Journal of Loss Prevention in the Process Industries 32 (2014) 358–366

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Accuracy improvement in evaluation of gas explosion overpressures in congestions with safety gaps

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ARTICLE INFO

Article history:
Received 11 June 2014
Received in revised form
2 October 2014
Accepted 13 October 2014
Available online 15 October 2014

Keywords:
FLACS
Data-dump
Gas explosions
Safety gap
Separation distance
Overpressure
Over-prediction

ABSTRACT

This paper reports a comparison of simulations and published data from experiments carried out by TNO Prins Maurits Laboratory on geometric configurations that involved safety gaps of various separation distances. The Computational Fluid Dynamics (CFD) based software – FLACS is utilized to conduct the numerical simulations. In the majority of cases, good agreement is found between the simulated results and those obtained by experiment in both the donor and acceptor modules. However, a large discrepancy in the overpressures in the acceptor module is seen when the size of the separation gap approaches one or two times of the module size. A Data-dump technique is used in this study to reset the turbulence length scale for these cases with different separation distances, five sets of explosion scenarios are then numerically simulated and the overpressures are compared with experimentally measured explosion overpressures. The overall results indicate that the software with the Data-dump technique is still an extremely effective tool when it comes to the evaluation of gas explosion overpressures in areas with large separation gaps.

1. Introduction

In the process industry, the safety gap which is an open space, with no congestion, deliberately placed in between congested process areas, is one of the most effective and widely used safety-in-design measures. The principle behind the operation of the safety gap is that it basically interrupts a positive feedback mechanism in congested areas. The positive feedback mechanism consists of the generation of turbulence, enhanced thermal and chemical mixing between combustion products and reactants, higher flame speeds and even higher pressures. The absence of obstacles in a safety gap eliminates the fluidobstacle interaction thereby preventing the generation of turbulence. It can be very effective in reducing pressures prior to the onset of detonation. Investigations of flame acceleration and overpressure in gas explosions, in most studies so far, have focussed on setups involving multi-obstacle groupings with successive, periodically spaced obstacles (Alekseev et al., 2001; Chan et al., 1983; EMEG, 1997; Kindracki et al., 2007; Lowesmith et al., 2011; Molkov et al., 2006; Wen et al., 2013), and a limited number of experimental studies have examined the effect of the safety gap on gas explosions (Gubba et al., 2008; Moen et al., 1980; Na'inna et al., 2013; Rudy et al., 2011; van den Berg and Versloot, 2003).

In most experimental explosion programs, investigation of the safety gap is conducted in highly confined chambers whereby tubes are arranged such that cylindrical flames propagate in one direction only, except for (van den Berg and Mos, 2002; van den Berg and Versloot, 2003) who carried out gas explosion experiments in vapour clouds containing two separate configurations of obstacles to develop practical guidelines with regard to critical safety gap. The experimental configuration generally consists of orthogonally arranged obstacles enclosed in plastic sheeting. Therefore, the flames propagate three-dimensionally in the tests. The configurations of (van den Berg and Versloot, 2003) with hemispherical flame propagation and multiple separation distances have been modelled in this study. The authors define the separation distance as the distance between the boundaries of the congested regions, i.e. the distance between the downstream end of the first module, where ignition is initiated and the upstream end of the second module to which the flame propagates after passing the separation.

Increasingly, Computational Fluid Dynamics has been used to calculate overpressures from explosions for cases in industry. CFD is generally considered to be more accurate than analytical or phenomenological models. However the method is time

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http://dx.doi.org/10.1016/j.jlp.2014.10.007
0950-4230/

Table 1
Definition of the obstacle configurations.

Case no.	Fuel type	VBR[a] (%)	Separation distance (m)	Cylinder diameter (m)	Pitch (m)	Dimension of the donor (m)	No. of tubes in a row
1	Ethylene	10.1	2.11	0.0191	0.089	1.408	16
2	Methane	10.1	0.22	0.0191	0.089	1.76	20
3	Ethylene	10.1	0.70	0.0191	0.089	1.408	16
4	Ethylene	10.1	0.35	0.0191	0.089	1.408	16
5	Ethylene	10.1	1.60	0.0191	0.089	1.06	12
6	Ethylene	10.1	0.35	0.0191	0.089	1.408	16
7	Ethylene	10.1	0.27	0.0191	0.089	1.06	12
8	Ethylene	10.1	0.27	0.0191	0.089	1.06	12
9	Methane	10.1	0.35	0.0191	0.089	1.408	16
10	Methane	10.1	0.35	0.0191	0.089	1.408	16
11	Methane	10.1	2.11	0.0191	0.089	1.408	16
12	Methane	10.1	0.70	0.0191	0.089	1.408	16
13	Methane	14	0.20	0.0191	0.134	1.596	12
14	Methane	14	0.20	0.0191	0.134	1.596	12
15	Ethylene	4.6	0.33	0.0191	0.134	1.33	10
16	Ethylene	4.6	0.40	0.0191	0.134	1.596	12
17	Ethylene	4.6	1.33	0.0191	0.134	1.33	10
18	Ethylene	4.6	1.60	0.0191	0.134	1.596	12
19	Methane	4.6	0.40	0.0191	0.134	1.596	12

[a] VBR is the volume blockage ratio, which is the ratio of the summed volume of the obstacles in an obstructed region and the volume of that region.

consuming and an increase in speed is achieved in some software by using sub-grid empirical models which are heavily validated. Of these the most well-known and widely used is the software FLACS (GexCon, 2011). FLACS, a strongly validated finite volume NS solver tool (Bleyer et al., 2012; Hansen et al., 2010; Middha et al., 2010, 2009) developed continuously for over 40 years for consequence prediction of gas explosion, has been utilized in this study.

The main purpose of this study is to evaluate the performance of FLACS for numerically modelling a series of explosion scenarios containing obstructed regions with separation spaces as described in the experimental program from the TNO Prins Maurits Laboratory.

2. Numerical models of separated congestions

2.1. Experimental set-up

In this study, the scenarios of the available tests extracted from the Research to Improve Guidance on Separation Distance for the Multi-energy Method (RIGOS)-research program (van den Berg and Versloot, 2003) has been modelled. The configuration set-up parameters are indicated in Table 1.

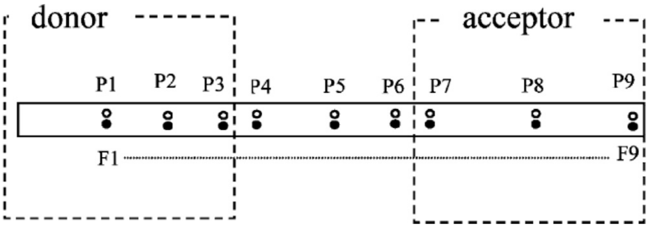

Fig. 2. Test layout.

As seen in Fig. 1, the test modules consist of a number of tubes in two separated modules, a plastic sheet is used to cover the two obstacle configurations which are placed on a concrete pad and filled with a flammable fuelair mixture. The gas clouds are ignited at the centre of the congestion and at the ground level in one module. This module is termed the donor module. The flame propagates through the donor module, reaches the safety gap, and propagates through the safety gap to the second module which is termed the 'acceptor'.

In the experiments, nine overpressure sensors are positioned in at regular distances along the axis of the donor–acceptor configurations. Here the authors simulate the entire setup, including the location of the sensors, which are represented in the simulations by using monitor points, and compare the pressures from sensors at the edge of each module obtained from experiments, with the results from the numerical simulations, Fig. 2.

2.2. CFD modelling using FLACS

In this study, three different volume blockage ratios (VBR) are utilized, as seen in Fig. 3, the donor modules in FLACS are numerically modelled with varying obstacle diameters and arrangements of obstacles. Specifically, all the cylinders, are of the same diameter ($D = 19.1$ mm), and are orientated orthogonally and regularly in the FLACS simulations. By varying the pitches of $P = 4.65D$ and $P = 7D$, two different volume blockage ratios of VBR = 10.1% and VBR = 4.6% modules are created (see Fig. 3(a) and (b)). A third type of configuration (VBR = 14%) is modelled by adding 24 regularly-patterned vertical tubes of 114 mm diameter, Fig. 3(c). The three obstacle modules are named as type 1, type 2 and 3, respectively. The acceptors in the configurations are identical in all simulations with the volume blockage ratios of VBR = 10.1% and pitch $P = 4.65D$, and all the simulations in FLACS are conducted by using the grid cell size of 0.03 m, which equates to 33% of the smallest pitch length ($P = 4.65D = 0.089$ m). The grid cell size of 0.03 m is determined based on a calibration using a series of different grid sizes.

Each simulation model in FLACS consists of two separate configurations of obstacles as seen in Fig. 4. The separation distances

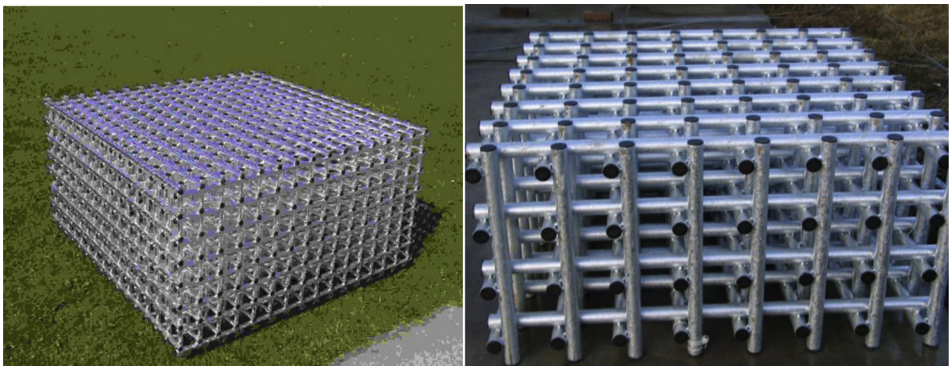

Fig. 1. Obstacle configurations in experiments.