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A CFD based explosion risk analysis methodology using time varying release rates in dispersion simulations

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ABSTRACT

A full probabilistic Explosion Risk Analysis (ERA) is commonly used to establish overpressure exceedance curves for offshore facilities. This involves modelling a large number of gas dispersion and explosion scenarios. Capturing the time dependant build up and decay of a flammable gas cloud size along with its shape and location are important parameters that can govern the results of an ERA. Dispersion simulations using Computational Fluid Dynamics (CFD) are generally carried out in detailed ERA studies to obtain these pieces of information. However, these dispersion simulations are typically modelled with constant release rates leading to steady state results. The basic assumption used here is that the flammable gas cloud build up rate from these constant release rate dispersion simulations would mimic the actual transient cloud build up rate from a time varying release rate. This assumption does not correctly capture the physical phenomena of transient gas releases and their subsequent dispersion and may lead to very conservative results. This in turn results in potential over design of facilities with implications on time, materials and cost of a project.

In the current work, an ERA methodology is proposed that uses time varying release rates as an input in the CFD dispersion simulations to obtain the fully transient flammable gas cloud build-up and decay, while ensuring the total time required to perform the ERA study is also reduced. It was found that the proposed ERA methodology leads to improved accuracy in dispersion results, steeper overpressure exceedance curves and a significant reduction in the Design Accidental Load (DAL) values whilst still maintaining some conservatism and also reducing the total time required to perform an ERA study.

1. Introduction

Explosion risk analysis (ERA) is routinely performed as part of safety studies for offshore installations in the oil and gas industry. Following the Piper Alpha accident and subsequent full scale experiments, it was realised that explosion models greatly under predicted the overpressures (Strehlow et al., 1979), (Van den Berg, 1985), (Tang et al., 1996). The industry has since focussed on carrying out ERA to determine the Design Accidental Loads (DAL) on safety critical elements of an offshore installation and to obtain improvements for a safer design against explosion hazards (Selby and Burgan, February 1998), (Walker, 2001), (Al-Hassan and Johnson, 1998), (Evans et al., 1999).

Numerous tools and methodologies have been developed to predict explosion loads using Computational Fluid Dynamics (CFD) (Huser and Kvernvold, 2000), (Qiao and Zhang, 2010), (Vianna and Cant, 2012), (Hansen et al., 2013), (Ferreira and Vianna, 2014). Due to the large number of scenarios that need to be modelled to achieve an accurate probabilistic description of overpressures, all these methods rely on simplifications and approximations to keep the number of dispersion and explosion simulations manageable.

The common simplification in the current tools and methodologies is to use constant release rates in the dispersion simulations. In doing so, the underlying assumption is that the flammable gas cloud size obtained at each time step of the dispersion simulation

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Abbreviations: ACH, air changes per hour; CFD, computational fluid dynamics; DAL, design accidental load; ERA, explosion risk analysis; FLACS, FLame ACceleration Simulator; FPSO, floating production, storage and offloading; HSE, health and safety executive, UK; IFBF, isolation failure and blowdown failure; ISBS, isolation success and blowdown success; LFL, lower flammability limit; NORSOK, “Norsk Sokkels Konkurranseposisjon”, the Norwegian initiative to reduce cost on offshore projects; Q6, increase in flammable cloud volume in each time step (FLACS parameter); Q9, equivalent stoichiometric cloud volume (FLACS parameter); TDIIM, time dependant internal ignition model; UFL, upper flammability limit.

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performed with a constant release rate is sufficient to mimic the actual transient cloud size from a time varying release rate. The use of constant release rates in dispersion simulations may be a reasonable assumption for systems that depressurise slowly (small release rates from a large inventory), but becomes progressively less accurate for increasing hole sizes where depressurisation rates are higher. This assumption is also not accurate for releases from small hole sizes that have large blowdown orifice and can depressurise quickly. The constant release rate dispersion simulations fail to capture the real release rate at any moment and also the total mass of fuel released in any given time frame. As a result, the equivalent stoichiometric cloud volume (Q9 parameter in FLACS) and the increase in the flammable cloud volume at every time step (Q6 parameter in FLACS) obtained from constant release rate simulations will have significant errors for all time steps of the simulation. Further details on this widely used simplification and its shortcomings are elaborated in Section 2.

Some of the methodologies involve creation of detailed response surfaces to predict the gas cloud volume based on a small set of dispersion simulations. While such approaches reduce the time required to perform an ERA study, they still use the same basic simplification as their dispersion simulations are also based on constant release rates as input (Huser and Kvernvold, 2000), (Qiao and Zhang, 2010), (Vianna and Cant, 2012), (Ferreira and Vianna, 2014).

The motivation of the current work is to propose an ERA methodology that improves upon the current approaches adopted in the industry by using time varying release rates in the CFD dispersion simulations to obtain fully transient results of Q9 and Q6 and improve accuracy. Moreover, FLACS being a transient code, there is no penalty incurred in the computational time required to perform a fully transient CFD dispersion simulation compared to carrying out a constant release rate simulation which, after sufficient run time, provides a steady state result. In fact, the modelling time to perform fully transient dispersion simulations is reduced because the simulations need to be run only for the release duration (which is generally shorter than the time required to reach steady state). The current work also proposes further ways to reduce the total time required to perform an ERA study.

1.1. *Software used*

FLACS (FLame ACceleration Simulator) is a 3-dimensional CFD software that has been developed specifically to cater to the oil and gas industry (Gexcon, January 2014). It is widely used in the industry to simulate gas dispersion and vapour cloud explosion scenarios in both offshore and onshore facilities (Huser and Kvernvold, 2000), (Qiao and Zhang, 2010), (Vianna and Cant, 2012), (Hansen et al., 2013), (Ferreira and Vianna, 2014). Hence, FLACS was used in this study to perform the CFD simulations. The software solves Favre-averaged transport equations for mass, momentum, enthalpy, turbulent kinetic energy, rate of dissipation of turbulent kinetic energy, mass-fraction of fuel and mixture-fraction on a structured Cartesian grid using a finite volume method. FLACS solves for the velocity components on a staggered grid, and for scalar variables, such as density, pressure and temperature, on a cell-centred grid. For more details and equations used in the software, the reader is referred to the FLACS manual (Gexcon, January 2014).

2. Problem statement

2.1. *Methodologies using time-averaged release rate*

In some ERA methodologies the average release rate up to the time of isolation is used as the constant release rate modelled in dispersion simulations. A full bore rupture scenario (500 mm hole size) is considered to showcase the comparison between results obtained using fully transient release rate profiles and time-averaged constant release rates. In this case, the average release rate calculated over the time period of 45s until isolation is achieved is 214 kg/s. Although the total mass of fuel released in both the simulations is the same at 45s after the release starts, the Q9 volume at this time are significantly different at 870 m^3 and

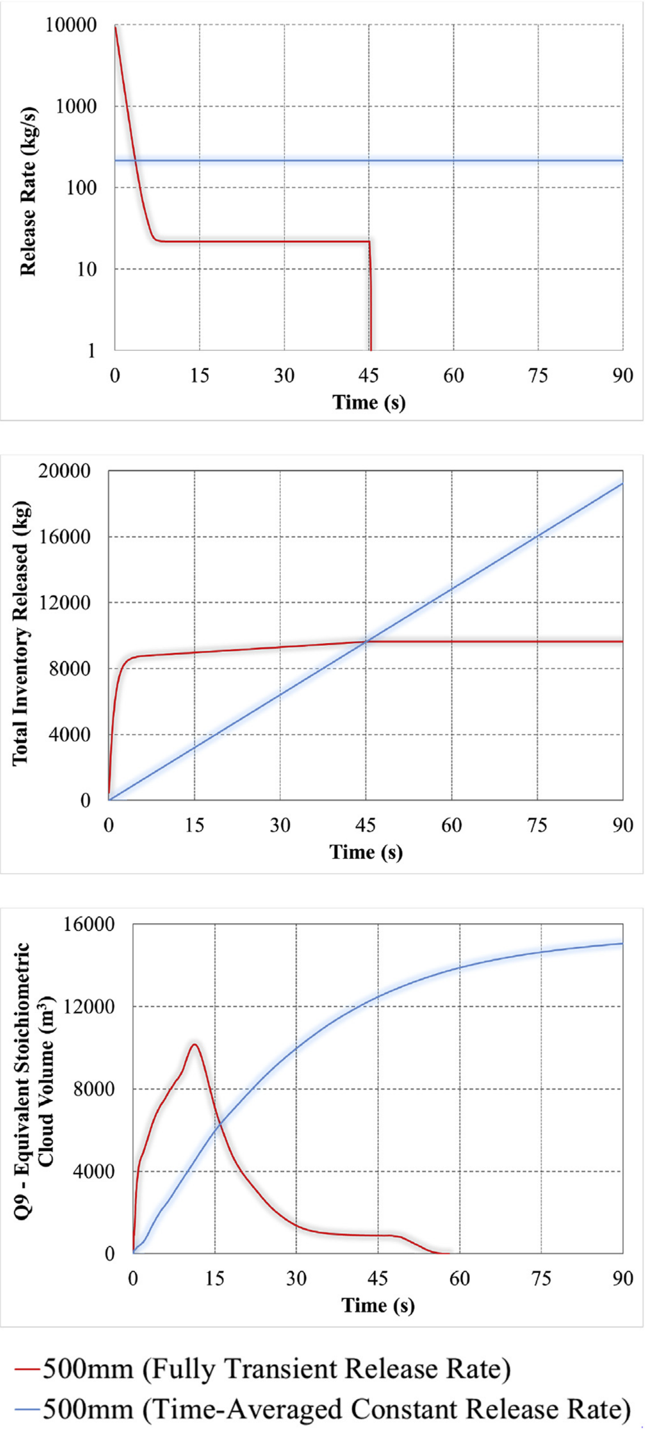

Fig. 1. Comparison of fully transient and “Time-Averaged Constant Release Rate” simulations.