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Fire protection as the underpinning of good process safety programs

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ABSTRACT

This paper will provide an overview of the role of fire protection engineers in the mitigation phase of a process safety program. Fire protection engineers are involved in the assessment of hazards and the selection of fire protection strategies which can reduce the risk to an acceptable level according to the stipulated goals and objectives. Fire protection strategies may include the installation of a variety of approaches, such as passive and active fire protection systems, manual intervention and siting. Passive systems include fire rated barriers and protection of openings in those barriers, while active systems include systems such as fire detectors and sprinklers. Manual intervention may include the manual activation of fixed fire protection systems or firefighting activities by facility fire brigades or municipal fire departments. The manual firefighting activities are typically considered to be in the 'response' phase.

1. Introduction

Numerous accidents involving process systems either include fires as part of the initiating event or occur subsequently. As such, fire safety strategies are employed to prevent fires and mitigate the consequences of those that occur. While fire protection can also be provided during the response phase during an ongoing incident, though such an approach should only be regarded as a matter of last resort and not be the principal means of providing fire protection.

This paper will concentrate on the involvement of fire protection engineering in the mitigation phase of a process safety program. Fire protection engineers assess the nature and magnitude of hazards and the selection of fire protection strategies which can be applied to reduce the risk to an acceptable level. While acceptable levels of risk may be implicitly included in codes and standards, engineering analyses may also be conducted to determine the level of risk provided by a potential incident and how such compare to the acceptable level of risk determined by managers. The engineering analysis of risk will need to assess the hazards generated by identified scenarios (as well as the probability of the respective scenarios) and the performance of proposed fire protection strategies in response to those scenarios.

Fire protection strategies may include the installation passive fire protection systems, active fire protection systems, manual intervention and siting. Passive systems include fire rated barriers and protection of openings in those barriers, while active systems include systems such as fire detectors and sprinklers. Manual intervention may include the manual activation of fixed fire protection systems or firefighting activities by facility fire brigades or municipal fire departments. The manual firefighting activities are typically considered to be in the 'response' phase. Siting involves the location of facilities such that there is adequate separation between a potential hazard and target as well as to facilitate access by emergency responders.

An analysis of the contribution of a particular fire protection system to the achievement of specified objectives should include an assessment of the effectiveness and reliability of the proposed fire protection systems. These objectives may be implicit; being incorporated into the basis of regulatory requirements in prescriptive codes, or may be explicit where performance-based designs are proposed. For example, an objective could be to limit fire spread due to radiant heat exposure from an incident involving a fire associated with a liquid spill. Because fire protection systems have many variations, with few standard, one-size-fits-all designs, understanding the performance objectives intended for the system is essential in order to identify the correct type of system, as well as to formulate the best design options for the selected system, as will be outlined in the remainder of this paper.

2. Passive protection methods

A fire resistant building assembly has an "ability to confine a fire, continues to perform a given structural function, or both" (IBC,

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2015). Generally, meeting prescriptive requirements is accomplished by identifying an assembly which has been subjected to a standard test at a laboratory such as UL. An example of a fire resistant assembly with a spray applied fire protection material on a steel column is illustrated in Fig. 1 (UL, 2015).

The fire resistance rating is derived from results obtained from a standard test (ASTM, 2015). Performance criteria stipulated in the standard reflect the intended functions of fire resistant assemblies. For example, the barrier function is assessed by criteria limiting the temperature rise on the unexposed side of the assembly to an average of 139 °C and 181 °C at a single point. These criteria are based on the spontaneous ignition temperature of ordinary combustibles which may be in contact with an unexposed surface of a fire barrier. The structural integrity function is fulfilled if there is no collapse or extraordinary deflection, or may be determined by temperature limits for steel components relating to the decrease in tensile strength with temperature, e.g. for steel columns an average temperature of 538 °C and 649 °C at a single point and for steel rebars the temperature limit is 593 °C.

A common misunderstanding is that the fire resistance rating infers the number of hours that an assembly will perform successfully in an actual fire. In ASTM E119, the following important statement is made concerning the relevance of the fire resistance rating acquired [2015]:

Sect 1.2: “It is the intent that classification shall register comparative performance to specific fire-test conditions during the period of exposure and shall not be construed as having determined suitability for use under other conditions or after fire exposure.”

It is important to recognize that the temperatures of the structural components and on the unexposed side will depend on the fire exposure. Further, while the test is a large-scale test, no attempt is made to scale the test results to the size of the actual assemblies or replicate the structural end conditions. As such, if the amount of time that a fire resistant assembly will continue to function despite exposure to an actual fire needs to be determined, the fire resistance rating isn't relevant.

Typically, the intent of a fire resistance analysis is to assess whether a structural assembly can withstand the effect of fire exposure for the entire duration as originally proposed by the National Bureau of Standards in its classic BMS 92 report (1942). A fire resistance analysis is involves a thermo-mechanical analysis (Milke, 1999), as depicted in the flowchart in Fig. 2. As indicated in the flowchart, the first step is to estimate conditions posed by proposed design fires. This output of this analysis results in a determination of the time-dependent temperature or heat flux exposure for the assembly. The next step is to conduct a thermal response analysis which involves analyzing the heat transfer of the fire to the assembly, where the output from the fire analysis serves as boundary conditions for the analysis. The thermal response analysis provides a determination of the temperature distribution caused by the fire exposure. These results may be compared to temperature endpoint criteria provided in ASTM E119, or may be used as inputs to the structural analysis in the next step. The structural response analysis consists of an analysis of deflections or stresses developed within the assembly and can be compared to prescribed endpoint limits (perhaps relating to maximum allowable stresses or deflections). Overviews of the components of the analysis are included in Buchanan (2007), Franssen and Iwankiw (2008), Milke (2008a), Fleischmann et al. (2008) and White (2008).

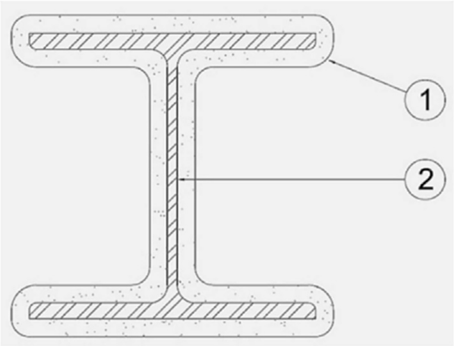

Fig. 1. Fire resistance rated steel column design (UL Design X701) (UL2015). 1. Spray applied fire protection material. 2. Structural steel column.

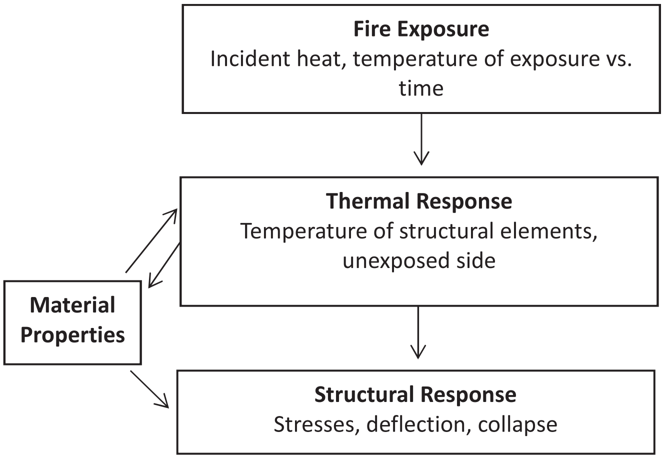

Fig. 2. Outline of thermo-mechanical analysis for fire resistance assessment.

As an example application of a performance-based fire resistance analysis, consider the impact of a fire exposing a steel tower supporting a foam turret protecting an off-loading facility of crude oil from a barge docked at a pier. The fire scenario involves a spill of crude oil on the barge. Detection of a fire is accomplished either by security personnel observing the fire or by a drop in pressure in the transfer line for the crude oil. Release of the foam system is done at a watchtower (a different tower than that supported the foam turret).

The analysis needs to address whether the foam system can be actuated prior to the steel components of the tower being heated to a failure temperature should a fire be initiated on a barge. While the security guard watchtower is constantly staffed, at times only one guard might be present who is also required to walk the property for a security check. This staffing situation requires that the analysis account for the possibility that the lone guard is at the far end of the property at the time of the fire and thus must estimate the time required for the guard to walk (or run) from the remote location and traverse the watchtower stairs to actuate the foam system.

The radiant heat flux from a hydrocarbon pool fire is dependent on the diameter of the pool. In addition, the smoke included in the plume has the ability to decrease the radiation emitted from the source (as compared to a plume that would contain only flames). The radiant heat flux, E, emitted from such a plume is estimated as (Beyler, 2008):

$$E = 58\left(10^{-0.00823D}\right)$$

Where:

E: radiant flux emitted (kW/m^2).

D: diameter of pool fire (m).

The radiant heat flux to a target from the flame is estimated