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Article

Physical-chemical contamination in fracking areas

María Eugenia Guerrero Useda

Universidad Estatal de Moldavia, Moldova Q1097810, Colombia; mguerrerouseda@gmail.com

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Abstract: Despite the scientific consensus on the need to limit global warming, the urgency for the autonomous provision of energy resources has led many States to authorize projects that apply non-conventional fossil fuel extraction techniques, such as horizontal drilling and high-volume hydraulic fracturing of shale. Although few studies present conclusive evidence, these techniques are accused of causing dangers to the environment and to the health of the people who work and live in fracking areas, so that the States are faced with the dilemma of extending their energy autonomy for a few years, squeezing their natural gas and oil reserves to the end, or seeking a balance with the planet by moving towards more sustainable energy sources. Based on the review of studies that present evidence of physical and chemical contamination and other impacts on the environment in areas where the fracking technique has been developed, a panorama of risks for people living near extraction platforms and the dangers of developing fracking projects in tropical climate zones is presented.

Keywords: hazard analysis; hydraulic fracturing; horizontal drilling; risk

1. Introduction

Hydraulic fracturing (fracking) together with horizontal drilling is a standard technique used to access gas and oil trapped in shale rock beds, widely applied in the United States where it has been used industrially since 1949 and has generated great economic benefits. In recent years fracking has spread to other countries where technically recoverable gas reserves have been estimated, including countries in the Latin American region such as Mexico, Venezuela, Colombia, Brazil, Paraguay and Argentina. As an anthropogenic activity, this technique is not risk-free [1].

Several publications point out that the application of fracking has a high potential to cause environmental pollution; it is mainly accused of producing noise [2], facilitating the surface emission of subsurface gases [3], polluting the air [4] and generating water and soil contamination by extraction wastewater lagoons.

However, only since 2013 have some scientific studies reported evidence of contamination in areas where the technique has been developed [5–7], without this implying the presentation of conceptual models of contamination or evidence of root cause analysis.

The research question that guided the review was the following: What physical and chemical risk events related to the application of the fracking technique and horizontal drilling are documented in recent scientific literature? The answer to this question is intended to shed light on the possible environmental impact of fracking in tropical areas.

2. Methodology

For the development of the review, the documentary technique was applied with reference to the works [8–10] with the application of bibliographic matrices and content analysis. The notions of risk factor, hazard, exposure, vulnerability, uncertainty, fracking, horizontal drilling and pollution were at the center of the documentary analysis developed on articles published in scientific journals, accident reports and risk alerts of the oil and gas industry.

The notions associated with risk analysis were taken from [11–13]. From the UNESCO thesaurus we took the grouping of terms under number 2.60 of the science group < Pollution, Catastrophe and Security > and from there the main terms: oil pollution, water pollution, air pollution, noise pollution, radioactive pollution and environmental quality.

The review of the topic focused on papers on the oil and gas industry produced mainly in the United States; for the subtopic of air pollution, water pollution and radioactive contamination by the oil industry, we also reviewed papers from Latin American countries, mainly Argentina [14], Brazil, Ecuador, Mexico and Venezuela.

In the subtopic of noise pollution, fracking works were reviewed in rural and urban areas of the United States (Pennsylvania), Mexico [15] and Argentina (Vaca Muerta Formation), where the soil (arid and semi-arid), climate and ecosystemic environments differ significantly from the Colombian areas where possible pilots for fracking have been prioritized, such as the Middle Magdalena Valley (La Luna Formation), with a tropical climate. A total of 32 articles, 10 reports and 15 grey literature papers were reviewed.

3. Fracking

Listed below are some facts about the technique, which are necessary to size the magnitude and scope of the hydraulic fracturing technique, hereafter referred to as fracking. The technique is used to extract oil and gas from blocks that are at a depth ranging from 2500 to 5000 m; depending on the rock formation, a well used for fracking needs between 8000 m^3 and 16000 m^3 of water and at least 25 sand cars to prepare a pumping mixture that typically consists of water (90%), sand (9.5%) and a cocktail of chemicals (0.5%) [16]. Although recently the technique has varied in terms of the composition of the injected liquid, its components are not fully known [17] as they are not in the public domain because they are considered trade secrets. It is known that the reflux fluid and the produced fluid are partially reused in the fracking technique [18].

There are many review papers that report the hydraulic fracturing technique and the possible dangers of environmental pollution, especially of water [19] and air resources generated by physical and chemical pollution sources [20–24,16]; however, when analyzing in depth the reported incident reports it is found that concentration data of the pollutants of interest before and after the incidents are missing, a situation that often occurs frequently in the oil and gas industry [23,25].

On the other hand, when reviewing the techno-scientific literature on the subject, there are studies that move in two directions, firstly, those that focus on analyzing the political discourse around fracking [4], public policies and regulations related to the extraction of shale gas, these works are developed mainly in the United States and the United Kingdom.

In the next place, there are works that review occupational health and safety issues developed mainly in the United States, and that review accidents in the fracking industry and occupational health issues of workers in exploration and extraction plants. It should be noted that by 2009 there were already more than 1.5 million miles of pipelines connecting extraction wells, processing plants, distribution facilities and customer distribution [3] and according to data from the U.S. Chamber of Commerce by 2013 there were 1.7 million jobs already created and a total of 3.5 million projected by 2035 for the fracking industry (See **Figure 1**).

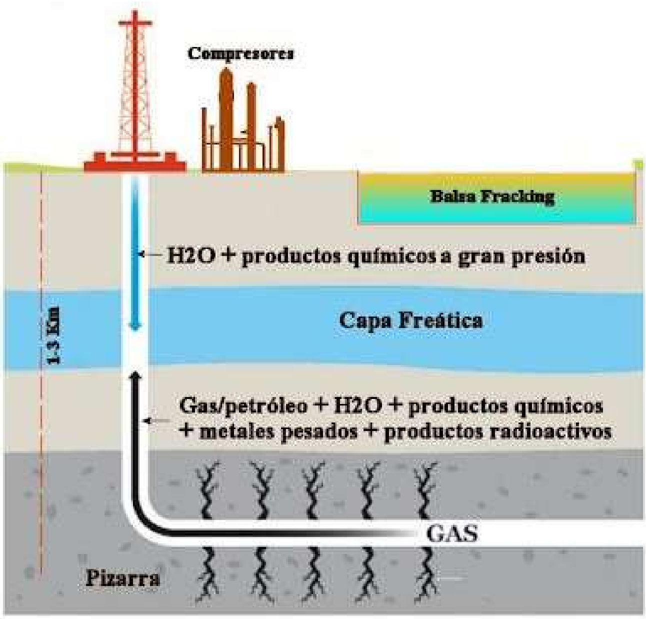

Figure 1. General scheme of the hydraulic fracturing process of a well. Source: Classroom Blog.

4. Risks due to gas and silica dust emissions

As noted, hydraulic fracturing is done for the purpose of releasing gas and oil trapped in the subsurface. In addition to shale gas, better known as shale gas, other gases present in the source rock such as benzene, methane, radium and radon are released to the surface, increasing the risk of air pollution especially in the platform construction and drilling phases [3,21].

During the last decade, the rapid increase of methane in the atmosphere has been noted. Thus, Robert W. Howarth concludes that shale gas production may have contributed more than half of the increase in global fossil fuel emissions and about one third of the total increase in emissions from all sources [5]. Additionally, Oyelakin reports the emission of toxic values of methane in storage areas of petroleum condensates obtained from fracking areas [6].

Primary and secondary pollutants with the potential to contaminate the air are associated with fracking and its network of facilities. In addition to methane, other pollutants of interest such as hydrogen sulfide, toxic vapors of the components present in the hydraulic fracturing fluid and criteria air pollutants are reported in [3]. In addition, Paulik and collaborators [7] measured by means of bracelets placed on the hands of workers and inhabitants of areas surrounding natural gas extraction wells and found that polycyclic aromatic hydrocarbons (PAH) are emitted and contaminate the air around the well, increasing personal exposure to workers and inhabitants of the area.

Between 2016 and 2018 in North Yorkshire, England, air quality and meteorological parameters (NOx, O3, NMHC, SO2, PM) were monitored in a rural area called Kirby Misperton where pre-fracking activities took place; there, a three-fold increase in nitrogen monoxide and a two-fold increase in nitrogen dioxide (NO2) were established, no significant changes in airborne particulate matter or non-methane hydrocarbons were recorded. Variations in air quality were attributed to increased vehicle and equipment operation at the site [26].

4.1. Methane

On methane and fracking several works are reported that consider a great contribution in greenhouse gas production and the impact on global warming, these works mostly appear published in journals that are not in the area of environmental engineering and refer to methane produced by the combustion of gas or oil obtained using the fracking technique; however in [27] it is estimated that the greenhouse gas footprint of shale gas is greater than that of coal or oil and that between 1.7 to 6% of the methane is vented or leaked to the atmosphere from the wellhead, pipelines and storage facilities.

An increase in methane emissions (up to 2%) has been established in the areas surrounding wells where hydraulic fracturing has been performed in the United States [28], this data is not the same for other geographic areas of fracking [29], however, the debate has focused on the problem of methane contamination of drinking water associated with shale gas extraction.

Thus, Osborn and collaborators [28] reported in 2011 high methane concentrations in water wells near wells with fracking in Pennsylvania, this work received several criticisms and gave rise to new studies that in 2013 concluded that methane is common in water wells in Susquehanna County (Pennsylvania) and its presence correlates better with topography and groundwater geochemistry, and less with shale gas extraction activities, thus concluding the lack of evidence to attribute the presence of methane in water wells to fracking developed in the area [30]. On the other hand, following [31], it is recommended to plan and maintain a prudent distance between hydraulic fracturing drilling and groundwater sources.

4.2. Radon (Rn)

It is an inert, tasteless, colorless and odorless radioactive gas; it is the densest known gas produced naturally by the decay of uranium. At least 34 isotopes of Rn are reported, ranging from Rn-195 to Rn-228, of which three are of interest: 222, 220 and 219, because they depend on uranium. The first is the most abundant in the environment (80%). The half-life of radon is 3.8 days, but its descendants, polonium 218 and polonium 214, tend to bind to particles that when inhaled can be retained in different sections of the respiratory tract. Radon progeny have a shorter half-life and emit alpha radiation (ionizing radiation, like radon 222) that is not very penetrating but is released within a few micrometers.

The inhalation of solid particles contaminated with short half-life descendants of radon represents a high health risk, since alpha radiation can impact lung epithelial cells, producing molecular alterations, with the probability of causing lung cancer. The United States has estimated an average level of 1.3 pCi/L of radon in indoor air and 0.4 pCi/L in outdoor air; the goal in this country is for the indoor radon level to approach the outdoor level. Several publications point out that with the increase of fracking operations in the United States, the level of radon in buildings has increased and invite the development of detailed studies [32–34].

As indicated, radon found in the environment comes from human activities. Radon enters the environment through the soil mainly from uranium and phosphate mining activities, fracking, and coal combustion. It is estimated that radon gas is released into the environment during fracking operations, but studies are few and inconclusive. James Burkhart and collaborators [32] developed measurements during different phases of the process of drilling and extraction of oil and gas in wells located in the Denver basin (Colorado), where the horizontal drilling and multihydraulic fracturing technique is applied, in the site were found significant increases of radon in the phases of separation and storage, where the radon in the open air was 4.5 pCi/L, a value that is 10 times above the outdoor level as indicated in the EPA1992 standard.

4.3. BTEX

Benzene, ethylbenzene, toluene, and three isomers of xylene comprise a group of contaminants found in crude oil, coal, and gas deposits. This group is of recent interest because of its reported presence in drinking water wells in fracking areas [35]. Some companies use it as a compound for fluid fractionation, with the risk that fracturing through the hydrological confining layer may create a hydraulic communication between the coal layer and a subway aquifer, contaminating it with BTEX.

It should be noted that not all countries require companies to disclose the chemicals that make up fracking fluid; in some countries, such as Australia, the use of BTEX in fracking operations is prohibited [36,29]. However, long-term exposure to the components of BTEX affects health widely, causing from ocular and respiratory symptoms to bone marrow and blood disorders [37].

4.4. Silica dust

Silica is present in several of the operations involved in the fracking process. Dump trucks loaded with fracking sand must be unloaded hot into sand motors, this mechanical operation is a major source of silica dust (sand containing quartz) that is expelled into the surrounding environment to which sand truck drivers and wellsite workers are exposed. Studies [37,38] show that crystalline silica is a potential risk for workers.

5. Noise pollution from fracking

Fracking is associated with increased noise pollution and the consequent risk to human health [39,40] and to the fauna species that inhabit the areas where this activity takes place [41]; however, noise studies on fracking operations are scarce.

From upstream fracking processes, seismic surveys, platform preparation, construction, operation and dismantling, resource supply vehicles and equipment operation, as well as compressors and power plants, all are sources of noise that have great potential to affect the health of workers, and reduce the comfort of wildlife, as has already been shown in migrant birds.

The fracking industry produces a complex of transient and chronic noises from different sources, which have yet to be studied in depth. Thus, as reported by Habicht, Hanson and Faeth in the platforms during fracking the noise reaches more than 100 decibels (dB) [42]; moreover, for more than two months noise levels of approximately 60–80 dB are maintained. In [2], noise measurements in fracking areas in southwestern Pennsylvania are reported. In this study, it was found that instantaneous daytime sound levels ranged from 45.0 to 61.0 dBA, while dosimeters recorded day-night levels of 53.5–69.4 dBA in open spaces and 37.5–50.1 dBA in enclosed spaces.

These results agree with [40], which reviewed an average noise level of 52 dBA with a standard deviation of 10 for several sites on a fracking platform. The noise level decreases as one moves away from the well (Within 90 m a maximum of 102 dB has been measured, and at 2 km a maximum of 52 dB) [43].

6. Discussion

Currently, most unconventional wells in which fracking is implemented extract shale gas, which is estimated to be less polluting than coal and oil. The gas recovery rate from a well ranges from 15% to 30% using fracking, while the conventional gas recovery rate with vertical wells is as high as 80%.

It should be noted that with the advent of the COVID-19 pandemic, the demand for oil worldwide was reduced, which affected the oil and gas industry; at the same time, the perception of danger increased in some communities in the face of environmental risks and, above all, in the face of emerging biological risks. Even projects such as Vaca Muerta in Argentina are now being questioned: they face higher production prices, lower sales prices, and opposition from Mapuche communities. Alfonso López Suárez estimates a drop of at least 9% in Colombia's crude oil production [44].

The documentary review points to the recognition that the different phases of the fracking technique entail latent risks for living beings. The platform workers, the inhabitants of the areas surrounding the platforms and the fauna inhabiting the ecosystems face potential dangers; on the other hand, the incidents mainly affect the workers (specifically drivers and operators monitoring the wells and storage areas).

6.1. Worker health and safety

For the fracking industry, the occupational risk, understood as the possibility of a worker suffering a certain harm derived from work, is latent. First of all, the chemical agents in the fracking fluid are not fully known, so their toxicology is not clear. On the other hand, although some reports of explosion incidents due to the accumulation of gases are known, it is car accidents with 30% and blows with objects with 20% that are at the top of the causes of fatalities in workers in the sector [45].

Thus, the CSB (Chemical Safety and Hazard Investigation Board) in a report on a gas well blowout at Pryor Trust Well 1H-9U occurred in 2018 cited [46] to point out that for the period 2005–2009, this industry presented an occupational fatality rate 2.5 times higher than the construction industry and 7 times higher than the general industry.

Few studies were found on the harm derived from fracking work, specifically occupational diseases. In relation to exposure to radon gas, studies were found that associate it with lung cancer [47,48] and studies that warn about the health impacts of chronic noise from compressors [49].

6.2. Vulnerability of local fauna and flora

Both the increase in light, noise and dust, as well as the water produced by hydraulic fracturing containing chemical contaminants, pose risks to wildlife. Lee and collaborators [50,51] warned about the risk to migratory birds, which leads us to review possible risks of fracking in areas such as the Middle Magdalena Valley (**Figure 2**) and the Special District of Barrancabermeja where pilot projects for fracking have been assigned, specifically in the area where the geological formations La Luna and Tablazo converge, where the potential extractable resources are gas and oil at depths of 1300 to 5700 m, with a net thickness of 70–170 m.

Figure 2. Unconventional reservoir potential in the Middle Magdalena Valley Basin in Colombia.

The Barrancabermeja oil zone is home to a rich aquifer system with several marshes (El Llanito, Miramar, San Silvestre, Juan Esteban), making it a habitat of great biodiversity of birds, mammals, and fish. But due to the confluence of anthropogenic activities - the petrochemical industry, agribusiness, tourism, hunting and fishing and the presence of a sanitary landfill and the illegal dumping of hydrocarbon residues that put pressure on the San Silvestre swamp, several species “including iguanas, turtles, otters, babillas, and caimans” are greatly diminished.

Additionally, species unique to the region such as the brown spider monkey (Ateles hybridus) [52] and the manatee (Trichechus manatus) [53], both in danger of extinction, are being affected (See **Figure 3**).

Figure 3. Brown spider monkey “teles hybrid S).

It should be noted that the noise and light from fracking operations disturb birds, many of which are pollinators, which ends up impacting the flora, already affected as a result of oil spills and upwelling (for example, aquatic plants or macrophytes that participate in the carbon cycle of aquatic ecosystems) (See **Figure 4**).

Figure 4. Manatee (Trichechus manatus).

7. Conclusions

Air pollution, gas emissions “such as benzene, radon and BTEX type compounds” and noise pollution are unavoidable facts in drilling and fracking works, therefore continuous and systematic monitoring actions must be developed throughout the life cycle of the wells in which this technique is applied. In Colombia, the areas prioritized for fracking pilot projects are located in a tropical altitude and warm thermal floor, areas with great ecosystemic wealth. To protect them, it is necessary to develop detailed studies -by operations and equipment- to determine the variables that may affect people's health and animal comfort, in addition to completing the environmental baselines already pointed out by several researchers in the guidelines to carry out PPII activities.

Most published articles on fracking impacts refer to the hazard and risk potential, very few present evidence of risk events materialized by the development of this activity, as do accident reports that are little circulated or have a smaller audience. Crystalline silica, particulate matter and benzene are less studied risks that require more attention. Studies on radon contamination in storage areas show the need to define surveillance and control measures, as well as the need to develop analyses on possible health damages for platform workers.

Noise and vibration in fracking zones affects people and wildlife species; this impact should be considered in potential projects in the tropics. The geography and ecology of the Middle Magdalena Valley and Cesar-Rancheria basins should be sufficiently described before proceeding with fracking pilot projects.

Intensive surveillance (control and measurement of variables) and transparency in the reporting of information are recommended for the local context.

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