Consequence modelling of a truck explosion

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Abstract. Nowadays, the transportation of hazardous substances required for various industrial works is a very common activity. In each national economy, safe transport of hazardous materials on land is an important issue. Much of these materials are either moved by trucks or trains. However, hazardous materials transportation is very likely to generate major accidents with irreversible consequences on surrounding population and on the environment along transportation routes. The current paper deals with analysis and simulation of the consequences of an explosion involving a truck transporting flammable gas cylinders materials. Consequence modelling involves the graphic representation or the calculation and estimation of numerical values which best describe the physical results of loss of containment scenarios which involve flammable/explosive/toxic materials with regard to their impact on surrounding assets or people. In the present study, state of the art software has been used for modelling and simulating the accident scenario, namely the initial fire and the subsequent explosion of the gas cylinders.

1 Introduction

On June 10th 2016, a truck which was carrying approximately 800 pieces of gas cylinders caught fire while on a national road in Romania between Urziceni and Buzau, on the radius of Mihailesti village.

For preventing casualties, on an area of approximately 500 meters people and cars have been evacuated. The truck fire resulted in the explosion of only several gas cylinders, but taking into account that it was carrying a large number of gas cylinders if firemen hadn’t intervened with celerity, the fire could have resulted in a major chain explosion of the cylinders. Figure 1 presents the spatial location of the fire and images from the development phases.

The investigation revealed that the truck had a tyre failure, and while it caught fire while being repaired by the driver. Fortunately, this road event did not result in any fatalities, but there has to be mentioned the fact that in the same village, in 2004, another truck which was carrying 20 tons of ammonium nitrate exploded, leading to the death of 18 persons and to the severe injury of other 13. Of the 18 persons who died in the 2004 Mihailesti truck explosion, 2 were journalists and 7 were firemen involved in extinguishing the truck fire.

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In this regard, the safety of roadways remains a critical topic. The current paper presents a computational analysis for modelling the extent and eventual consequences which may have been generated by the 2016 truck fire, in case a larger amount of the gas cylinders exploded, and the Boiling Liquid Expanding Vapour Explosion (BLEVE) phenomenon occurred. BLEVE represents a mechanical explosion generated by over-pressurization, not being considered a chemical explosion generated by air-gas mixtures [1-3].

![Location of the truck fire](image)

**Fig. 1.** Truck fire location and fire-development phases

## 2 Transportation fire and explosion accidents

In each national economy, safe transport of hazardous materials on land is an important issue. Much of these materials are either moved by trucks or trains. Previous accidents involving transportation of hazardous materials are worrying about a multi-faceted security issue.

Hazardous materials transportation involves a serious threat to the population residing in the vicinity of road networks, the environment of areas near to transport routes and the assets nearby.

Transportation accidents generating fire and explosion phenomena are quite rare, but the damage caused can affect targets of all kinds located nearby: persons, environment and built assets. Such fires and explosions are likely to cause thermal and mechanical damages [4-8], and they are related to transportation, loading/unloading activities worldwide, being classified as follows:

- **pool fire**: fire of combustible liquid pool resulting from a vessel leak;
- **jet fire**: combustion of flammable gas/vapour released through a leak of a pressurized vessel;
- **flash fire**: fast combustion of a flammable cloud generated by vaporisation or evaporation;
- **VCE – Vapour Cloud Explosion**: flammable vapour release from a vessel followed by the generation, ignition and explosion of the flammable cloud;
- **BLEVE – Boiling Liquid Expanding Vapour Explosion**: explosion resulting from a vessel’s failure, vessel which contains liquid at a temperature which is significantly above the normal atmospheric pressure boiling point, blast and projectiles representing the immediate effect of BLEVE-type explosions.

### 3 Consequence modelling tools

Assessing the consequences of industrial or of road accidents resulting in fires and explosions has been the subject to research studies worldwide [9-11]. Increasing knowledge and the occurrence of new technologies in all industries, including transportation, leads to the necessity to implement modern safety principles for preventing human accidents and damage to equipment and installations [12-15].

Major accidents can be defined as hazardous emissions, fires or explosions which are generated by uncontrolled situations in any process or establishment and which can lead to serious danger for humans or the environment, involving hazardous substances [16-19]. Therefore, major accidents can be related accompanied by one or more phenomena, as follows: thermal radiation, pressure wave and projection of fragments, toxic materials releases.

Major accidents are likely to affect persons, assets and the environment, the consequences on humans being injuries or even fatalities, and on the property being usually destruction.

Given the development of computational tools, both hardware and software, nowadays for estimating the effects of accidents can be sued mathematical models, consisting of sets of equations which can describe and predict certain physical phenomena, such as thermal radiation, maximum pressure, direction of projectiles and distances travelled a.s.o. [20-25].

Process Hazard Analysis Software Tool – Phast developed by Det Norske Veritas – DNV is one of the world’s most used software for modelling consequences of potential accidents, from leakage, to diffusion and explosion or toxicity. Computational simulations of fire and explosions and their corresponding results have to be validated with experimental results, but such experimental results are quite difficult to obtain [26-29]. For analysing the accident scenario presented in this paper, there was used the latest version of Phast, including the 3D explosion component, since the software has been validated with numerous fires and explosions experiments [30-33].

Phast is a state-of-the-art hazard analysis software package, which can be used in every stage of design or operation, in various industries with potentially toxic or explosive atmosphere.

### 4 Problem setup and analysis

In order to predict the consequences which could have been generated by the explosion of the all gas cylinders carried by the transportation truck which caught fire in 2016 in Mihailesti, certain assumptions have to be made.

Setting up the initial condition models based on computational fluid dynamics represents the first step for the computational analysis of accident consequences, first of all being required to estimate the amount of materials involved in the accident and the emission rate [34-39]. However, this is very hard to know all the factors involved in such a modelling, therefore being required to use simplified assumptions or standard models [40-42].

This study aims to model the consequences of the accident in case approximately 200 full gas cylinders exploded, a second scenario is presented with regard to modelling the
consequences of almost 400 full gas cylinders explosions, and a third one involving 700 ags cylinders, taking into account that it is more than likely for some of the transported cylinders to have been empty.

PHAST commercial software used for performing the analysis is maybe the world’s most used risk modelling tool and it is designed for assessing the development of potential accidents, starting from the initial leakage point, to diffusion of the hazardous substance involved, up to the analysis of explosion and toxicity effects.

One of the most critical input parameters is represented by the weather conditions. Meteorological stability, season temperatures and humidity, wind speed and direction have a crucial role during the modelling of such type of accidents. Nevertheless, the risk assessment is influenced largely by the amount and type of material involved which is also an important factor during computational modelling of accidents. Regarding the calculation time, the more complex the operating conditions set up as input the more time will be required for performing the calculations, the type of vessel and amount of material involved in the accident having a strong impact on the calculation time.

For carrying out the consequence modelling, an important factor is to estimate the amount and nature of material involved in the incident. Therefore, there will be considered the following specifications for the gas cylinders: gas comprised is n-butane, 26 litres/full cylinder, and pressure 10 bar.

Weather conditions play an important role on the modelling, PHAST using Pasquill’s classes as input for meteorological stability, as presented in Table 1, where A corresponds to very unstable, B corresponds to instability, C corresponds to slight instability, D corresponds to neutral, E corresponds to slightly stable, and F corresponds to very stable.

Data generated after performing the calculations can be displayed in various forms such as GIS, graphs or reports, depending on the requirements of the analysis.

Table 1. Pasquill classes - meteorological stability

| Wind speed (m/s) | Day time | | Night time |
|------------------|----------|-----------------|-------------|
|                  | Radiation intensity size | Strong | Moderate | Slight | Cloudy | Sunny |
| < 2              | A        | A – B           | B         | F       | F      |
| 2 ~ 3            | A – B    | B               | C         | E       | F      |
| 3 ~ 5            | B        | B – C           | C         | D       | E      |
| 5 ~ 6            | C        | C – D           | D         | D       | D      |
| 6 >              | C        | D               | D         | D       | D      |

Most relevant input data for the three scenarios analysed are presented below:

- Material: N-BUTANE
- Mass inventory: Scenario 1: 3041.84 kg, Scenario 2: 6083.67 Kg, Scenario 3: 10646.4 kg;
- Volume inventory: Scenario 1: 5.2 m³, Scenario 2: 10.4 m³, Scenario 3: 18.2 m³;
- Temperature: 15 degC;
- Pressure (gauge): 10 bar;
- Elevation: 1.5 m;
- Catastrophic rupture;
- Explosion method: Multi-Energy: Uniform confined;
- Explosion mass modification factor: 3;
- Calculate lethality: Yes;
- Number of input radiation levels for Fireball, Jet Fire and Pool Fire: 3;
- Intensity levels: 4; 12.5; 37.5 kW/m²;
- Release location elevation: 1.5 m;
- Use vessel burst pressure: Yes;
- Vessel burst pressure – gauge: 10 bar;
- Material characteristics: Flammable only.

In figures below are presented a part of the data generated following the consequence modelling of the three accident scenarios (a. corresponds to Scenario 1, b. corresponds to Scenario 2, c. corresponds to Scenario 3).
Simulations have been performed for the following weather conditions: wind speed: 1.5 m/s; Pasquill stability class F - stable, sunny, moderate wind; atmospheric temperature 15 deg C.

Since a lot of factors are involved in the development of a hazardous event, its’ computational modelling has to use input data as close as possible to the reality. However, not al the time such data are available, being also the case for the current study For example, the exact quantity of hazardous material involved is not known, namely how many of the 800 gas cylinders were empty. The quantity of material involved is therefore assumed for simulation purposes. Also, this leads to an uncertainty for comparing the results of the modelling with the actual consequences of the accident (thermal and dynamic effects).
Fig. 3. GIS catastrophic rupture

5 Conclusions

The results of the modelling presented in this paper can be used for identifying causes of accidents and their effects on nearby persons and surrounding buildings. Taking into account the results of computational modelling, there can be drawn up and implemented controlling and safety measures.
The aim of this study was to show the usefulness of computational risk assessment tools for investigating road accidents involved by vehicles transporting flammable materials. Once with the increase of the quantity of the flammable material taken into account for modelling, the safety distance moves further. Future research of explosion type accidents using computational tools will deal with case studies from industrial facilities and which provide results from technical investigations, in order to compare them with the ones of the modelling.

Computational consequence analysis and risk assessment software are very useful tools for implementing designing and implementing safety measures in any industry involving storing, handling, transportation, processing of hazardous toxic/flammable substances, thus leading to an increased level of safety for persons and surrounding assets.

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