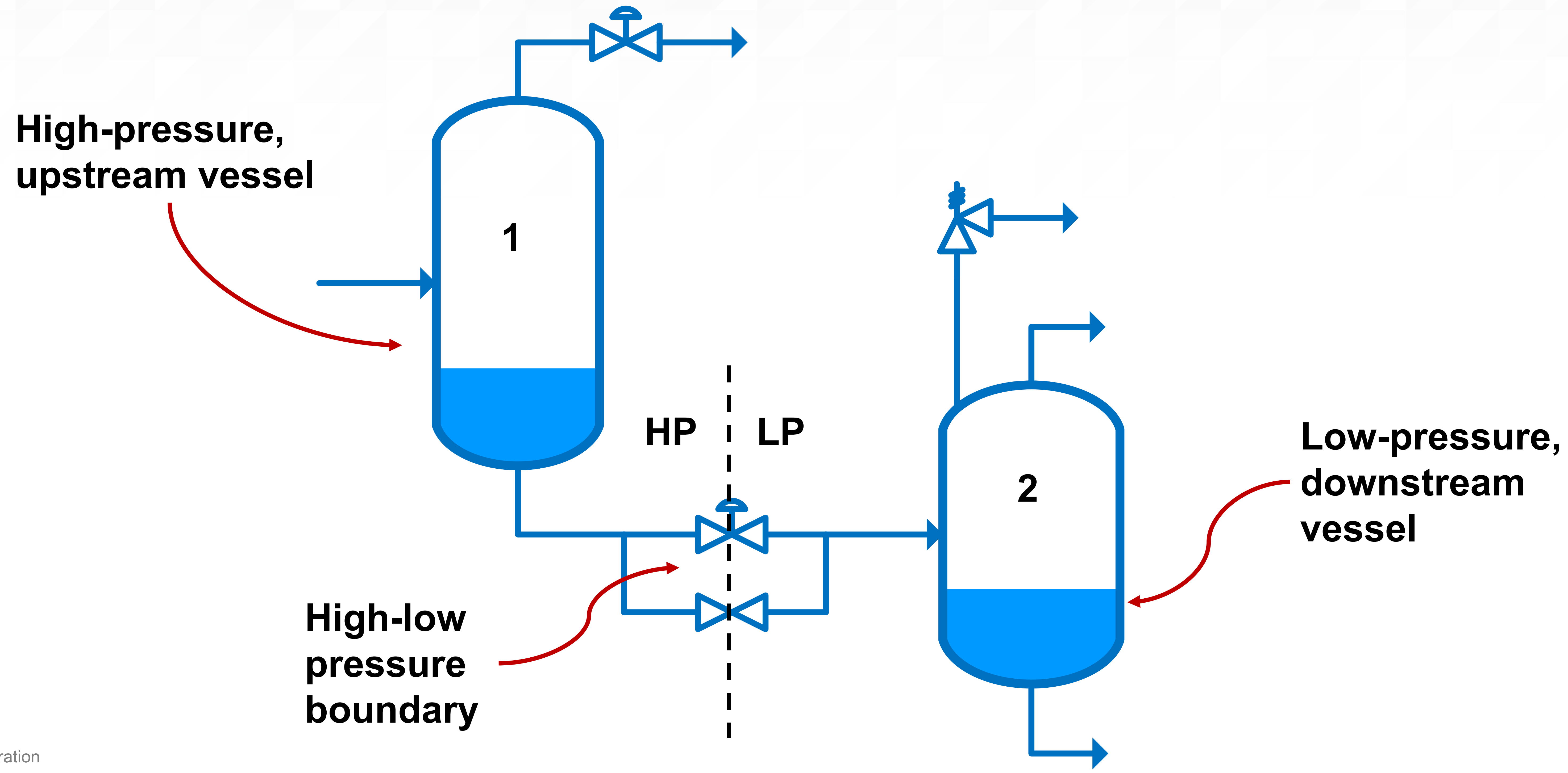


Design Issues:

- Pressure relief valve had been sized for fire
- Low-level trip on the HP separator liquid level was credited to prevent breakthrough, but operators had disabled it

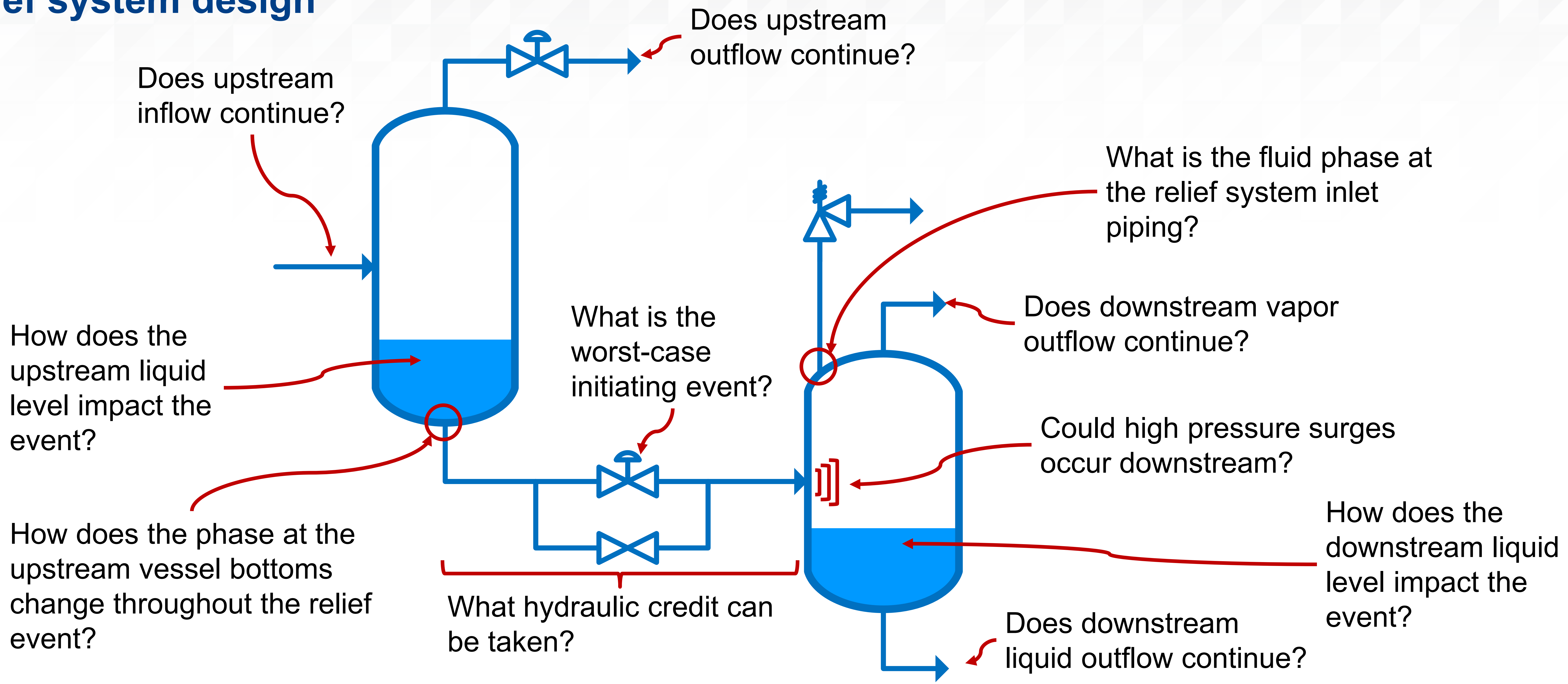
Source: HSE (1989), The fires and explosion at BP Oil (Grangemouth) Refinery Ltd. Edinburgh. HSE
Source: Wikipedia: Grangemouth Refinery

Vapor breakthrough may occur if the liquid seal is lost between a high-pressure and low-pressure system



Source: ioMosaic Corporation

Vapor breakthrough is a complex, dynamic scenario with many elements to consider in relief system design



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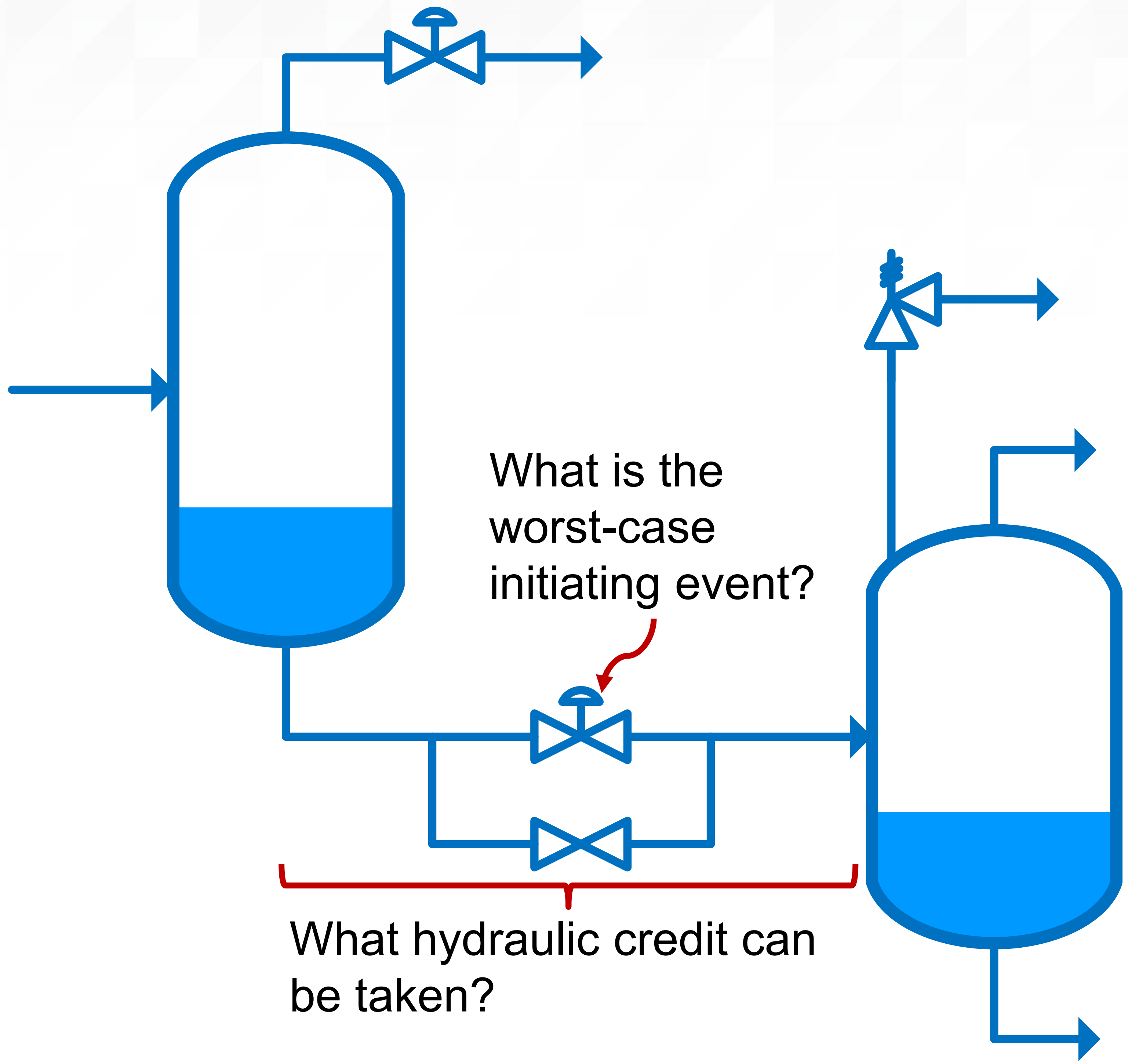

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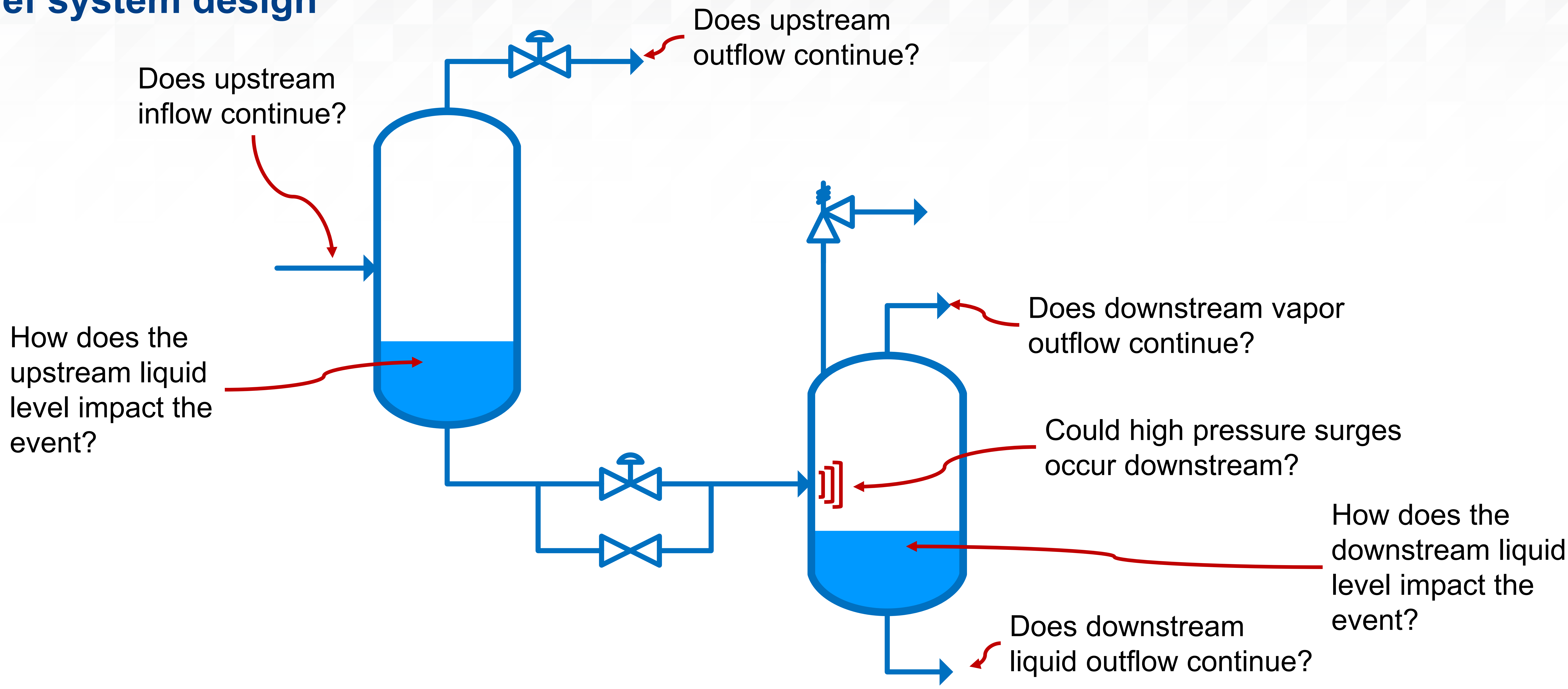
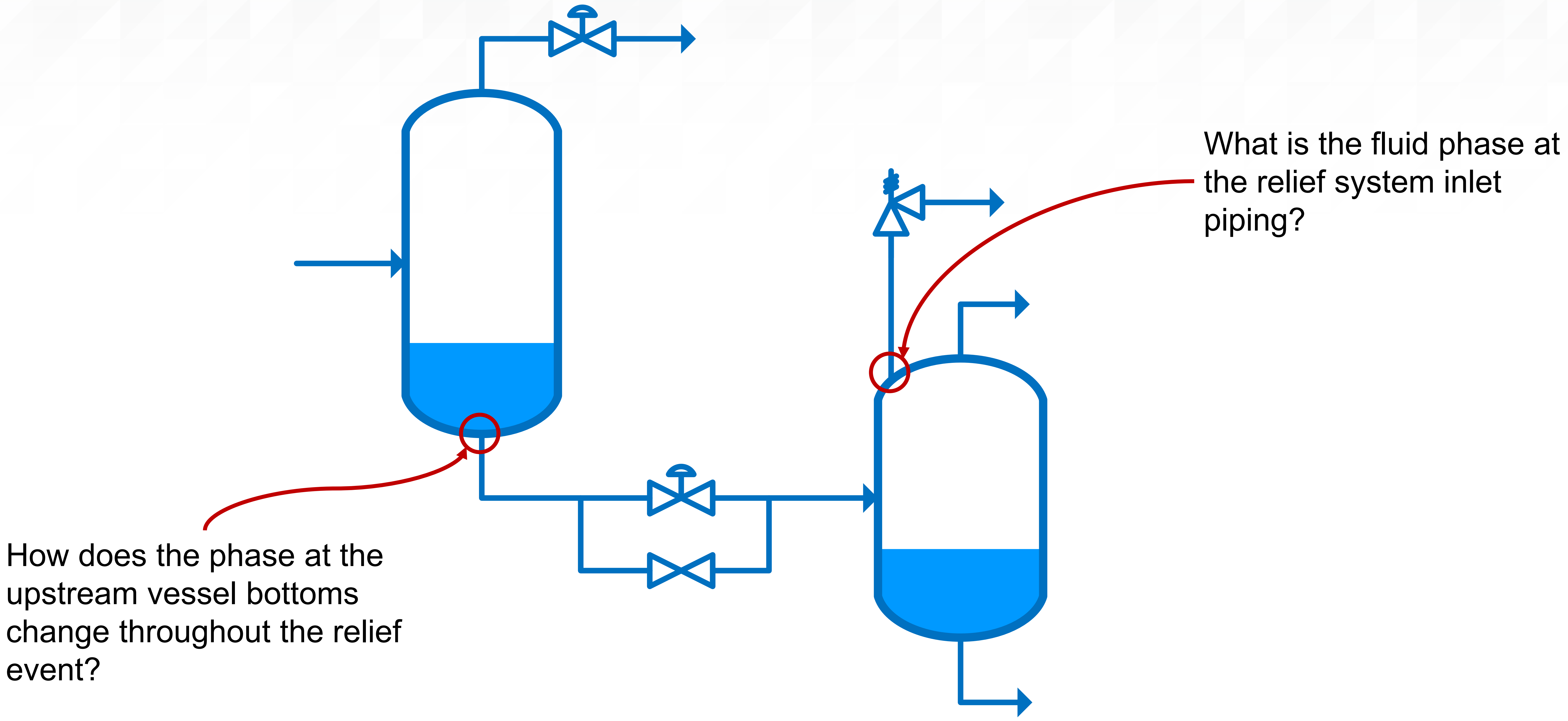


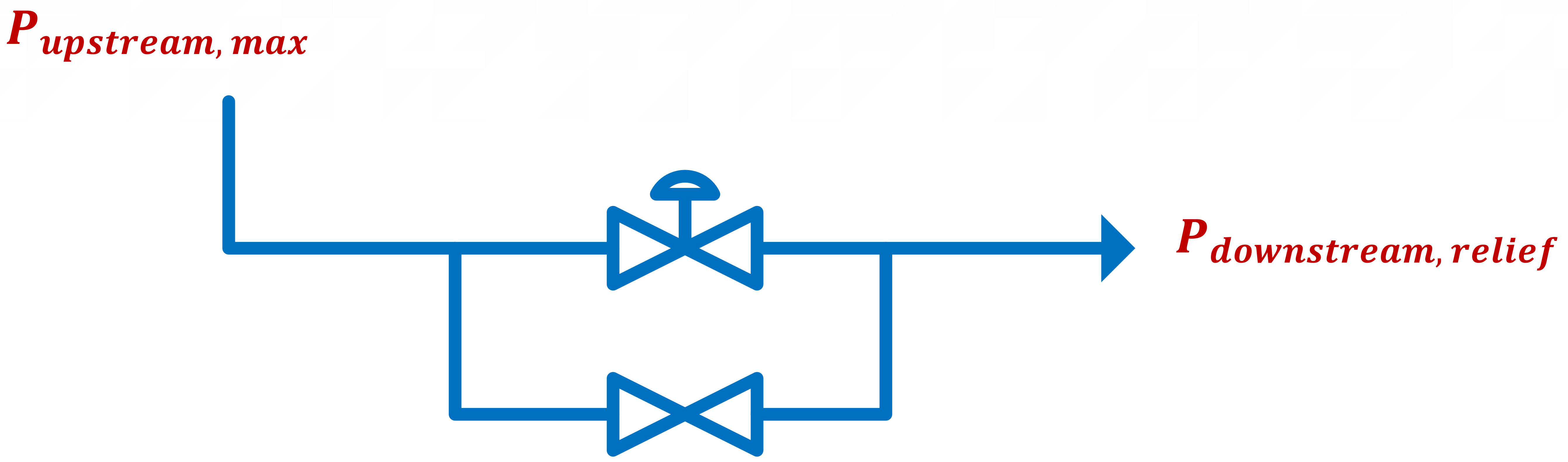
Source: ioMosaic Corporation

Vapor breakthrough is a complex, dynamic scenario with many elements to consider in relief system design



Source: ioMosaic Corporation

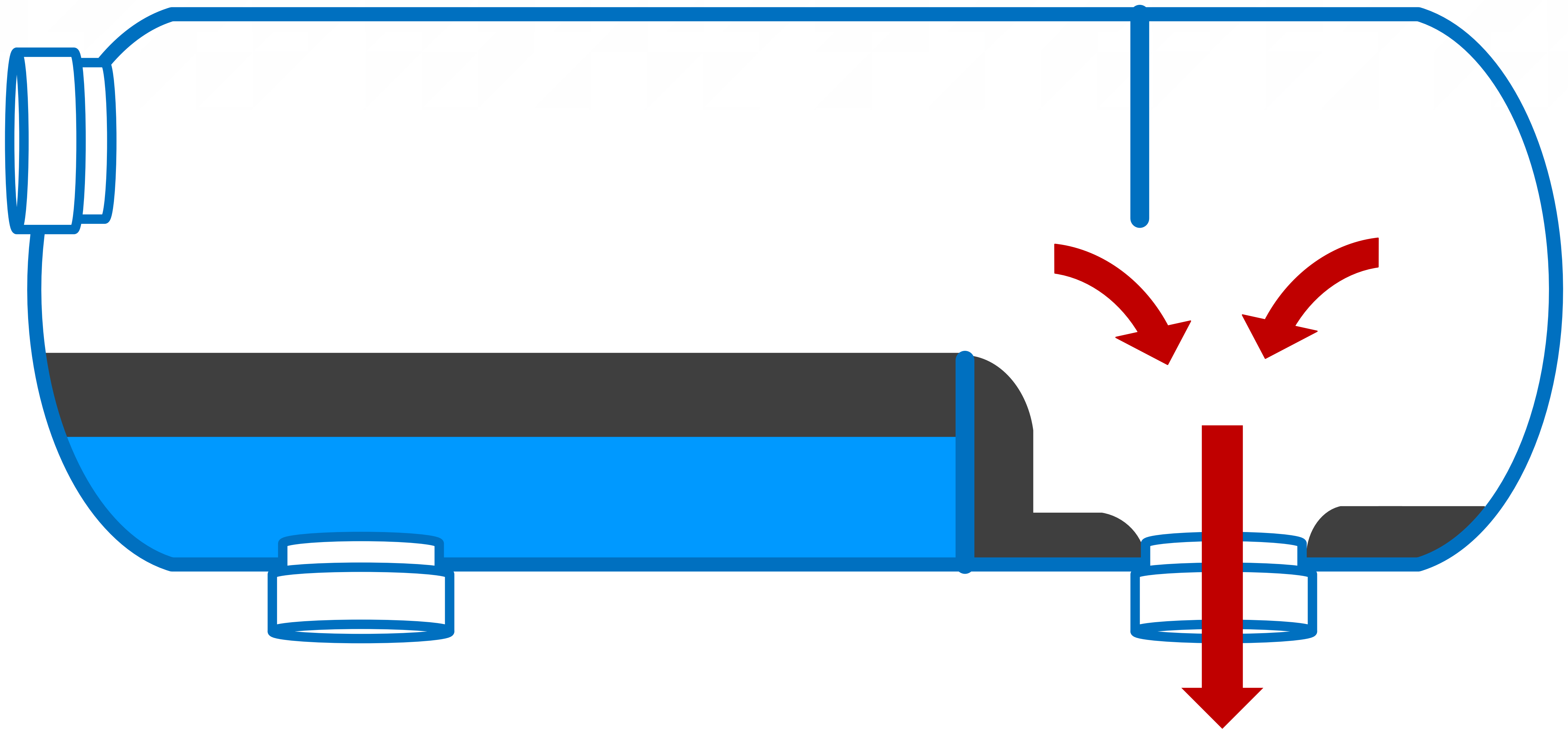
Steady state methodology for vapor breakthrough sizing are often used for a conservative relief sizing



- The relief requirement is typically determined with hydraulic calculations

Source: ioMosaic Corporation

100% vapor may still break through even if liquid remains in the upstream vessel, so be cautious crediting two-phase flow

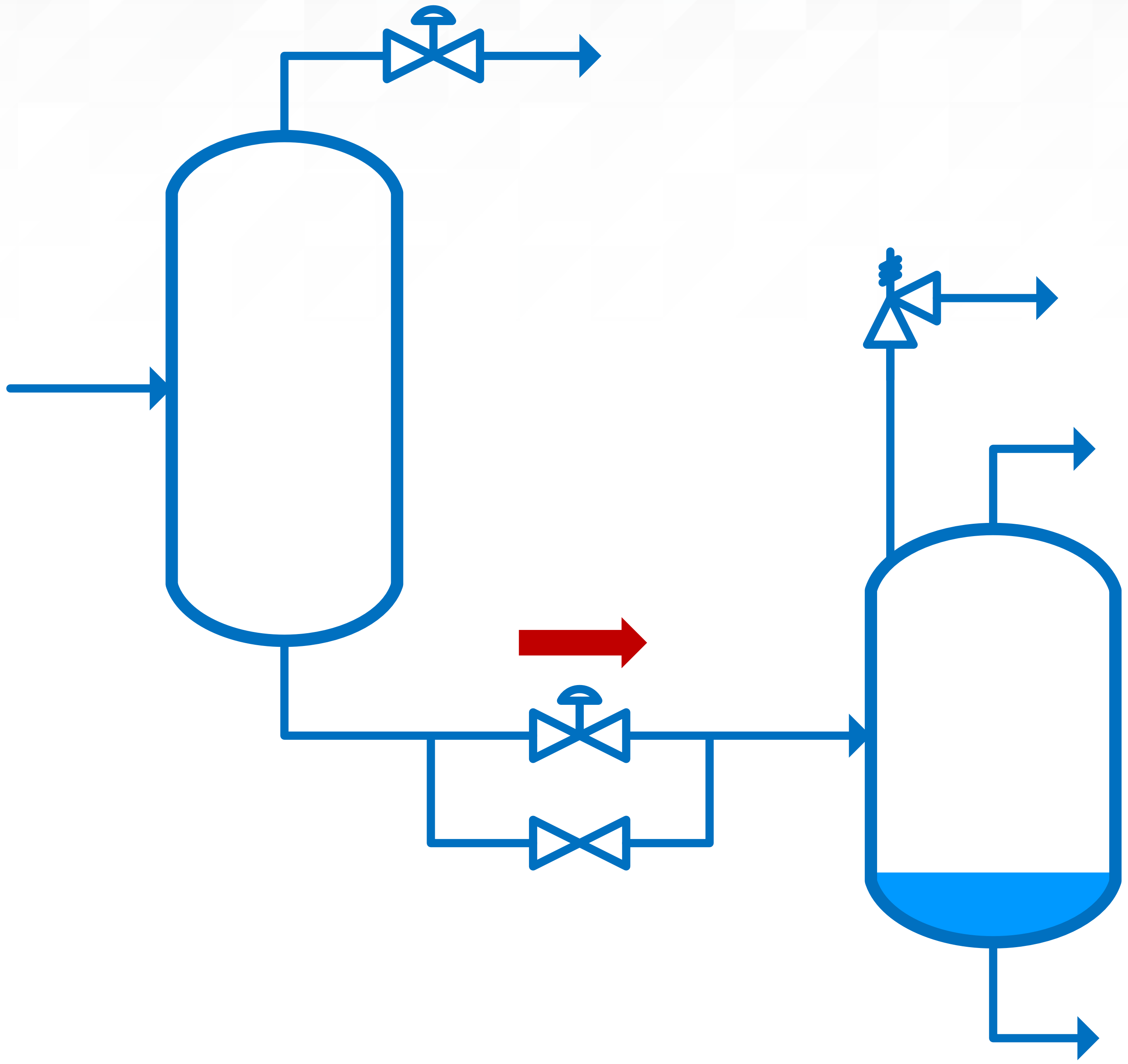


100% vapor may still break through due to:

- Sloshing liquid
- High vapor velocity
- Complex internal geometries

Source: ioMosaic Corporation

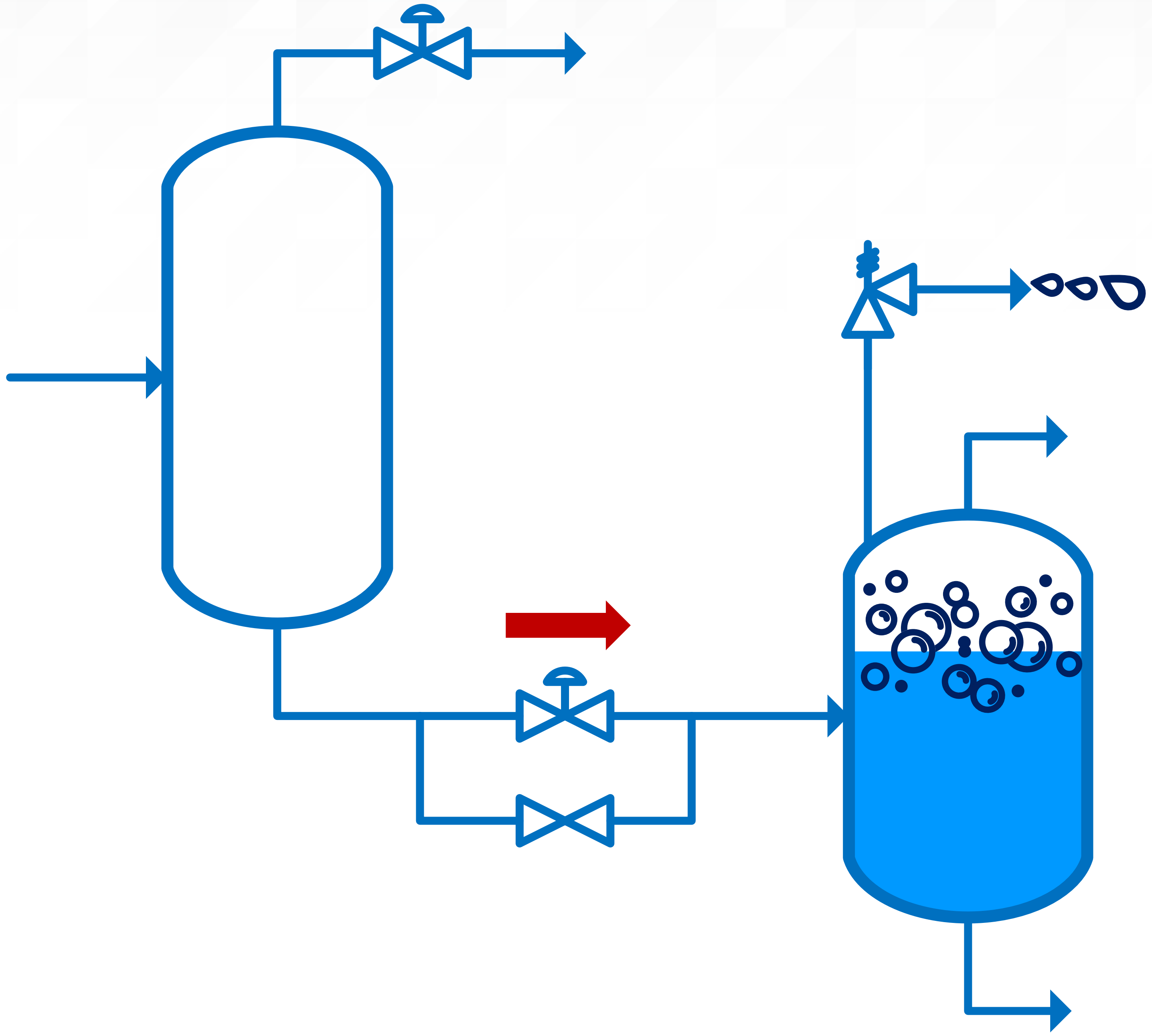
1. The liquid partially fills the downstream vessel



- The downstream liquid level is low (usually below the inlet nozzle)
- Complete vapor/liquid disengagement occurs
- **The relief valve discharges vapor only**

Source: ioMosaic Corporation

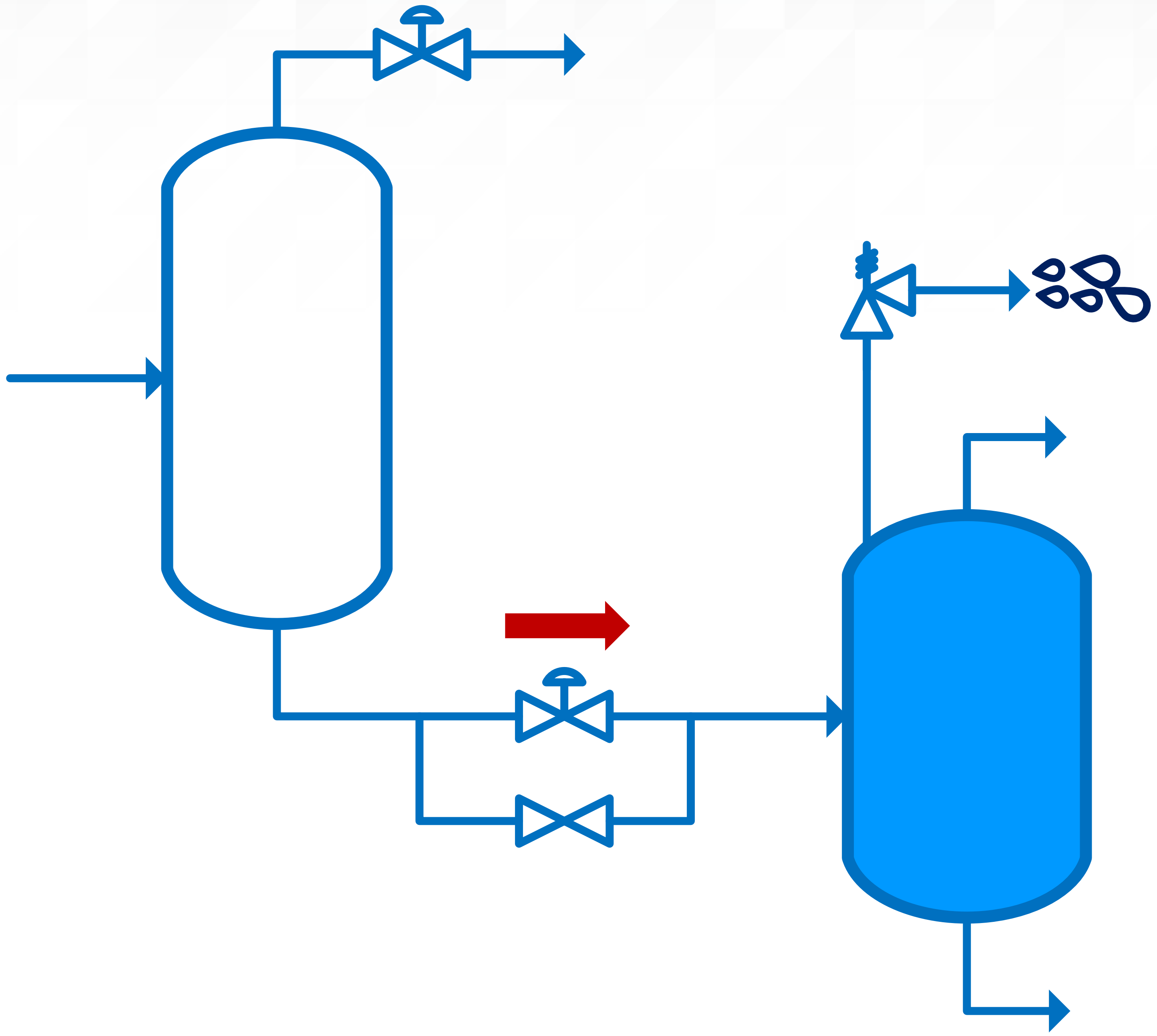
2. The liquid significantly fills the downstream vessel



- The downstream liquid level is significantly high (above inlet nozzle, but not filled)
- Partial vapor/liquid disengagement may occur
- **The relief fluid is expected to be 2-phase**

Source: ioMosaic Corporation

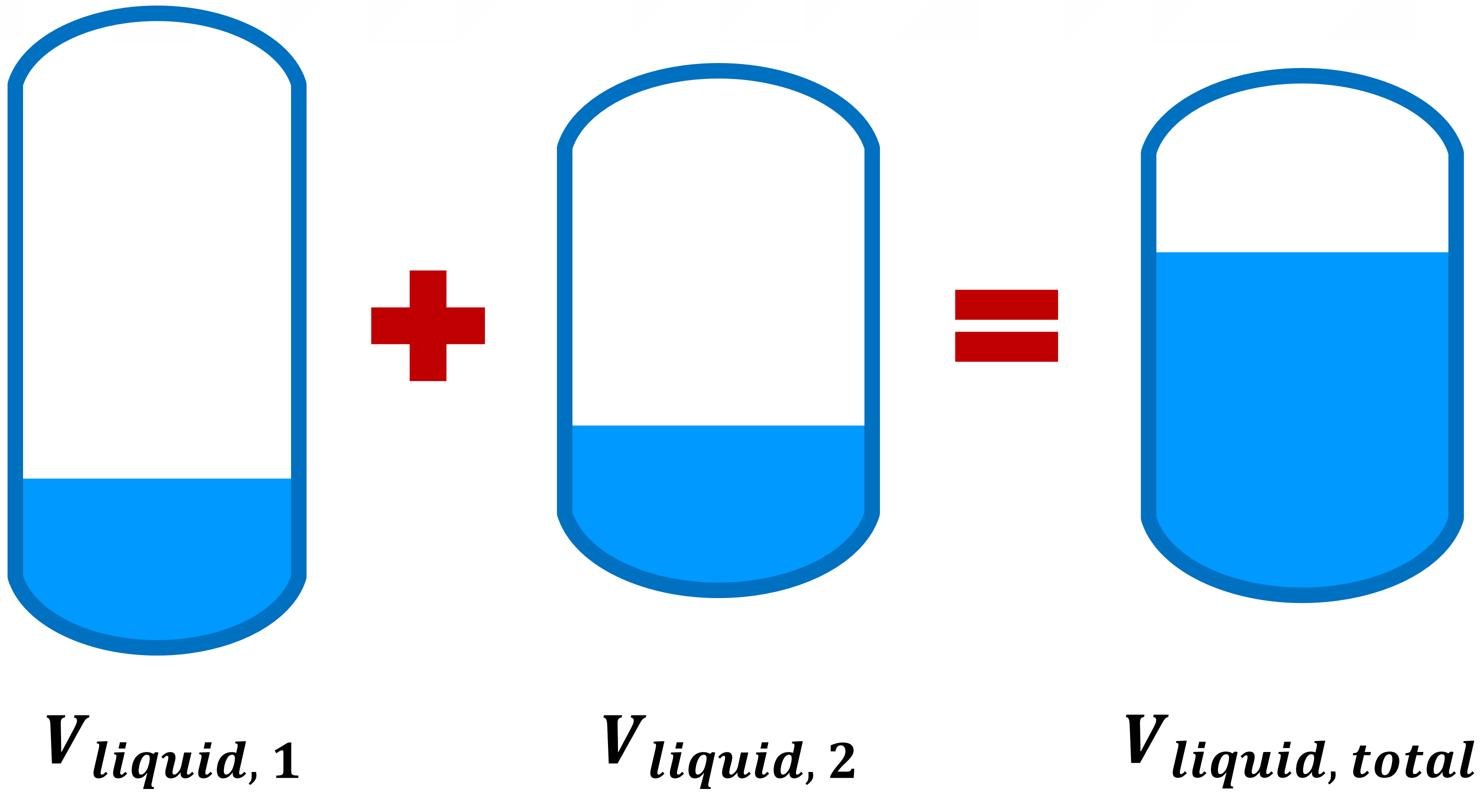
3. The liquid overfills the downstream vessel



- The downstream vessel becomes liquid full
- Limited vapor/liquid disengagement may occur
- **The relief fluid is expected to contain a significant amount of liquid**

Source: ioMosaic Corporation

The resulting downstream liquid level can be calculated with a simple volume balance



- $V_{liquid,\,1} + V_{liquid,\,2} = V_{liquid,\,total}$

However, this methodology has limitations:

- Flow may continue
- Flashing of liquid to vapor may occur
- *For accuracy, use a **dynamic** analysis!*

Source: ioMosaic Corporation

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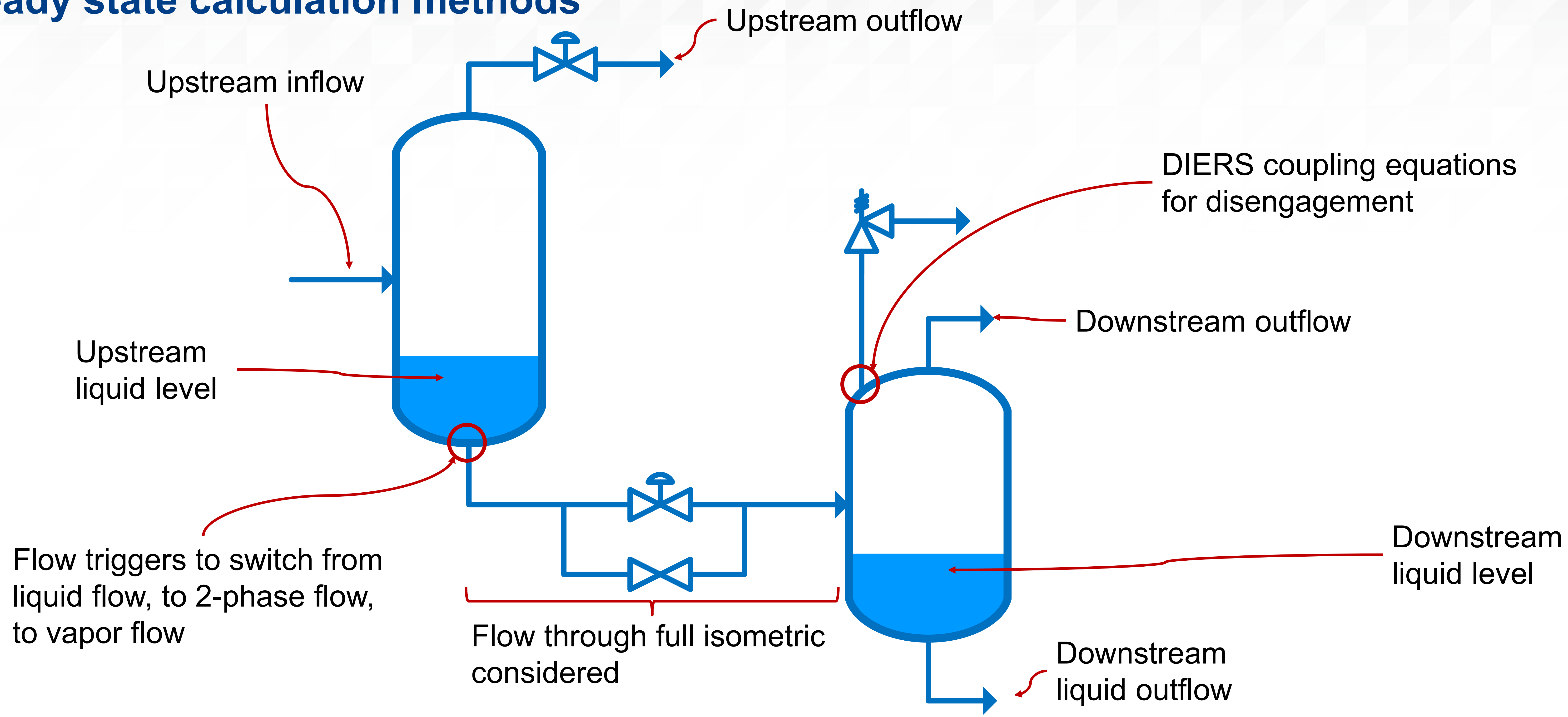
Considerations when setting up the model

- Process Safety Office® SuperChems™ was used to model the scenario with lumped dynamic modelling to account for changing vessel, flow and incorporation of DIERS coupling equations
- Which flows continue, which stop?
- When does flow from upstream transition from 100% liquid flow ?
- What is the relief fluid phase?
- **What is the worst-case operating condition?**

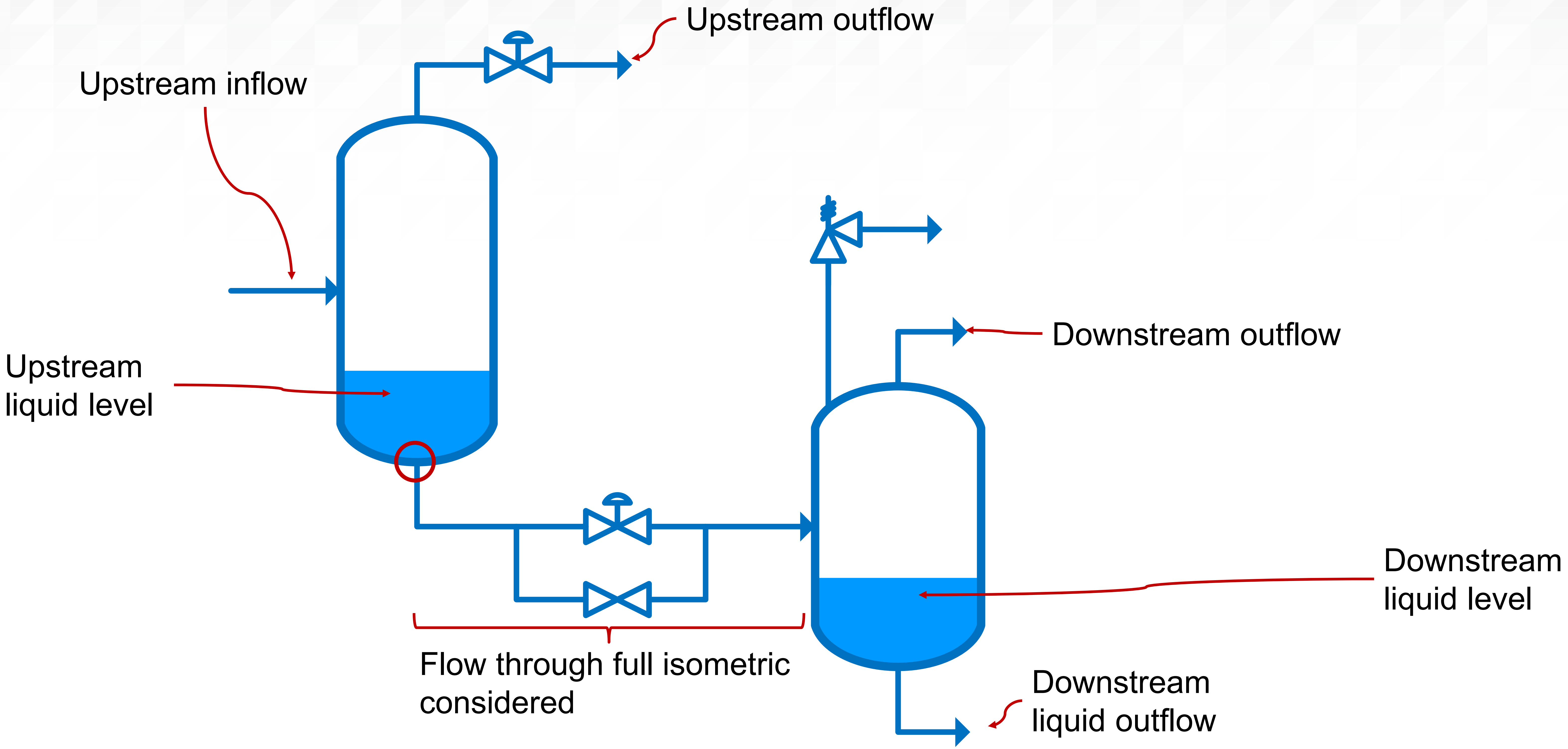
Source: ioMosaic Corporation

Dynamic modelling of vapor breakthrough can capture many more phenomena than steady state calculation methods



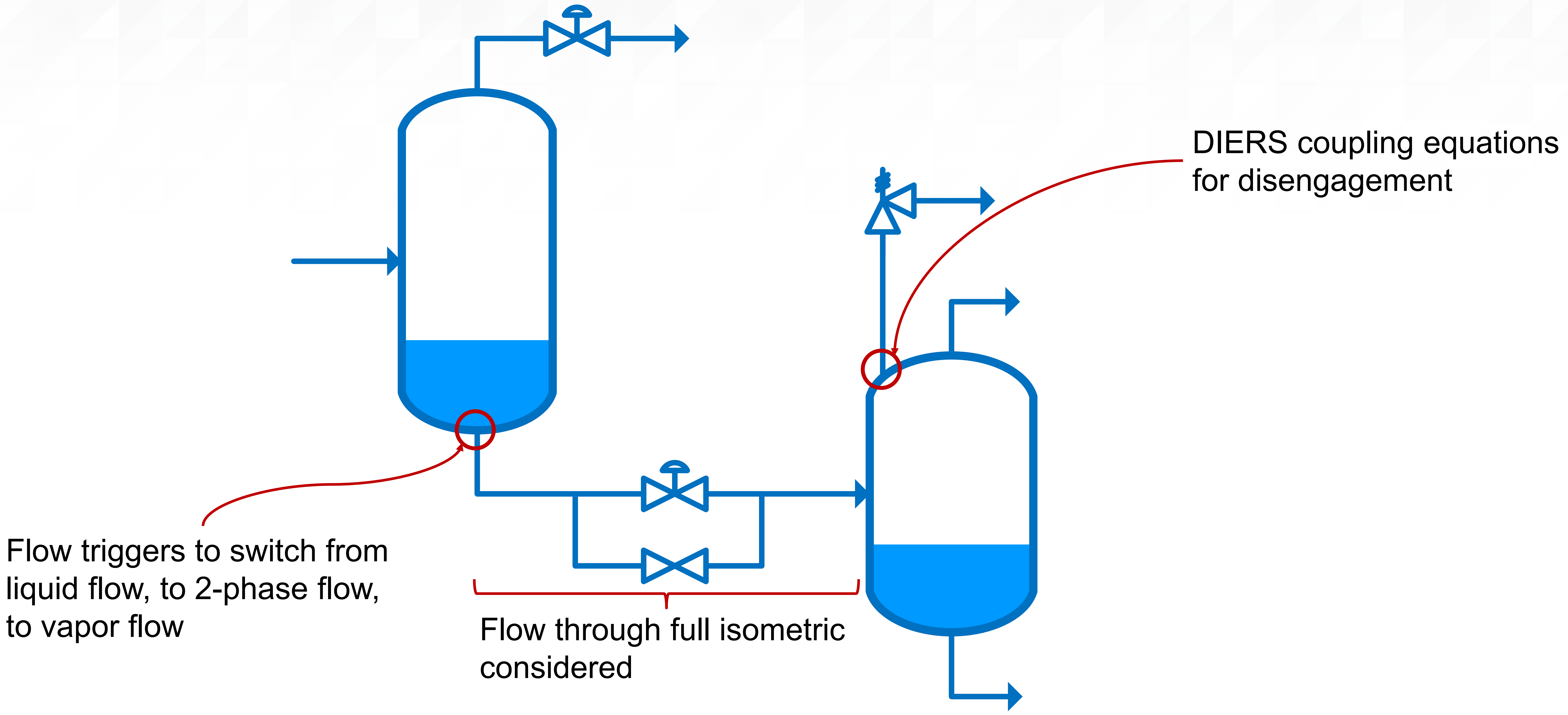
Source: Melhem, G.A. (2017), The Anatomy of Liquid Displacement and High-Pressure Fluid Breakthrough. ioMosaic Corporation.

The dynamic inflows, outflows, and liquid levels should be included



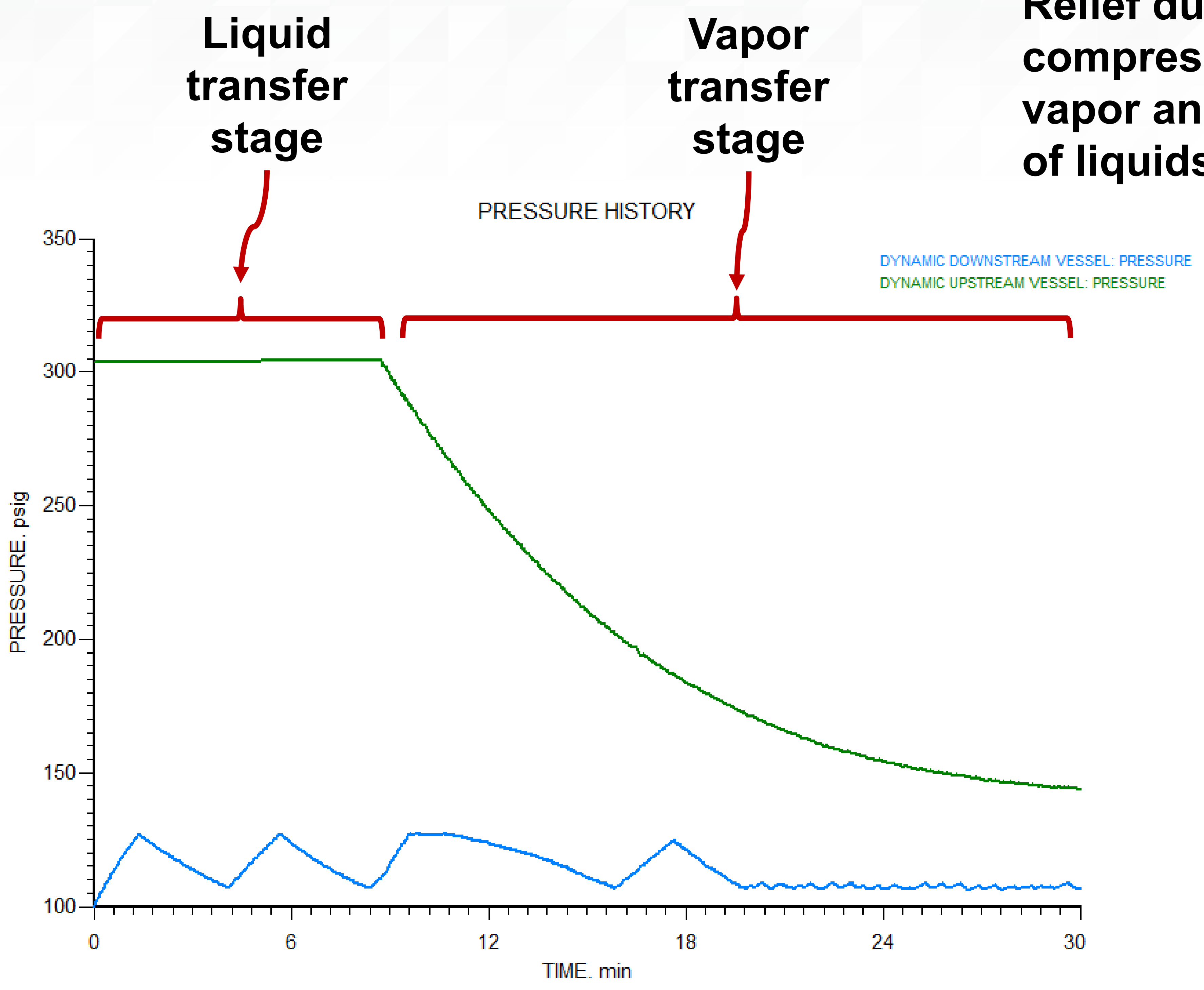
Source: Melhem, G.A. (2017), The Anatomy of Liquid Displacement and High-Pressure Fluid Breakthrough. ioMosaic Corporation.

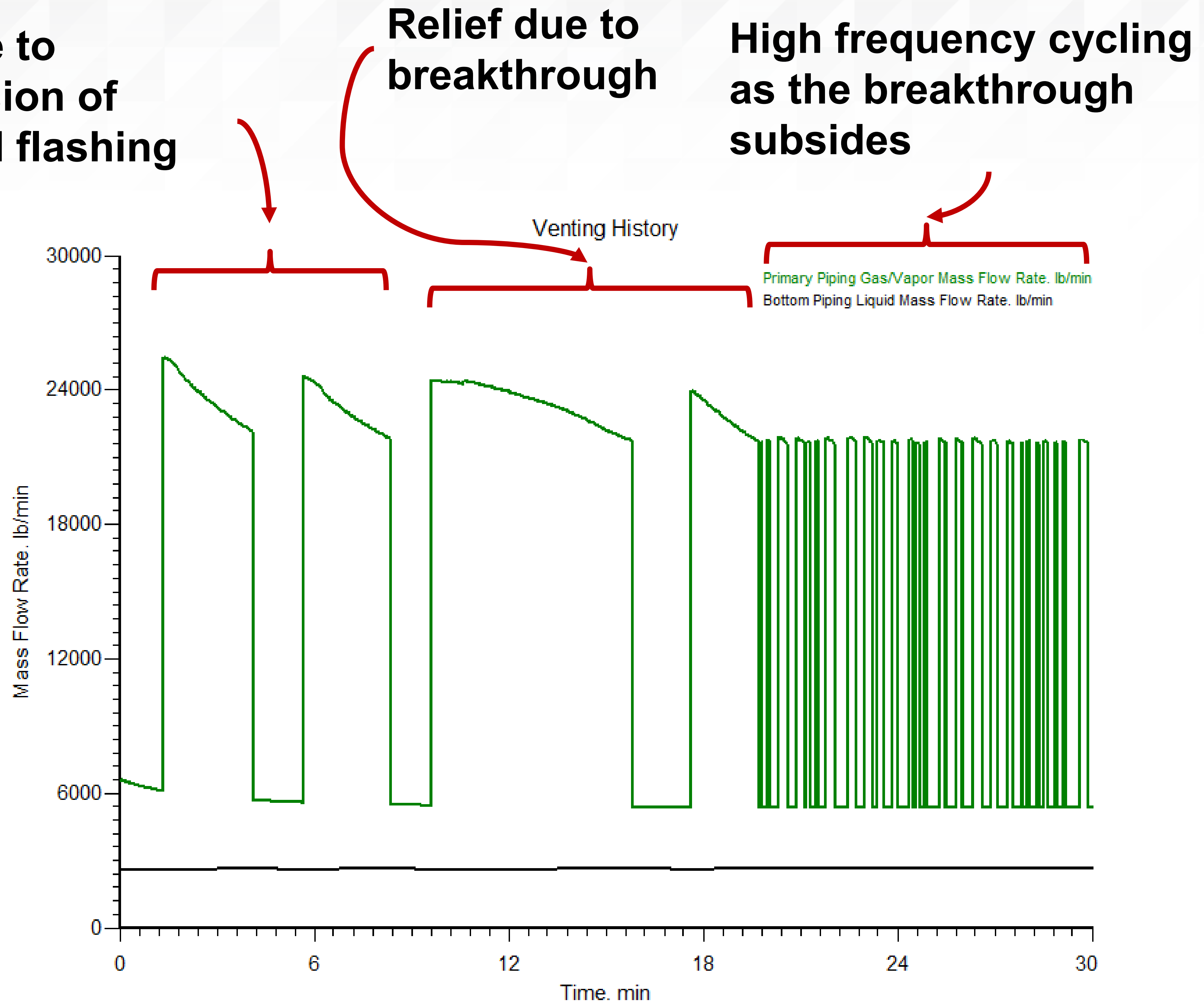
It is important to consider the phase of the flow leaving each vessel



Source: Melhem, G.A. (2017), The Anatomy of Liquid Displacement and High-Pressure Fluid Breakthrough. ioMosaic Corporation.

Best estimate churn turbulent flow predicts vapor only relief flow





Source: ioMosaic Corporation and Process Safety Office® SuperChems™

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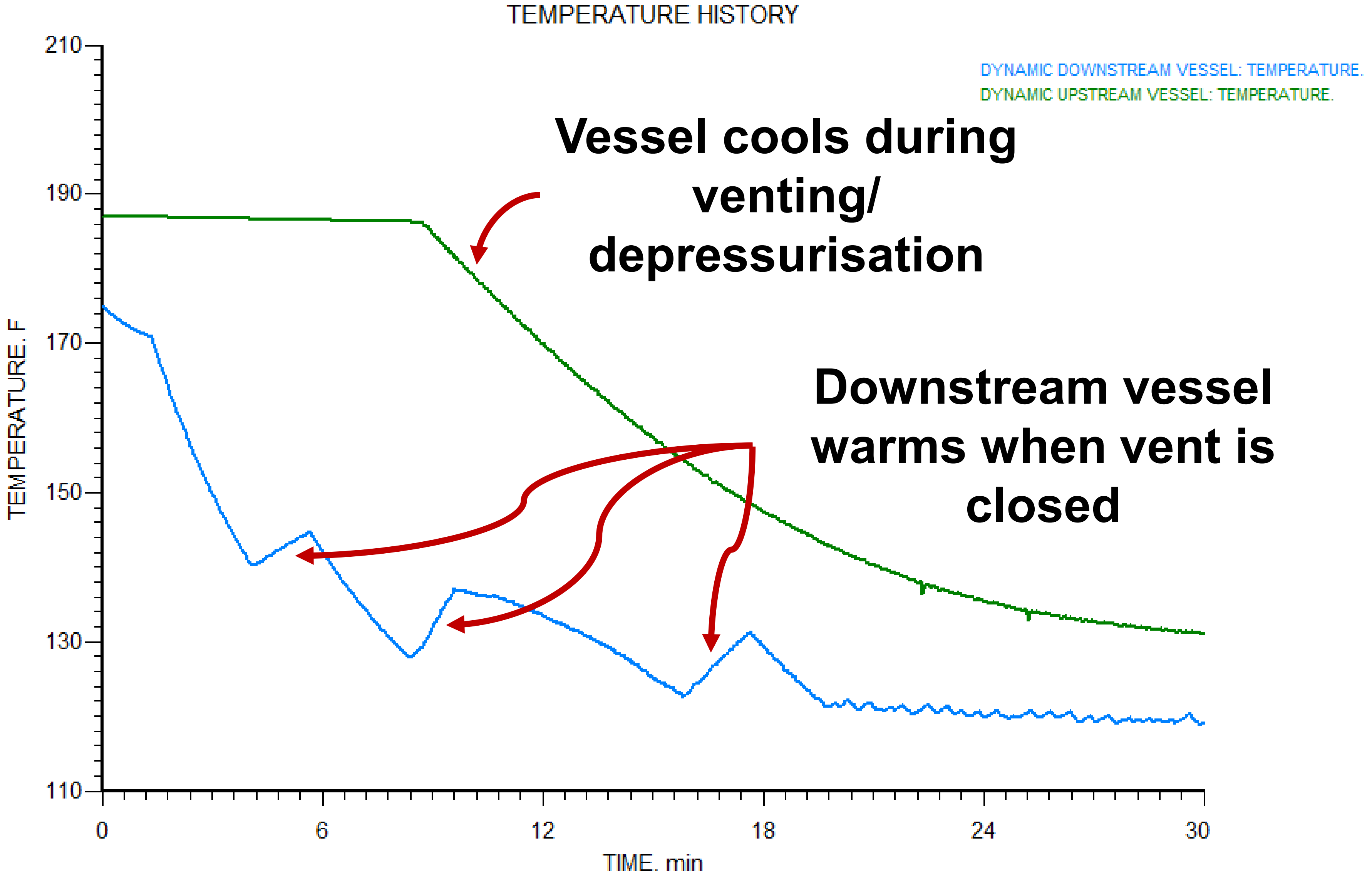
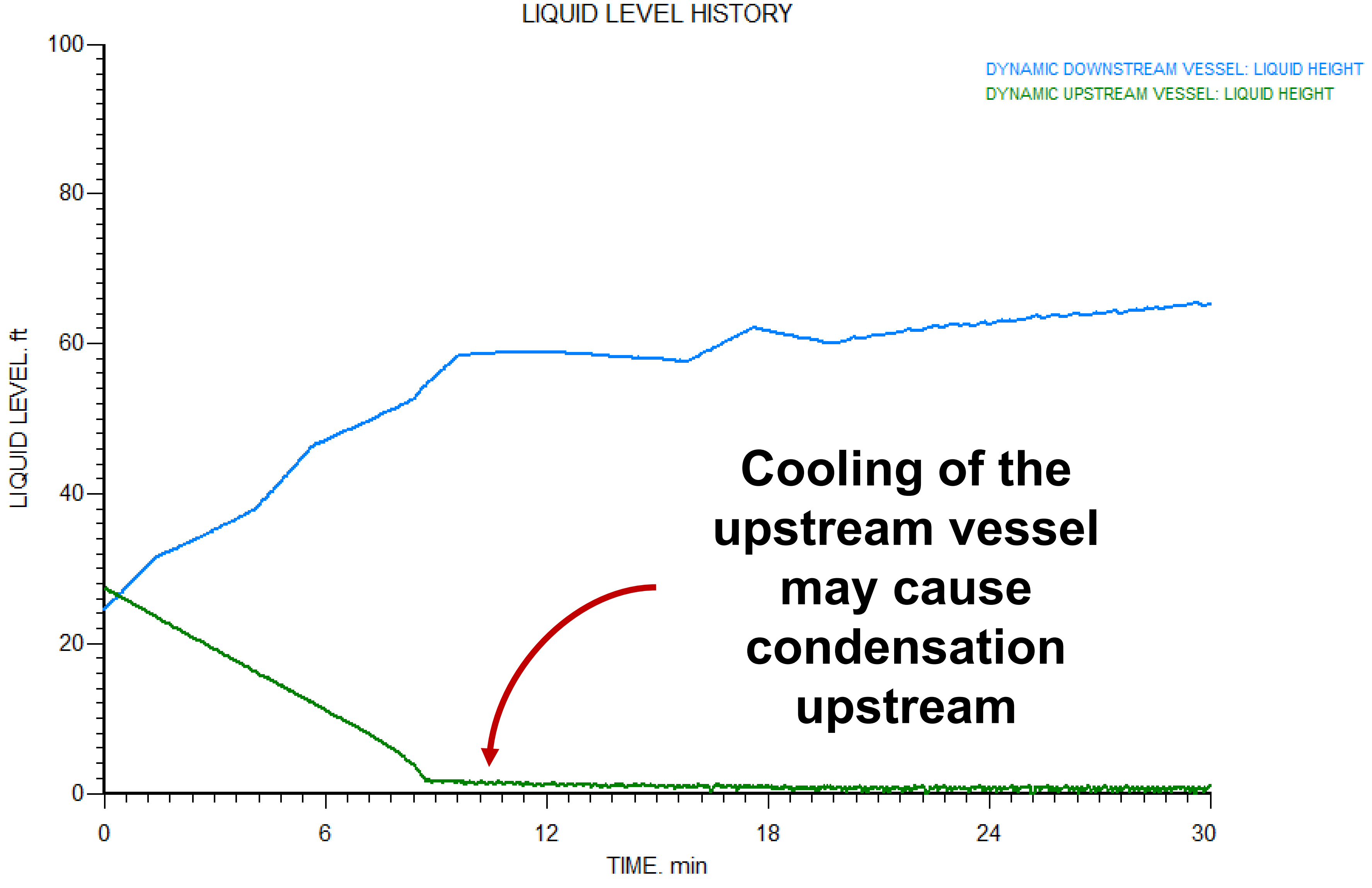
Dynamic results also give interesting insight into the dynamic temperature and liquid volumes





Source: ioMosaic Corporation and Process Safety Office® SuperChems™

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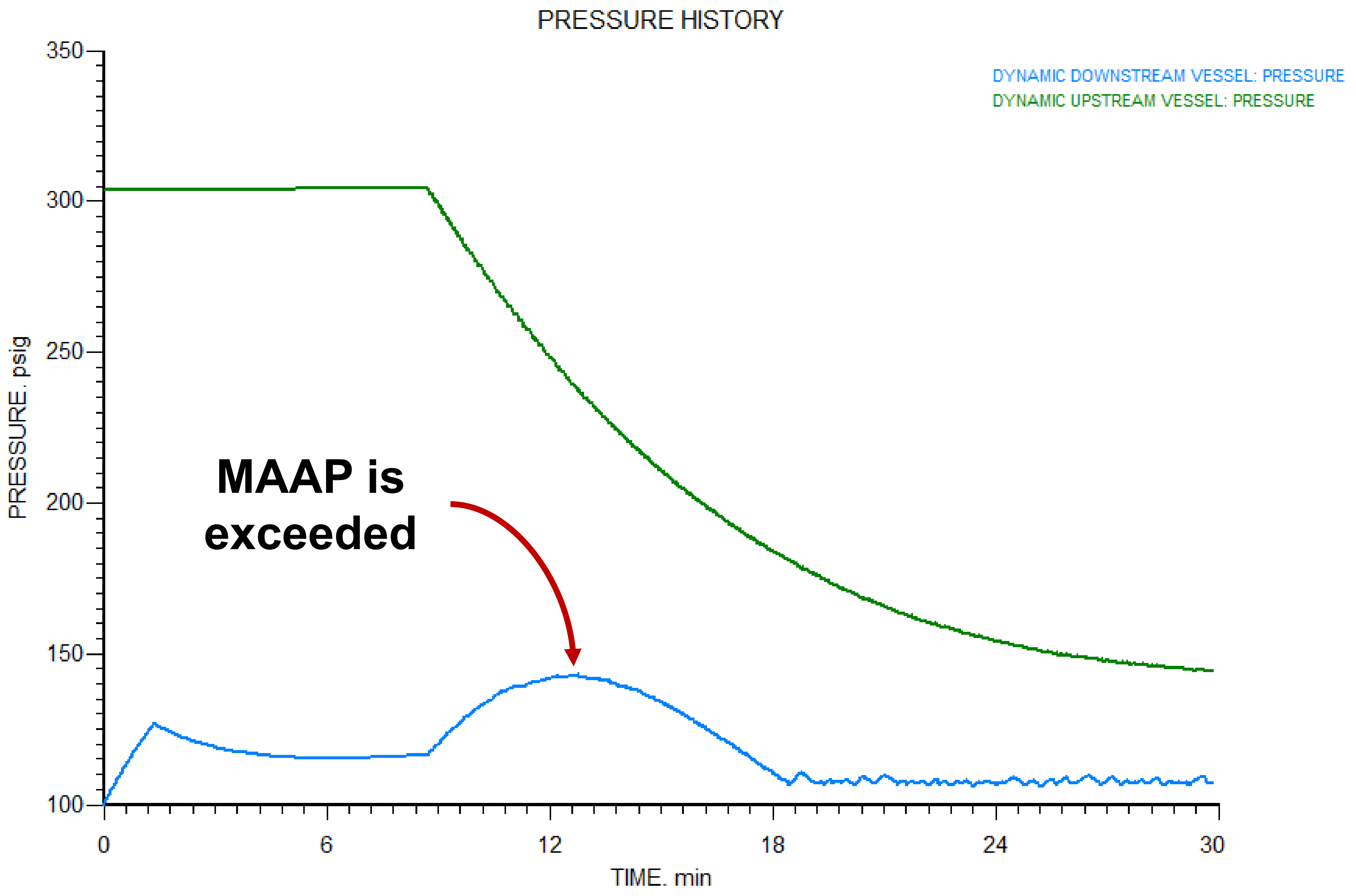
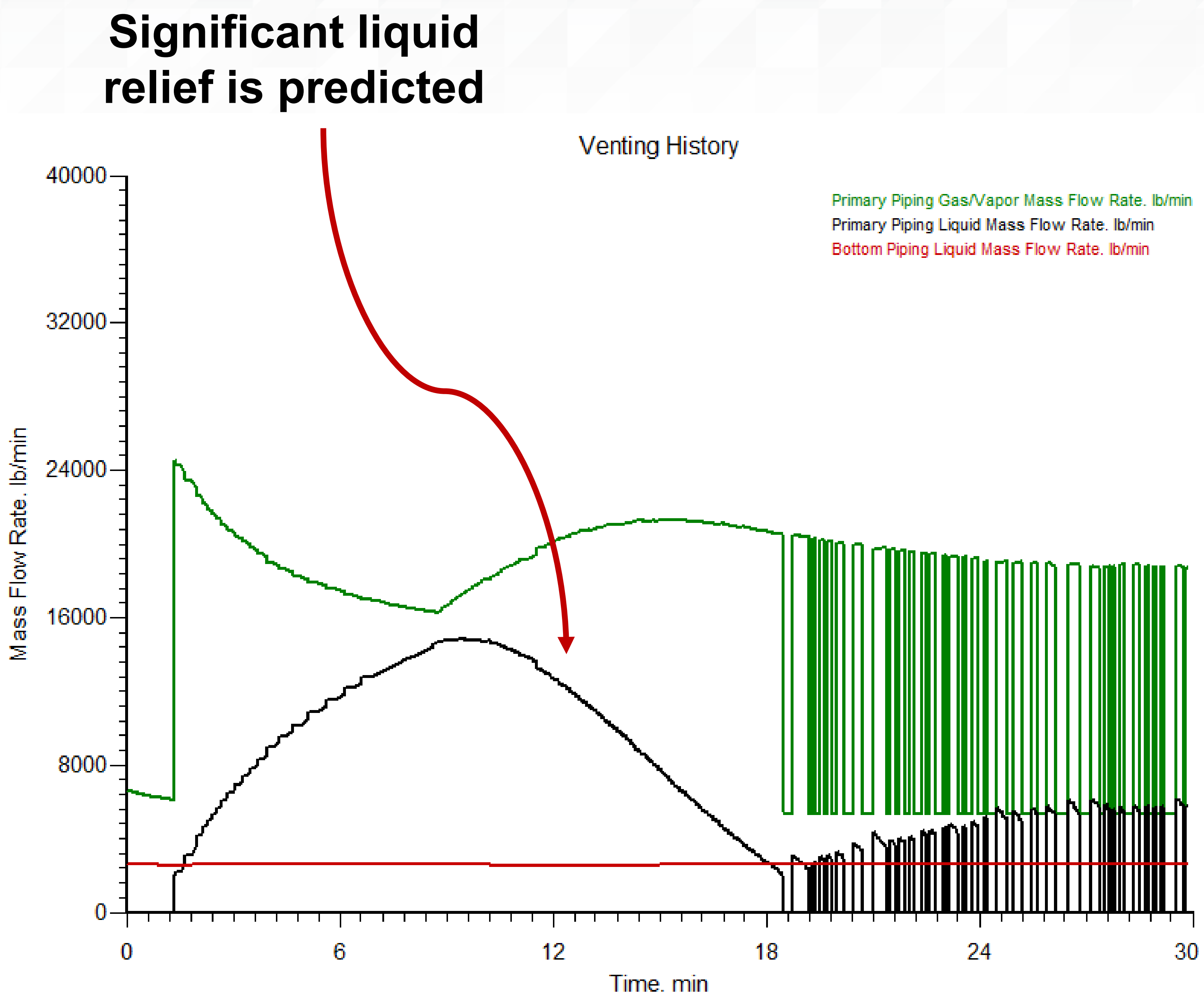
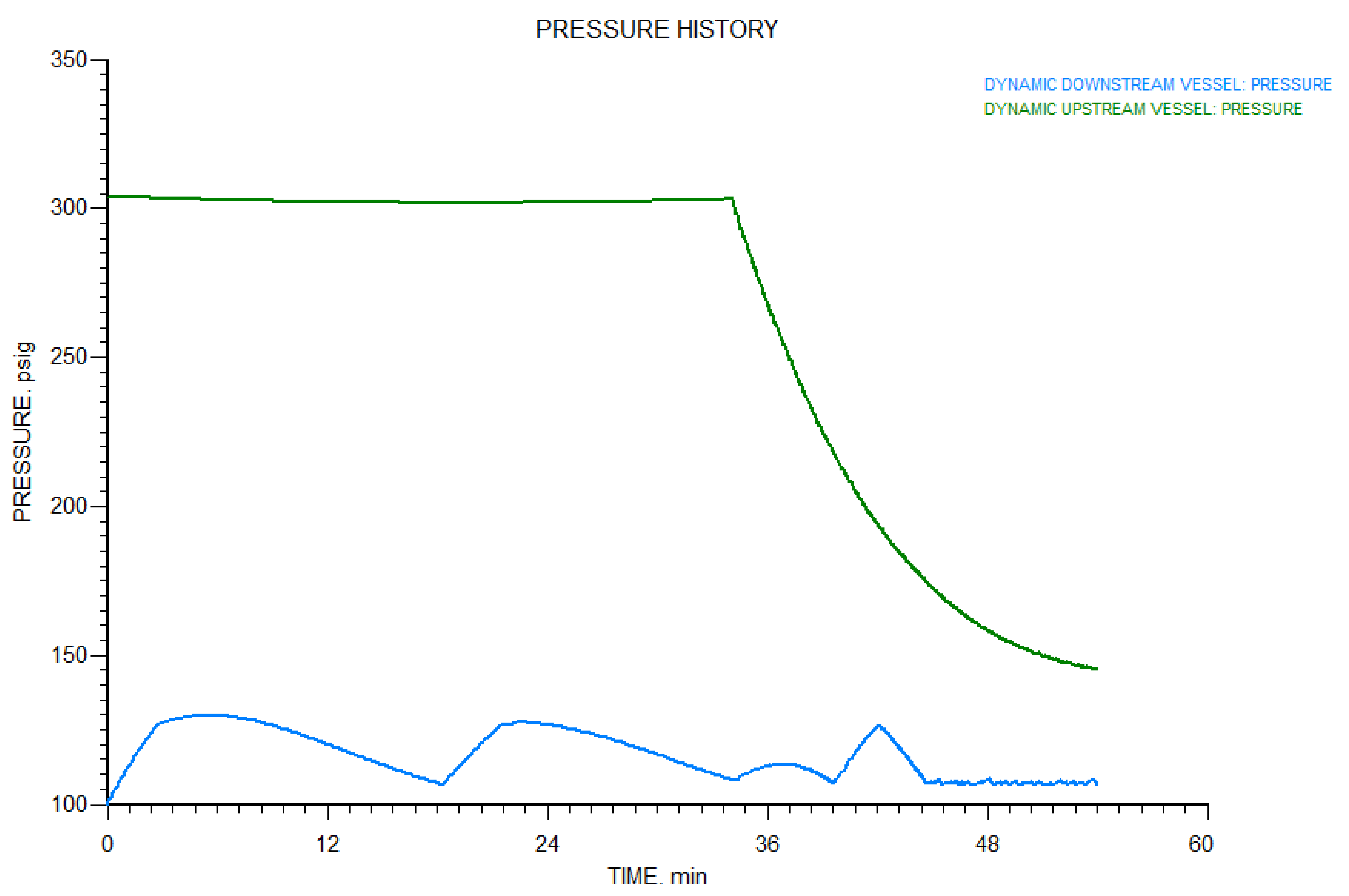
Best estimate bubbly flow predicts 2-phase relief, which hinders effective depressurisation in the downstream system

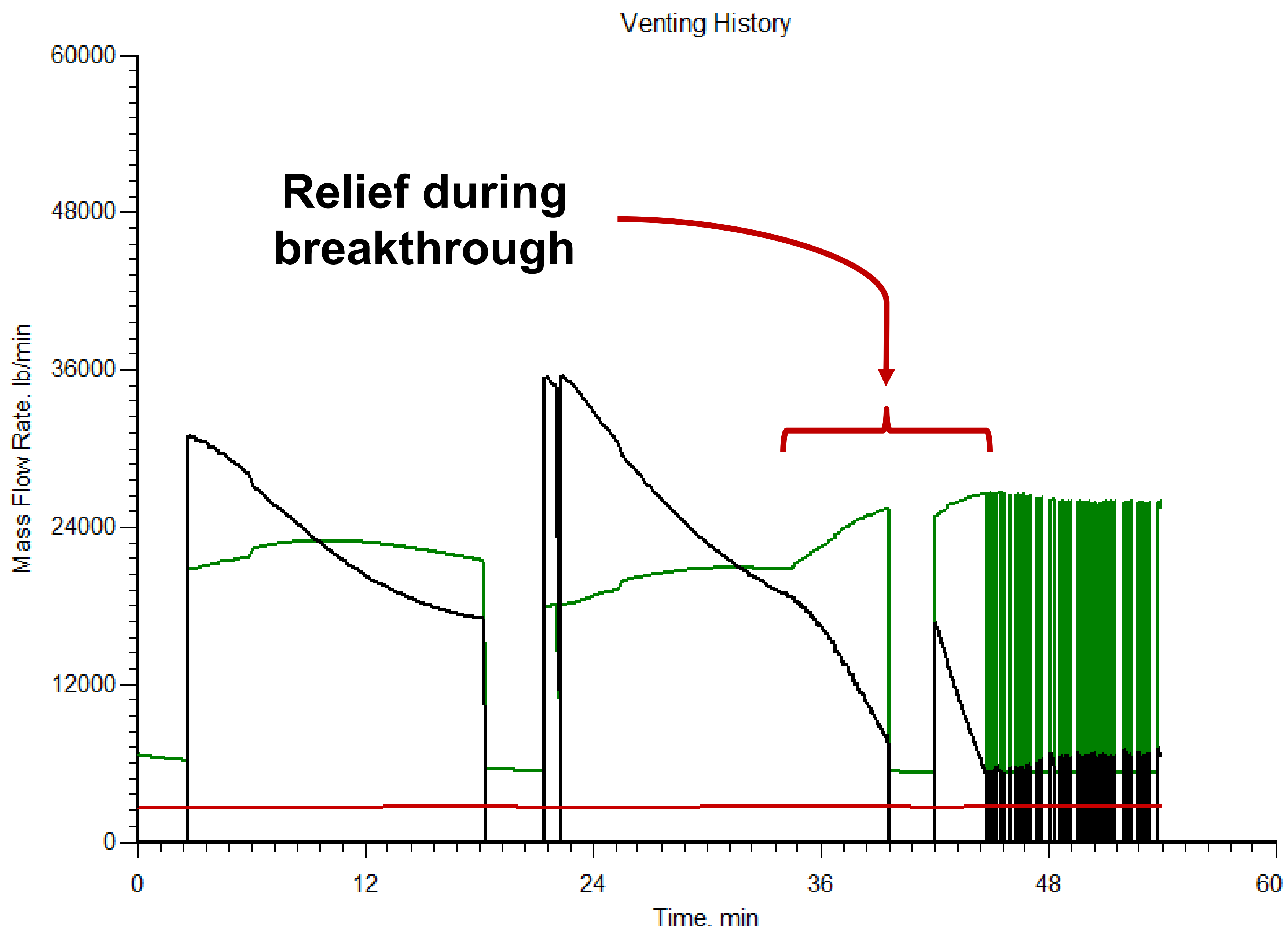




Source: ioMosaic Corporation and Process Safety Office® SuperChems™

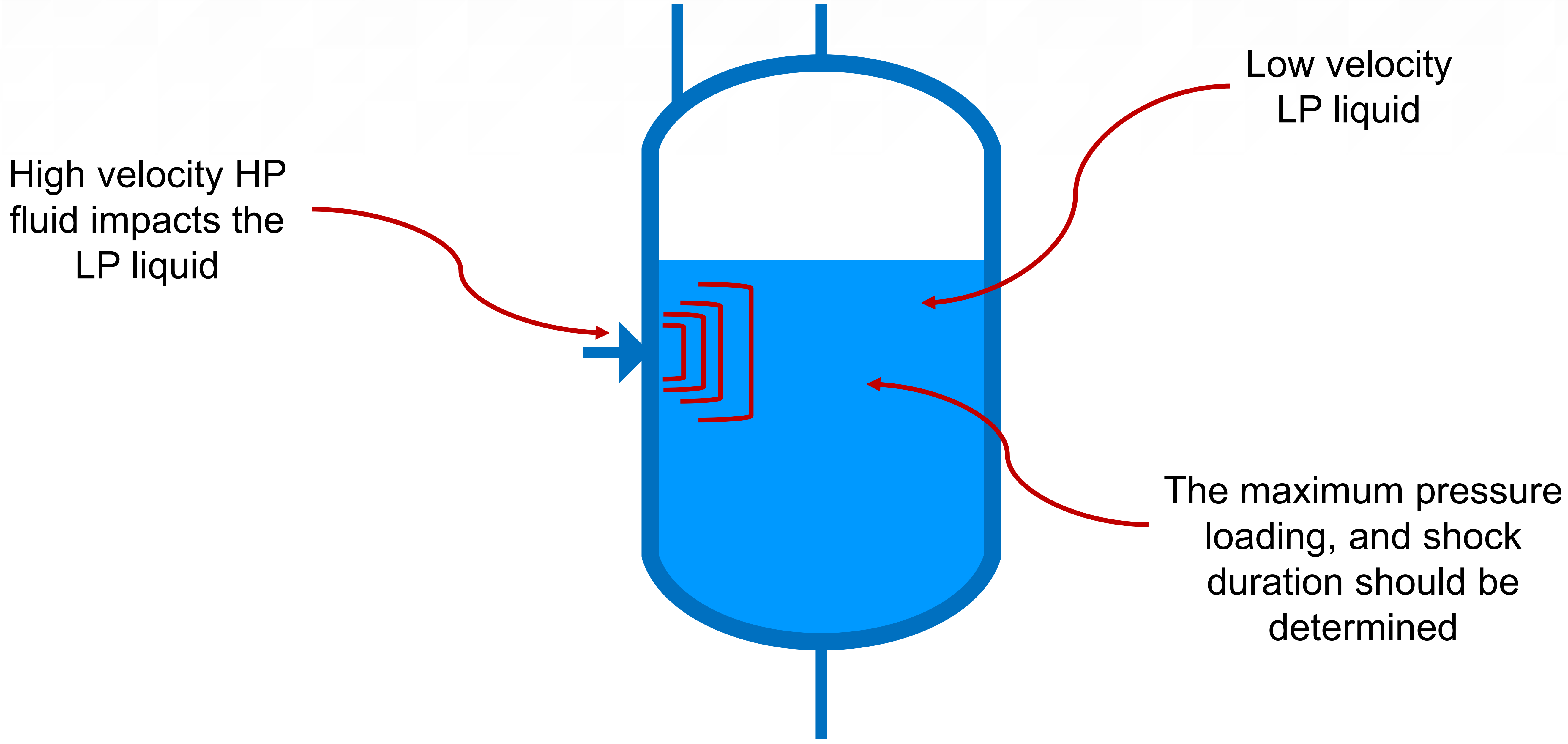
Higher starting liquid levels result in significantly more liquid relief due to less complete disengagement for best estimate churn turbulent flow





Source: ioMosaic Corporation and Process Safety Office® SuperChems™

High pressure surges should also be considered especially when the downstream liquid level is high, and the pressure differential is large



Source: ioMosaic Corporation

Dynamic simulation of vapor breakthrough can give us useful insights into the anatomy of the relief event

- Calculate more accurate relief requirements
- Capture important phenomena

However, be careful!

- Model the worst-case scenario
- Trial multiple modes of operation

Source: ioMosaic Corporation

Conclusions

- Steady state methods are the most conservative and simple approach
- Remember to consider the possibility of 2-phase relief flow and overfilling downstream
- Dynamic models can provide greater insight and more accurate sizing for vapor breakthrough scenarios
- Ensure the worst-case scenario is captured

For more information, please contact

Daniel Wilkes, Consultant
wilkes.d.uk@ioMosaic.com

ioMosaic International Limited
16-18 Queen Square
BATH BA1 2HN
+44 (0)1225 530510

www.ioMosaic.com
sales@ioMosaic.com

About ioMosaic Corporation

Through innovation and dedication to continual improvement, ioMosaic has become a leading provider of integrated process safety and risk management solutions. ioMosaic has expertise in a wide variety of areas, including pressure relief systems design, process safety management, expert litigation support, laboratory services, training, and software development.

ioMosaic offers integrated process safety and risk management services to help you manage and reduce episodic risk. Because when safety, efficiency, and compliance are improved, you can sleep better at night. Our extensive expertise allows us the flexibility, resources, and capabilities to determine what you need to reduce and manage episodic risk, maintain compliance, and prevent injuries and catastrophic incidents.

Our mission is to help you protect your people, plant, stakeholder value, and our planet.

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