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Influence of scenario choices when performing CFD simulations for explosion risk analyses: Focus on dispersion

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ABSTRACT

Explosion risk analyses (ERAs) are widely used as means for deriving the dimensioning accidental loads (DALs) for design of offshore topside facilities. ERAs can predict explosion loads in detail, including overpressures, differential pressure, and drag loads (FABIG TN-08). Loads with returning frequencies of 1E-04 per year are commonly adopted as DALs and are effectively incorporated in standards and legislation such as NORSOK Z013 (NORSOK, 2010) and ISO 19901-3 (ISO, 2010). Detailed guidelines for how to perform these analyses are described in the Norwegian standard NORSOK Z013. Computational fluid dynamic (CFD) simulations form a key part of these analyses and how these simulations are performed, influence the accuracy and uncertainty of the predicted loads. Dispersion simulations are a particular important part of these studies as they both define the size of the clouds and give basis for detailed ignition probability modeling. This paper explores how explosion risk and the dimensioning accidental loads are affected by dispersion scenario choices and address the associated uncertainty. This research work is conducted as a part of an explosion risk analysis for a large process area of an FPSO. This study involved extensive CFD efforts with more than 3000 CFD simulations minimizing the use of simplifications. Subsequent steps involved testing various means of simplification and also an assessment of how the choices made by individual analysts could influence the results.

1. Introduction

Explosion risk analyses (ERAs) are widely used as means for deriving the dimensioning accidental loads (DALs) for design purpose. Explosion risk analyses (ERAs) predict explosion loads, such as overpressure and drag loads, on selected targets with the corresponding return period (FABIG TN-08). Detailed guidelines on how to perform ERAs are described in the standard NORSOK Z013 (NORSOK, 2010) and ISO 19901-3 (ISO, 2010). The implementation of this guideline is however varying depending on the analyst performing the ERA. The differences reside in the detail of conducting these studies. ERAs rely on the accuracy of important issues like geometry (Chan et al., 1983; Berg et al., 2000), leak frequency calculation, implementation of safety philosophies (shutdown, blowdown etc.) and ignition modeling (Scandpower, 2007). CFD simulations constitute a key part of an ERA and the influence of which scenarios are investigated on the results. Dispersion simulations can deviate largely depending on the number of leak sources considered, their locations and directions. Explosion simulations can differ via the size of clouds, position of clouds and location of ignition. Because only a limited number of scenarios can be investigated, the choices of simulations can be a point of divergence for analyses conducted by different analysts.

The research work described in this paper does not aim to validate the CFD code FLACS which has been extensively validated and is widely used for dispersion and explosion applications in the petroleum industry (GexCon, 2012). FLACS solves the governing equations for fluid flow such as conservation of mass and momentum and transportation of energy. Turbulence is modeled in the code using the two-equation model for transportation of turbulent kinetic energy and its dissipation (κ-ε). FLACS discretizes the simulation domain using a rectilinear grid which implies that all obstacles in the domain are modeled in a rectilinear shape. The physics, numerical methods, capabilities, range of applicability and

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inherent limitations of FLACS are all well documented in the user manual and technical reference of the code (GexCon, 2012).

This research work looks at the influence of scenario choices and number of dispersion simulations performed on the resultant explosion risks. Different dispersion setups representing various ways of conducting this part of the analysis are compared and benchmarked against a reference setup. The study is performed for the process area on-board an FPSO. Important features to note are this ship is a weathervane vessel for which there is a lower variance in wind direction and the process area is bounded by both sides of blast walls. An illustration of the facility is provided in Fig. 1.

It should be noted that the results of this study hold for this case or similar cases with identical conditions. Particularly, fixed installation with greater variance in wind direction and installations with more obstructions may be expected to experience even greater sensitivity to the studied parameter.

The subsequent section gives a brief discussion on the most important parameters to consider when performing an ERA. The major part of the work investigates the influence of CFD scenario choices on the explosion risk analyses. All CFD-simulations in this work are carried out using the FLACS code (GexCon, 2012). FLACS is widely used for dispersion and explosion applications by researchers and engineers (Hansen et al., 2005, 2013; Bakke et al., 2010). The influence of different dispersion scenario setups on the results of an ERA is evaluated and discussed lengthily in the paper. Dispersion simulation results from different scenario configurations are also processed and presented in detail. Their influence on the dimensioning accidental load (DAL) by explosion simulations is elaborated and assessed.

2. CFD simulations in general

The core of this study discusses the importance of proper selection and conduction of scenarios in an explosion risk analysis. Ideally, in a probabilistic analysis the investigated scenarios need to represent the whole range of possible outcomes from any given dispersion and explosion scenario. The simulation of all possible scenarios is practically impossible at least within reasonable time. Therefore, the selection of representative scenarios to simulate is usually a necessity and mainly based on engineering judgment and experience in order to cover the vast majority of possible scenarios. The number of simulated scenarios differs widely depending on the nature of the project and approach adopted by the analyst. The aim is to keep balance between a good representation of all possible scenarios and affordable simulation efforts leaning more towards the reasonable side rather than very conservative or non-conservative.

The work in this paper concentrates efforts on questioning how dispersion simulations are conducted in an explosion risk analysis. As part of the current study ventilation (as an input to the dispersion simulations) and explosion simulations are described. However, no sensitivity study is conducted for ventilation and explosion scenarios in order to quantify their influence on the final risk results.

2.1. Ventilation simulations

The ventilation study is the basis for dispersion analysis. Ventilation simulation results are used to assess the ventilation level of an area, identify potential stagnation areas and visualize wind flow patterns resulting from different wind angles. In probabilistic studies the results from a ventilation study are coupled with weather data to provide exceedance curves for air changes per hour (ACH). Such curves may be used for benchmarking against ventilation requirements such as NORSOK Z013 (NORSOK, 2010). It should be pointed out however that the importance of fulfilling the NORSOK requirement is often not sufficient and ventilation levels by themselves are no guarantee for low explosion risk. When performing a ventilation study all likely wind directions are simulated with the prevalent wind speed in order to establish a good picture of ventilation. The selection of representative wind directions to be used for dispersion simulations is normally done based on the results of ventilation simulations bearing in mind the geometry of the area, wind flow patterns, level of ventilation and wind statistics.

2.2. Dispersion simulations

The main focus of this work is on the influence of the number of scenarios investigated and the very choice of these scenarios of dispersion simulations on explosion risk analyses. The aspects of dispersion modeling and affecting factors are described in this section. The setup of dispersion simulations is discussed and the sensitivity of results on various scenario configurations is analyzed.

The number of parameters driving and affecting dispersion scenarios is much larger than in ventilation for instance. The various driving factors determining the number of dispersion scenarios are:

- leak rate;
- wind speed;

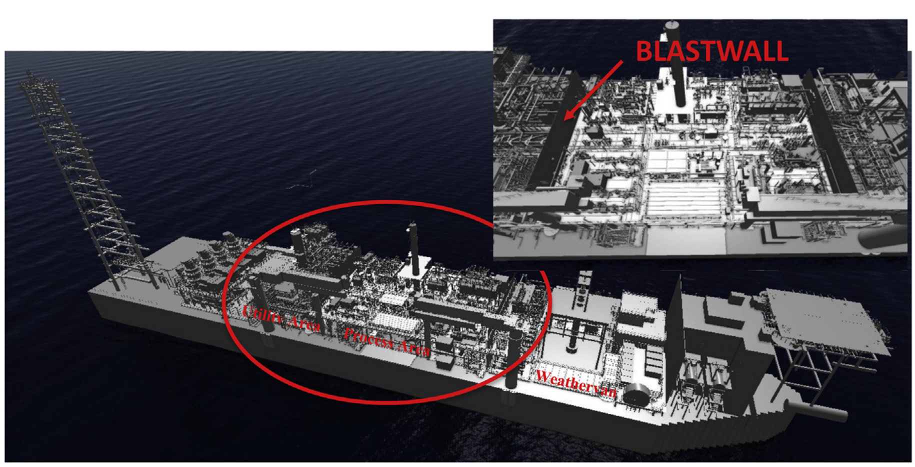

Fig. 1. Overview of the FPSO and close view of the process area and the blastwall used as a reference target to monitor overpressures.