Journal of Loss Prevention in the Process Industries 50 (2017) 205–220

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Accounting for channeling and shielding effects for vapor cloud explosions

James Wesevich[a], Paul Hassig[b], Lisa Nikodym[b], Vincent Nasri[a], John Mould[b,*]

[a] Thornton Tomasetti, 115 Wild Basin Road, Suite 309, Austin, TX 78746, United States
[b] Thornton Tomasetti, 19200 Stevens Creek Blvd., Suite 100, Cupertino, CA 95014, United States

ARTICLE INFO

Keywords:
Facility siting
VCE
CFD
Blast pressure and impulse
Petro-chemical facility safety

ABSTRACT

Vapor cloud explosions (VCEs) can cause significant damage to nearby buildings, facilities and infrastructure with potential loss of life and significant business interruption, so the accuracy of predicting blast loads on facility buildings is critical in estimating these losses. Closely spaced buildings and process equipment outside of the congested region of a VCE provide a complicated flow field for an expanding blast wave. Their presence can channel and shield the blast, resulting in significant effects on the blast load magnitude and waveform shape. Currently, the most common way to estimate applied blast pressures resulting from VCE's is to use simplified methods that account for the total energy from the stoichiometric portion of the vapor cloud, fuel reactivity, and level of congestion and confinement, such as the TNO Multi-energy, equivalent TNT, CAM, and BST methods.

These simplified tools assume an unobstructed line-of-site condition, which can overestimate and/or underestimate blast loads. This paper illustrates the use of a fast-running Computational Fluid Dynamics (CFD) approach that can account for channeling and shielding effects without having to use a turbulent combustion model. This approach provides a convenient tool for designers and process safety planners to more accurately quantify the hazard from postulated VCE hazards that include site-specific channeling and shielding effects. The accuracy of the approach is demonstrated via comparisons of CFD simulations to experimentally measured waveforms. Computed pressure and impulse are also compared to the BST predictions for unobstructed and obstructed sites.

1. Introduction

Our objective is to accurately and efficiently assess the VCE loads on structures in order to design the most effective and lowest cost retrofits possible. We seek to avoid the excessive conservatism of some commonly used simplified approaches, while also improving estimates where the simplified approaches underestimate the true loads. We also want to avoid the cost of computing detailed loads within the potentially congested and confined combustion region. Typically, this requires a detailed CFD turbulent combustion analysis using codes such as FLACS or AutoReaGas. This is an expensive and time-consuming modeling effort, which we do not address here. On the other hand, Hansen and Johnson (2015) noted that far-field pressures were not the focus of FLACS and that computing them requires careful tuning of the mesh and time step rather than accepting the default settings. The method described here does not implement turbulent combustion but is designed to propagate blast loads across a facility.

In this paper, we focus on the loads applied to structures outside of the vapor cloud combustion region. Often structural designers estimate loads using TNO Multi-energy, equivalent TNT, CAM, or BST simplified methods. Our premise is that these approximations are considered acceptable for an unobstructed site. We then develop an equivalent VCE source in a CFD code calibrated to match the desired peak pressures, impulse and waveforms at the ranges where the structures of interest are located. This approach falls in the class of CFD methods termed "Simplified Combustion Models in CFD" in (Center of Process Safety, 2010a). They note:

> The advantage of this class of CFD VCE codes (BWTI, CEBAM) is that the use of the flame speed table eliminates the effort of turbulent combustion modeling. The resolved mesh formulation adopted in the codes allows irregular geometries to be represented. The main application area for these codes is engineering-level analyses involving scenarios where blast wave shielding and focusing are relevant, such that simplified methods neglecting these effects would yield inaccurate results.

The remainder of the paper is as follows. Section 2 describes the method, Section 3 presents the approach for determining initial input

---

* Corresponding author.
E-mail addresses: jwesevich@thorntontomasetti.com (J. Wesevich), phassig@thorntontomasetti.com (P. Hassig), lnikodym@thorntontomasetti.com (L. Nikodym), vnasri@thorntontomasetti.com (V. Nasri), jmould@thorntontomasetti.com (J. Mould).

http://dx.doi.org/10.1016/j.jlp.2017.09.015
Received 28 March 2017; Received in revised form 24 September 2017; Accepted 27 September 2017

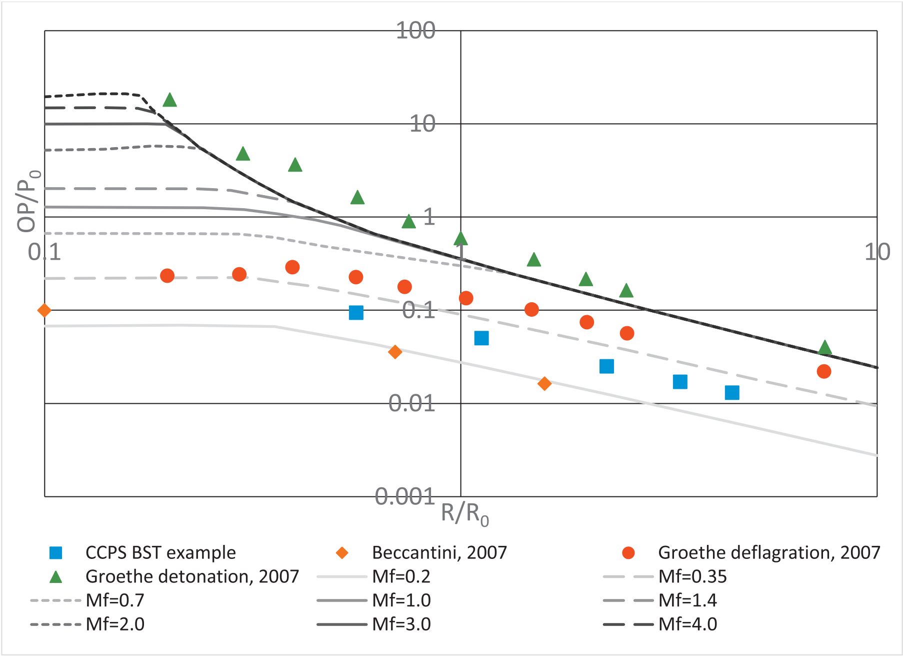

Fig. 1. Validation cases relative to BST chart.

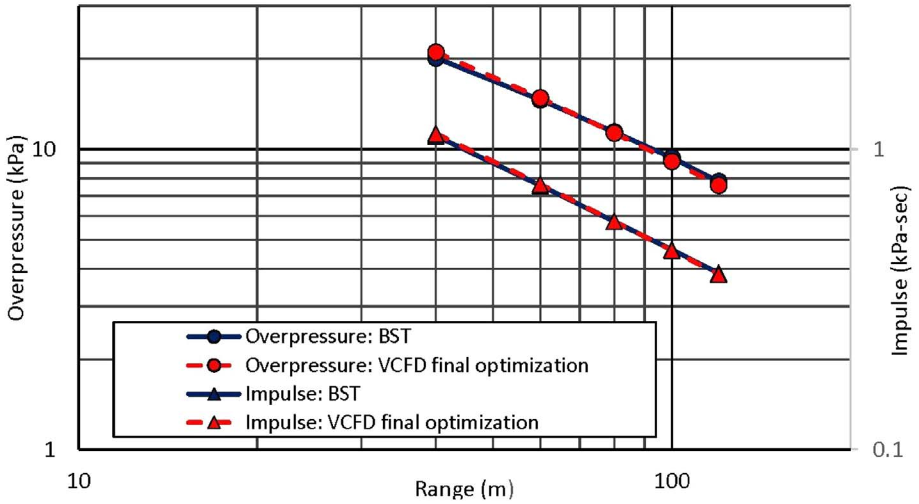

Fig. 2. Simplified CFD Pressure and Impulse fit to BST.

parameters for the calculation using fast-running 1D CFD methods, and validation versus test cases. Section 4 illustrates shielding and channeling effects for canonical building arrangements, and finally, Section 5 shows typical examples demonstrating the advantages of this method over more simplified tools.

2. Methodology

The first step is to estimate the pressure and impulse versus range for an unobstructed site using one of the simplified methods. Here, we have chosen BST for illustration. The second step is to develop an equivalent VCE source in a CFD code. For this we use VCFD (Hassig, 2017), a CFD code developed by Thornton Tomasetti.

VCFD solves the compressible Euler equations in a finite-volume formulation over a Cartesian grid. It implements the AUSMDV flux-splitting scheme (Wada and Liou, 1997) to evaluate cell-to-cell fluxes. This is an advection upstream splitting method, which combines flux vector splitting, and flux difference splitting. Flux vector splitting is more heavily weighted in regions of high pressure gradient whereas flux difference splitting is more heavily weighted in smooth gradient regions. VCFD implements the MUSCL-Hancock method with "total variation diminishing" (TVD) conditions to provide second-order accurate solutions in space and time. For the modeling of explosive-generated blast propagation, this method produces accurate pressure waveforms at far field. For such scenarios, the VCFD computational strategy is to define and run a carefully selected series of expanding grids that capture the detonation and the propagation of the resulting pressure waves. For example, a VCE calculation can be run in 1D spherical geometry until just before the blast wave impacts the first structure. Subsequent time-integration in 2D/3D are very efficient, as VCFD currently supports symmetric multi-processing (SMP) parallel computations using OpenMP (OpenMP, 2017) directives that fully utilize the multi-core multi-CPU resources available on a single computer.

VCFD was initially developed for simulating high explosive detonation effects on military and civilian structures and is fully coupled with the NLFlex (Vaughan, 2017) finite element structural dynamics software. It has been verified by comparisons to analytical shock solutions and code-to-code comparisons with other CFD software. It has been validated against many field and lab scale tests including cased and embedded munitions as well as bare charges. Of particular interest,