BEYOND QUANTITATIVE RISK ANALYSIS RESULTS

Part II: Fires and Domino Effect Characterization

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Abstract

The main purpose of a Quantitative Risk Assessment (QRA) is to evaluate the risk levels of a process due to potential Loss of Containment scenarios (LOCs). Moreover, analysis of detailed QRA results can be the basis for more specific studies for facility and critical equipment siting, and domino effects analysis due to thermal radiation of fires.

This poster focuses on illustrating a risk-based fire assessment in order to provide detailed results for domino effects/escalation analysis. The analysis takes into account the following information: (1) identification of the total number of fire outcomes (i.e., pool fires, jet fires, or flash fires) which impact a given structure; (2) individual frequency and associated heat flux of each identified outcome. The fire risk-based assessment is illustrated by completing the following three steps: (1) identification of structures impacted by a certain heat flux due to fires at a given frequency threshold/criteria; (2) prediction of the Time To Failure (TTF) of equipment identified in step 1, and (3) estimation of TTF conditions for domino effect/escalation analysis; i.e., consequence modeling.

Quantitative Risk Assessment Flowchart

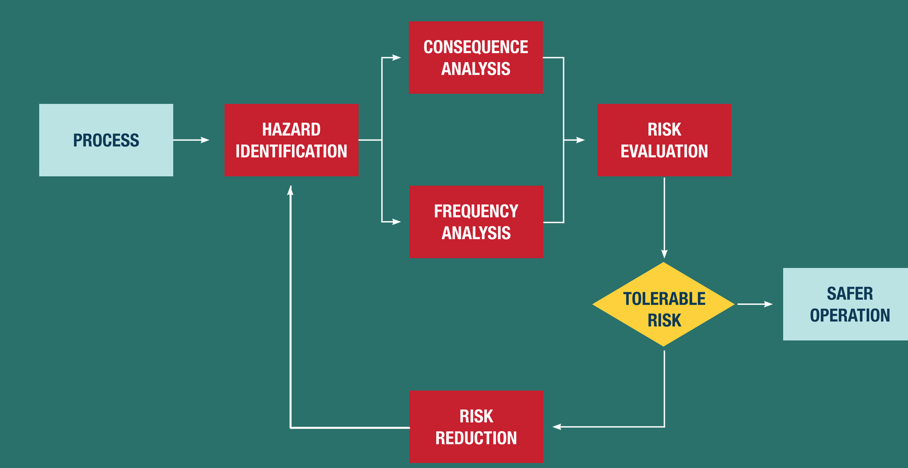

Figure 01

Simplified Quantitative Risk Assessment (QRA) Flowchart

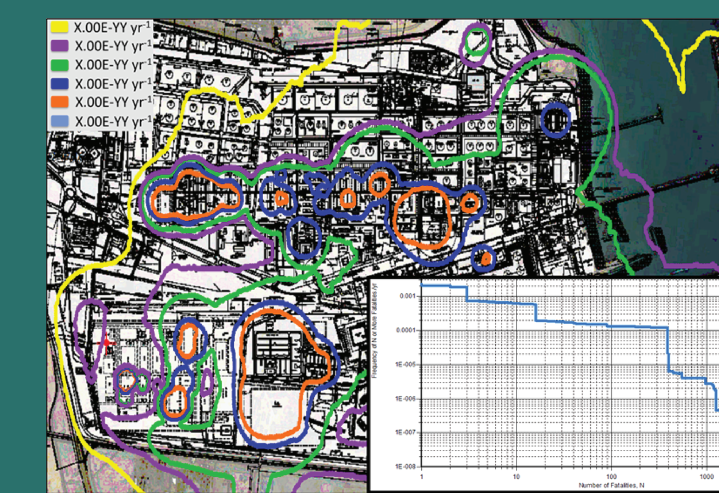

Figure 02

Example of QRA Results: Individual Risk Contours and FN Curve

Beyond QRA Results

Results from QRA development following world-wide risk-based criteria (e.g., references [1], [2], [3]) are the basis for emergency and land use planning, providing the foundation for risk reduction decision-making. With these results, a more dedicated fire assessment can be performed by addressing escalation due to domino effects, and also facility siting, and evaluation of impacts for safety critical equipment, occupied buildings, and/or key structures.

Risk-Based Fire Assessment based on Heat Flux Exceedence Analysis

A risk-based approach requires the identification of a hazard level (e.g., heat flux due to fires) which will not be exceeded at a given frequency threshold. Heat Flux Exceedance Curves (HFECs) can be developed by applying the following steps:

(1) Identification of fire-related outcomes (including both immediate and delayed ignition fires) that impact a given location of interest; i.e., structures or equipment

(2) Frequencies of occurrence of outcomes producing a specific level of heat flux are added

(3) All cumulative frequencies at different heat flux values are plotted with the aim to identify which structure or equipment is affected by a certain heat flux at a given frequency threshold/criteria. Figure 03 illustrates and example with the analysis of four Safety critical equipment present in a refinery at different locations.

Note that the Safety Critical Equipment 01 (SCE01) is predicted to be impacted by a heat flux of 37.5 kW·m-2 at a given frequency threshold of 5.00E-05 yr-1.

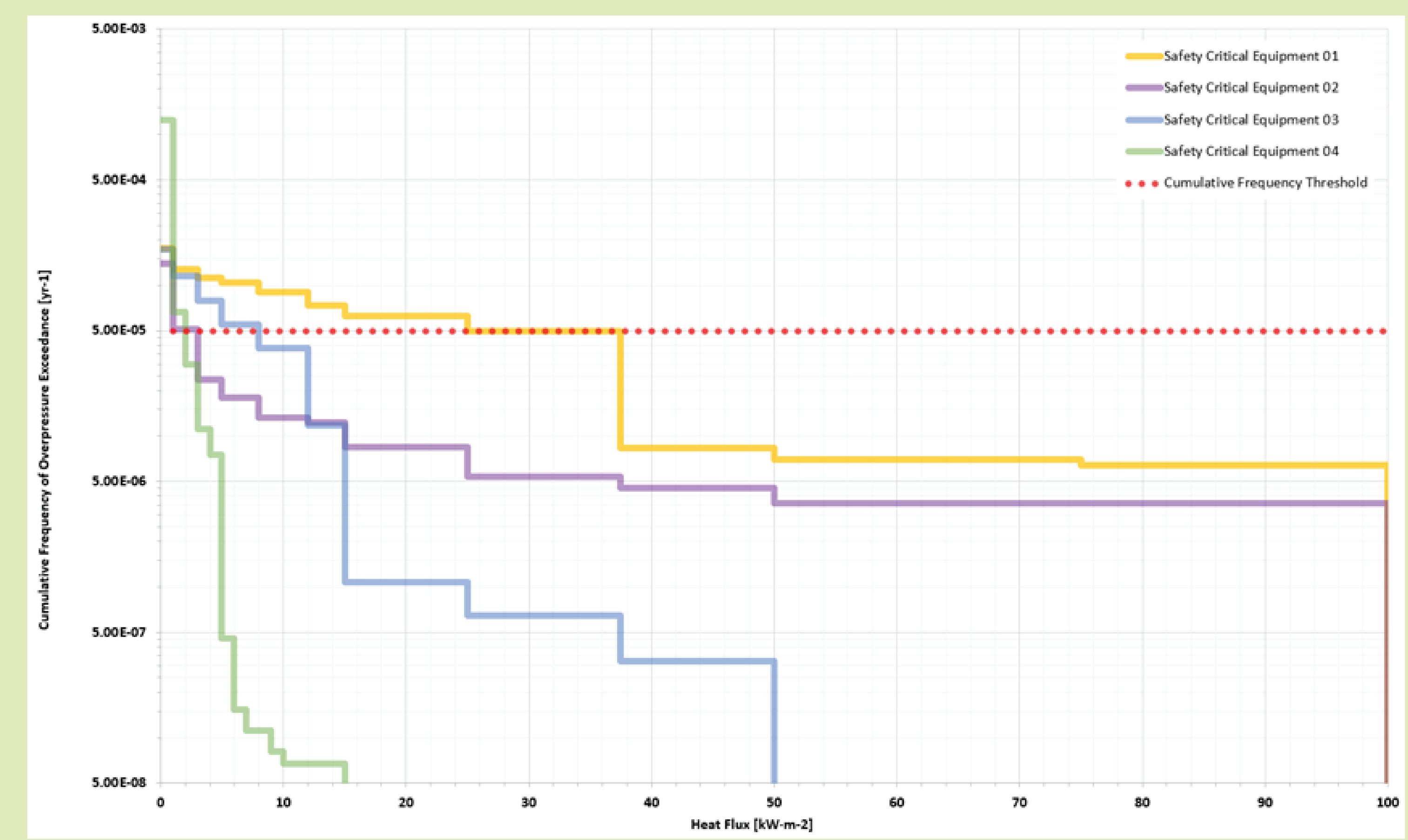

Figure 03
Example of Heat Flux Exceedence Curve

Wall Dynamics for TTF Prediction and Associated Conditions

Using SuperChems™ [6], SCE01 is evaluated using a dynamic segmented vessel model. Heat transfer analysis is applied per wall segment:
(1) Ambient heating to wall segment heat transfer options include insulation, solar heating, rain, water sprays, pool fires and flame jets
(2) The wall segment to fluid heat transfer includes radiation, natural convection, forced convection, film boiling, and pool boiling

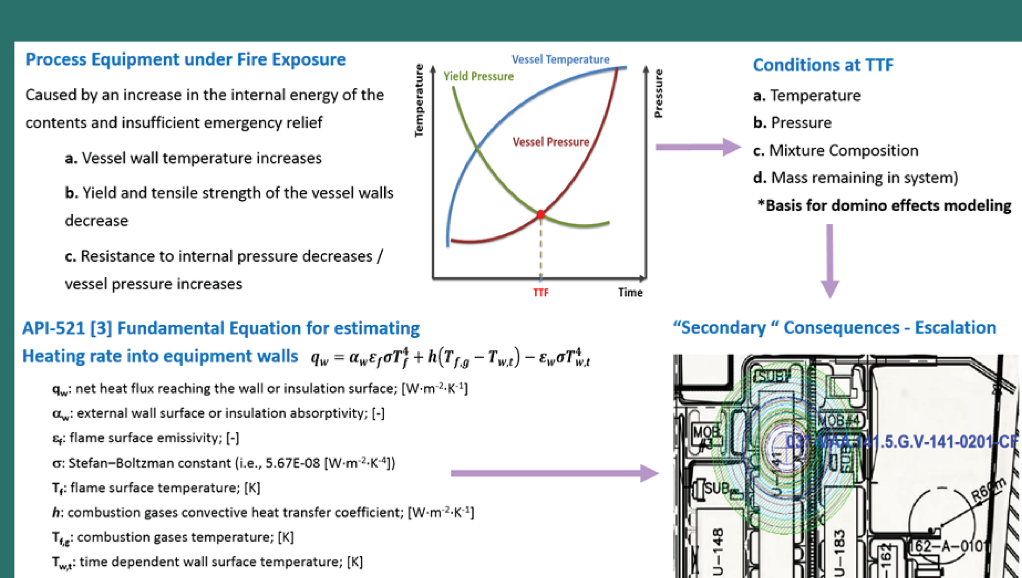

Figure 04
Failure of a Process Equipment under Fire due to Overtemperature

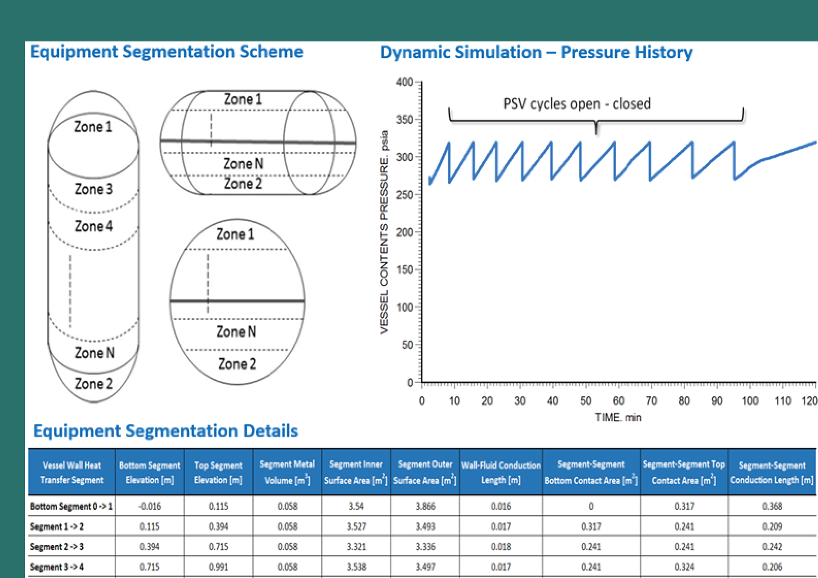

Figure 05
Equipment Segmentation Scheme, and Example of a well-sized PRV

Analysis of Results and Risk Reduction Measures

Figure 06 illustrates the failure stress and internal hoop stress for SCE01 [8]. TTF is predicted when the wall tensile strength intersects the internal hoop stress. The hoop stress history confirms that the installed PRV is sized appropriately. While a PRV does not ensure the mechanical integrity of a system under fire exposure (especially vapor filled), it influences the predicted TTF and conditions within in the system.

Figure 07 is intended to illustrate how additional mitigation measures may impact the TTF [8]. This simulation specifically addresses the SCE01 evaluation including one (1) inch of fire-proof insulation. Results confirm that the equipment is not expected to fail.

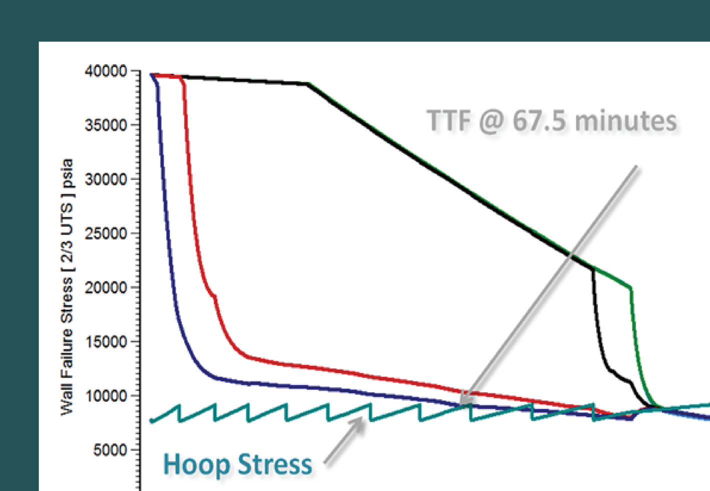

Figure 06
TTF prediction using SuperChems™ Wall Dynamics

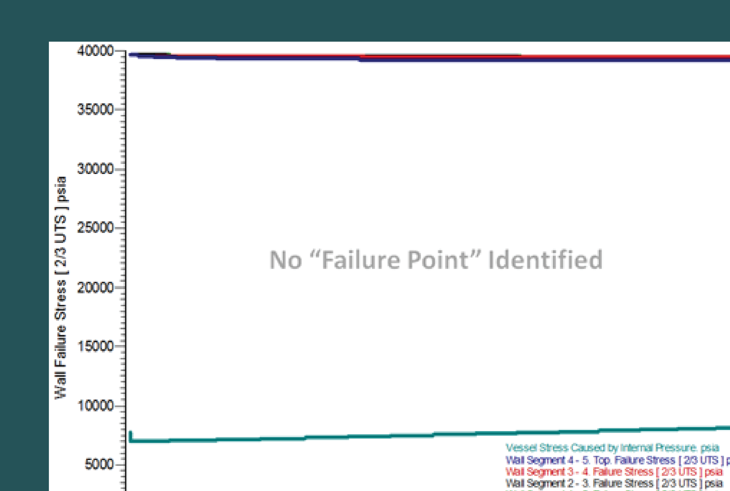

Figure 07
Example of Fire-Pool Insulation as an Effective Risk Reduction Measure

Conclusions

A risk-based approach is proposed for identifying structures, buildings, and/or safety critical equipment expected to be exposed to fire thermal radiation at a given frequency threshold/criteria. Heat Flux Exceedance Curves (HFEC) allow this approach.

A detailed dynamic simulation using wall segmentation approach implemented in SuperChems™ allows prediction of TTF, and the associated conditions for further domino effect/escalation analysis. This approach is valuable for sensitivity analysis when considering safeguards that could be installed which would increase the TTF prediction: (1) optimization of the emergency relief system size, (2) definition of the activation time and size for an emergency depressuring valve, (3) minimum insulation thickness and material properties to be considered (i.e., thermal conductivity, heat capacity), (4) minimum required cooling load and duration if sprinkler systems are considered to be installed.

References

[1] CCPS. (2000); "Guidelines for chemical process quantitative risk analysis". Second Edition. New York, Center for Chemical Process Safety of the American Institute of Chemical Engineers.
[2] VROM (2005), Guidelines for Quantitative Risk Assessment. Publication Series on Dangerous Substances (PGS3); CPR-18E.
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[6] ioMosaic Corporation (2016). "SuperChemsTM Expert 8.1", ioMosaic Corporation. www.iomosaic.com
[7] G. A. Melhem and D. Gaydos, "Properly Calculate Vessel and Piping Wall Temperatures During Depressuring and Relief", Process Safety Progress, doi: 10.1002/prs.11689.
[8] J. Dunjó and G. A. Melhem, "Catastrophic Vessel Failure due to Fire Exposure – Wall Dynamics & Consequence Analysis", 11th Global Congress on Process Safety, Austin, 2015.