CFD-based Transient Ignition Modelling of Gas Leaks in Enclosures

***Govindan Radhakrishnan Kumaresh[1], Ingar Fossan[1] , Marutha Muthu Venkatraman[2], Knut Erik Giljarhus[2], Øystein Spangelo[2], Stian Jensen[2], Nguyen Vinh-Tan[3] and Liu Yushi[3]**

[1]Lloyds Register Global Technology Centre Pte. Ltd., 1 Bukit Batok Street 22 #03-03B, GRP Industrial Building, Singapore 659592
[2]Lloyds Register Consulting – Energy AS
[3]Institute of High Performance Computing, 1 Fusionopolis Way, #16-16 Connexis, Singapore 138632

*Corresponding author: Kumaresh.govindan-radhakrishnan@lr.org

Gas explosion hazard in offshore facilities such as enclosed modules with ventilation systems is a crucial factor to be assessed while conducting a Quantitative Risk Assessment (QRA). Computational Fluid Dynamics (CFD) methods help to characterize the consequences of hazardous events such as cloud dispersion over complex process facilities in a detailed manner. This paper emphasize on using CFD tool, OpenFOAM, for detailed assessment of transient gas dispersion and ignition probabilities inside an enclosure. This custom made tool accounts for the transient gas leak behavior based on real time gas detection and emergency shutdown (ESD) systems as well as initiation of Blow Down (BD). The consistent results from CFD tools and the ability to present them clearly help in taking concrete safety actions against consequences. These measures can include positioning and number of gas detectors, ignition source isolation, voting philosophy in terms of initiation of emergency shutdown systems, structural integrity of explosion barriers, layout of evacuation routes, venting of the affected area and evacuation of personnel.

Keywords: Risk Management, OpenFOAM, Ignition Modelling, Gas Dispersion, CFD, Quantitative Risk Assessment

Description:

Offshore process modules often have enclosed structures that handle flammable gases in high pressure segments. Upon rupture, the leak starts with a constant release rate determined by the pressure inside the segment. When the resulting gas cloud is detected, emergency shutdown and blow down system is activated and the gas leak rate decays with time until it completely stops. This transient leak phenomenon is crucial while assessing the risk associated with leaks.

Such transient leaks occurring inside mechanically ventilated enclosures carries greater risks than leaks occurring at naturally ventilated open areas. The flammable gas cloud build-up inside the enclosure over time is of critical interest in risk assessments. The transient gas cloud build up depends on different parameters such as initial gas leak rate, leak duration, HVAC systems and enclosure size.

The transient gas cloud development will be combined with an ignition model to calculate the probability of ignition inside enclosures. The total probability of ignition inside an enclosure is the sum of ignition probability from continuous ignition sources and discrete ignition sources within enclosures. The probability of ignition within an enclosure depends upon parameters associated with different equipment; such as electrical equipment, rotating equipment and the other equipment within the enclosures.

cloudIgnitionFOAM Solver Capability:

The capabilities of OpenFOAM are best used in this solver by coupling all three critical phenomenon mentioned below for risk assessments in enclosures.

- Coupled Transient Leak rate Calculations
- Methane Gas leaks in Mechanically ventilated enclosures
- Transient Ignition Modeling

An enclosure with two suction fans of 12 air change per hour (ACPH) and 10 porous louvers to allow air to enter, is used to develop and test the OpenFOAM solver, cloudIgnitionFOAM. The methane reservoir conditions, emergency shutdown system conditions, leak location, leak direction, leak area, point and line of sight detector locations, and locations of electrical and rotating equipment and associated ignition probability parameters are given as input to the solver.

The simulation is initially run for 300 seconds to set up the initial flow field due to HVAC systems inside the enclosure before the onset of the gas leak. An internal release cell is then set up inside the domain and a high momentum jet release is specified at the gas leak location. The initial gas leak rate is maintained based on the pressure in the segment until at least two of the specified gas detectors reach the set concentration level. In practice the set point is 20% of Lower Flammability Limit (LFL) of the released gas. In this case methane is specified as the release gas whose LFL is 5 vol.%, hence when two detectors reaches the set point of 1 vol.% methane concentration, the leak is said to be detected and the emergency response system is activated to close the valves. In the OpenFOAM solver, this implies calculating the transient leak rate decay and updating the mass flow rate specified in the release location dynamically during the simulation run time. The gas leak stops when the calculated value is less than the cut-off value (0.1 kg/s) or when the entire segment is completely drained. Figure 1 shows the transient leak calculated by OpenFOAM when the leak is detected 3.2 seconds after onset. Different gradient in the transient leak rate is result of sequence of actions by the emergency response system.

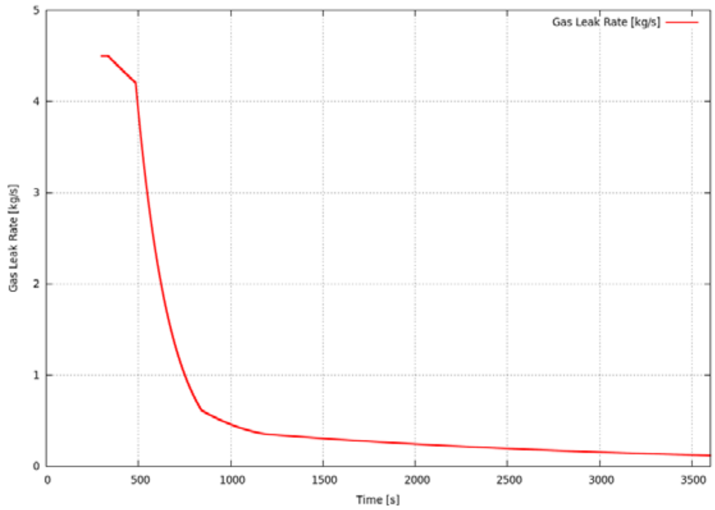

Figure1: Transient decay of Methane Leak from 4.5 kg/s

The transient flammable gas cloud build up is monitored inside the enclosure. For the released methane gas, the Lower and Upper Flammability Limit (UFL) is 5 vol.% and 15 vol.% respectively, and the volume of the enclosure that sees gas within this range of concentrations (i.e. the volume of flammable gas) is monitored over the runtime. For a typical gas release in the enclosure, a double peak in the flammable volume is a critical phenomenon to be observed. At the initial stage when the leak rate is high, the flammable volume will increase to a certain extent and then drop back as most of the enclosure will be filled with methane above UFL, which is inflammable. For an extended duration the enclosure will be completely filled with gas above UFL. Due to initiation of emergency systems, the leak rate is reduced after some time and is eventually stopped and the effect of the HVAC suction fans becomes prominent. While the fans evacuate the gas out of the enclosure, the gas concentration inside the enclosure is reduced and it is again filled with methane gas between LFL and UFL. This causes a secondary peak of flammable volume which drops back to zero when all gas is vented out through the suction fans. The developed OpenFOAM solver calculates the probability of ignition in each control volume as a function of time. Figure 2 below shows the flammable cloud buildup inside the enclosure and the associated cumulative ignition probability over time.

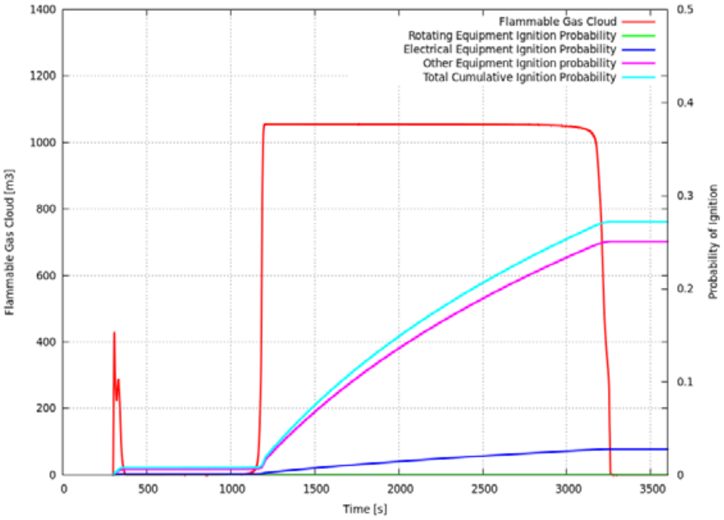

Figure2: Transient Gas Cloud and Ignition Probability

The contribution of continuous sources and discrete sources towards ignition probability is individually calculated and saved as a variable which can be later post-processed in Paraview. The cumulative probability of ignition and contribution from different equipment is calculated at every time step and the results are monitored in run time during the simulation. Figure 3 below shows the cross section of the enclosure at 20 seconds after leak onset and the associated ignition probability per unit volume.

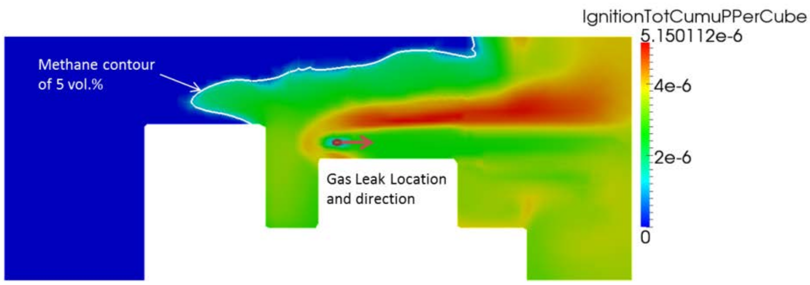

Figure3: Total Ignition Probability per m3 at 20s after leak onset

The white contour in Figure 3 shows the Methane contour at 5 vol.% at 20 seconds after leak onset. Within this flammable volume, the associated cumulative ignition probabilities are presented. These results will give industry not only the total risk associated with gas leaks but also the location of such high risks for respective releases. Hence, the developed OpenFOAM solver serves as a completely coupled dynamic tool which can be used to evaluate the transient ignition probability while conducting risk assessments.