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Methodology for the quantification of toxic dispersions originated in warehouse fires and its application to the QRA in Catalonia (Spain)

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ABSTRACT

A tool for the quantification of the consequences of toxic dispersions coming from fires in warehouses has been developed. This tool is expected to be applied in the framework of the risk assessment in Catalonia, specifically in the Quantitative Risk Assessment. The present study is based on the criteria gathered in the technical guide BEVI 3.2 and the methodology CPR-15 used in the Netherlands. Hence, the approach performed accepts the main body of the foresaid methodology but implements a different and free source dispersion model, a modified Gaussian model that takes into account the warehouse effect. In the work conducted, a historical analysis of accidents involving fire in warehouses has been performed in order to justify the importance of assessing their potential toxic dispersions. Furthermore, the tool has been tested in different case studies providing results that have been compared with other methodologies, observing similar results that can be useful for the stakeholders and decision makers in the framework of the risk assessment.

1. Introduction

Fires in warehouses are a special type of accidents due to their effects, which involve both thermal and toxic consequences. Whereas the thermal consequences are well known and normally taken into account in risk studies, the air toxic consequences related to this type of dispersions are more controversial and generally underestimated or not considered in well established guidelines (UNEP, 1993; CCPS, 1998).

It is important to highlight that the behaviour of the plume originated in a fire is highly influenced by the level of confinement of the location where the fire takes place. Thus, if the fire is unconfined, the plume is expected to rise due to the high temperature of the fumes making its toxic consequences almost negligible due to the height achieved. However, the evolution of the plume in a confined fire is completely different mainly during its first stage. This special behaviour is related to a decrease of the fumes temperature caused by the effect of the warehouse walls. Therefore, the plume disperses near the ground into the surrounding area of the warehouse making its toxic consequences more severe.

Besides, in the high confinement conditions, the turbulence associated to the phenomenon, is a key parameter that should be also taken into account. The origin of this turbulence depends on two aspects: the effect of the warehouse volume, which creates a vortex (LEE vortex) that brings the plume into a turbulent zone (see Fig. 1), and the source of the plume (i.e. fire), which is a pulsing and a turbulent phenomenon itself.

Furthermore, the turbulence involves different parameters such as diffusivity and dissipation, which make difficult to simulate the warehouse fire involving a lot of uncertainty in the calculation of its consequences.

The calculation of major accidents' consequences is normally required by specific legislation depending on each country (it can be performed also for private purpose). Having a glance on the major accidents legislation in Europe, regulated by the SEVESO directive (Directive 2012/18/EU, 2003, SEVESO III), it is important to bear in mind that there is no specific law that includes an accurate approach for the quantification of the toxic dispersions occurred in warehouse fires. Furthermore, Spain does not contribute either with any regulation regarding this type of accident (RD 1254/1999).

In Catalonia, there is a willing to provide a solution for taking into consideration these toxic dispersions into the risk studies required in the framework of the major accidents legislation. In fact, there exists a technical guide, (Instrucció 14/2008 SIE), which establishes the need of including the consequences of the toxic

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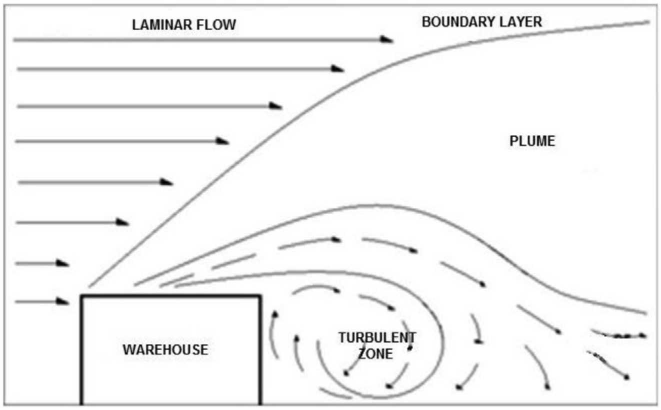

Fig. 1. Plume dispersion in a warehouse fire chart.
Adapted from Mannan (2005).

dispersions originated in warehouse fires. Moreover, the foresaid technical guide identifies the methodology CPR-15 (Ministry of VROM, 1997), currently applied in the Netherlands, as the most consistent approach to follow in case that a risk assessment of a warehouse is required. Nevertheless, the Catalan manual mentions that this methodology needs to be translated, updated and validated according to the Catalan standards before its application.

Thus, the tool presented in this paper has been developed taking into consideration the Dutch procedure as a solid approach for the construction of its main parts. This tool pretends to update and adapt the methodology proposed in the Netherlands for its use within the framework of the risk assessment in Catalonia.

2. Historical analysis

In order to understand better the behaviour of fires that occur in warehouses, it is of high importance to know the most common causes and consequences related to this phenomenon.

To achieve this goal, a historical survey of accidents involving a warehouse fire has been conducted. This historical analysis has been performed gathering information from different databases.

Most of the data used were from the Major Hazard Data Service (MHIDAS) database (MHIDAS, 2007), run by the UK Health and Safety Executive. However, although the aforementioned database includes accidents recorded during the 20th century in almost one hundred different countries (14,168 records), the last version available only covers accidents until 2007. Thus, other databases have been also consulted to take into consideration accidents occurred after 2007 such as Major Accident Reporting System (MARS, 2000), Failure and Accidents Technical Information System (FACTS, 2009) and *Analyse, Recherche et Information sur les Accidents* (ARIA, 2006).

In order to conduct the research, the following definition of warehouse fire adapted from BEVI 3.2 (2009) was taken into account:

"Fire occurred in a warehouse that stores hazardous materials, which has a high level of confinement and apart from the thermal consequences it involves a fumes dispersion that is generally toxic".

Nevertheless due to the broad definition of the warehouse fire phenomenon, a number of criteria have been considered in order to take only into account those accidents related to the activity of the chemical industry. Consequently, the following accidents have been excluded:

- Accidents related with military practices
- Accidents caused by natural disasters
- Accidents caused by terrorist actions
- Accidents related with fireworks
- Accidents involving arsons

Moreover, the accidents occurred before the 60s were not take into account either, since they happened in different safety conditions compared with the ones implemented nowadays in most of the industries.

After applying these criteria, the number of selected accidents was reduced considerably; however, the accuracy and quality of the warehouse fire's sample was increased. Finally, a collection of 167 accidents was obtained, being the largest sample of this type of accident analysed until now in a scientific journal.

In the following sections, the main features of the selected accidents with a fire in a warehouse are analysed.

2.1. Distribution of accidents over the time and their location

The information related to the evolution of the number of accidents along the time is presented in Fig. 2. As it can be seen, the number of accidents presents an increasing trend until the early 90's. However, this tendency experiments a change after the early 90's and starts decreasing. Whereas the increasing trend can be justified with the enormous growth that the chemical industry suffered until the 90's, the decreasing tendency is related to the enhancement of the safety in most of the facilities and the bloom of concepts such as safety culture, fire protection engineering and inherent safer design.

Moreover, there exist other studies related to accidents in the chemical industry in which a decreasing trend of the number of incidents have been observed as well (Darbra et al., 2010).

Regarding the location of the accidents, three main groups were established:

a. The European Union (31.7%)
b. Other developed countries: Australia, Canada, Japan, New Zealand, Switzerland, Norway and the United States (40.7%)
c. The rest of the world (27.6%)

As it can be seen, in the developed countries ('a' and 'b' groups) the number of accidents registered is greater than in 'the rest of the world' (group 'c'). These results are logical if it is accepted that developed countries present stricter legislation that requires an exhaustive register of major accidents (BS, 2004) and that chemical industry has been established in these countries for a long time. However, it is important to be critical with the results and highlight that, due to the fast growth of some developing countries (China,

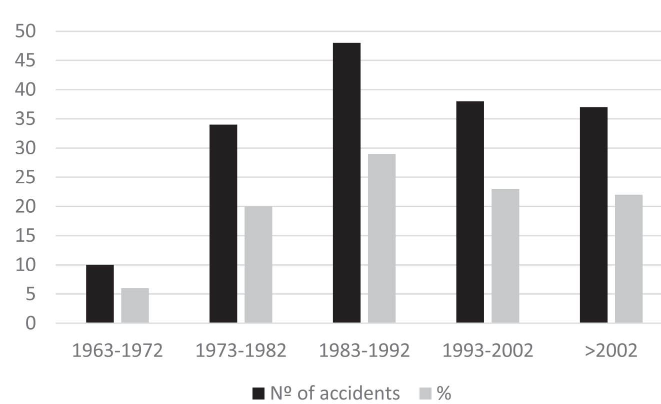

Fig. 2. Distribution of the accidents over the time.