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Experimental and numerical methodology for the analysis of fireproofing materials

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ABSTRACT

In this study, a methodology for the assessment of fireproofing materials performance is presented. The methodology is based on a combined experimental and numerical approach. A modified version of the ASTM E162 standard fire test was used to expose specimens of steel board protected with different types of fireproofing materials to a steady radiation source. The temperature of the steel board was recorded with an infrared camera in order to evaluate the heat up due to the fire and characterize the protective performance. Experimental results were used to validate a simplified mono-dimensional model which allowed simulating more severe conditions and different protection configurations. A specific key performance indicator (KPI) was used for the quantitative assessment of fireproofing effectiveness. Finally, the professional career of Menso Molag, safety pioneer in the framework of hazardous materials transportation, was outlined.

1. Introduction

Severe fires, mainly due to the ignition of accidental releases, may affect process equipment or transport vessels leading to a catastrophic loss of containment (Center for Chemical Process Safety [CCPS], 2000; Cotgreave, 1992; Cowley & Johnson, 1992; Khan & Abbasi, 1999; Lees, 1996; Roberts, Medonos, & Shirvill, 2000). In the case of flammable liquefied gases (such as Liquefied Petroleum Gas - LPG, propylene, ammonia, etc.), this type of rupture may be followed by a BLEVE (Boiling Liquid Expanding Vapour Explosion) and associated fireball with extremely severe consequences for workers and population (Abbasi & Abbasi, 2007, 2008; CCPS, 1996; Reid, 1979; Roberts, 1981, 1982; Manas, 1984).

Hence, a key issue to enhance safety and to reduce the risks related to both fixed installations and hazardous materials transportation is the development and the application of specific protections, able to reduce the thermal weakening of the fired equipment.

The adoption of passive fire protection materials (PFP), e.g., installation of protective coatings able to withstand severe fire exposure conditions, may represent a highly safe and effective solution (Di Padova, Tugnoli, Cozzani, Barbaresi, & Tallone, 2011; Roberts, Shirvill, Waterton, & Buckland, 2010; Tugnoli, Cozzani, Di Padova, Barbaresi, & Tallone, 2012). It is worth mentioning that, depending on the fire exposure severity and applied PFP material layer, this type of measures may not totally avoid the occurrence of catastrophic failure and thus BLEVE, as remarked by Salzano, Picozzi, Vaccaro, and Ciambelli (2003). Nevertheless, since the presence of PFP reduces the temperature and pressure increase in the vessel, a stretch in the time to failure (Droste & Schoen, 1988; Molag & Kruithof, 2005; Salzano et al., 2003; Steel Construction Institute [SCI], 1992; Townsend, Anderson, Zook, & Cowgill, 1974) may be obtained leaving a safety margin for the external emergency teams' intervention for equipment cooling and fire suppression (Hobert & Molag, 2006; Landucci, Gubinelli, Antonioni, & Cozzani, 2009), thus eventually preventing the accident escalation.

PFP systems are widely applied in fixed installations (e.g., storage units, critical process units, etc.) and several standards rule the specific design and testing of materials (American Petroleum Institute [API], 2010; International Organization for Standardization [ISO], 2007; National Fire Protection Agency [NFPA], 1991; SCI, 1992; Underwriters Laboratories Inc. [UL], 1994). On the contrary, several issues are still open concerning the possible implementation of effective fire protections, based on thermal coatings, for road and rail tankers in the specific European context (European Commission, 2006a, b; Paltrinieri et al., 2009). In this case, severe exposure conditions and specific issues related to transportation (e.g., damage to coating following accidents or collisions, defective coating installation, deterioration due to coating erosion/corrosion, etc.) must be taken into account (Birk, 1999; Birk, 2005; VanderSteen & Birk, 2003);

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besides, emergency response may be not as effective as in the case of fixed installations, thus a higher strength in the protective performance is required (Molag & Kruithof, 2005).

Hence, PFP testing in severe fire conditions is of fundamental importance for the development of robust fireproofing that could be suitable also for the application on road tankers or tank wagons.

Several experimental configurations reproducing typical fire scenarios on real scale have been proposed in the last 30 years, in order to test materials performance (Birk, Poirier, & Davison, 2006; Droste, Probst, & Heller, 1999; Droste & Schoen 1988; Kielec & Birk, 1997; Landucci, Rossi, Nicolella, & Zanelli, 2009; Townsend et al., 1974). Those tests, carried out on large or pilot scale were aimed at the characterization of both materials and protected structures response to fire (Cowley and Johnson, 1992; SCI, 1992). The main advantage of such large scale tests is that design guidelines for PFP systems to be applied on industrial equipment can be directly derived, without requiring scale up protocols (Cowley & Johnson, 1992; NFPA, 1991; Roberts et al., 2010). On the other hand, large scale tests are not easily reproducible and require high financial efforts for experimental set up preparation and management. In addition, their realization may arise environmental and safety concerns.

Therefore, in order to carry out a preliminary design and screening of technological solutions for PFP systems development, bench scale laboratory tests are an effective solution, with lower costs both for equipment and tested specimens (American Society for Testing Materials [ASTM], 1994a, b; Cowley & Johnson, 1992; Landucci, Rossi, et al., 2009).

In the present study, a methodology for the fireproofing performance assessment is presented. The method is based on combined experimental and modeling activities.

The experimental set-up for the evaluation of fireproofing materials performances is based on a modified version of the ASTM E162 standard test for materials surface flammability evaluation (ASTM, 1994a), which allows reproducing severe fire exposure conditions on small scale. Several commercial inorganic materials are selected and compared in the study. Next, a mono-dimensional model, developed following a simplified thermal nodes approach (Modest, 2003), is presented. The model, validated against the experimental results, allows both to extend the results obtained in the tests to more severe fire exposure conditions and to evaluate a specific Key Performance Indicator (KPI) to support the effective design of passive fire protections.

Finally, the contribution of the safety pioneer Menso Molag in the field of hazardous materials transportation safety progress will be analyzed, evidencing the key aspects related to fire protection of road and rail tankers.

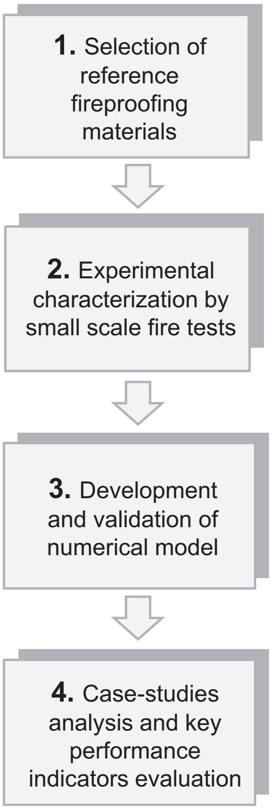

Fig. 1. Overview of the methodology for the evaluation of fireproofing materials performance.

2. Materials and methods

2.1. Overview of the methodology

The proposed methodology for the assessment of Passive Fire Protection (PFP) materials performances combines the results of experimental characterization with the modeling of the behavior of protected steelworks during the fire exposure. The methodology steps are summarized in Fig. 1.

The first step consists in the selection of fireproofing materials to be analyzed (step 1 in Fig. 1) and the focus was on inorganic fireproofing solutions, considering commercially available products designed for insulation of industrial equipment, as well as for fireproofing of road/rail tankers and structural elements. Experimental characterization of materials behavior is performed through a small scale fire test, featuring the experimental set up described in ASTM standard E162 (ASTM, 1994a). This standard provides a laboratory test procedure for measuring and comparing the surface flammability of materials when exposed to a fixed level of radiant heat energy. It is intended for use in measurements of the surface flammability of materials exposed to fire.

In this work, the test is modified in order to increase the severity of fire exposure (step 2 in Fig. 1). Panels made of the tested PFP material coupled with a steel board, aimed at reproducing the presence of a protected steel structure, are exposed to a steady radiative source and the heat up of the steel is monitored. The detailed description of experimental procedure is presented in Section 2.2.

Due to the heterogeneity of tested products, the information obtained in the standard tests alone cannot provide sufficient elements for the assessment of PFP performances: a uniform screening criterion and a specific performance assessment tool are required. To the purpose, the experimental results are analyzed, integrated and extended through a numerical approach, based on the implementation of a simplified model for reproducing the temperature profiles in the specimen exposed to fire (step 3 of Fig. 1). The input data required for the development of a robust model are essentially the thermal properties of selected materials (namely density, heat capacity, thermal conductivity and emissivity). Details on model characteristics are discussed in Section 2.3.

Table 1
Geometry of the tested samples of fireproofing materials.

Dimensions	Tested material		
	Type 1 (Rock wool)	Type 2 (Fiber mineral wool)	Type 3 (Silica Aerogel)
Height (mm)	150	150	150
Length (mm)	460	460	460
Thickness (mm)	20	12	6