Hydrogeology Journal – Electronic Supplementary Material

Gas well integrity and methane migration: evaluation of published evidence during shale-gas development in the USA

Patrick A. Hammond

Maryland Department of the Environment

1800 Washington Blvd., Baltimore, MD 21230, USA

phone: (410) 537-3587 (W), (410) 544-9194 (H)

email: patrick.hammond@maryland.gov

and: phammond@broadstripe.net

Tao Wen, **Susan L. Brantley**

Earth and Environmental Systems Institute

2217 EES Building

Pennsylvania State University

University Park, PA 16802, USA

Terry Engelder

Professor of Geosciences, Emeritus

443 Deike Building

Pennsylvania State University

University Park, PA 16802, USA

Notable early incidents before HVHF

Prior to the development of high volume hydraulic fracturing (HVHF), several subsurface blowouts related to gas migration from production wells and injection wells at gas storage facilities were reported. Harrison (1983) provided an example where a blow-out impacted domestic wells at Shaw's Corner, Crawford County, PA, that occurred in early 1981. A few months after drilling, completion, and hydraulic fracturing of a gas well about 914 m (3000 feet) from their wells, 20 homeowners reported problems, including several explosions. The blow-out may have been caused by closing and pressurizing an open-hole annulus for several months, allowing shallow nonproductive methane to migrate to the water supply aquifer.

Another example, the Parsons well in Jackson County, WV, was described by the US EPA (1987). The Kaiser gas well KEM#24446 was completed in 8/25/1982 and was cemented in three sections: 76.5 m (251feet), 743 m (2437 feet) and 1382 m (4534 feet) where gas shows were recorded, and then was perforated between 1285 and 1330 m (4216 and 4364 feet) in the Devonian Brown Shale (driller's term). A report was received in 1984 that the Parsons water well, located within 305 m (1000 feet) of the Kaiser well, was contaminated. A State Health Department water analysis report indicated there was a hydrocarbon odor, but the samples was not analyzed for gas. It was also noted that a gelatinous material along with white fibers were found in the water samples. Although it was alleged to have been contaminated by fracturing fluids, no results of chemical analyses were reported. A water well inspection report indicated that the water well problem was first noted in March-April 1984, when a rotten egg odor and the flammability of the gas at the vent tube was noticed. No forensic investigation was conducted to determine whether the source of the methane was from the producing interval or shallower nonproducing zones, nor whether the possible fracturing fluid may have come from unlined waste disposal pits.

Mamm Creek, CO (Thyne, 2014) and Bainbridge Township, OH (ODNR, 2008)

Shortly after the development of HVHF techniques, there were two highly visible incidents of stray gas migration related to lost circulation and inadequate or low primary top of cement (TOC).

In January 2004 shallow, pressured gas zones were encountered while drilling the Swartz 2-15B (02) well, Mamm Creek Field, Garfield County, CO. It appears that the intent was to cement the production casing to surface; however, there was loss of mud circulation at depth. Loss of circulation indicates that drilling fluids did not return to the surface and were lost to a permeable formation or feature, such as a cavernous limestone, and then the cement was also lost to the same formation or feature. This caused the primary TOC to be emplaced more than 4000 feet lower than expected, i.e., only 25 m (82 feet) above the top of gas and about 122 m (400 feet) above the first perforation. A temperature survey shows a temperature decline at the depth of lost circulation of 1219 m (4328 feet) indicating an upward flow of gas, starting 91.4 m (300 feet) below the TOC. Hydraulic fracturing continued through March 2004. On April 1, gas bubbling from West Divide Creek was reported and elevated levels of methane and benzene were measured in samples collected from the stream. The proposed migration pathway was up the gas well annulus, then along a fault to the creek 914 m (3000 feet) away. On April 4, a cement squeeze was performed to remediate the gas well and the methane and benzene levels started to drop within 12 days, with most of the decline occurring after installation of an air sparging remediation system (Thyne, 2014).

In the second incident, at Bainbridge Township, Geauga County, OH, the English 1 gas well was completed and hydraulically fractured on November 13, 2007. The well had lost circulation at depth, which limited the primary TOC to only about 24 m (80 feet) above the first perforated zone. In addition, a small volume of oil and brine fluids were flowing out of the annulus at the surface during hydraulic stimulation. On December 15, gas accumulated in a nearby house basement causing an explosion. On the same day, the water in a nearby well was blown 4.6-5.5 m (15-18 feet) in the air and gas then blew out of the well for several days. Combustible gas levels in the second water well, as well as many of the other wells in the neighborhood, exceeded the safe level of 5% in air. The source of the gas was not determined, since the formations overlying the target Clinton Sandstone also contain gas. Two squeeze cement jobs were performed on the English 1 on 15-17 December 2007 that reduced, but did not eliminate, the methane contamination in the house wells (ODNR, 2008). A panel of experts indicated that groundwater was not degraded, contaminated, or polluted by oilfield brine, crude oil, or hydraulic fracturing fluids in the vicinity of the gas well (ODNR, 2008).

Evidence of microbial alteration to late-collected samples in Dimock PA (Hammond, 2016)

Of the 2010 samples collected at Dimock, two had been sampled in 2009 (WW-E and WW-H) and were substantially altered. Two (WW-P and WW-R) had C1:C2 ratios >2,500, but thermogenic isotopic signatures. Hammond (2016) suggested they had a microbial origin (Whiticar, 1999), but at a depth greater than 610 m (2,000 ft), based on the studies of Kotelnikova (2002) and Baldassare (2014), although one cannot completely exclude the possibility of microbial oxidation as paired isotope data were not provided. Three had isotopic signatures indicating shallow thermogenic origins, but one (WW-M) also had a C1:C2 ratio >2,500, suggesting a microbial gas component. The data indicate that the methane was significantly isotopically enriched in the heavy isotopes in 2012 in wells WW-B and, probably, WW-C, relative to the 2009 data, and WW-Q relative to the 2010 data, likely due to microbial oxidation. The methane in 2012 in wells WW-E and WW-F was isotopically depleted relative to the 2009 data, probably due to addition of methane contributed from methanogenic microbiota. There were lesser changes in the isotope signatures for WW-G, -J and –L. By 2012, in at least eight, and possibly nine, of the 10 wells sampled, the methane isotopic compositions had changed since remediation, most likely because of microbial oxidation or methanogenesis. The methane in the last well (WW-P) appears to have a natural origin, unaffected by shale-gas well operations.

ESM References

Baldassare FJ, McCaffrey MA, Harper JA (2014) A geochemical context for stray gas investigations in the northern Appalachian Basin: implications of analyses of natural gases from Neogene- through Devonian-age strata. AAPG Bull 98(2):341–372. https://doi.org/10.1306/06111312178

Hammond PA (2016). The relationship between methane migration and shale-gas well operations near Dimock, Pennsylvania, USA, Hydrogeology J. 24(2):503-519. https://doi.org/10.1007/s10040-015-1332-4

Harrison SS (1983) Evaluating system for ground-water contamination hazards due to gas-well drilling on the Glaciated Appalachian Plateau, Groundwater 21(6):689-700. https://doi.org/10.1111/j.1745-6584.1983.tb01940.x

Kotelnikova S (2002) Microbial production and oxidation of methane in deep subsurface. Earth Sci Rev 58:367–395 https://doi.org/10.1016/S0012-8252(01)00082-4

ODNR (2008). Report on the investigation of the natural gas invasion of aquifers in Bainbridge Township of Geauga County, Ohio. Ohio Department of Natural Resources (ODNR), Division of Mineral Resources Management, Columbus, Ohio. http://oilandgas.ohiodnr.gov/portals/oilgas/pdf/bainbridge/report.pdf. Accessed 30 October 2018

Thyne GD (2014) Summary of hydrogeology investigations in the Mamm Creek Field Area, Garfield County, Science Based Solutions LLC, Laramie, Wyoming, prepared for Garfield County February 6, 2014. https://www.garfield-county.com/oil-gas/documents/Summary-Hydrogeologic-Studies-Mamm%20Creek-Area-Feb-10-2014.pdf. Accessed 11 October 2018

US EPA (1987) Report to congress, management of wastes from the exploration, development, and production of crude oil, natural gas, and geothermal energy, volume 1 of 3, oil and gas. United States Environmental Protection Agency (US EPA), Office of Solid Waste and Emergency Response, Washington, DC. EPA/530-SW-88-003. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000ESA8.TXT. Accessed 9 October 2018

Whiticar MJ (1999) Carbon and hydrogen isotope systematics of bacterial formation and oxidation of methane. Chem Geol 161(1):291–314. https://doi.org/10.1016/S0009-2541(99)00092-3