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Research note

The Effects of Hydraulic Fracturing on the Environment and Some Possible Remediation Strategies

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Abstract

Oil and gas production has been a vital economy booster for the United States. It directly supports around 9.8 million jobs and additionally, 2.1 million jobs have been created, supporting oil and gas industry. Shale and natural gas production by hydraulic fracturing (HF) technology that began in 1940s, relies on injecting fracking fluids (FFs) into the well bore to crack shale rock. Studies indicate that despite all the positive impacts of HF on the economy, massive wastes produced form HF operations and the toxic chemicals used in FFs are contaminating drinking water resources, lands and the ecosystems, and negatively impacting human health. Soils polluted by fracking wastes contain harmful chemicals such as radium, selenium, and lead which can endanger farming lands, livestock, poultry, and humans. Furthermore, significant methane emissions during fracking operations may contribute to global warming, leading to major climate changes. Nonetheless, studies are being conducted to further upgrade fracking technology and develop recyclable and eco-friendly FFs to reduce such negative environmental and health impacts. This paper discusses the controversies surrounding HF and ways to make the process beneficial to economic growth, environment and public health.

Keywords: Environment, contamination, drilling, fracking fluid, human health, hydraulic fracture (fracking), hydraulic fracture wastewater, natural gas, oil, pollution.

1.0 Introduction

Production of oil and natural gas has always been a vital economy booster for the U.S. Shale and natural gas production from hydraulic fracturing (fracking) has created hundreds of thousands of jobs and led to the development of many large chemical companies and businesses (Loris, 2012). Natural gas provides for 25% of total electricity generated in the U.S., and there is a great abundance of natural gas deposits (about 4,244 trillion cubic feet) in the U.S. (Loris, 2012). Therefore, the extraction of natural gas is a very lucrative job creator. In fact, a study in 2015 commissioned by the American Petroleum Institute found that the oil and gas industry in the U.S. has created more than ten million jobs across the nation (Caves, 2017). Another estimation shows that the oil and gas production sector is directly supporting 9.8 million jobs in the U.S., which is about 5.6% of the total U.S. employment, and additionally, 2.1 million jobs are associated with the subsectors that support oil and gas production. According to a Reuter's analysis, in 2013 alone, low-cost natural gas has contributed about $2.08 trillion to the U.S. manufacturing sector (Google, 2017).

Fracking industry in U.S. is booming. It is estimated that over the next 20-30 years, an additional 300,000 new wells could be drilled by using fracking technology (Finkel and Law, 2011). Although there is a prosperous economic outlook for the fracking industry, a lot of negativity surrounds hydraulic fracturing (HF) operations. Most of this negativity stems from the environmental hazards associated with fracking. Before divulging the effects of HF on the environment and possible remediation strategies, let us first discuss the actual process of HF.

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2.0 Process of Fracking

Extraction of natural gas and oil by HF began in the 1940s and has gained momentum in recent years. The extraction of natural gas from HF is also known as "unconventional production" (Pichtel, 2016). This production involves not only drilling vertically into the ground, but also horizontally to reach the target formation (oil site). In the HF process, fracking fluid (FF), also known as a "slurry," is injected into the well bore, which is drilled into the ground to depths between five thousand to ten thousand feet before extending horizontally for approximately another mile (Gruber, 2014). Casings of cement and steel are wrapped around the well bore before the slurry is injected. These extra layers prevent leakage of the FFs into aquifers and groundwater. After the slurry is injected into the drill bore at high pressures, it creates small fractures in the shale rock formation allowing natural gas and petroleum to pass through and eventually be collected (Adams, 2011).

Fracking fluids contain about 98 to 99.5 % water and sand with the rest being chemicals, such as proppants, acids, buffers, and biocides (Earthworks, 2015). These chemicals are used to change the pH and viscosity of the FF. It may seem like a small amount of chemical usage, however, when considering that millions of gallons of water are used in FFs (2,500,000-4,200,000 gallons per well), HF procedures can use 80-330 tons of chemicals (Earthworks, 2015). Some of the injected FF can return to the surface known as flowback (Earthworks, 2015). Injected water along with the water that already exists with the petroleum reserves (produced water) is brought up to the surface with the crude oil or natural gas (Veil *et al*., 2004). A mixture of produced water, injected water, slurry chemicals, and hydrocarbons return to the surface of the well and collectively termed, Hydraulic Fracturing Wastewater (HFW).

3.0 Environmental Impacts of Fracking

Freshwater is a precious resource and is necessary for sustaining all forms of terrestrial life on earth (Zaman and Sizemore, 2017). The water used in HF is typically drawn from available groundwater or surface water resources which are close to the HF well (Marie *et al*., 2016). This large amount of water withdrawals can potentially impact drinking water resources especially when the water availability is insufficient to accommodate all users in the area. According to the Louisiana Ground Water Resource Commission, drinking water wells near the Haynesville Shale area ran out of water due to HF activities, drought and lack of precipitation (Marie *et al*., 2016). Although, far more incidences of HF operations show little to no impact on drinking water resources, surface and ground water levels should always be monitored in areas with considerable HF operations, such as North Dakota, Pennsylvania and Texas.

Although HF began in the 1940s, it wasn't until the late 2000s when the public became increasingly aware of the chemical ingredients of the FFs and the environmental impacts of these chemicals. Table 1 shows the components, properties and actions of HFs.

Various chemicals present in the FFs, such as polycyclic aromatic hydrocarbons, methanol, formaldehyde, ethylene glycol, glycol ethers, hydrochloric acid, sodium hydroxide, petroleum distillates (containing benzene), ethylbenzene, toluene, xylene, and naphthalene are toxic to human health as well as to wildlife with many of these chemicals are considered to be carcinogens (Earthworks, 2015). Presence of benzene based chemicals at levels greater than 5.0 parts per billion is malicious (Earthworks, 2015, Yost *et al.*, 2016). Furthermore, volatile organic compounds such as 1,2-Dichloroethane present in the HFF can easily enter the air and threaten wild life and ecosystems (Earthworks, 2015). If these harmful chemicals are not disposed of properly, they can easily contaminate our environment and pose health risks. Such environmental contaminations are mostly caused by pipe overflows, leaks, blowouts, deliberate improper disposal, holding ponds (storage areas for HFW) and natural events (Pichtel, 2016). Data suggests that most of the HFW spills are caused by equipment failure or human error (Marie *et al*., 2016). Major wastewater spills and their impacts have been reported from West Virginia and other parts of the country (Adams, 2011, DRC, 2015, Lockwood, 2016).

The effects of HFW on soil can also be detrimental. Leaks or improper disposal of HF wastes are known

Table 1: Major Components Present in HFs (Source: Loris, 2012).

Components	Properties	Actions
Sand	Proppant	To fracture and allows oil to move to the well.
Hydrochloric or muriatic acid	Acid	To clean up the perforations in steel tube casting improving accessibility.
Peroxydisulfates	Breaker	To reduce HFF viscosity.
2-Bromo-2-nitro-1,2-propanediol, Glutaraldehyde	Bactericide	To prevent microorganism growth in HFF.
Acetic acid, Carbonates of Sodium/Potassium	Buffer	To stabilize the pH of the fluid.
Potassium chloride, tetra methyl ammonium chloride	Clay stabilizer	To prevent clay formation.
Methanol, oxygen scavengers	Corrosion preventer	To reduce rust in steel tubing.
Polyacrylamide, acrylate	Friction reducer	To minimize friction and help HFF flow smoothly.
Potassium hydroxide, borates, phosphate esters with metals	Cross-linkers	To increase HFF viscosity.
Petroleum distillate	Gelling agent	To increase thickness and density of HFF.
Polyacrylate, ethylene glycol	Control of precipitation	To prevent precipitation of calcium and barium sulfate salts.
Aromatic hydrocarbons	Nonpolar solvents	To help wettability of contact surface of HFF and break emulsions.
Ethoxylated alcohols, methanol, isopropanol	Surfactants	To help fluid recovery by increasing surface tension of HFF

Figure 1: Fracking wastewater spills near Bear Den Bay, North Dakota (Source: DRC, 2015; Lockwood, 2016).

to be responsible for creating residues of radium, selenium, lead, and other contaminants in the soil and water in areas close to the fracking regions (Lauer *et al*., 2016, Lockwood, 2016). A recent Duke University study shows the presence of lead, ammonium, selenium, and other toxic contaminants along with high salts in areas close to fracking regions in western North Dakota (Kelly, 2016). Furthermore, the radioactive element, radium, is also found in brines in those areas.

Soils polluted by HFWs put farm lands, livestock, poultry, and farmers at stakes. Forests can also be potential victims to HF pollutions. In 2008, a deciduous forest in West Virginia (Fernow Experimental Forest) was damaged by HFWs where about 303,000 liters of HFW was dumped onto 0.20 hector area of the forest floor from a gas well. Following this dumping, severe pollution of ground vegetation was detected, and about ten days later premature dropping of tree leaves were reported. Two years later, fifty-six percent of the trees within the contaminated area were dead (Adams, 2011). This study reported that the levels of sodium and chloride in the HFW contaminated site were tremendously higher than the control site. Such HFW spills can result in increased levels of salinity in groundwater and/or surface water reservoirs (Marie *et al*., 2016). Results indicated that the salinity threshold of the hardwood forest was completely surpassed, resulting in the trees dying off caused by hyperosmotic action. The study also showed that acidity of the HFW polluted area was much lower than normal supporting the fact that low acidity is also detrimental to the trees. Furthermore, land application of HFW is considered an acceptable form of disposal in several states. This practice should be rethought and reformed to regulate the disposal of HFW in all states (Adams, 2011).

During fracking operations, FF can be leaked into underground drinking water resources. Therefore, the structural integrity of the well bores is very important. Well bores should be sturdy enough to withstand the high pressure of the FFs (Marie *et al*., 2016). Leaking of FFs into groundwater resources occurs when the casing of cement around the well bore is inadequate. Exposure to corrosive chemicals, formation stresses, and operational stresses (pressure and temperature fluctuations during hydraulic fracturing) can degrade casing over the life of the well (Marie *et al*., 2016). Typically, older wells are more prone to have leakages. Near Killdeer, North Dakota, leaked FFs form busted well bores caused contamination of groundwater resources (Marie *et al*., 2016).

Another major environmental issue associated with HF is methane emissions. The emissions are typically generated from shale gas (petroleum) extraction, and shale gas production has increased over 40% in the U.S. (Howarth, 2015). Shale gas is made of mostly methane and is emitted into the environment during the production process. Satellite data shows that approximately 12% or more methane from total production is ejected into the air over the full life cycle of the shale gas, from well to delivery to consumers. Methane absorbs 100-fold more heat than carbon dioxide (CO_2) on a mass-to-mass basis, which makes methane an incredibly powerful greenhouse gas (Stocker *et al*., 2013). Due to an increase in shale gas production over the recent years, the total greenhouse gas emissions in the U.S. has increased and it is predicted that this growth will continue through 2040 (Howarth, 2015). If this rate of emission of greenhouse gas continues, the Earth is predicted to warm by 1.5°C within the next 15 years and by 2°C within the next 35 years, which can significantly alter the climate of the planet (Shindell *et al*., 2012). Reduction of carbon dioxide emissions alone will have negligible effect on slowing the rate of global warming as compared to reducing methane emission because, as mentioned earlier, methane is a more powerful heat absorbing gas than CO_2.

4.0 Human Health Impacts of Fracking

The chemicals used in FF for fracking operations are hazardous to the ecosystems, and detrimental to human health (Earthworks, 2015, Yost *et al.*, 2016). Humans may get exposed to fracking chemicals by ingesting contaminated drinking water, inhaling chemical vapors from wastes stored in pits, tanks or dumped on lands, or through direct skin contact. Colborn *et al.* (2010) published a comprehensive paper on the health effects of 632 chemicals used in fracking technology in the U.S. They observed that over 75% of these chemicals could affect various sensory organs; 40-50% could affect cardiovascular, nervous and urinary systems; 37% could affect endocrine systems; and 25% could cause cancer and mutations in humans. Cardiovascular and respiratory illnesses and damages to lungs, liver, kidneys, blood, and brain along with carcinogenic effects of fracking chemicals have been reported by other investigators (Finkel and law, 2011; Peng *et al.*, 2009; Schmidt, 2011).

5.0 Remediation Strategies

Ideally, HF wells should be in a place where the groundwater tables and the oil sources are at the greatest possible distances from each other. Migration of HFFs into drinking water resources has been reported to increase as vertical separation distance between the targeted oil reserves and the underground drinking water resources decreases (Marie *et al*., 2016). To minimize this problem, powerful new software and mapping techniques can be developed to fully analyze and predict locations of fractures. Studies can also be designed to determine whether certain fractures have resulted in FFs leaking into groundwater (Banerjee, 2015). Unfortunately, despite the advances in HF technology, enough data is still unavailable to assist identifying possible fracture locations in wells.

Methane emissions from HF also pose a threat to the environment, the U.S. Environmental Protection Agency (EPA) has suggested that atmospheric methane load could be reduced by simply decreasing the release of methane in the atmosphere. Furthermore, by replacing the in-building use of natural gas for domestic space and water heating with high-efficiency electric heat pumps, the greenhouse gas emissions can also be reduced (Howarth, 2015). The use of renewable energy sources like solar and wind energy can also greatly reduce the greenhouse gas footprints.

The development of more potent but environmentally friendly FFs should be researched further. A new type of FF is being reported which can potentially be more environmentally friendly and more effective and versatile than currently used FFs (Shao *et al*., 2015). This fluid is a CO_2-reactive aqueous solution which contains less toxic polyallylamines. The new FF enhances rock permeability and requires a lot less pressure as compared to other FFs when injected into the well bore. The new FF can also be recycled allowing it to be much more viable for enhancing hydrocarbon production (Shao *et al*., 2015).

As discussed earlier, HFWs contain many harmful chemical compounds. The impacts of these chemicals could be minimized if the HFWs could be filtered properly. Although, such treatments of HFWs could be very difficult, a study on the separation of oil particles from produced water found that magnetic nanoparticles could be used to remove droplets of oil present in HFWs. In this study, magnetic nanoparticles were inserted into the HFWs, causing oil droplets to attach to the nanoparticles, which eventually led to the separation of oil droplets from produced water (Ko *et al*., 2014).

6.0 Discussion and Conclusion

Energy production has always been an important part of the U.S. economy. The contribution of HF technology in energy production is enormous. It has created a remarkable energy boom and generated hundreds of thousands of jobs in the energy sector. The growth of this technology has reduced the price and availability of natural gas and has significantly lowered the operational costs of many industries (chemical, fertilizer, plastic, etc.) that rely on fossil fuels as their energy sources (Loris, 2012).

Fracking is thriving in all 35 oil and gas producing states of the U.S. (Ridlington, E. *et al.* 2016). Despite the positive contributions, fracking technology is under scrutiny as fracking operations are causing possible earthquakes (Bame and Fehler, 1986; Fehler, *et al*., 1987; Holland, 2013), and land and drinking water contaminations (Loris, 2012). In North Dakota alone, where fracking industry is booming, over 4000 spills have been reported so far. These spills have contaminated surface water bodies with radium, selenium, thallium, lead, and other toxic chemicals (Ridlington, E. *et al.* 2016). Some of these chemicals are not only radioactive, but also can persist at unsafe levels for years.

Produced water (water trapped underground with the gas and oil during fracking operations) that is brought to surface along with oil and gas, is known to be the largest volume of waste product produced by oil and gas industries (Veil, *et al*., 2004). Managing and recycling produced water is difficult as it contains hundreds of chemicals which are hazardous to the environment and human health. Studies also indicate that the chemicals associated with such oil and gas operations have long lasting and severe health consequences, such as cancer, cardiovascular, nervous, respiratory and urinary diseases (Colborn, 2010).

HF technology has made not only an enormous contribution in job creation and energy production in the U.S., but also a vital means in the production of everyday necessities such as vehicle fuel, plastic, fertilizer and rubber. Furthermore, it has made oil and gas much cheaper and accessible, and reduced U.S. dependency on imported fossil fuels. However, the environmental and human health impacts of fracking operations are also undeniable. Therefore, it is essential that we save this important industry without costing our ecosystem and health. This can be achieved by developing fracking technologies that are sensible and ecofriendly. Fracking industries and the scientist community must coordinate their efforts in developing more efficient, versatile and environmentally friendly FFs. Although, we see some progress in this direction (Shao *et al*., 2015), it is far from enough. Fracking industries must step up their efforts and deploy more resources to develop practical solutions to this gridlock. That will be a good business practice and will help everyone.

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