ADVANCED PROCESS MODELLING FORUM 2017
London 25–26 April

High-fidelity dynamic flare analysis for downstream oil & petrochemicals

James Marriott, Paul Frey - PSE

Overview

High-fidelity dynamic flare analysis for downstream oil & petrochemicals - *James Marriott, Paul Frey, PSE*

- Motivations for dynamic analysis
- Introduction to dynamic flare system design & analysis
- Case examples

High-fidelity dynamic flare analysis for downstream oil & petrochemicals

Motivations for dynamic analysis

Design / Brownfield Facilities

- Industry Conventional methods of calculating Flare loads are **highly conservative**

- In petrochemical facilities the flare system is usually sized based on global scenarios: those affecting multiple parts of the processing plant: typically total power failure or cooling water failure
  - Unbalanced heat is driving the relief load
  - Flare load is the summation of all individual loads assumed to start at peak rate simultaneously

- Licensors have no motivation to do detailed study as it has limited **economic impact** on their design.

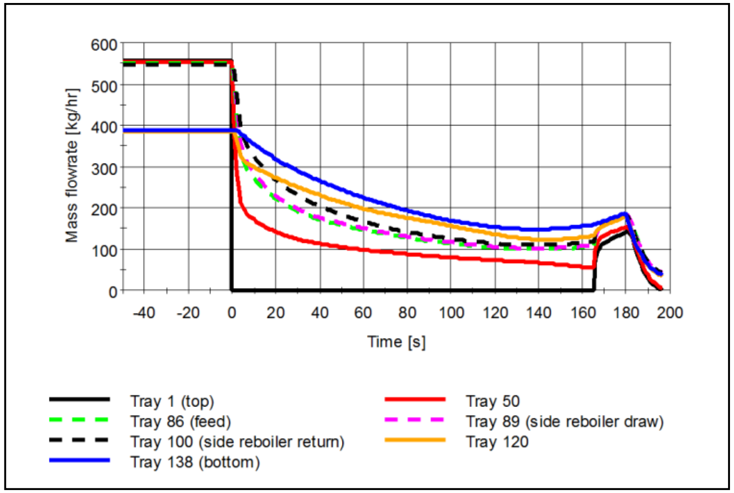
- Contractors have no motivation to reduce capital investment as this is the basis for man-hour costs.

Design / Brownfield Facilities

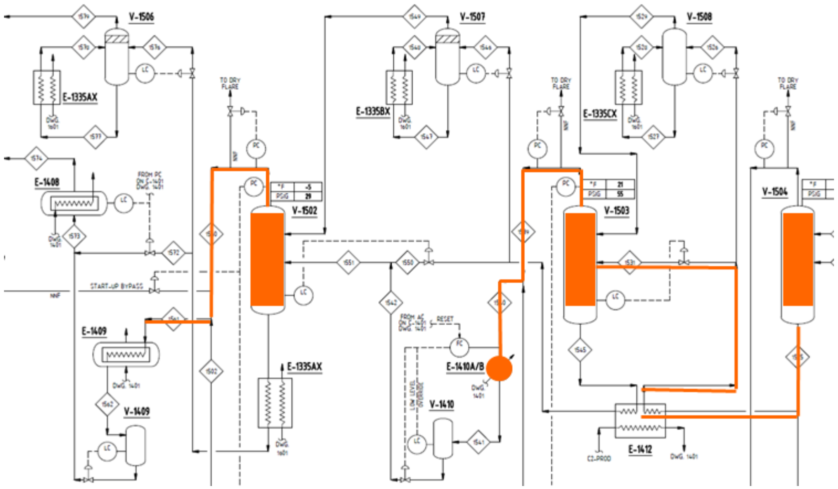
- On a recent Ethylene fractionator dynamic study - a conservative, preliminary basis, demonstrated the relief load to be 141,200 kg/hr [37% of current mitigated basis]

- This load under SIS failure is dependant on the amount of condensing refrigerant in the heating system – Dynamics showed potential to achieve near **zero load** by application of additional SIS within the refrigerant loop to isolate system inventory.

- The cost of the flare system was $40 – 50M as determine during FEED



Lummus process

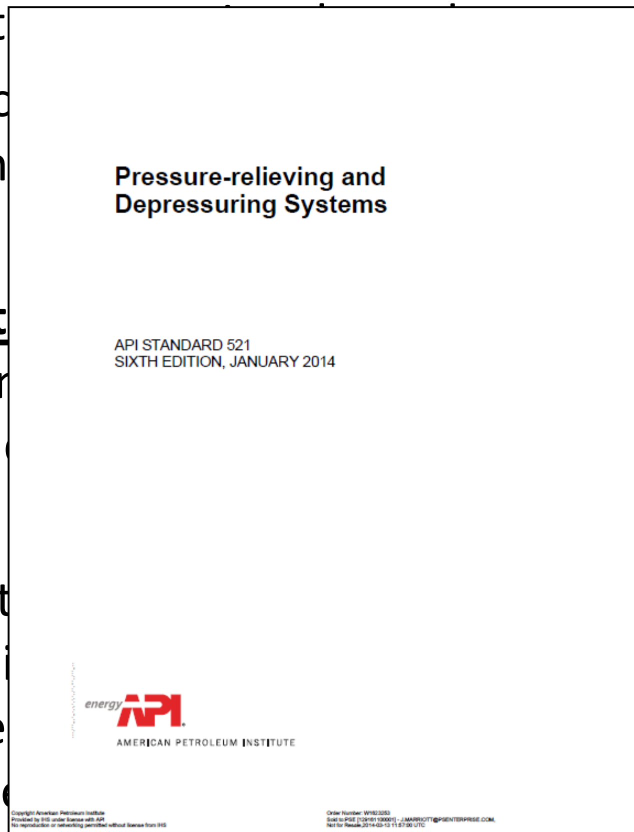


General

- **Avoid** significant and **costly** system **overdesign** of the flare system typical t [...] nalysis.
  - Significant c [...] n in piping materials, h [...] d plot space.

- **Accurate quant** [...] ads coupled with flare dynar [...] ce in design margins and un [...] pansion

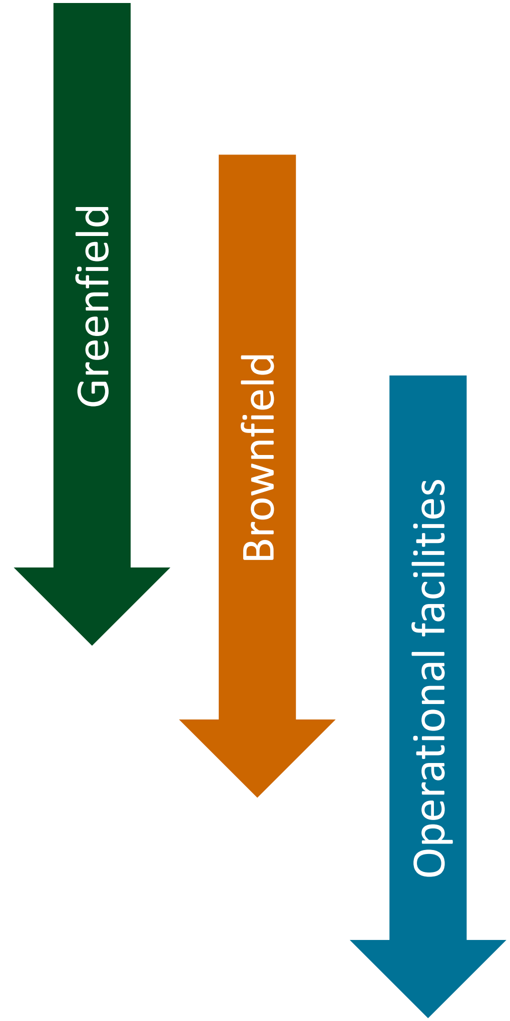
- Gain an underst [...] ehaviour of the facility and i [...] pment and safety instrume [...] cy situations (which are by d [...] **he performance of an existing safety system** against process historian data (e.g. Osisoft PI)



Pressure-relieving and
Depressuring Systems

API STANDARD 521
SIXTH EDITION, JANUARY 2014

energy API
AMERICAN PETROLEUM INSTITUTE



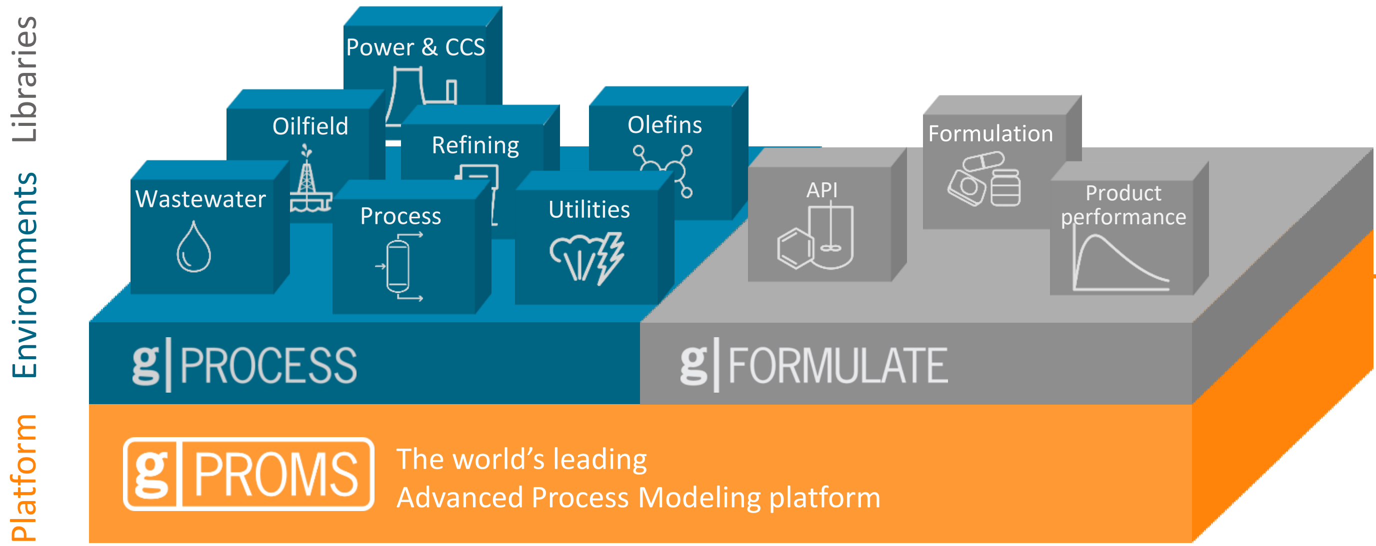
High-fidelity dynamic flare analysis for downstream oil & petrochemicals

Introduction to dynamic flare system design & analysis

The gPROMS software suite – 2017

"Simple" products
gPROMS ProcessBuilder

Formulated products
gPROMS FormulatedProducts



A single powerful software platform
serving *diverse sectors*
via high-value applications

Efficient software development & maintenance

Platform functionality

Process modelling

- Equation-oriented solution power
- Custom model construction
- Steady-state and dynamic simulation and optimisation
- Advanced parameter estimation
- Powerful dynamic and mixed-integer optimisation
- Global system analysis
- High-performance computing

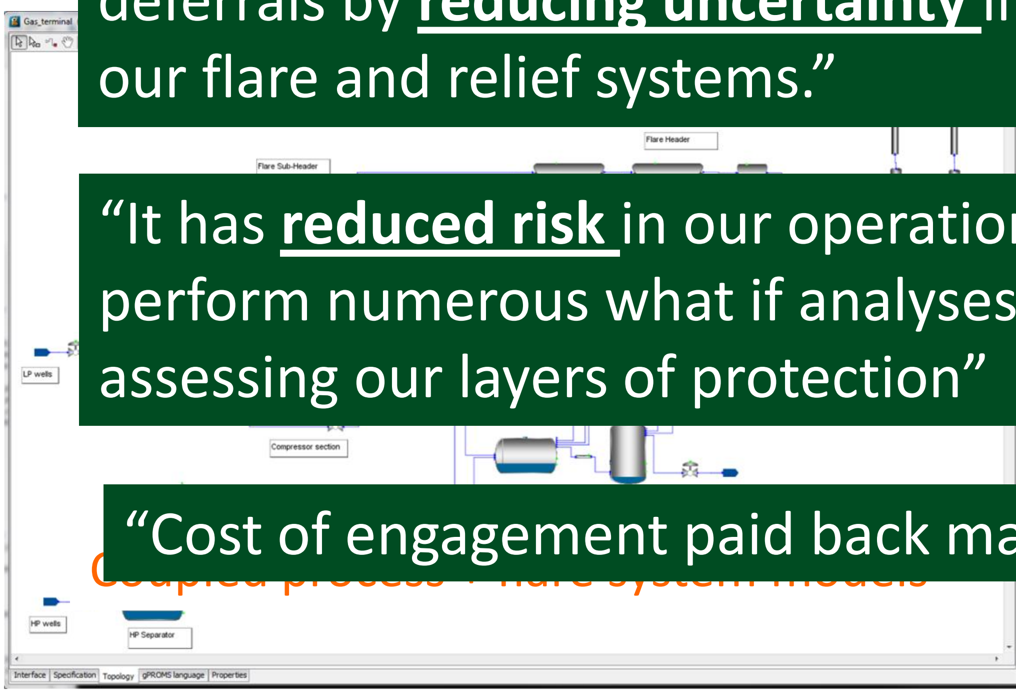
Materials modelling

- Molecular & ionic species
- Complex species & mixtures
- Gas, liquid, solid phases
- Phase & reaction equilibrium

Last year's APMF

Luke Hanzon, BP Alaska
Advanced Process Modeling Forum – Houston & London, April 2016

...cess and ...l of BP Alaska's oil & gas processing facilities [t...



"Our ability to now simulate a variety of conditions has enabled us to **reduce plant downtime** and production deferrals by **reducing uncertainty** in our understanding of our flare and relief systems."

"It has **reduced risk** in our operations by allowing us to perform numerous what if analyses, more **accurately** assessing our layers of protection"

"Cost of engagement paid back many times over"

Coupled process + flare system models

PSE case examples - overview

PSE has completed process safety assessment on over 80 facilities for: Gas plants, LNG, olefin recovery, refineries, offshore oil & gas platforms.

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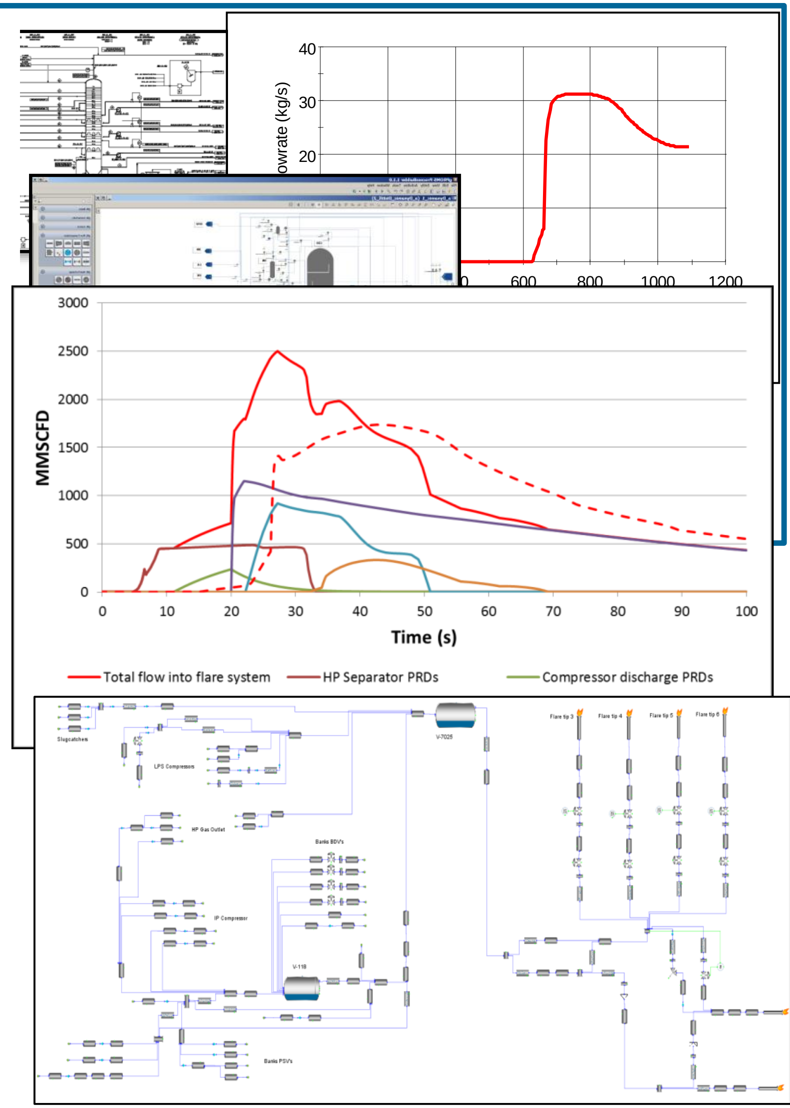
In the last 12 months:

- Ethylene production (across three different ethylene licences):
  - Two ethylene fractionators
  - One quench tower
- Refinery (CDU)
- Petrochemicals (Xylene splitter, De-isopentaniser)

Requirements for dynamic analysis

1. **Dynamic assessment of the individual flare loads**
   - Conventional methodologies show little relation to what actually happens ….
   - ➢ Requirement: Avoid simplifying assumptions
2. **Time dependency**
   - Relief in most plant wide relief scenarios in petrochemical facilities arises from vaporization of liquid inventory, this varies around the facility: relative timing of the relieving events is a key outcome of a dynamic study
   - ➢ Requirement: Model interaction between units
3. **Flare pressurization**
   - For large systems the time to pressurize the flare system can be considerable : full flaring rate is never seen
   - ➢ Requirement: Coupled process and flare system analysis



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Case 1 – Olefins plant total power failure

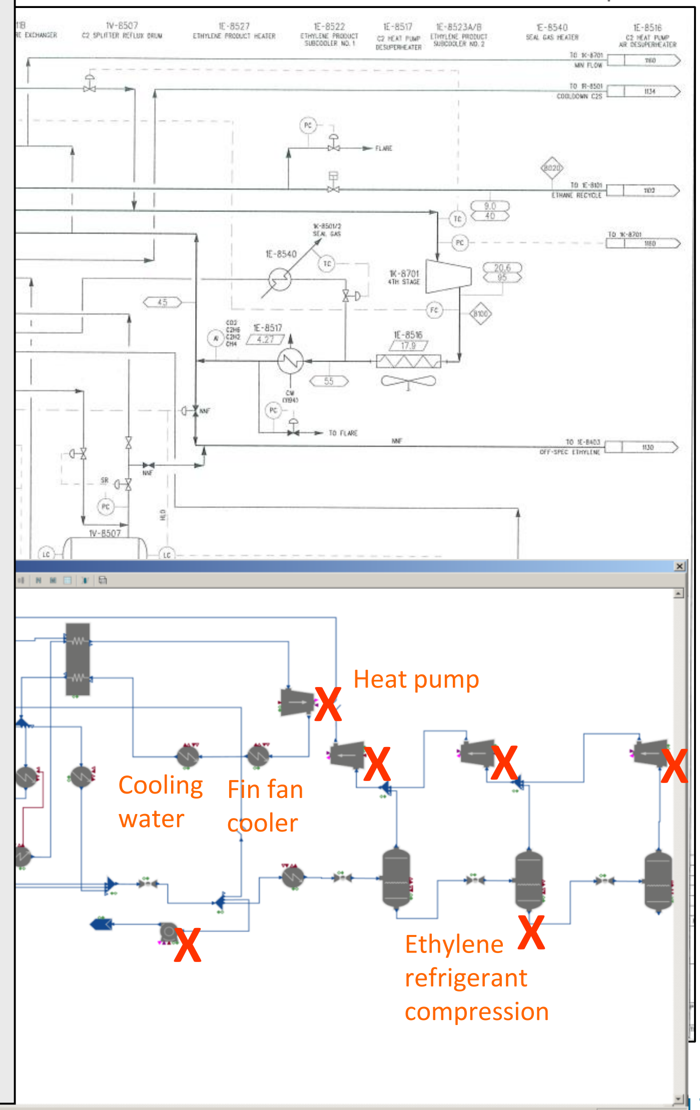
Ethylene fractionator – Scenario

Full dynamic representation of Column and heat integration configuration

Power failure scenario

- Electrical equipment: drives fail immediately.
  - Heat pump (compressor) will stop
  - Bottom product pump will stop
  - Ethylene refrigerant compressor will stop – ethylene refrigerant flow will stop
  - Fin fan cooler will stop
  - Cooling water will stop in heat exchangers
- Control Valves:
  - Pressurised feed flow from demethaniser bottoms regulated via level control valve.
    - Feed valve assumed to remain open (conservative)
    - There is significant continuing liquid inventory in the upstream demethaniser

Stone and Webster process



Case 1 – Olefins plant total power failure

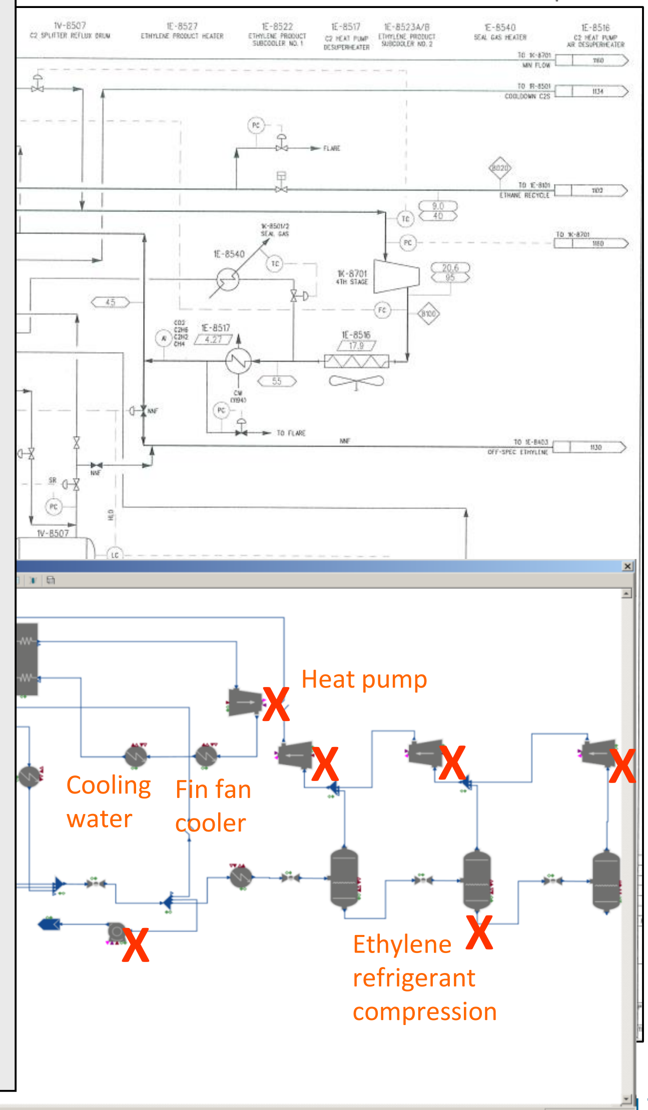
Ethylene fractionator – What happens?

Full dynamic representation of Column and heat integration configuration

Stone and Webster process

What happens?

- Because heat pump stops, all flow through the heat integrated side of the heat exchangers (including column reboiler) will stop
  - Thermosyphon will continue due to the significant residual heat in the reboiler
- Cold reflux will not be returned to column
- Top and bottom products will stop creating a blocked in system
- FEED continues to add inventory and flash vapour
- Heating is now **unbalanced** due to the residual heat capacity in the reboiler
- *If* the pressure gets above relief set pressure the valve(s) will open.
- The peak flowrate, when it occurs and for how long it lasts, **depends on the rate of liquid evaporation and material coming through the feed**



Conventional relief load calculation

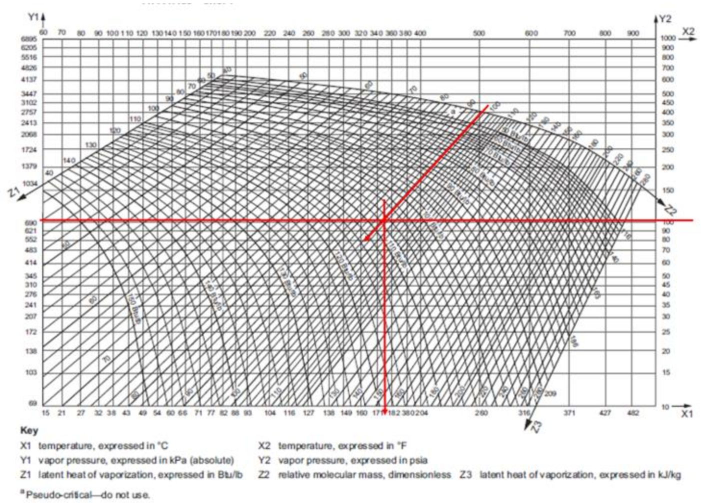
1) Conventional flare load calculation (Unbalanced heat methodology):

Total load based on (a) + (b)

a) Residual reboiler duty divided by top tray latent heat at relieving conditions.
   - EPC design guidelines typically calculate residual duty as 30% of design reboiler duty.
   - Design reboiler duty is appropriate e.g after start ups with clean U values equates to 15% margin above maximum steady state simulation heat duty -> 49kg/s (53030*1.15*0.3/373.8)

$$Q_{excess} = F.h_F + Q_F - B.h_B - D.h_D + Q_S - Q_C - S.h_S - (F-B-D-S).h_L$$

$$R = Q_{excess} / \lambda$$



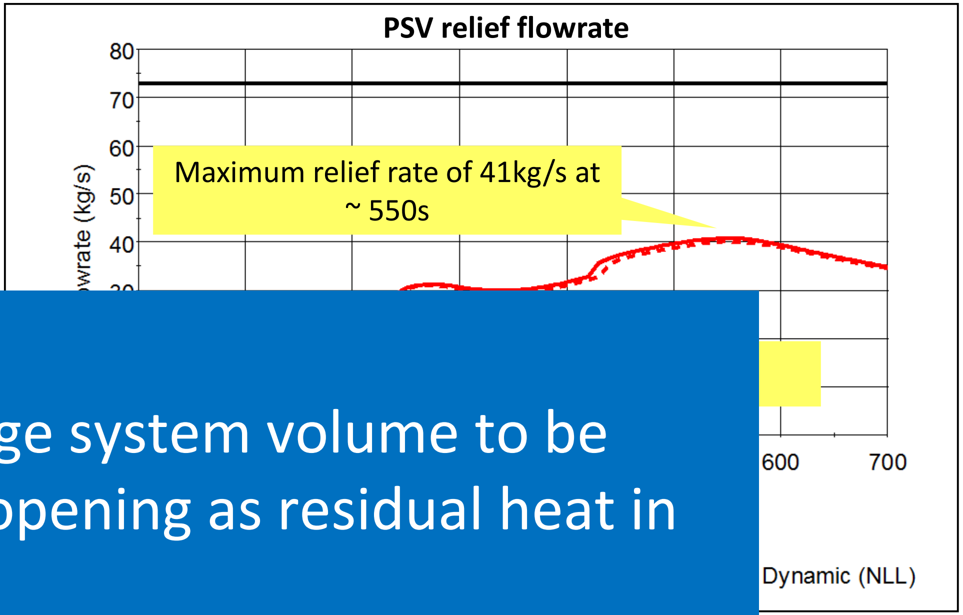
b) Flash vapour from feed at relieving conditions -> 24 kg/s

➢ **Total = 73 kg/s**

Dynamic relief load calculation

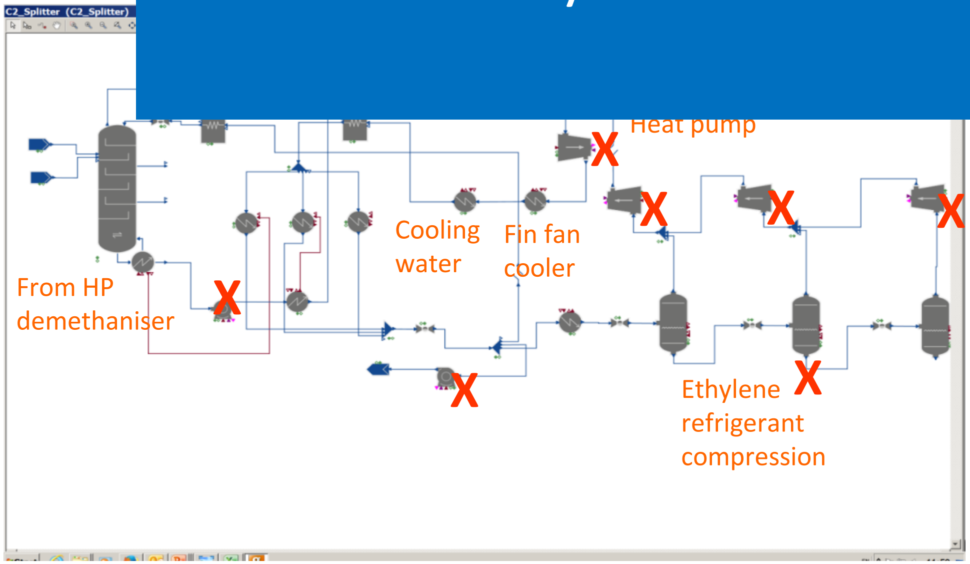
2) Dynamic flare load calculation:

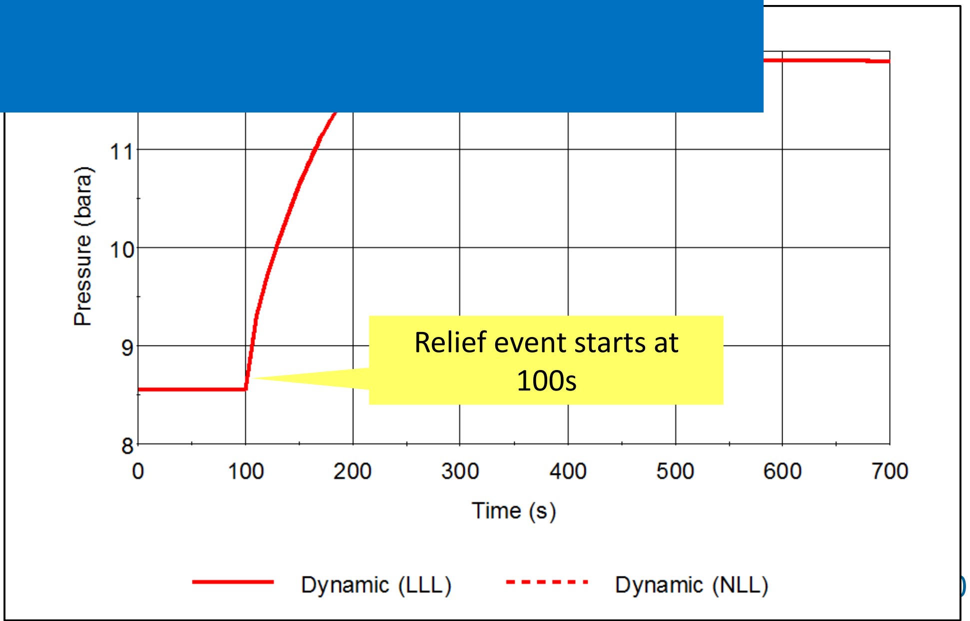
- Overhead cooling and reflux flow stop, no top or bottom products
- Residual heat available from integrated r
  c
- F



44% reduction in relief load

- Load reduction is due to the large system volume to be pressurized before relief valve opening as residual heat in reboiler decays





Sensitivity to liquid level is shown

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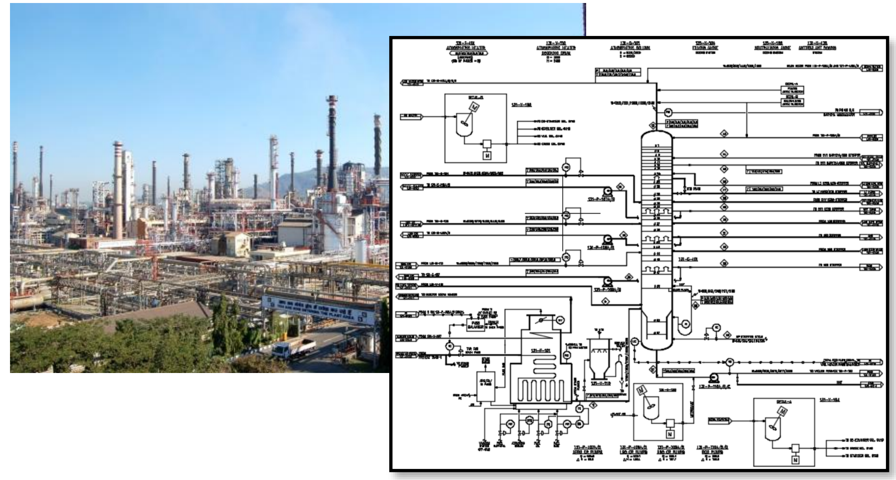
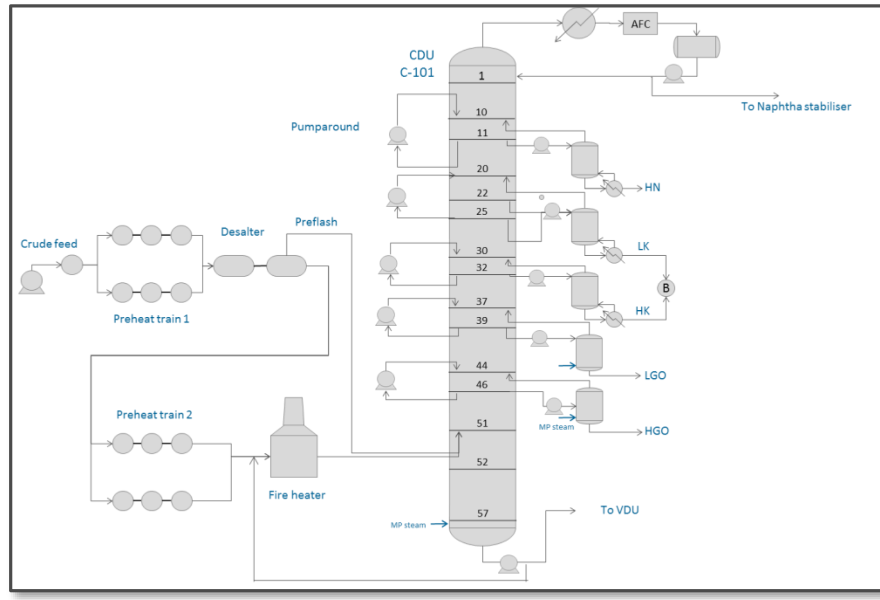
Case 2 – Crude Distillation Unit under total power failure

Case 2 - Crude Distillation Unit under total power failure

Case study

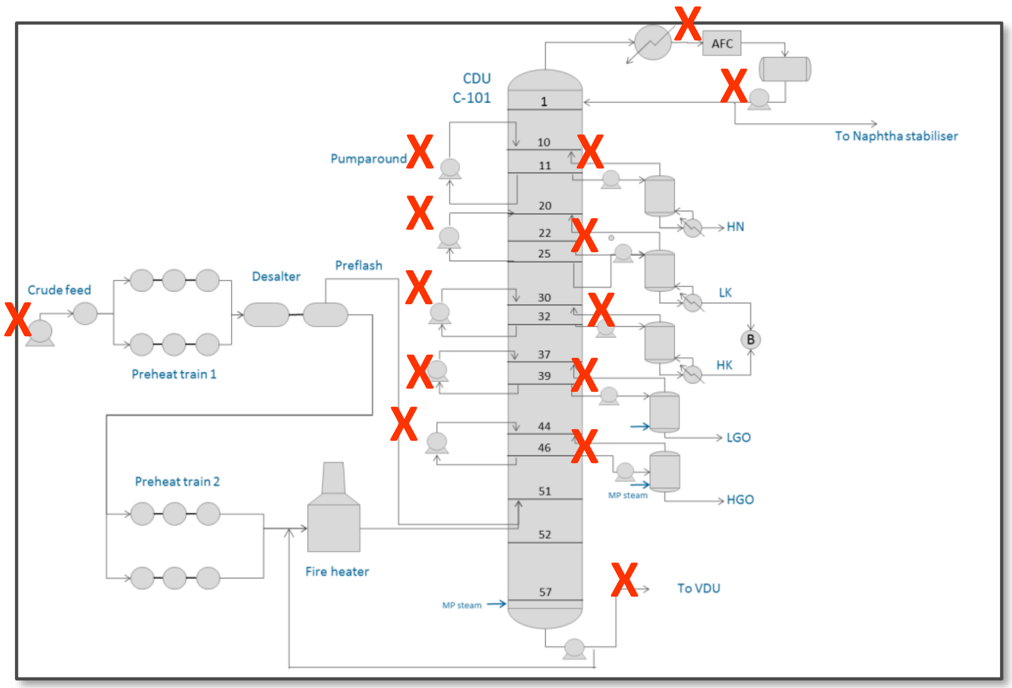
- Assessment of dynamic relief behaviour of a 20 year old CDU as part of overall refinery revamp
- Requirement of re-evaluation of flare relief loads for site-wide dominant scenarios using dynamic simulation
  - **Total power failure**
- CDU is one of the main relief contributors => detailed analysis





CDU – Scenario

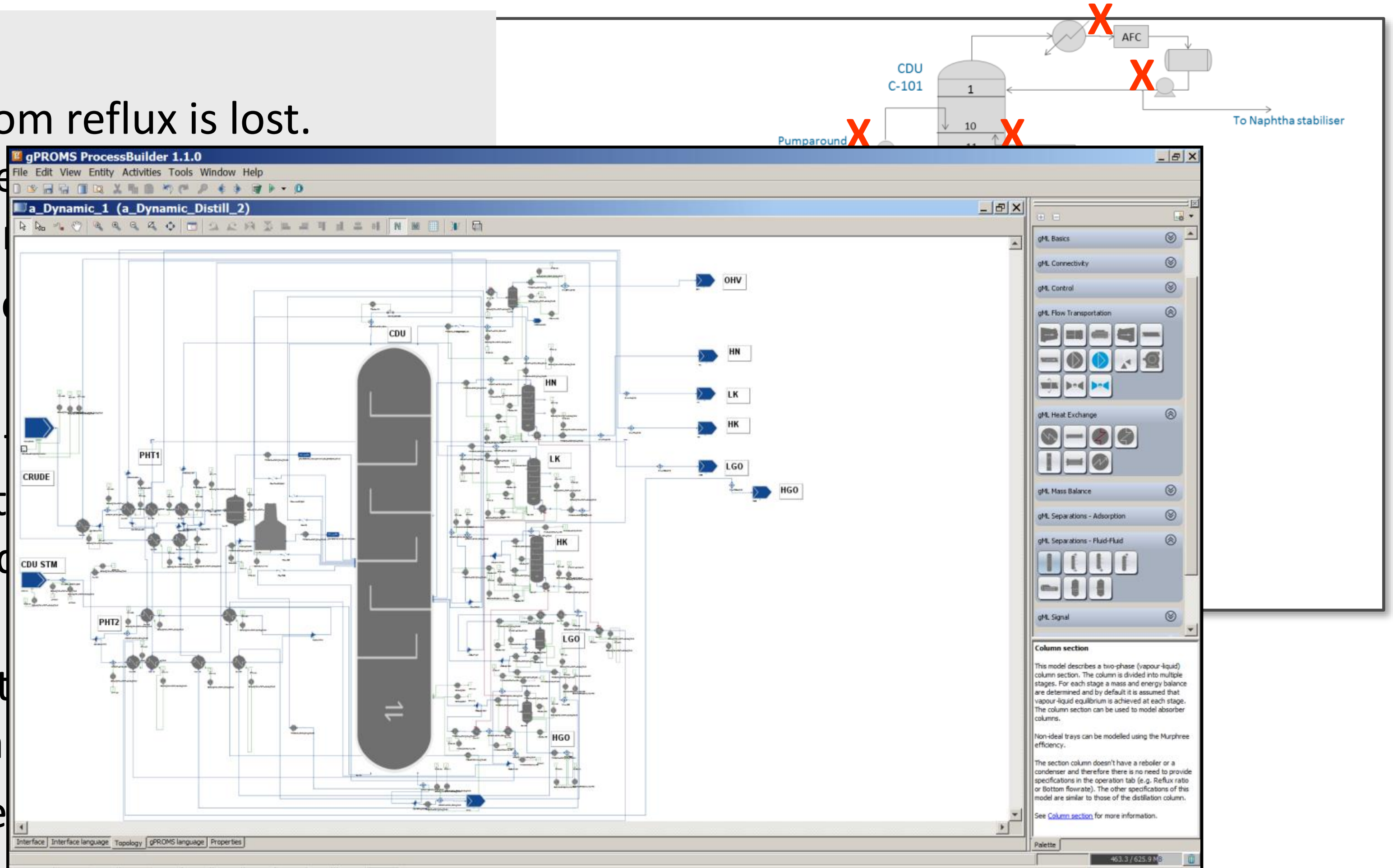
- Electric equipment: will fail immediately.
  - Feed pump, pump around cooling, side stripper pumps and reflux return
  - Air-Fin Cooler fans
  - Bottom product turbine pump will remain in operation
- Valves:
  - Bottom product to VDU will stop
  - Furnace protection valve fails fully open – bottom product is recycled back to the furnace
  - Fuel Gas valves are tripped closed by power failure signal, but worst case is to assume trip fails



Conservative but credible basis

CDU - What happens?

- Feed flow stops
- Cooling of CDU from reflux is lost. Condenser drum e… stops all condensi…
- HP steam to CDU …
- The pressure and … column will start t… now **unbalanced** … cooling
- *If* the pressure get… pressure(s) the va…
- The peak flowrate … how long it lasts, **depends on the rate of liquid evaporation**



Conventional relief load calculation

1) Conventional flare load calculation (Unbalanced heat methodology):

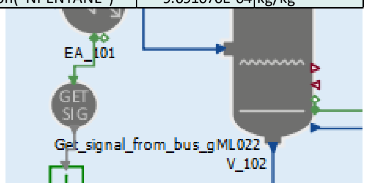
Excess heat in column assumed to act on top tray liquid composition

- **Relief Flowrate = 88.08 kg/s (317088 kg/h)**

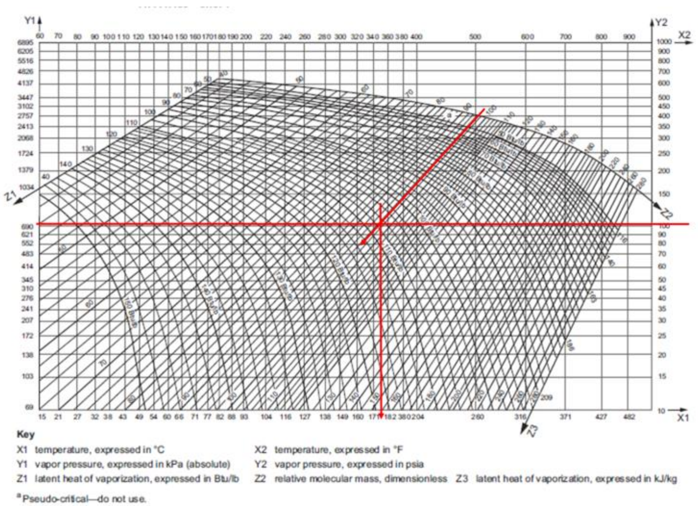
Condenser inlet

Mass flowrate	88.0804	kg/s
Hot stream inlet pressure	2.64959	bar
Hot stream inlet temperature	409.044	K

Variable	Value at time 0.00000	Units
Mass fraction("WATER")	2.128170E-02	kg/kg
Mass fraction("PROPANE")	1.616580E-03	kg/kg
Mass fraction("ISOBUTANE")	7.322650E-03	kg/kg
Mass fraction("ISOBUTYLENE")	1.239070E-04	kg/kg
Mass fraction("NBUTANE")	4.020190E-02	kg/kg
Mass fraction("CIS2BUTENE")	1.916940E-13	kg/kg
Mass fraction("ISOPENTANE")	3.193890E-03	kg/kg
Mass fraction("NPENTANE")	9.691070E-04	kg/kg



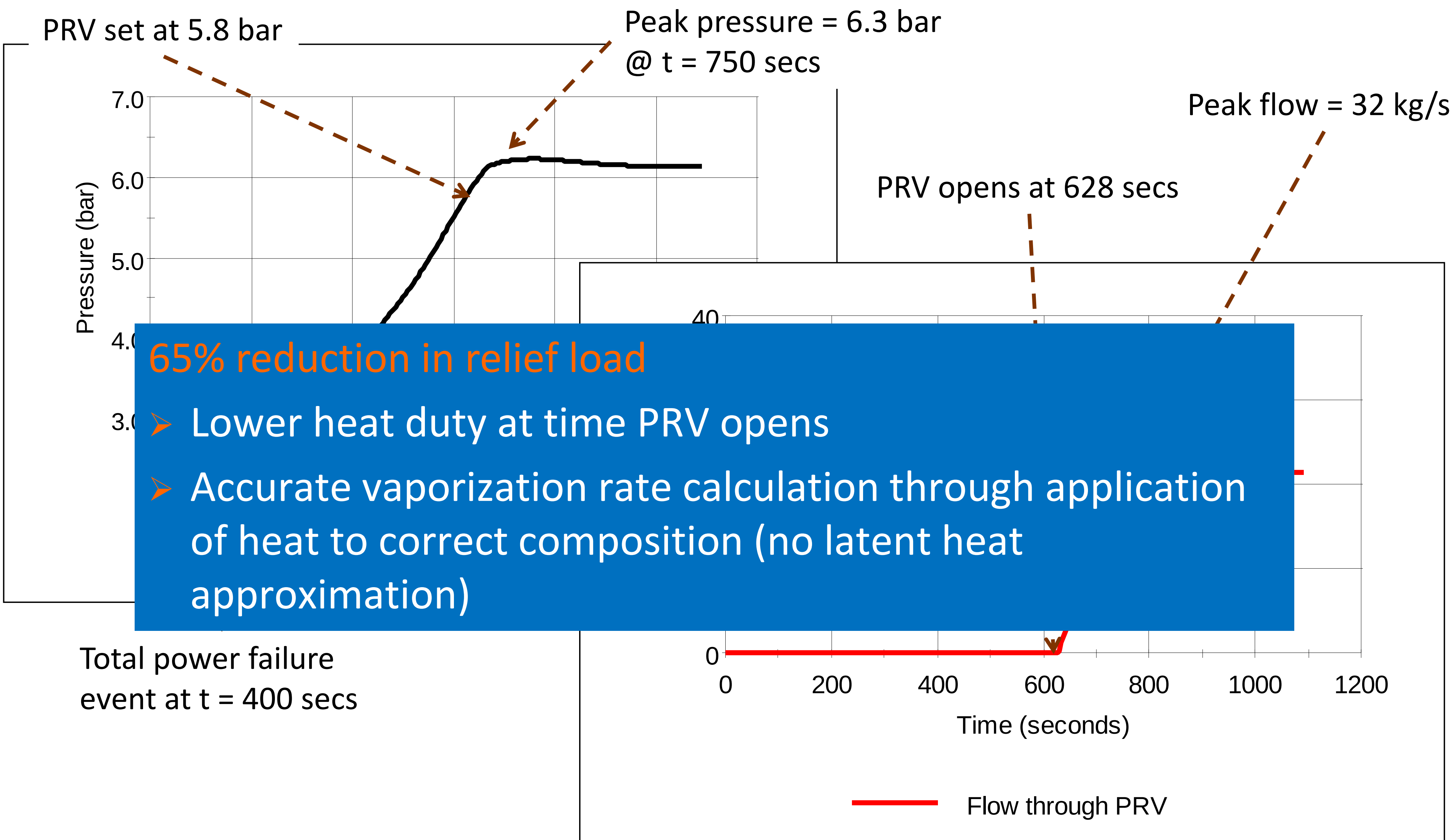
Reflux drum



$$Q_{excess} = F.h_F + Q_F - B.h_B - D.h_D + Q_S - Q_C - S.h_S - (F-B-D-S).h_L$$

$$R = Q_{excess} / \lambda$$

Dynamic relief load calculation



65% reduction in relief load

- Lower heat duty at time PRV opens
- Accurate vaporization rate calculation through application of heat to correct composition (no latent heat approximation)

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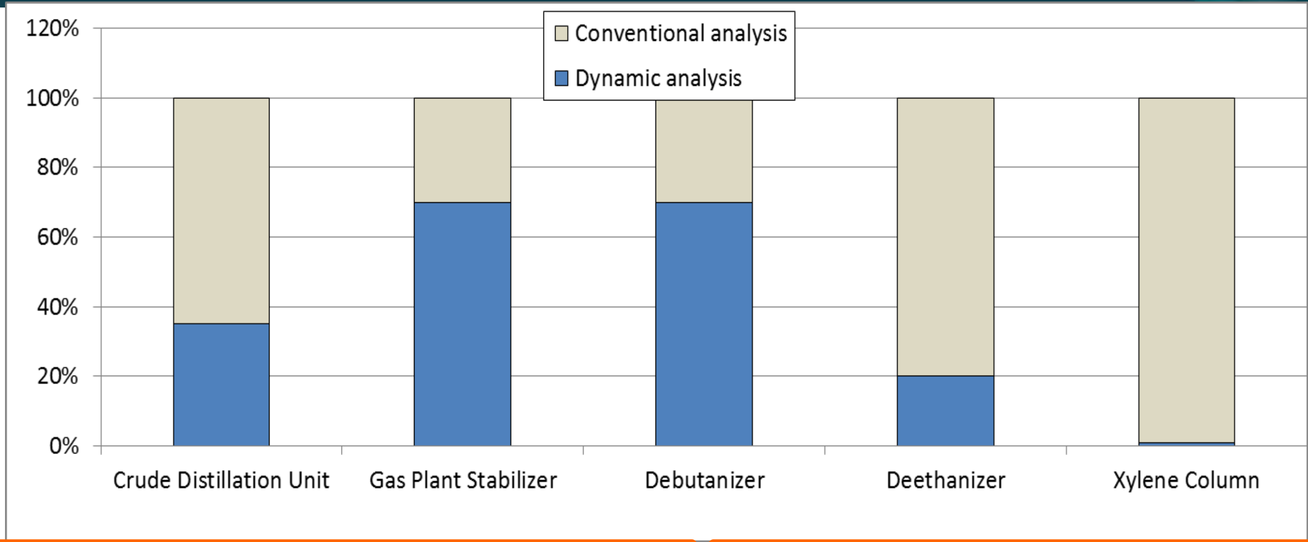
Conclusions

Conclusions



- Accurate application of heat to the correct fluid composition in column
  - Rectification heating
  - Re-boiler
  - Feed introduction
- Column takes time to pressurise
- No requirement to use latent heat approximation
- Evolution of column inventory in time
- Change in heat transfer rate with time in reboiler / furnace

Industry demand

PSE has completed process safety assessment on 80 facilities in the last five years with experience in dynamic flare system design and assessment for: Gas plants, LNG, olefin recovery, refineries, offshore oil & gas platforms

1. **Dynamic assessment of the individual flare loads**
   - Conventional methodologies show little relation to what actually happens ….
   - ➢ **Benefits of dynamic assessment can vary from a 10% reduction to 100% reduction**
2. **Time dependency**
   - Relief in most plant wide relief scenarios in petrochemical facilities arises from vaporization of liquid inventory, this varies around the facility: relative timing of the relieving events is a key outcome of a dynamic study
   - ➢ **Further reductions in peak flare loads of at least 30% are not uncommon.**
3. **Flare pressurization**
   - For large systems the time to pressurize the flare system can be considerable : full flaring rate is never seen
   - ➢ **Further reduction in the observed flaring rate: Full flaring rate is never seen in KO drum or at the flare tip(s)**

Thank you