ADVANCED PROCESS MODELLING FORUM **2014**

Oil & Gas Safety – API 521 and the importance of high-fidelity modelling

James Marriott, Head of PSE Oil & Gas

Overview

- Background
- Industry standard guidelines
- Blowdown system analysis
- System blowdown
- Concluding remarks

Oil & Gas Safety – API 521 and the importance of high-fidelity modelling

Background

Advanced Process Modelling

- Oil & Gas processing plants are primarily designed for normal steady-state operation
  - standard steady-state process modelling tools aim to support this activity
    - …. for the process
    - …. for the process safety system
  - in general use for ~30 years
- Increasingly essential to consider abnormal and transient operations

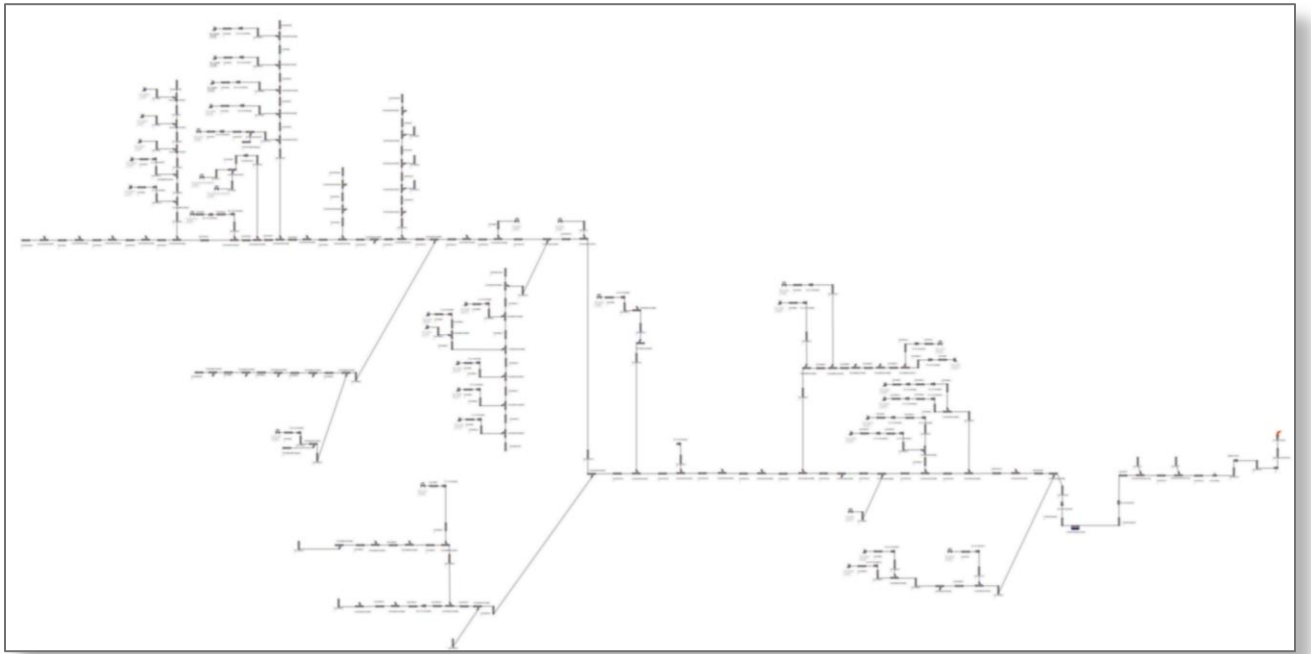
"A disproportionate percentage of process safety incidents have occurred during transient operations, which include those conducted infrequently such as start-ups or shutdowns as well as abnormal or emergency events. "

Scott W. Ostrowski and Kelly K. Keim, ExxonMobil

Requirement for Advanced Process Modelling

Pressure relief and blowdown systems

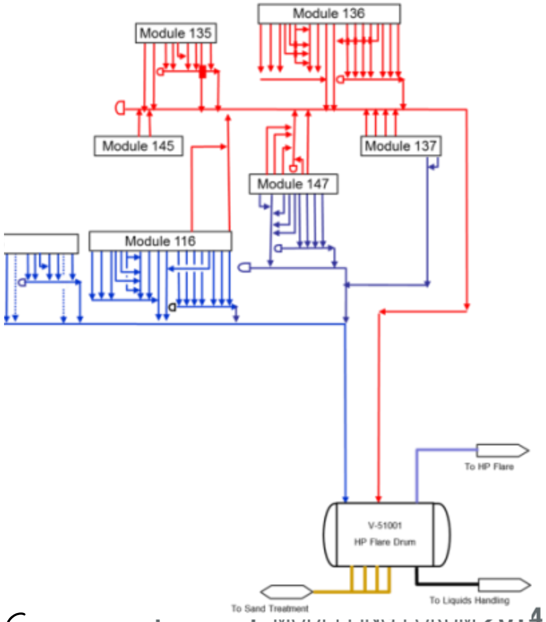
- **Pressure relief and blowdown systems**
  - is a collection of controls, valves and pipes by which pressurised gas (& liquid) contained within a process, piping, or pressure vessel, can be safely relieved
  - is designed to prevent the release of flammable or hazardous gas to the atmosphere, by routing it to one or more flare tips for controlled combustion



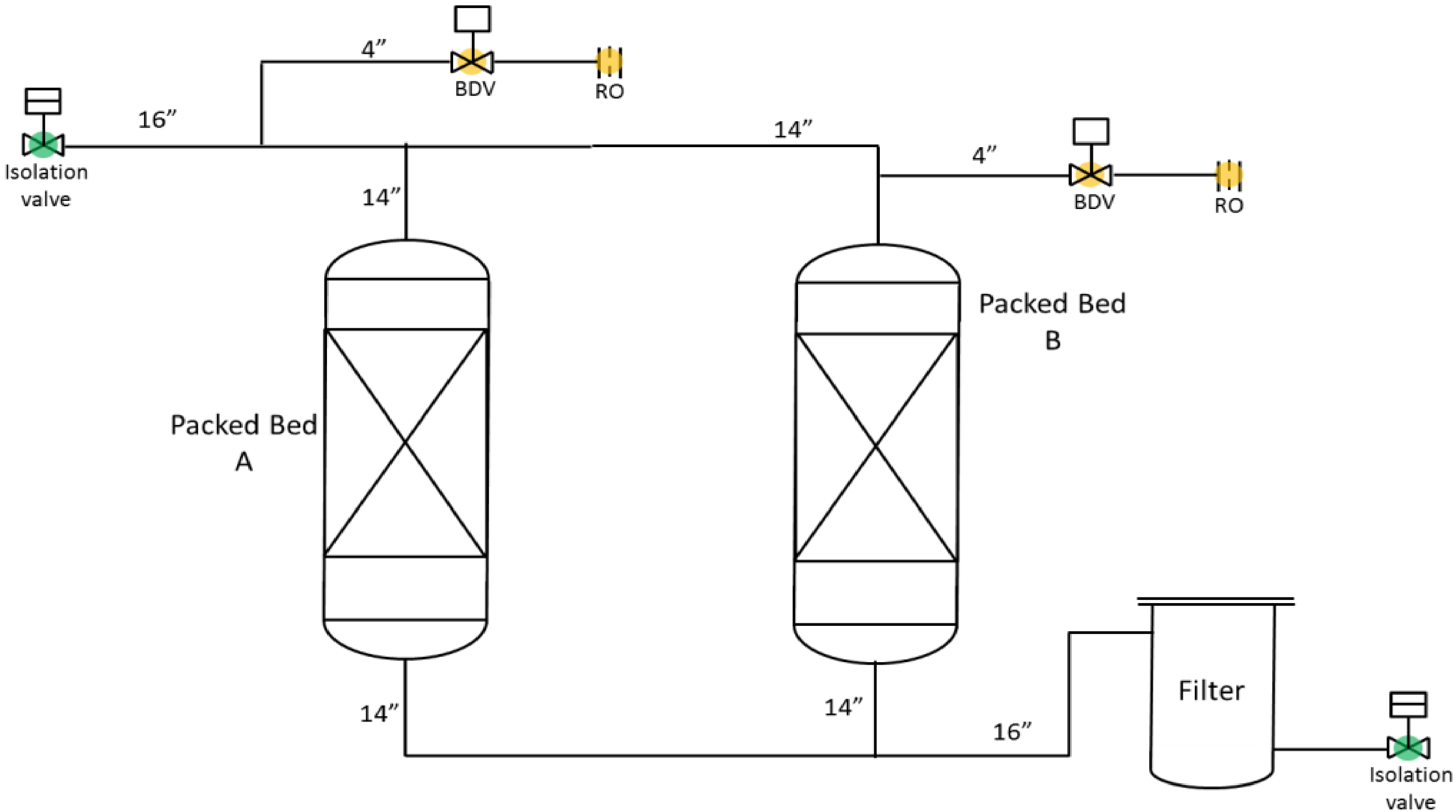
Flare systems are installed on
chemical plants,
refineries,
oil & gas processing facilities

What are they used for?

- ## Emergency use
  - Over-pressure protection
    - pressure exceeds design pressure in system as a result of an unplanned event (e.g. fire, blocked outlet..)
    - Pressure Safety Valves lift automatically and/or Bursting Disks blow
  - Plant depressurisation
    - In an emergency situation, production is stopped and the entire plant is depressurised (blowdown) to remove the hydrocarbon inventory
    - The plant is segregated into a number of isolated segments
      - vented (often simultaneously) into the flare system
- ## Operational use
  - Start-up / shutdown
  - Process upset
  - Maintenance



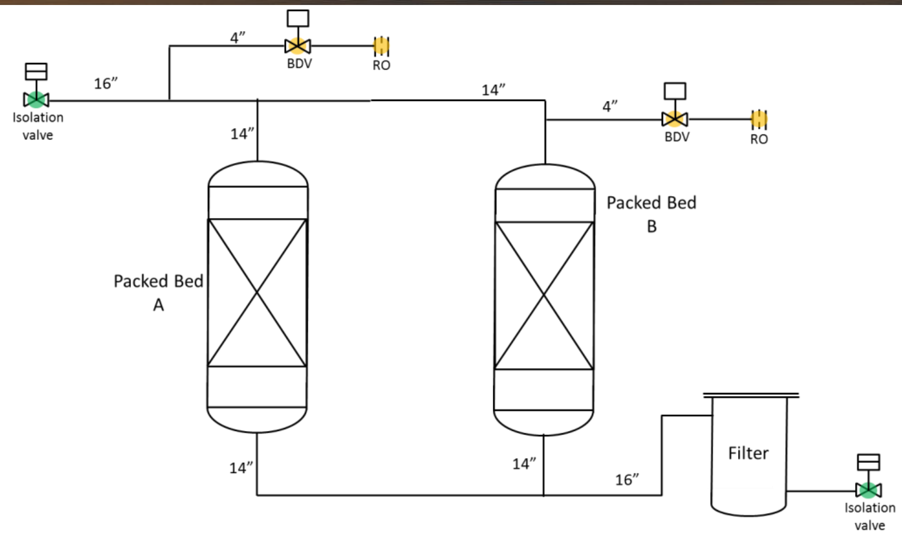
Blowdown systems



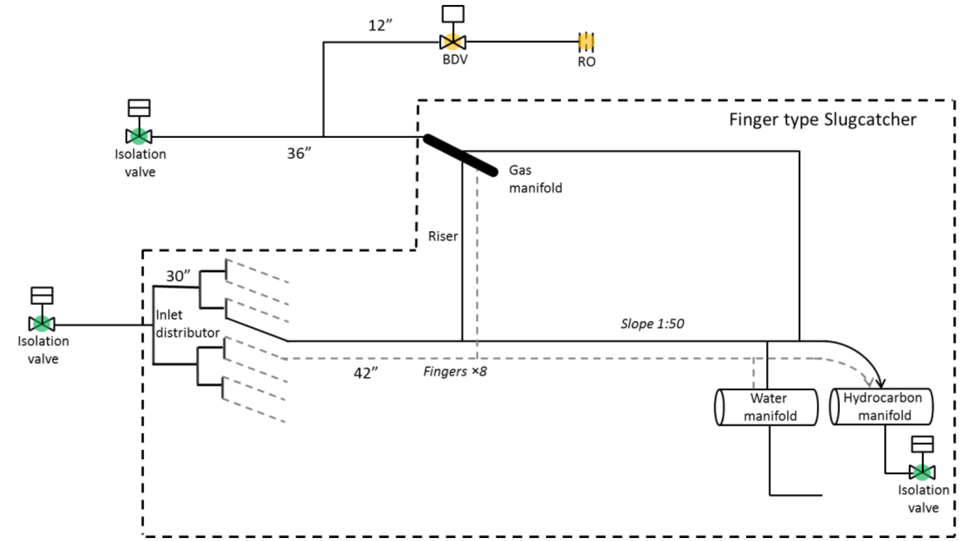
Gas sweetening system

Gas sweetening system

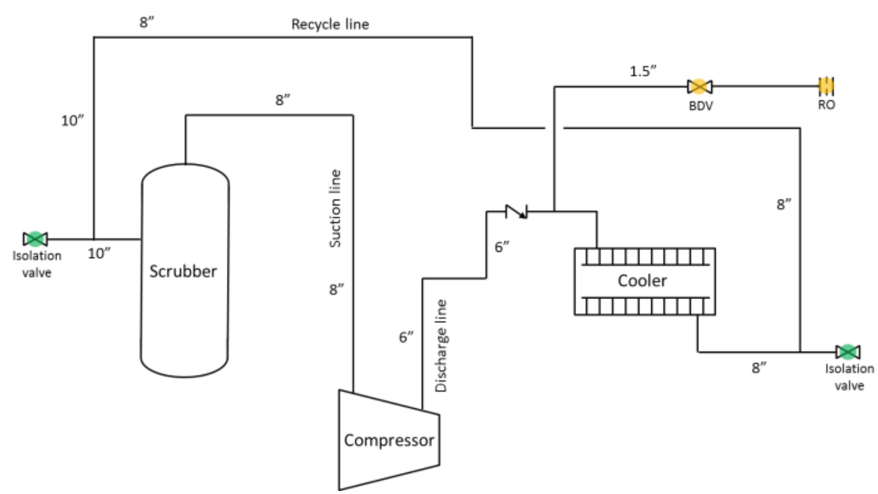
Blowdown systems



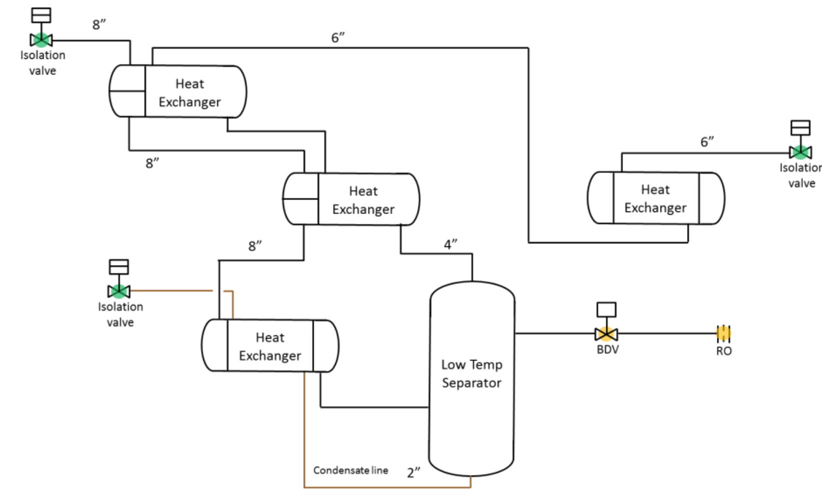
Gas sweetening system



Finger type slug catcher



Compressor system



Low temperature separator

What could go wrong?

- **The blowdown operation itself may be hazardous….**

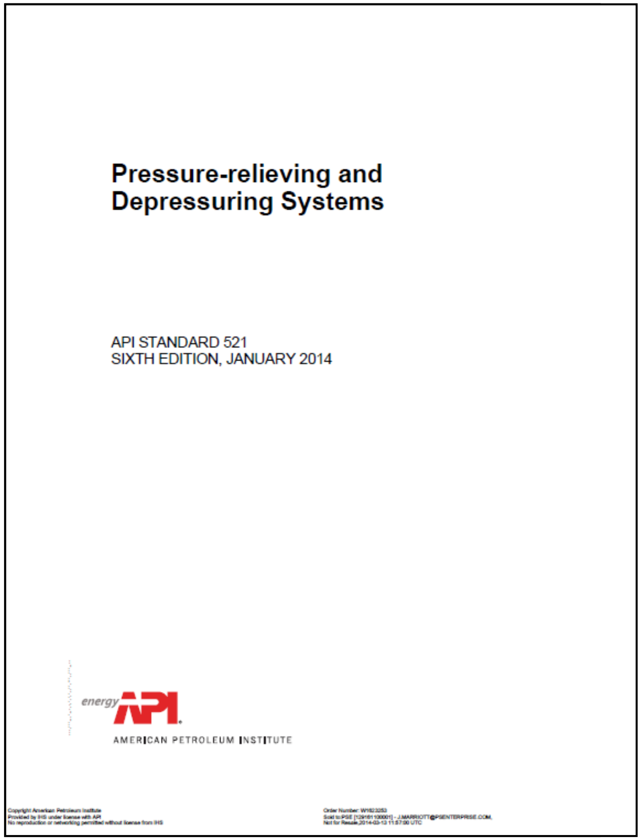
1. A large amount of material must be disposed of simultaneously
2. Fluid may become very cold due to Joule-Thomson expansion
3. New phases may form
   - water-containing solids

In most cases in O&G facilities, the blowdown operation sets the **minimum metal temperature** for the process equipment and so has critical implications on metal selection and facility cost

Oil & Gas Safety – API 521 and the importance of high-fidelity modelling

Industry standard guidelines

API 521 6^{th} edition [January 2014]


Pressure-relieving and
Depressuring Systems

API STANDARD 521
SIXTH EDITION, JANUARY 2014

Fire analysis

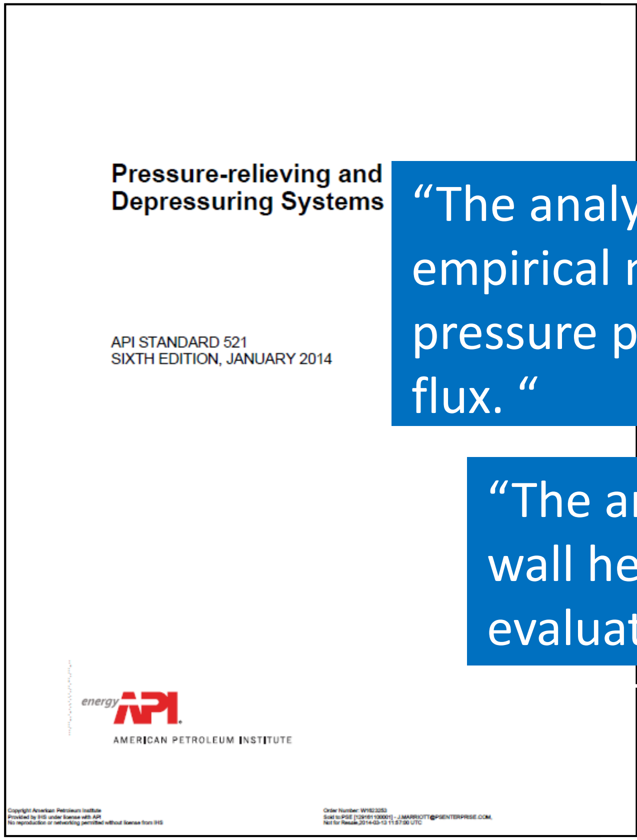
- The new edition introduces a analytical method for calculating heat loads for pool and jet fire analysis

Brittle fracture risk assessment

- The new edition highlights the importance of accurate assessment of low temperature / brittle fracture risks both
  - upstream of the blowdown valve (in the process)
  - and downstream in the flare piping.

- In all cases **rigorous modelling techniques** are recommended, with a particular focus on cases where pipe / vessel wall temperatures are expected to impact material selection criteria.

API changes – Fire analysis


Pressure-relieving and Depressuring Systems

API STANDARD 521
SIXTH EDITION, JANUARY 2014

energy API
AMERICAN PETROLEUM INSTITUTE

Fire analysis

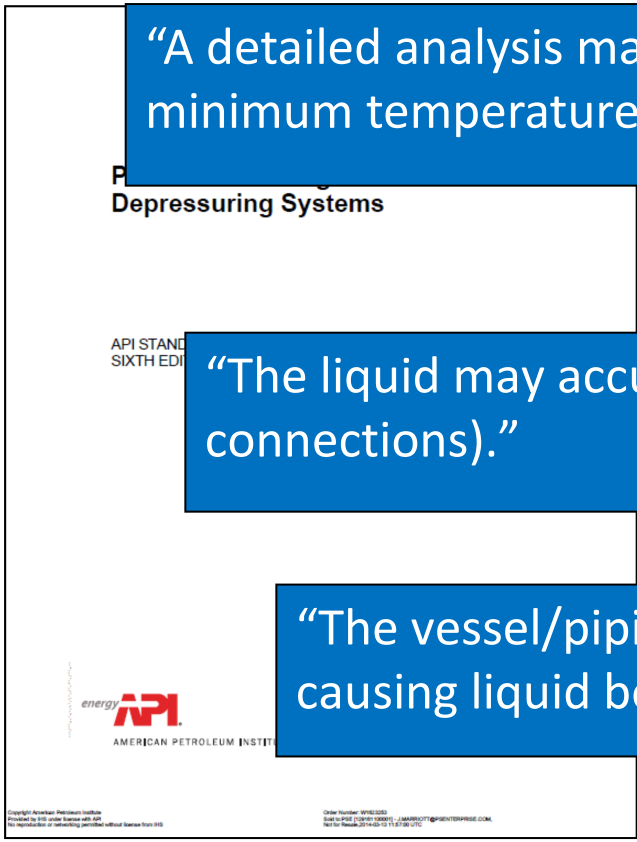
- The new edition introduces a analytical method for calculating heat loads for pool and jet fire analysis

"The analytical method can be used as an alternative to the empirical method for calculation of the size of PRDs and the pressure profile, both of which involve the surface average heat flux. "

"The analytical method can also be used to calculate the wall heat-up which involves the local peak heat flux and to evaluate fires where the empirical method does not apply"

- In all cases **rigorous modelling techniques** are recommended, with a particular focus on cases where
- pipe / vessel wall temperatures are expected to impact material selection criteria.

API changes – Low temperature (process equipment)



Fire analysis

“A detailed analysis may be required to determine the minimum temperature occurring during depressuring.”

l method for
fire analysis

Brittle fracture risk assessment

- The new edition highlights the importance of accurate

“The liquid may accumulate in the low points (e.g. bottom of vessels, drain connections).”

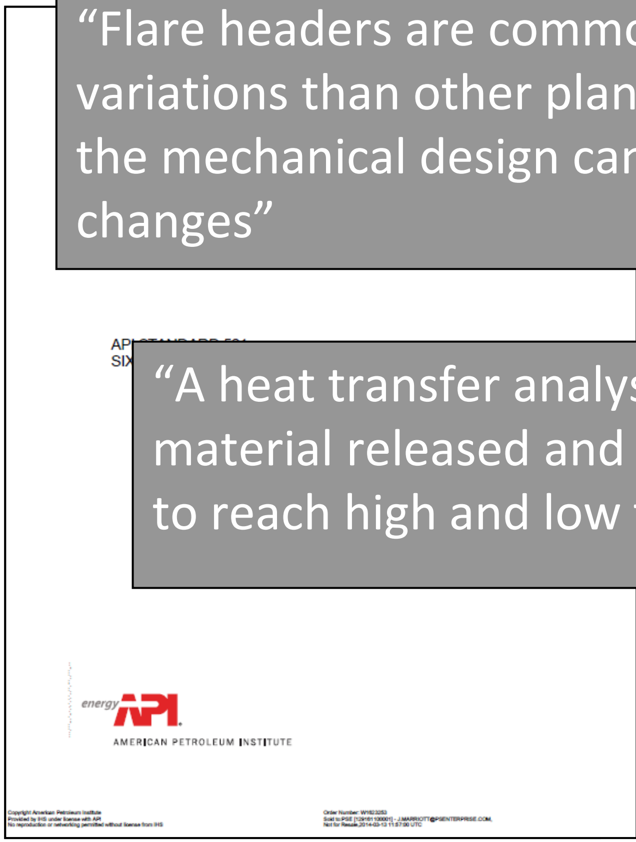
  - upstream of the blowdown valve (in the process)
  - and downstream in the flare piping

“The vessel/piping wall may be at a higher temperature than the liquid, causing liquid boiling in these low points and low local temperatures.”

recommended, with a particular focus on cases where pipe / vessel wall temperatures are expected to impact material selection criteria.

Industry standard guidelines

API changes – Low temperature (flare)



“Flare headers are commonly exposed to a broader range of temperature variations than other plant piping. This requires a careful analysis to ensure that the mechanical design can tolerate the full range of expected temperature changes”

Brittle fracture risk assessment

- The new edition highlights the importance of accurate

“A heat transfer analysis may also be performed that considers the amount of material released and the duration of those events which can cause the header to reach high and low temperature extremes.”

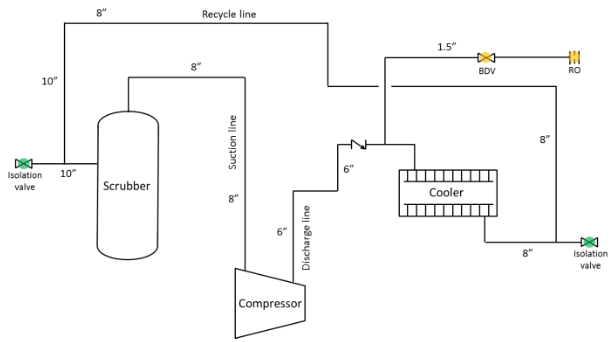
  - and downstream in the flare piping.

- In all cases **rigorous modelling techniques** are recommended, with a particular focus on cases where pipe / vessel wall temperatures are expected to impact material selection criteria.

Oil & Gas Safety – API 521 and the importance of high-fidelity modelling

Blowdown system analysis

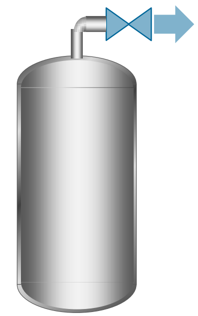
Conventional analysis



Isolated blowdown segment

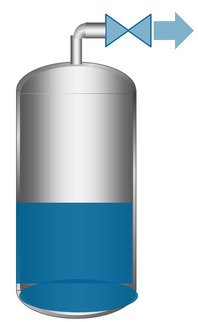
Step 1

Lumping blowdown segments into an "equivalent" vessel



Step 2

Determine MMT with an equilibrium-based simulation with tuneable parameters



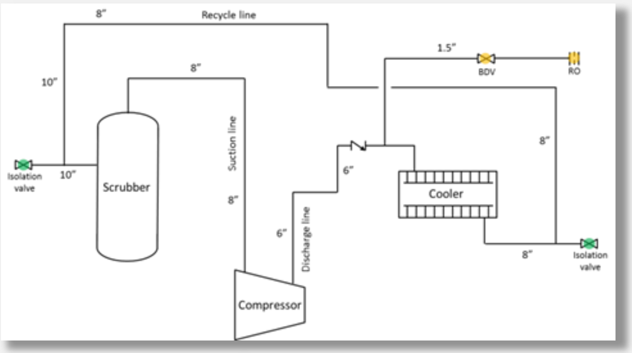
Details vary dependent on companies involved

- Validated models are available "*but are not commonly used*"

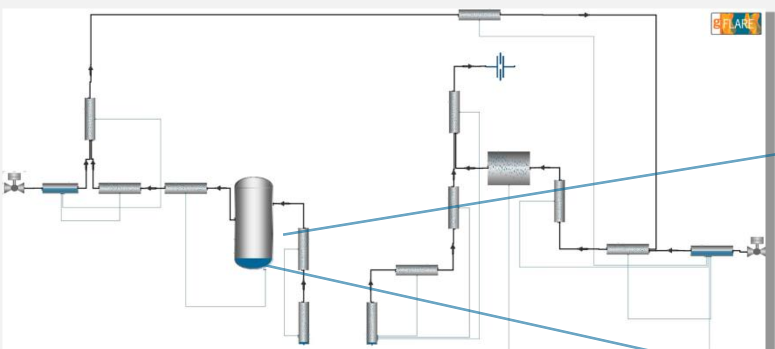
  HSE - Fire and Explosion Strategy [2003]

PSE started development of its gFLARE Advanced Depressurisation library in 2010

gFLARE for Advanced Depressurisation calculations



Isolated blowdown segment



Geometrical system representation in gFLARE

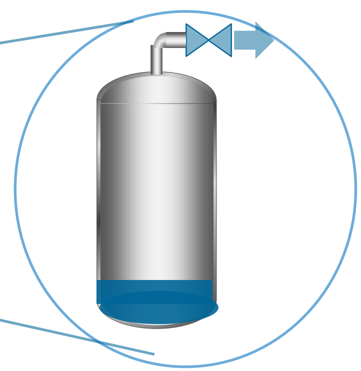
1. System level analysis and representation
   – Systematic workflow for describing accurately

     specific system level information
     – geometry
     – material of construction
     – locations where liquid may accumulate

Engineering knowledge and judgement

2. Advanced Process Modelling technology
   – Accurate prediction of physical behaviour

     of the system: validated

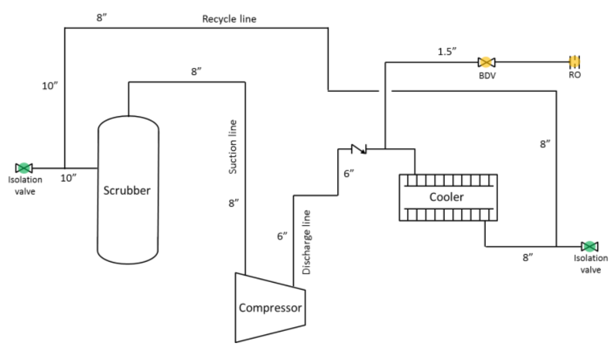


Advanced process modelling techniques and environment

Oil & Gas Safety – API 521 and the importance of high-fidelity modelling

System blowdown

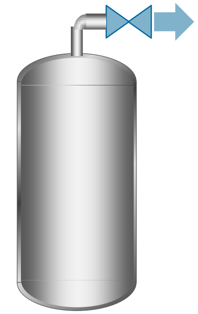
Conventional analysis methodology



Isolated blowdown segment

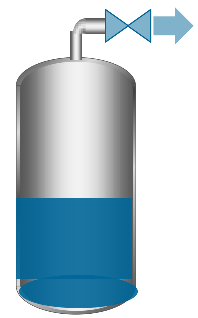
Step 1

Lumping blowdown segments into an "equivalent" vessel



Step 2

Determine MMT with an equilibrium-based simulation with tuneable parameters



Wide spread-use of non validated models and parameters

- *Isentropic efficiency*
  - Engineering studies use values anywhere from 40% to 100%
- *Non-equilibrium*
  - Engineers recognise this and may set up a non-physical recycle stream on the vapour phase

Conventional approach – experimental validation

BLOWDOWN OF PRESSURE VESSELS
II. Experimental Validation of Computer Model and Case Studies

M. A. HAQUE, S. M. RICHARDSON (FELLOW), G. SAVILLE, G. CHAMBERLAIN* and L. SHIRVILL*

Department of Chemical Engineering, Imperial College, London
**Shell Research Limited, Thornton Research Centre, Chester*

A computer program called BLOWDOWN has been developed which can be used to simulate the rapid depressurisation or blowdown of a vessel containing hydrocarbons. The program has been validated by comparison with a large number of experimental measurements, most of which were made on a full-size vessel. Case studies have been conducted to illustrate typical practical applications of the program.

INTRODUCTION

A computer program called BLOWDOWN has been developed which can be used to simulate the blowdown of a vessel containing hydrocarbons. A description of the program has been given in a first paper[1]. This second paper gives a description of the way in which BLOWDOWN has been validated by comparison with a large number of experimental measurements covering a wide range of different conditions, most of which were made on a full-size vessel. The validation is intended to permit confidence to be placed in the predictions made using the program. This paper also gives a description of two case studies which illustrate typical applications of BLOWDOWN. The first is for blowdown of a suction scrubber for a gas compressor, where the effects of small amounts of liquid formation by condensation from the gas are investigated. The second is for blowdown of a gas-condensate separator, where the differences between blowdown from the top and from the bottom are compared.

BLOWDOWN EXPERIMENTS

Blowdown experiments have been conducted using ifferent size vessels oriented vertically or horizontally nd containing a range of different fluids with blowdown rom the top, bottom or side through chokes of various ifferent sizes.

Vessels

The experiments were conducted using three different essels:

Vessel 1 (torispherical ends). Length 3.240 m (2.250 m an-to-tan), inside diameter 1.130 m and wall thickness 9 mm.

Vessel 2 (flat ends). Length 1.524 m, inside diameter .273 m and wall thickness 25 mm.

Vessel 3 (flat ends). Length 0.671 m, inside diameter 040 m and wall thickness 5 mm.

Vessel 1, which is in fact a full-size suction scrubber (or nock-out pot) for a gas compressor, and vessel 3 were always oriented vertically. Vessel 2 was oriented either vertically or horizontally. The use of three vessels permitted checks to be made on the predictions of BLOWDOWN for a wide range of length-scales. Since these checks showed that the predictions are scale-independent and since vessel 3 is so much smaller than any vessel used in practice, the results for vessel 3 are not discussed further in what follows.

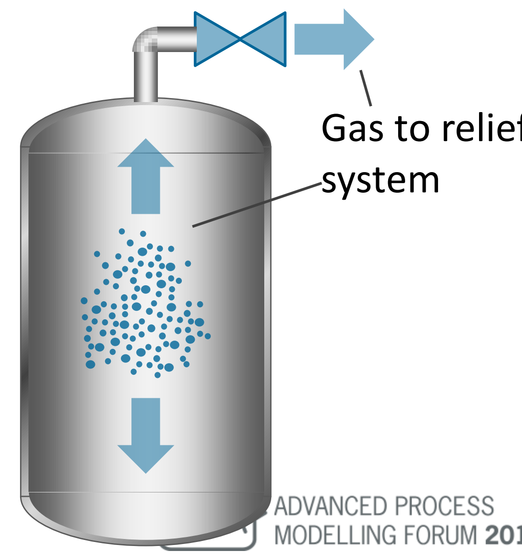
Instrumentation

Transducers were used to measure the pressure in vessels 1 and 2 to an estimated accuracy of ±0.2 bar. Pressure gauges were also used to give direct, if less accurate, measurements. Bare-wire thermocouples were used to measure the temperature of the fluid within the vessels and also of the inside and outside vessel walls to an estimated accuracy of ±0.5K. The thermocouples for measuring fluid temperatures were attached to multi-arm spiders radiating from a central support in each vessel: 120 thermocouples were used in vessel 1 and 64 in vessel 2. The two wires of each thermocouple for measuring wall temperatures were separately spot welded to the wall approximately 4 mm apart, in order to measure the true wall temperature (the use of a preformed thermocouple attached to the wall gives significant errors when there are large temperature gradients normal to the wall in the fluid by the wall): 36 thermocouples were used in vessel 1 and 12 in vessel 2, with in each case half on the inside and half at corresponding positions on the outside. The thermal response time of each thermocouple is estimated to have been of order 0.1 s, which is much less than the time-scale of any physically significant temperature changes.

It was also possible to withdraw samples of the fluid from the top and bottom of vessel 1 at arbitrary stages during blowdown and then to measure the composition of the samples using a mass spectrometer and a gas chromatograph. In addition, a windowed port was attached to the upper part of vessel 1 and a mirror set at an angle of 45° to the vertical within the vessel. A video camera was then used to view the fluid within the vessel both horizontally, across the upper part of the vessel occupied by gas, and vertically downwards, from the part occupied by gas to the part occupied by liquid. In this way,

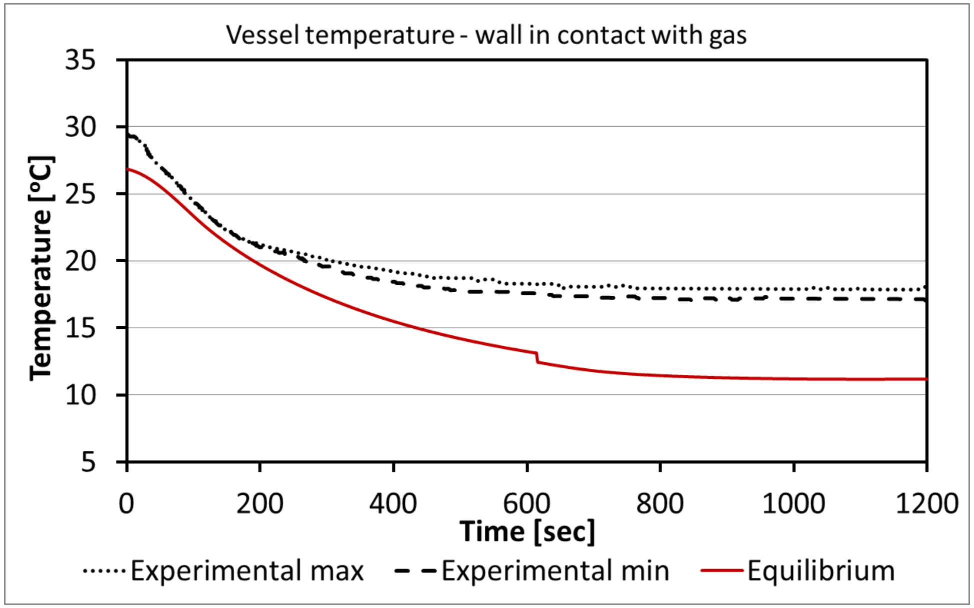
0957–5820/92/$05.00+0.00

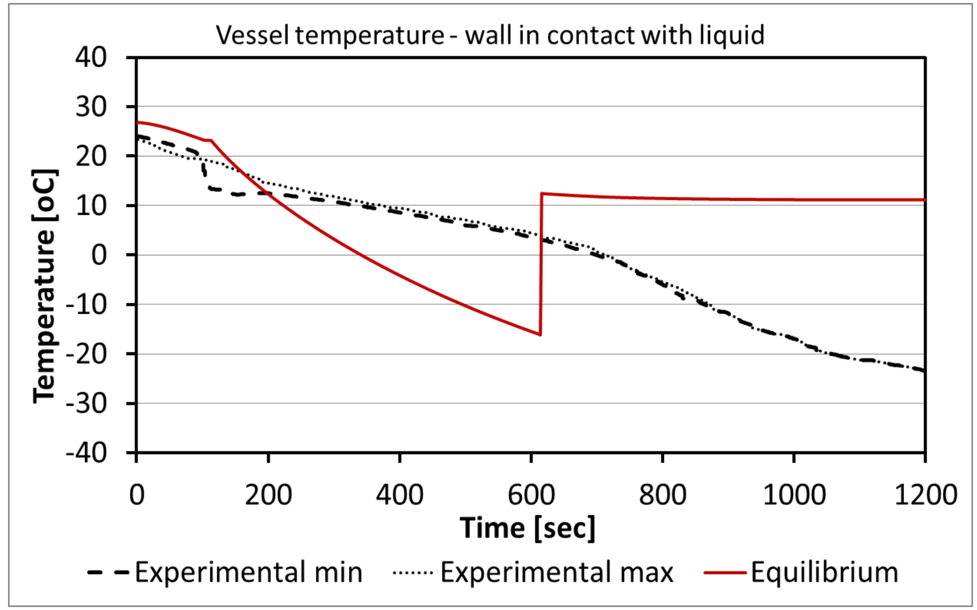
- Full-scale vessel blowdown
  - Vertical: 3.2m / 1m vessel
  - Horizontal: 1.5m / 0.27m
- Mixtures:
  methane, ethane & propane
- 18 experiments: gas & liquid phase
  - well instrumented equipment



Conventional approach – experimental validation

Experiment S9: **120 bar, 300.25 K; C1: 85.5%, C2: 4.5%, C3: 10,% C4 trace**





Under-predicts metal temperature in contact with gas
Inaccurate but conservative

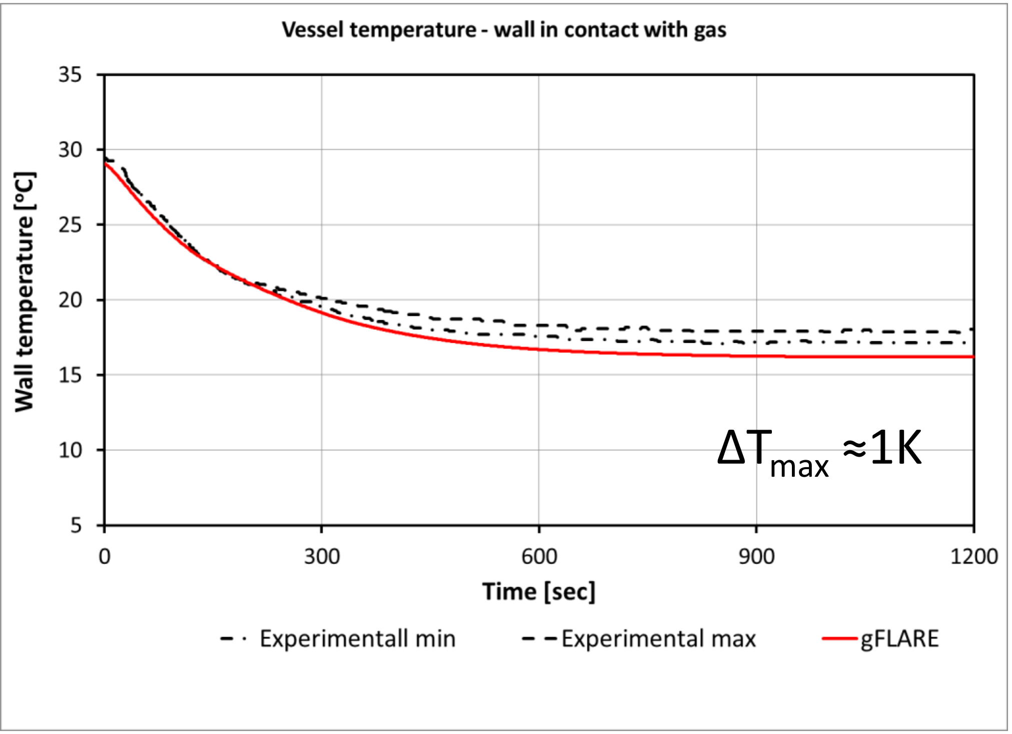
Quantitatively and qualitatively incorrect predictions for the wall temperature in contact with the liquid – that are not conservative

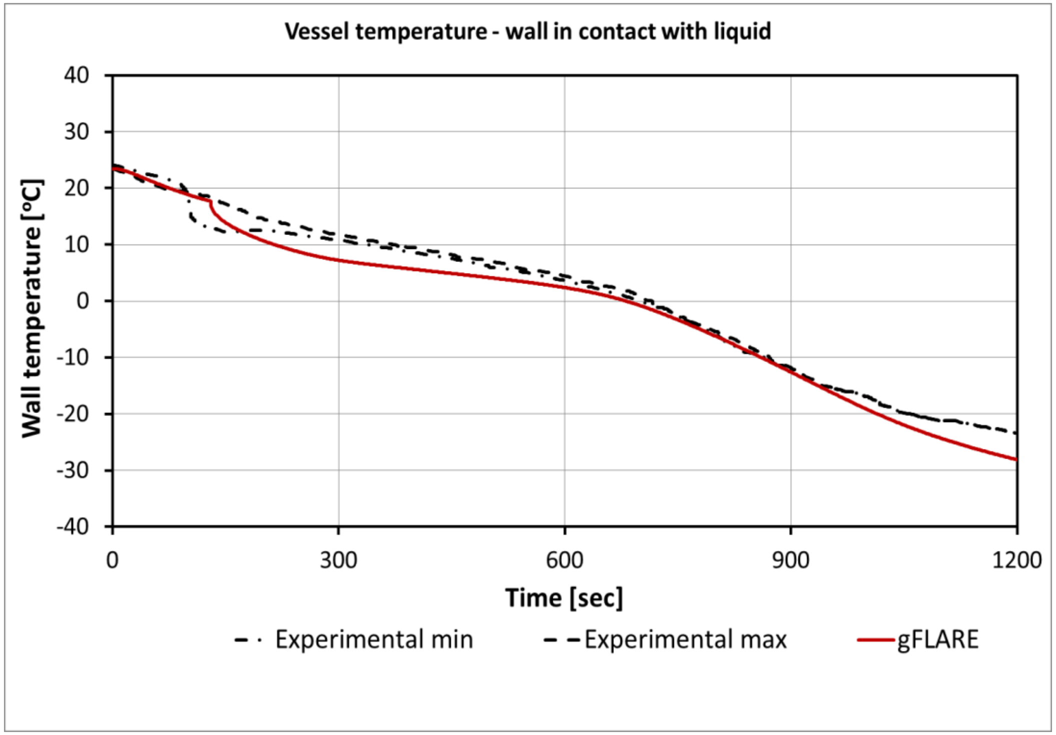
Poor, potentially unsafe, predictions if/when liquid condensation occurs

M.A Haque et al., Blowdown of pressure vessels, *Trans IChemE Part B Process Safety Environmental Protection, 70 (BI) 1 and 10, 1992*

gFLARE – experimental validation

Experiment S9: 120 bar, 300.25 K; C1: 85.5%, C2: 4.5%, C3: 10,% C4 trace





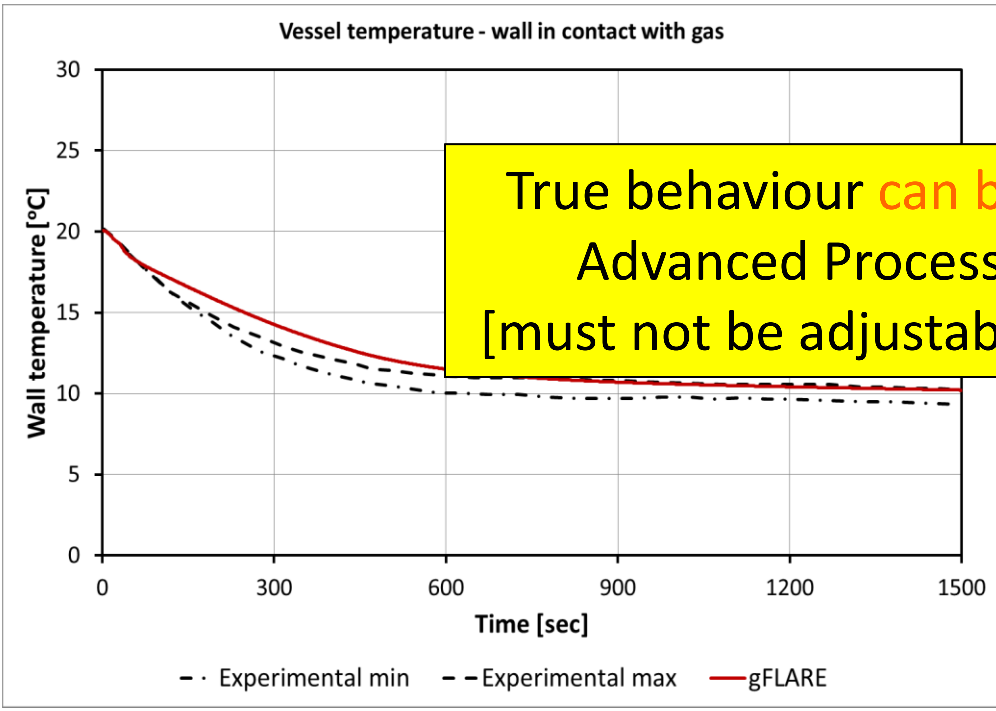
M.A Haque et al., Blowdown of pressure vessels, *Trans IChemE Part B Process Safety Environmental Protection*, **70** (BI) 1 and 10, 1992

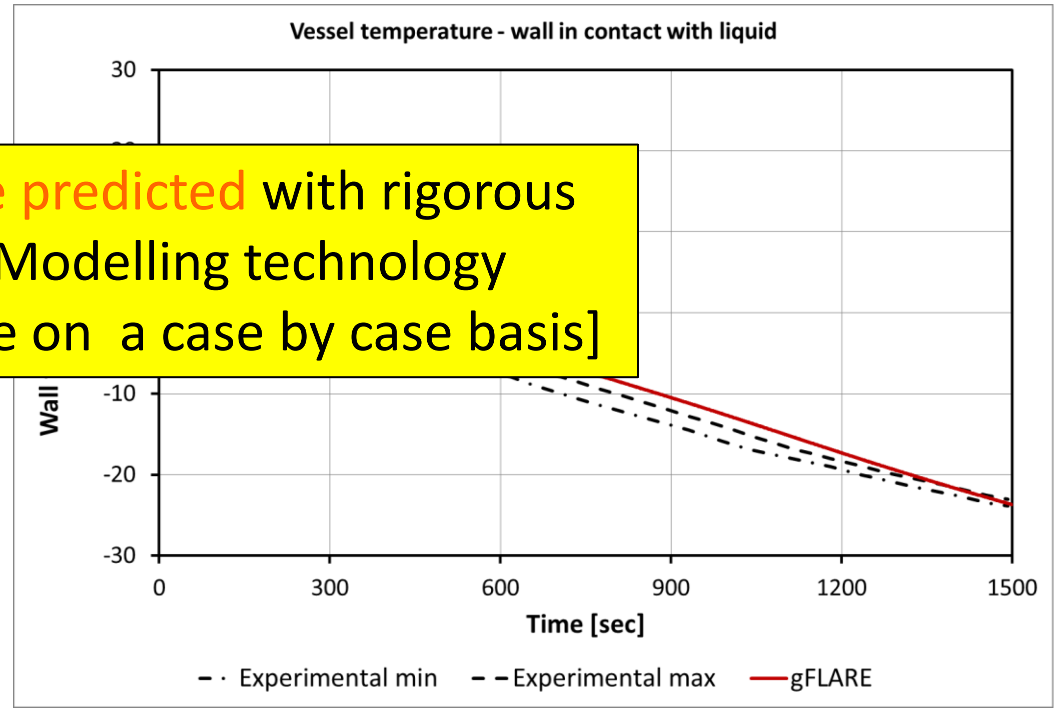
gFLARE – experimental validation

~~Experiment S9: 120 bar, 300.25 K; C1: 85.5%, C2: 4.5%, C3: 10,% C4 trace~~

Experiment S12: 118 bar, 297 K, C1: 66.5%, C2: 3.5%, C3: 30%, C4 trace

Same model,
no adjustable parameters



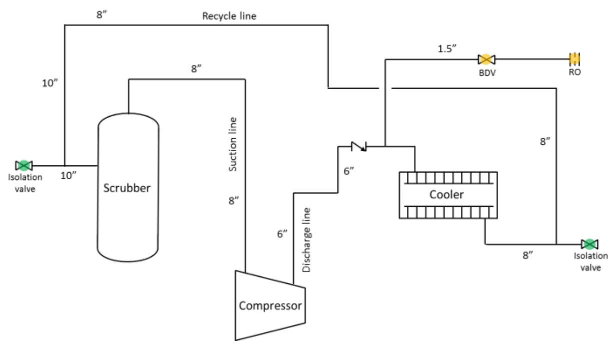


True behaviour can be predicted with rigorous Advanced Process Modelling technology [must not be adjustable on a case by case basis]

M.A Haque et al., Blowdown of pressure vessels, *Trans IChemE Part B Process Safety Environmental Protection,* **70** (BI) 1 and 10, 1992

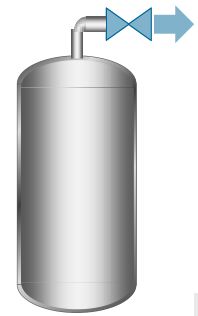
Conventional analysis methodology

Isolated blowdown segment



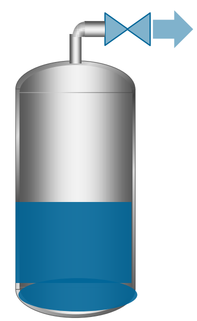
Step 1

Lumping blowdown segments into an "equivalent" vessel

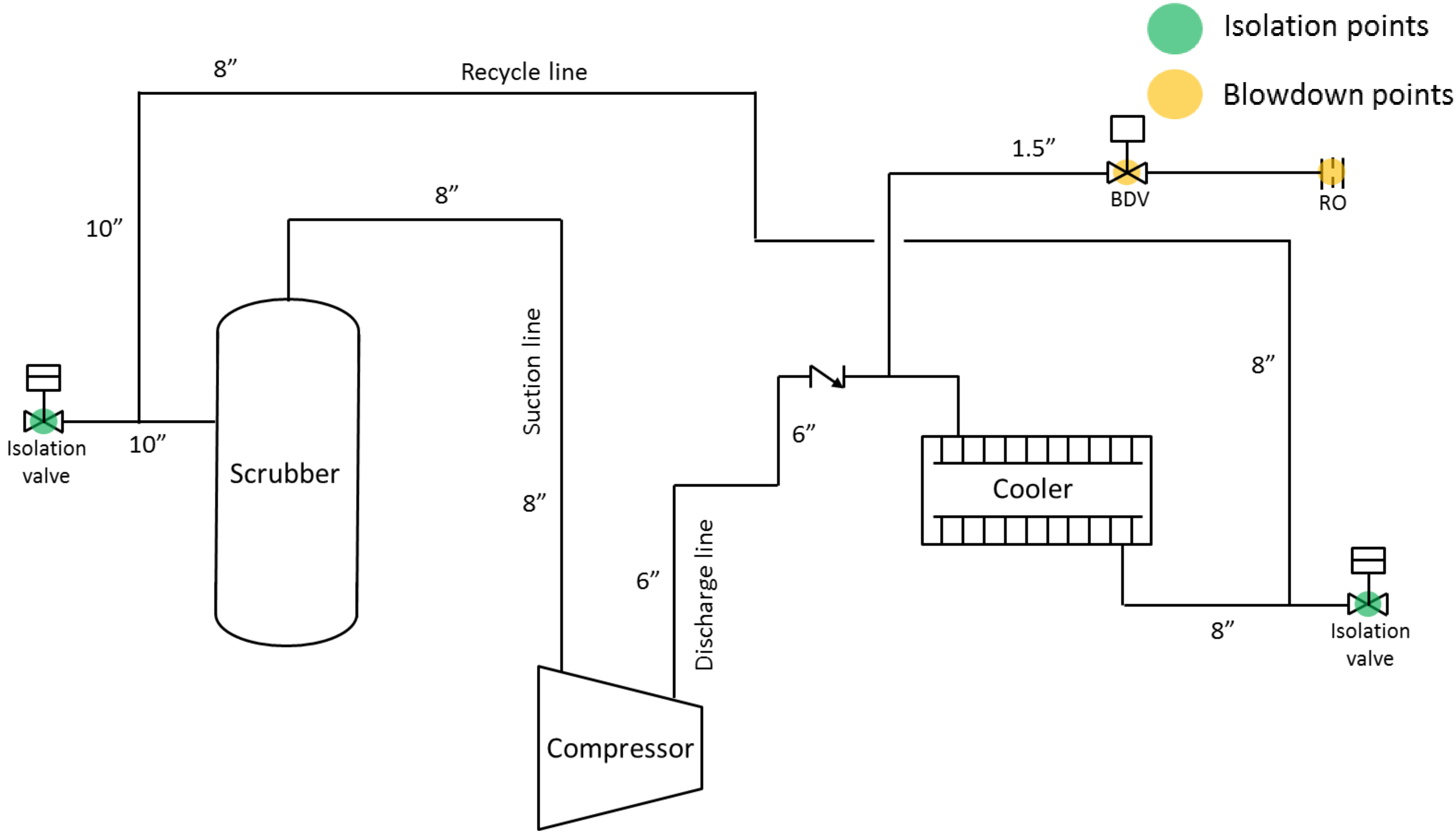


Step 2

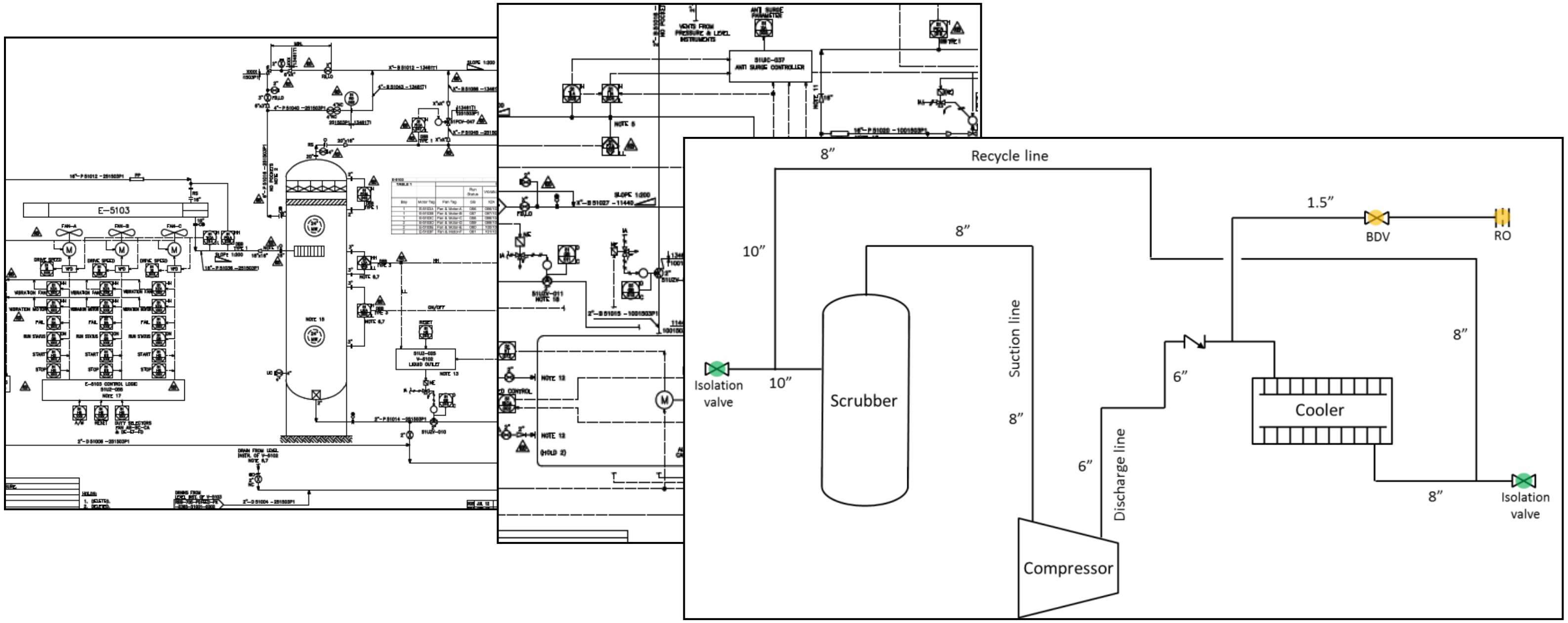
Determine MMT with an equilibrium-based simulation with tuneable parameters



Compressor system



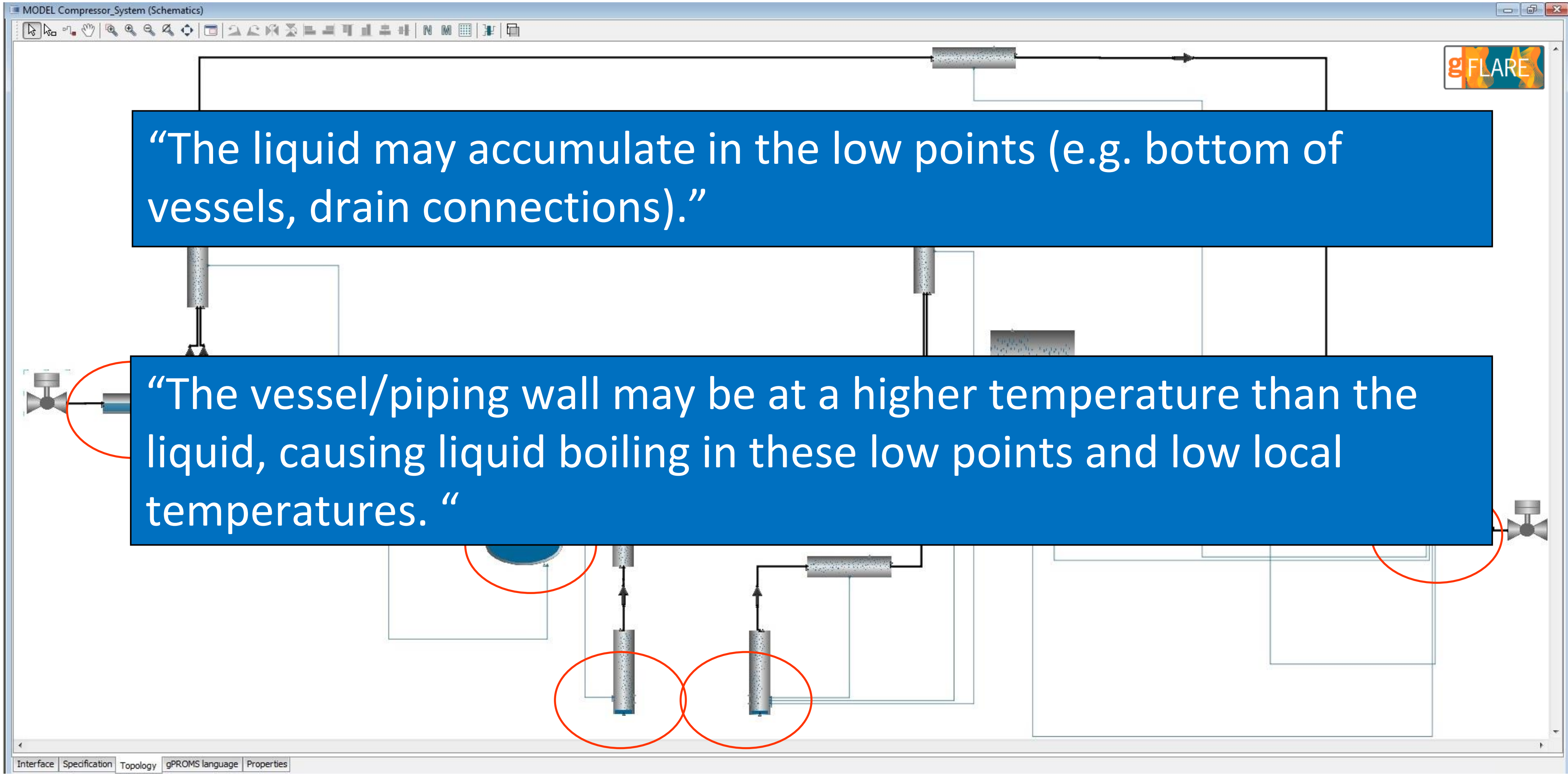
Compressor system - analysis



The engineer should determine

- pipe and equipment dimensions from data sheets and piping isometrics
- if and where condensate liquid can form and accumulate

Compressor system - gFLARE

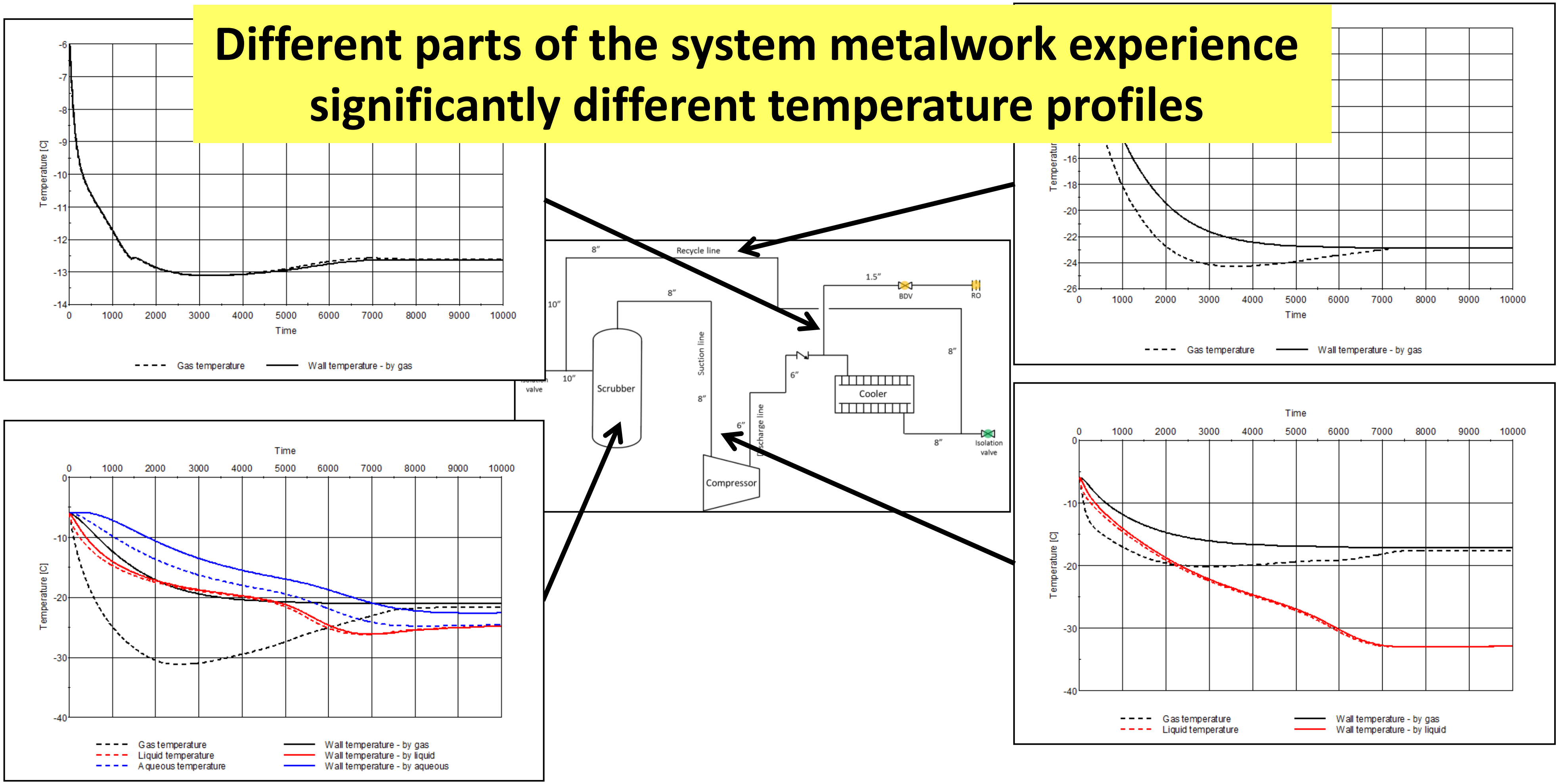


"The liquid may accumulate in the low points (e.g. bottom of vessels, drain connections)."

"The vessel/piping wall may be at a higher temperature than the liquid, causing liquid boiling in these low points and low local temperatures. "

Compressor system – gFLARE distributed approach

Different parts of the system metalwork experience significantly different temperature profiles



Minimum metal temperature = -33°C

Oil & Gas Safety – API 521 and the importance of high-fidelity modelling

Concluding remarks

Concluding remarks

- Conventional analysis approaches for determining the minimum metal temperatures during blowdown can introduce significant errors: **differences as much as 30ºC** are not uncommon
- 6th edition of the API 521 standard (Jan 2014) makes a number of **new recommendations** for brittle fracture risk assessment during process blowdown operations
- Advanced Process Modelling affords considerable safety and economic benefits.
  - Example 1 - the application of the methodology advocated here **saved several hundred millions of dollars** with regards to material selection for a recent FEED project
  - Example 2 – in many projects risks missed with conventional screening calculations have been identified using the rigorous modeling methodology

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Thank you