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Analysis of a gas explosion in Dimock PA (USA) during fracking operations in the Marcellus gas shale

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ABSTRACT

On January 1, 2009, a concrete slab covering a water-pump vault of a water well 400 m north of a Marcellus gas well in Dimock, Pennsylvania, USA was reported to have split into three pieces while being overturned. It was suggested that the cycling on of a water pump sparked the deflagration of a methane-air mixture causing the slab to overturn. Here, the conditions necessary to generate an explosion consistent with evidence, mainly a split and overturned concrete slab unmarked by soot or other evidence of a flame, are analyzed. Using more than one approach, calculations show that the maximum pressure to lift the concrete slab was roughly 0.3 bar. Considering among others the flammable range of methane, the explosion pressure as a function of equivalence ratio, the presence of methane gradients inside the vault, the absence of soot and possible ignition sources, the analysis did not yield a well-defined, credible gas explosion scenario to explain the observed damage, although the possibility cannot be ruled out with absolute certainty.

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1. Introduction

Worldwide, the media called attention to the impacts on the environment and human health that hydraulic fracturing, fracking in short, had during the extraction of shale gas and tight oil deposits. Video of an opened tap with burning water in the kitchen of a house is well known (Schlanger, 2014), although such phenomena occur naturally including the so-called ‘eternal flame’ in the western part of New York State (Etiope et al., 2013).

Recent peer-reviewed literature focuses on the occurrence of methane in tap water in areas where natural gas is produced, especially in relation to fracking (Darrah et al., 2014; Molofsky et al., 2013; Osborn et al., 2011). The origin of methane in tap water may be thermogenic and/or biogenic (Osborn et al., 2011), it may be a consequence of hydrogeologic and topographic features of the area (Molofsky et al., 2013) or a consequence of incorrect casing and cementing during well completions leading up to fracking (Darrah et al., 2014). The potential hazard of fracking in relation to human safety came into sharp focus in 2009 when it was said to be responsible for a gas explosion. Sometime during daylight hours on January 1, 2009 the concrete slab covering a water-well pump vault about 400 m north of a Marcellus gas well in Dimock, PA, was disturbed (Legere, 2009). An event caused the concrete slab covering the well vault to split and overturn. The Pennsylvania Department of Environmental Protection (PA-DEP) concluded that a methane explosion was the most likely cause of the incident, based on the evidence available, which was an overturned concrete slab to the water well vault (Lustgarten, 2009).

Given the role of this explosion as an iconic image for water contamination associated with the gas industry, it is important to understand the facts of the 2009 New Year’s Day event. The assumption is that a flammable methane-air mixture was ignited by a spark when a water pump sitting on the floor of the vault cycled on. No one was home and the water line was frozen so if the pump cycled on, it did so spontaneously and without any of the ordinary triggering mechanisms (McGraw, 2011).

To this day, the literature contains little in the way of quantitative data describing the outcome of in- ground water well pit or vault explosions. Newspapers dating back more than 120 years carry reports of water well explosions in a number of the states sitting over Devonian gas shale in North America. The number of American newspaper reports is extensive and in Table 1 only those explosions involving fatalities are listed. In nearly all cases, the explosions were triggered by human actions and in some cases resulted in extensive burns, if not death.

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Table 1
Historical overview of methane explosions in water wells. These water wells are located over Devonian gas shale in the northeastern United States.

Origin	Date	Location	Fatalities	Source
Water well	8/8/1890	Hamilton, Ohio	3	Anonymous (1890)
Dug well	6/30/1904	Hocking, Ohio	1	Anonymous (1904)
Water well	10/27/1910	Lorain, Ohio	1	Anonymous (1910)
Water well	9/20/1913	Lebanon, Pennsylvania	1	Anonymous (1913)
Water well	05-10-1920	Livingston, New York	2	Anonymous (1920)
Water well	06-02-1948	Wabash, Indiana	1	Anonymous (1948)
Water well	07-04-1969	Luzerne, Pennsylvania	4	Meyers (2003)
Basement	12/15/2007	Jefferson, Pennsylvania	3	Lusgarten (2009)

Fig. 1. Methane explosion in basement of house causing damage to the foundation in Chagrin Falls, Ohio, USA (Bair et al., 2012). The foundation has been cracked and paint peeled just above the vent points in the foundation.

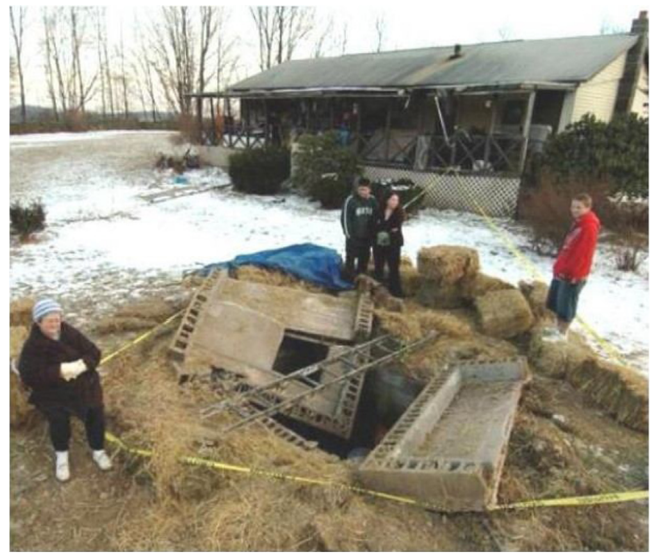

Fig. 2. Dimock water well vault and the two sections of the split and overturned concrete slab with the top course of concrete blocks still attached. View looking to the southeast. A reporter from the Scranton Times-Tribune appeared with a photographer the morning after the event in question (Legere, 2009). The reporter believes that the broken concrete slab had not been moved between the time of the January 1st 'explosion' and the time of this photograph was taken less than 24 h later (L. Legere, 2013, personal communication).

One example with which to compare the Dimock water-pump vault is a buried water tank in Decatur, IL, which partially filled with gas. When an electric pump switch provided an ignition spark, a hole was blown in the ground comparable to the size of the water tank (Browers, 2014). Volumetrically, the Decatur water tank and Dimock water-pump vault are similar but the outcome was different. The explosion in Decatur was powerful whereas the Dimock event was not. Another datum against which the Dimock incident can be measured is a violent explosion inside a well pit near Spring Mills, Pennsylvania, USA (Gold et al., 1970). This explosion created a cone-shaped crater in bedrock, the Ordovician Hatter Limestone, with a rim crest diameter of 7.6 m and a depth of 3.6 m. The energy of this explosion, attributed to the ignition of gasoline vapors from a leak in a nearby gasoline tank, threw the water pump 56 m into an adjacent field.

A third event that has considerable similarities with Dimock comes from Chagrin Falls, OH, USA, where gas migrated up a water well and mixed with air at explosive levels in a basement (Bair et al., 2012). The natural gas – air mixture was ignited with the resulting pressure wave lifting one end of the home from its foundation just enough to jostle some concrete foundation blocks (Fig. 1). Heat from the venting flame peeled paint from the outer wall of the home but did not cause a fire. This natural gas – air deflagration could be traced back to methane migrating into the local water table from the outside of an incorrectly cemented casing of a nearby gas well less than 300 m to the south. The difference between the Dimock and Chagrin Falls gas wells is that in the former case the top of the open hole was 468 m below the surface in a 2271 m deep Marcellus gas shale well, whereas in the latter case the top of the open hole was 80 m below the surface in a 1197 m deep Clinton sandstone well, a conventional well.

What these examples also show is that the conditions leading to the respective incidents have a significant influence on their outcome and can range from severe damage down to a weaker flash fire.

2. Description of the event

As there are no witnesses to the Dimock event and no direct measurements available, the best piece of the evidence for what happened is the concrete cover. Assuming the concrete slab to be thrown upward by the deflagration of a methane-air mixture, the spot where and how it landed gives an indication of the impulse and force needed. There are at least four photographs in the public domain that record the vault, the concrete slab covering the vault, and the slab's trajectory (Fig. 2).

The concrete slab with one course of concrete blocks still attached was split during an upward acceleration with the two pieces subsequently overturning before coming to rest. Two-thirds of the slab was thrown eastward and the remaining one-third was thrown westward (Fig. 3).

The western third may have been overturned with the western wall of the vault acting as a fulcrum. More than 50% of the eastern two-thirds of the slab landed back on top of the vault which means that the outside edge of the eastern slab did not turn on a fulcrum but rather was lifted clear of the vault and spun in space before dropping back down. The lifting forces were uneven as indicated

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