Natural gas pipeline explosions. Case study: the Ferăstrău-Oituz accident (1984), Romania

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Abstract. This paper deals with the analysis of hazards associated with accidental release of high pressure from gas-pipeline transportation system that causes explosions. Natural gas is a naturally gaseous hydrocarbon mixture that is formed under the earth's surface. Natural gas is perceived as a clean fuel and is relatively environmentally friendly. When burned, it leaves very little hydrocarbon residue when compared to other types of fuels. The primary constituent of natural gas is methane, it may also contain C_2+ hydrocarbons, N_2, CO_2, He, H_2S, and noble gases. Different gas processing technologies can be employed to remove constituents other than methane. Due to importance of natural gas as a fuel and the increasing global demand of it, this article reviews a detailed analysis of the natural gas transportation accident in 1984 at Ferăstrău-Oituz, Bacău County, Romania. Based on reports found in the Archive Natural History Museum of Mediaș, a scenario was considered and the physical effects of the explosion were determined.

Key Words: natural gas, explosion, Ferăstrău-Oituz, analysis, equivalency.

Introduction. Natural gas is a colourless highly flammable gaseous hydrocarbon consisting primarily of methane and ethane. It is a type of petroleum that commonly occurs in association with crude oil. A fossil fuel, natural gas is used for electricity generation, heating, and cooking and as a fuel for certain vehicles. It is important as a chemical feedstock in the manufacture of plastics and is necessary for a wide array of other chemical products, including fertilizers and dyes. Natural gas is often found dissolved in oil at the high pressures existing in a reservoir, and it can be present as a gas cap above the oil. In many instances it is the pressure of natural gas exerted upon the subterranean oil reservoir that provides the drive to force oil up to the surface. Such natural gas is known as associated gas; it is often considered to be the gaseous phase of the crude oil and usually contains some light liquids such as propane and butane. For this reason, associated gas is sometimes called ”wet gas”. There are also reservoirs that contain gas and no oil. This gas is termed nonassociated gas. Nonassociated gas, coming from reservoirs that are not connected with any known source of liquid petroleum, is “dry gas” (Encyclopædia Britannica 2019).

Natural gas is a mixture of gases, which can be very different depending on the nature of the deposit. Much of it is made up of methane (CH_4), to which sometimes appreciable amounts of saturated hydrocarbons (alkanes), ethane (C_2H_6), propane (C_3H_8), unsaturated hydrocarbons, alkenes and aromatic hydrocarbons are present. The main component of natural gas is methane, that is lighter than air and has a specific gravity of 0.554. Methane is only slightly soluble in water. It burns readily in air, forming carbon dioxide and water vapour; the flame is pale, slightly luminous, and very hot. The boiling point of methane is -162°C (-259.6°F) and the melting point is -182.5°C (-296.5 °F). Methane in general is very stable, but mixtures of methane and air, with the methane content between 5 and 14 percent by volume, are explosive (Gas Encyclopedia 2013).

Explosions of such mixtures have been frequent in coal mines and collieries and have been the cause of many mine disasters.

Material and Method. In recent years, increased attention has focused on the dangers associated with non-radioactive materials, such as petroleum products. Many technological accidents have occurred in the petrochemical industry, accidents involving highly flammable substances such as natural gas and other derived products.

Natural gas has a very complex behaviour and presents the main four types of hazards:

- fire or explosion;
- vapor cloud formation;
- toxic fumes;
- contamination of the environment (Guo & Ghalambor 2012).

According with Gas Encyclopedia (2013), natural gas is a colorless, odorless, water-insoluble gas that ignites very easily, the auto-flame temperature being 650°C. It burns with pale bluish flame, the calorific power is 11910 kcal kg^{-1}.

The flame produced propagates at high velocity in the mass of the gas, so the phenomenon seems instantaneous. If the combustion is complete, the combustion gases contain carbon dioxide and water vapor. Incomplete combustion produces carbon dioxide which can pose a deflagration ignition hazard when an explosive mixture of carbon dioxide and air is formed. Natural gas in enclosed spaces forms explosive mixtures with air, between 5-15%. The deflagration wave speed is 2300 m s^{-1}. The minimum explosive content of oxygen at the dilution of the mixture with carbon dioxide is 15.6% and with nitrogen is 12.8%. Incomplete combustion of natural gas results in very toxic oxide. On toxicity, the first serious disturbance to contaminated air intake occurs when the content is 25-30%. Inspiring a mixture of 80% natural gas and 20% oxygen causes only headaches (Saeid et al 2019).

Several acccidents occured in the last century involving natural gas pipelines. In scientific literature (EGIG 2008) are presented dozens of accidents, major accidents involving fatalities and human injuries.

One of the accidents is the Ferăstrău-Oituz (1984) accident, which will be discussed and analysed in more details in this paper. The description of the accident is based on the official papers and reports of the Archive Natural History Museum of Mediaș, completed with official articles from history of Onești city (Chisaliță 2016).

The aim of the paper is to present the physical effects analysis of natural gas pipelines explosion using a simulation made with the ALOHA software. Also, the paper aims to present the analysis of consequences as a part of the risk analysis (Vianello & Maschio 2011).

Case study: the Ferăstrău-Oituz explosion (1984), Bacău County, Romania. In the early morning of 2nd April 1984, the Eastern II pipeline exploded near Ferăstrău-Oituz village (Figure 1). Following the explosion, a pipe of 10 meters in length and a laying weight of about 3 tons was projected into the air, reaching a distance of about 15 meters from the damaged area, creating a crater with a diameter of approximately 20 m and a depth of 5 m. The accident resulted from a human error during the maintenance process.

In 1975, floods of exceptional intensity were caused on the Oituz river in the aftermath of the heavy rains, which was not recorded in the last decades. In some areas, the Oituz river bed has undergone a number of modifications and has caused bank bursts. The Eastern II pipeline was directly exposed to the destruction of water, floats and vibrations in the area of Ferăstrău-Oituz. In order to repair the pipe, due to the fact that the pre-fabricated reinforced concrete washers could not be made by the specialized company in the short term that was required, than for half of the length, a second solution was used to repair the pipe with used and downgraded drilling pads. In the time required for the execution of the work, the beginning of the execution of the designed works have surpassed the design phase and the technical problems were solved with solutions of the design experts that were on the field at the moment.

Under the pressure of political factors, the gas pipeline operator only had one month to fix the damages, so it did not existed the possibility of a quick acquisition of a 800 mm tubular material in the assortment corresponding to the design pressure of the 50 bar pipeline, therefore were used inappropriate materials (Figure 2, purchased for other works). This is considered the worst industrial catastrophe in the history of natural gas exploitation in Romania (Chisaliță 2016).

Figure 1. The location where the accident occurred (Source: http://wikimapia.org/34954252/ro/Locul-accidentului-din-1-2-aprilie-1984-Explozia-magistralei-de-gaz-METAN-la-Fer%C4%83st%C4%83u).

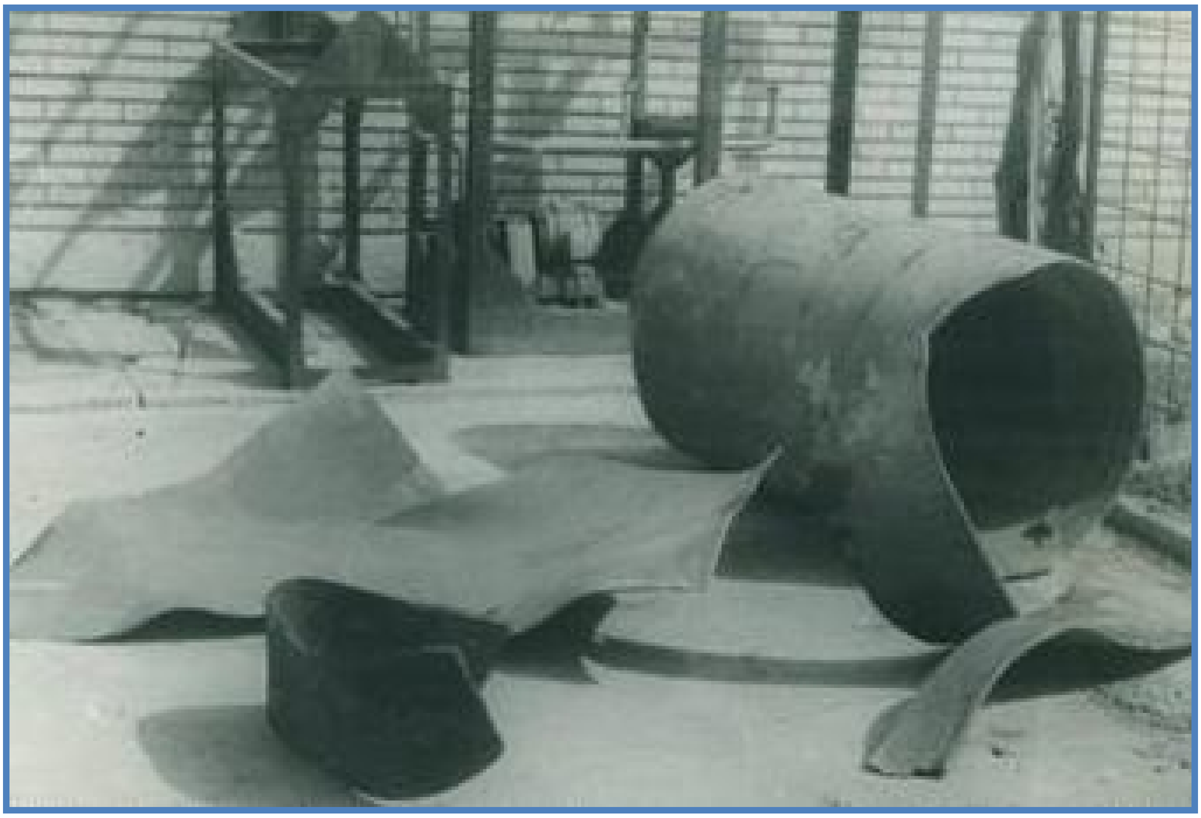

Figure 2. Tubular material destroyed by the explosion.

Based on the above presented data, simulations of the explosion were performed using the ALOHA software (Figure 3), considering a specific scenario. The ALOHA software simulations are widely used for the estimation of physical effects of explosions. The software generated threat zone estimates (Figure 4) for the explosion. ALOHA can model toxic gas clouds, flammable gas clouds, BLEVEs (Boiling Liquid Expanding Vapor Explosions), jet fires, pool fires, and vapor cloud explosions.

Simulation performed with the ALOHA software is done for a 30" diameter pipe, 50 bar pressure, about 350 m long in normal weather conditions (wind speed 5 m s^{-1}, ambient temperature 2°C, humidity 64%).

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SITE DATA:
  Location: FERĂSTRĂU-OITUZ, BACĂU, ROMÂNIA
  Building Air Exchanges Per Hour: 1.07 (unsheltered single storied)

CHEMICAL DATA:
  Chemical Name: METHANE
  CAS Number: 74-82-8                    Molecular Weight: 16.04 g/mol
  PAC-1: 65000 ppm   PAC-2: 230000 ppm   PAC-3: 400000 ppm
  LEL: 50000 ppm     UEL: 150000 ppm
  Ambient Boiling Point: -161.9° C
  Vapor Pressure at Ambient Temperature: greater than 1 atm
  Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 5 meters/second from 90° true at 3 meters
  Ground Roughness: urban or forest      Cloud Cover: 5 tenths
  Air Temperature: 2° C                  Stability Class: D
  No Inversion Height                    Relative Humidity: 64%

SOURCE STRENGTH:
  Flammable gas is burning as it escapes from pipe
  Pipe Diameter: 30 inches               Pipe Length: 350 meters
  Unbroken end of the pipe is connected to an infinite source
  Pipe Roughness: smooth                 Hole Area: 707 sq in
  Pipe Press: 50 atmospheres             Pipe Temperature: 2° C
  Max Flame Length: 84 meters
  Burn Duration: ALOHA limited the duration to 1 hour
  Max Burn Rate: 240,000 kilograms/min
  Total Amount Burned: 6,925,515 kilograms

THREAT ZONE:
  Threat Modeled: Thermal radiation from jet fire
  Red   : 262 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)
  Orange: 366 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)
  Yellow: 567 meters --- (2.0 kW/(sq m) = pain within 60 sec)
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Figure 3. Simulation with ALOHA software.

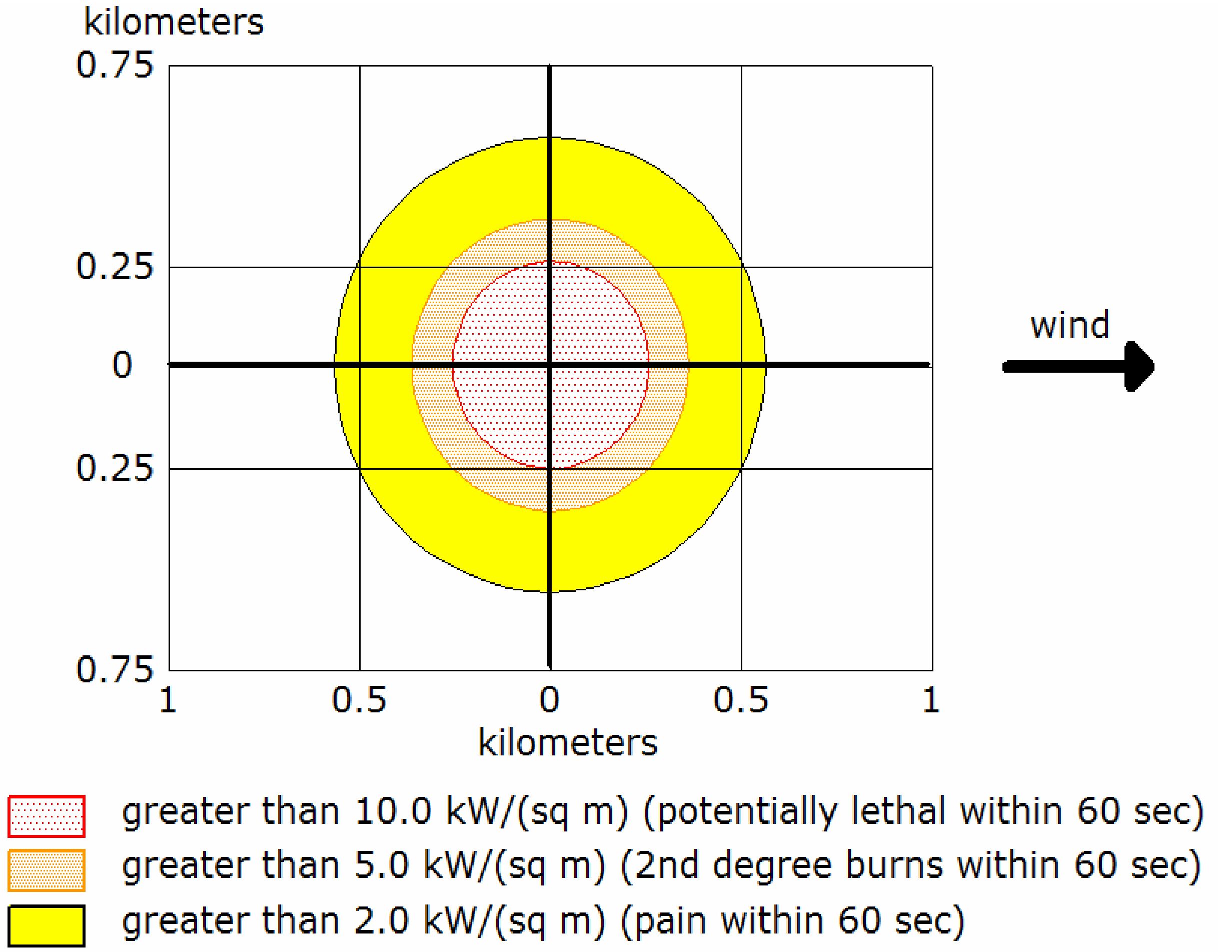

Figure 4. The standard areas of danger according to ALOHA software.

Results and Discussions. The effect of thermal radiation resulting from the occurrence of a fire jet (Table 1) is observed:

- at a distance of 262 m from the point source, the thermal radiation is 10.0 kW/ m^2 with a lethal potential in 60 seconds;
- at a distance of 366 m from the point source, the thermal radiation is 5.0 kW/ m^2 with a potential for second degree burns in 60 seconds;
- at a distance of 567 m from the point source, thermal radiation is 2.0 kW/m^2 with pain potential in 60 seconds.

Table 1

Physical effects of the explosion in function of thermal radiation

Distance from the point source	*Thermal radiation*	*Effects*
262 m	10.0 kW / m^2	Lethal potential in 60 s
366 m	5.0 kW / m^2	Second degree burns in 60 s
567 m	2.0 kW / m^2	Pain potential 60 s

The results show a high difference in the effects at distances that does not differ much. The thermal radiation effects that people experience depend upon the length of time they are exposed to a specific thermal radiation level. Longer exposure durations, even at a lower thermal radiation level, can produce serious physiological effects. The threat zones displayed by ALOHA represent thermal radiation levels.

According with some recent studies (Heus & Denhartog 2017):

- at heat radiation levels between 1.0 kW / m^2 and 3.0 kW / m^2 a person should be protected by standard workwear;

- at heat radiation levels between 3.0 kW / m^2 and 4.6 kW / m^2 a person should be protected by firefighters clothing;

- at heat radiation levels between 4.6 kW / m^2 and 6.3 kW / m^2 a person should be protected by aluminized clothing.

At heat radiation levels above the 6.3 kW / m^2 the effect of thermal radiation resulting from the occurrence of a fire jet is lethal.

This outlying data point does provide some insight into the measurement variability and some caution to the still somewhat limited size of this dataset.

A conclusion of the author is that unless lessons learned from past accidents are not applied and best practices are not implemented in the industry and transportation, accidental and deliberate accidents will continue to occur.

The method proposed in this study proposes a simple, but technically very useful answer for assessing industrial accidents or land use planning.

A more detailed analysis of the Ferăstrău-Oituz explosion is necessary for the determination of a more detailed data report of the accident.

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Received: 02 September 2019. Accepted: 22 October 2019. Published online: 30 October 2019.
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How to cite this article:
Cătăraru L. D., 2019 Natural gas pipeline explosions. Case study: the Ferăstrău-Oituz accident (1984), Romania. Ecoterra 16(3):17-22.