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Influence of active mitigation barriers on LNG dispersion

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ABSTRACT

In recent years, particular interest has been direct to the issues of risk associated with the storage, transport and use of Liquefied Natural Gas (LNG) due to the increasing consideration that it is receiving for energy applications. Consequently, a series of experimental and modeling studies to analyze the behavior of LNG have been carried out to collect an archive of evaporation, dispersion and combustion information, and several mathematical models have been developed to represent LNG dispersion in realistic environments and to design mitigation barriers.

This work uses Computational Fluid Dynamics codes to model the dispersion of a dense gas in the atmosphere after accidental release. In particular, it will study the dispersion of LNG due to accidental breakages of a pipeline and it will analyze how it is possible to mitigate the dispersing cloud through walls and curtains of water vapor and air, also providing a criterion for the design of such curtains.

1. Introduction

In the past years, interest has increased in the issues of risk associated with the storage, transport and use of LNG due to the increasing consideration that it is receiving for energy applications. A series of experimental and modeling studies to analyze the behavior of LNG have been carried out to collect an archive of evaporation, dispersion and combustion information (Britter and Griffiths, 1982; Ermak et al., 1982; Koopman et al., 1982; Luketa-Hanlin, 2006; Puttock et al., 1982). Based on this information, several modeling based works have been developed to represent LNG dispersion in realistic environments (Blocken, van der Hout, Dekker and Weiler, 2015; Koopman and Ermak, 2007; Koopman et al., 1989; Luketa-Hanlin et al., 2007; Schleder et al., 2015; Zhang et al., 2015); these models can be used both to estimate the hazardous area in case of an accidental release of LNG, as well as to investigate the efficiency of potential mitigation measures (Busini et al., 2012; Busini and Rota, 2014; Derudi et al., 2014; Kim et al., 2014).

Recently, the effect of mitigation barriers with different shapes has been investigated, resulting in the conclusion that passive barriers act only as a physical hindrance without enhancing the mixing rate between cloud and air due to the remarkable inertia of large LNG releases (Busini and Rota, 2014). Other works, based on experimental tests or modeling, support the idea that forced dispersion is more appropriate for diluting hazardous gas clouds, suggesting the use of spray curtains (Bara and Dusserre, 1997; Buchlin, 1994; Diaz-Ovalle et al., 2012; Rana et al., 2008; Rana et al., 2010).

The purpose of this work was to analyze, through a Computational Fluid Dynamics (CFD) model, the dispersion of a dense gas, namely LNG, to provide a criterion for designing an active barrier (i.e. a barrier releasing some fluid within the cloud) that can dilute the cloud below the lower flammability limit (LFL). It should be noted that, in this work, the presented methodology was applied to the LFL as threshold for flammable vapor dispersion distances, but the same methodology can be applied to the 50% of the LFL threshold.

2. Material & methods

The commercial package Fluent 12.1.2 (ANSYS Inc., 2009) was used for all the computations, together with the boundary conditions summarized in Table 1. The k–ε model complemented with the Atmospheric Stability sub-Model (ASsM) (Pontiggia et al., 2009) was used for representing the effects of the turbulence.

3. Proposed methodology

Since one of the main characteristics of cold and dense clouds is

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Table 1
Boundary conditions.

Ground	Wall @ 298 K, roughness = 0.01 m
Walls	Adiabatic wall, roughness = 0.01 m
Pool	During atmospheric stabilization: Wall @ 298 K, roughness = 0.01 m During pool evaporation: Mass flow inlet After the end of pool evaporation: Adiabatic wall
Wind inlet, domain sides, sky	Velocity inlet
Wind outlet	Pressure outlet

their ability of reducing turbulence thus reducing the effects of terrain and obstacles (Busini and Rota, 2014; Koopman et al., 1989), in this work the efficiency of active mitigation barriers, designed with the aim of diluting the dense gas cloud through jets of steam or air, was investigated.

The methodology used to define the characteristics of an active mitigation barrier necessary to stop cloud dispersion is sketched in the flow diagram in Fig. 1 and discussed later on. It should be noted that before starting the procedure a maximum allowed hazardous distance should be defined: that is, the maximum distance from the source at which the concentration of the cloud can reach the LFL value (X_{cld_max}), and a maximum mitigation wall height both in terms of executive/structural and visual impression (h_{obs_max}).

The first step of the methodology is the simulation, using a suitable CFD model, of open-field cloud dispersion, that is in the actual environment in which the release takes place without any

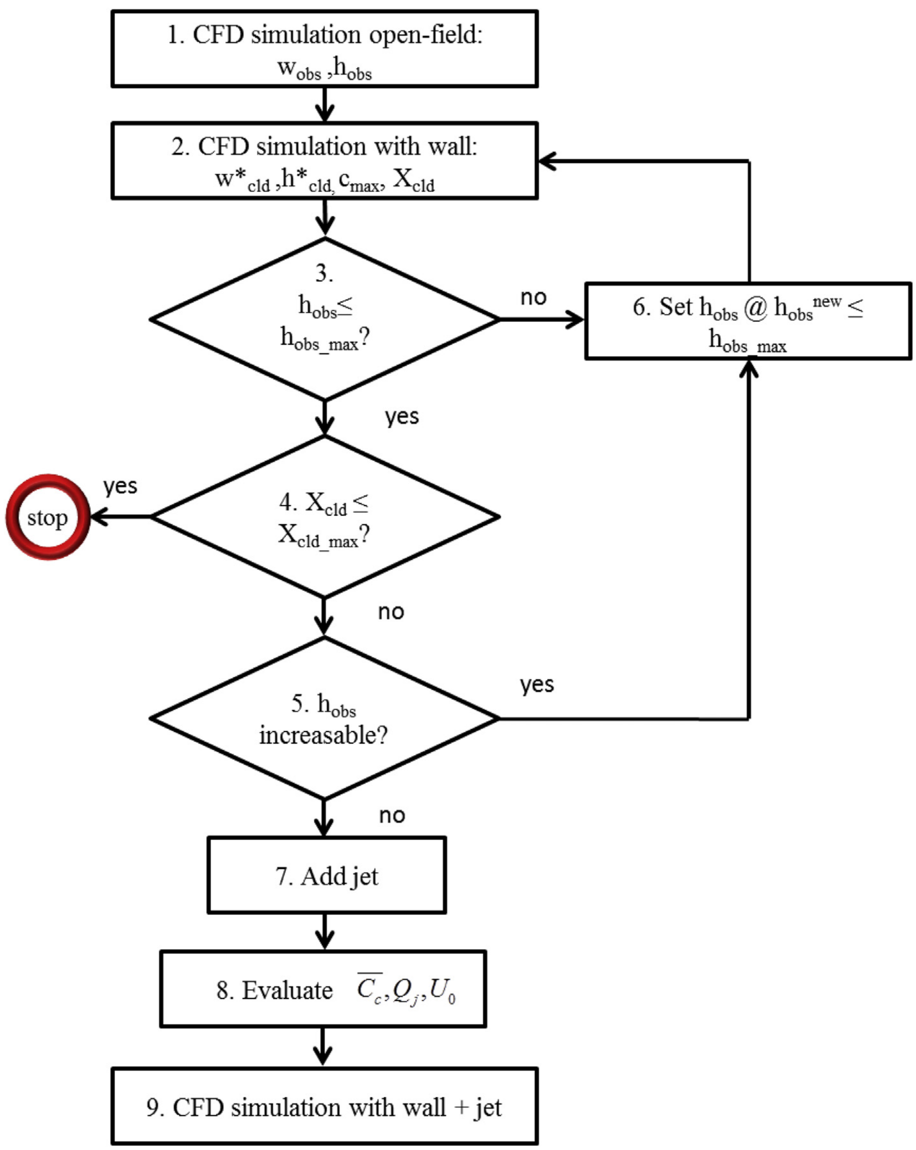

Fig. 1. Flow diagram of the proposed methodology; h_{obs} and w_{obs}: minimum dimensions of the mitigation wall, w^*_{cld} and h^*_{cld}: cloud width and height at the mitigation wall distance, X_{cld_max} maximum distance from the source at which cloud concentration can reach the LFL value, h_{obs_max} maximum mitigation wall height, C_{max} maximum cloud concentration in correspondence with the wall position, the top-hat concentration, hypothesizing a Gaussian distribution, Q_j: the flow rate of the jet, U_0: initial jet velocity.