Shale Gas: Hydrofracking, its Effects and Possible Remediation

Waheed Gbenga Akande

Abstract Unconventional petroleum and natural gases such as shale oils and shale gases have been considered in recent times as the alternative energy sources to augment global conventional petroleum reserve to keep pace with global energy demand considering enormous reserves of these resources all over the world. The United States of America is the pioneer in unconventional petroleum exploration, development, and production, and the lessons learnt in the US are now being transferred to other parts of the world to develop their unconventional petroleum resources. Horizontal drilling and hydraulic fracturing (hydrofracking or hydrofrac) are the emerging technologies to exploit gas shale resources. Hydraulic fracturing operations for shale gas production have certain effects such as surface water and groundwater contaminations, undue pressure on public water supply, greenhouse gas emissions, and seismic events on the local environments, man, ecosystems, and groundwater systems; and the severity of these impacts depends on chemical composition of shales/shale gases, wellbore integrity, chemicals used in fracking fluids and management of various stages of shale gas development and production. It is suggested as a remediation measure that the environmental impact assessment (EIA) should be carried out by interested companies in shale gas business and their reports submitted at an early exploration stage to the host government or relevant agencies. Environmental-related legislation and regulation as well as safety guidelines for drilling and production of shale gas such as disclosure of chemicals in fracking fluids should be enforced. Intensive and collaborative researches should be supported by various energy stakeholders such as governments, academia, shale gas prospectors, and non-governmental organizations (NGOs) to understand the chemical constituents of shale deposits and shale gases, monitor the impacts of shale gas extraction on the groundwater system, and determine possible connection between hydrofracking and seismic events. It is concluded that with this intensified research into shale gas exploration, development and production in mind, better technologies which are more environmentally friendly to exploit gas shale assets will soon emerge.

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Introduction

The current trend in decline in global petroleum reserve and inability of the conventional petroleum and natural gases to keep pace with global energy demands has necessitated looking for other alternative energy sources. Recently, this has made oil and gas industries, academia, researchers, and governments across the globe to intensify their efforts in real-time investments in unconventional petroleum sources such as shale oils and shale gases. These efforts are justified considering the proved enormous reserves of unconventional petroleum in many parts of the world such as in the United States of America, European countries, and even now in developing nations. The United States of America has been in forefront in the business of unconventional petroleum with the giant strides to develop the resource beginning as far back as the late 1970s (Wang and Krupnick 2013). Shale gas production accounted for only 1.4 % (approx. 7.6 billion cubic meters, 7.6 bcm) of total US natural gas production in 1990 (EIA 2010), 1.6 % in 2000 (Wang and Krupnick 2013), 4.1 % by 2005 (Wang and Krupnick 2013), 14.3 % (93 bcm) in 2009 (EIA 2010b), and skyrocketed to an astonishing 23.1 % by 2010 (Wang and Krupnick 2013). This remarkable growth of shale gas development and production in the United States remains an impetus for increasing interest in exploring shale resources in other parts of the globe. A number of countries, including China, Mexico, Argentina (Gonzalez 2012; Orihuela 2012), Poland, India, and Australia (IEA 2012) are currently considering or are in the process of developing their own shale gas resources (Wang and Krupnick 2013).

Shale gas has been defined as a natural gas that is trapped within fractures and pore spaces within fine-grained sedimentary shale rocks (Llewellyn 2009). As opposed to conventional petroleum where we have independent petroleum sources (source rocks) and reservoirs, and the petroleum expulsion and migration take place from the former into the latter; hydrocarbons mainly natural gas of predominantly methane composition are only stored in the matrix of unconventional petroleum sources (shales).

Shale gas is one of the unconventional petroleum sources (others being coal bed methane, CBM, shale oil, tar sands, gas hydrates, tight gas, etc.) that currently attract attention to increase global petroleum reserve base. Shale gas extraction and its operational requirements are to some extent slightly different from those of other unconventional petroleum sources. The advances in technologies have revolutionized the way shale gas extraction is now being carried out worldwide. Hydraulic fracturing, hydrofracking or hydrofrac, has become an emerging technology that is now being employed for shale gas extraction. This chapter looks into the aspect of shale gas extraction using hydrofracking, its effects on man, local environments, and the ecosystem in the shale gas fields arising from both natural and mechanical defects during methane gas extraction, possible environmental implications and remediations.

Principle of Hydrofracking and Shale Gas Extraction

The principle of hydrofracking is based on creation of macrofractures in shale source rocks to connect pores, fissures, and microfractures thereby making migration and flow of shale gas to the wellbore possible. Two complementary drilling techniques have been identified and are now in use for shale gas extraction, and these are horizontal drilling and hydraulic fracturing (Fig. 1). These techniques are in addition to traditional vertical well drilling which the operation normally starts with. Figure 2 shows different components of a modern shale gas well.

According to the Tyndall Centre (2011), these drilling techniques are used in combination with one another to extract shale gas and they are briefly explained below:

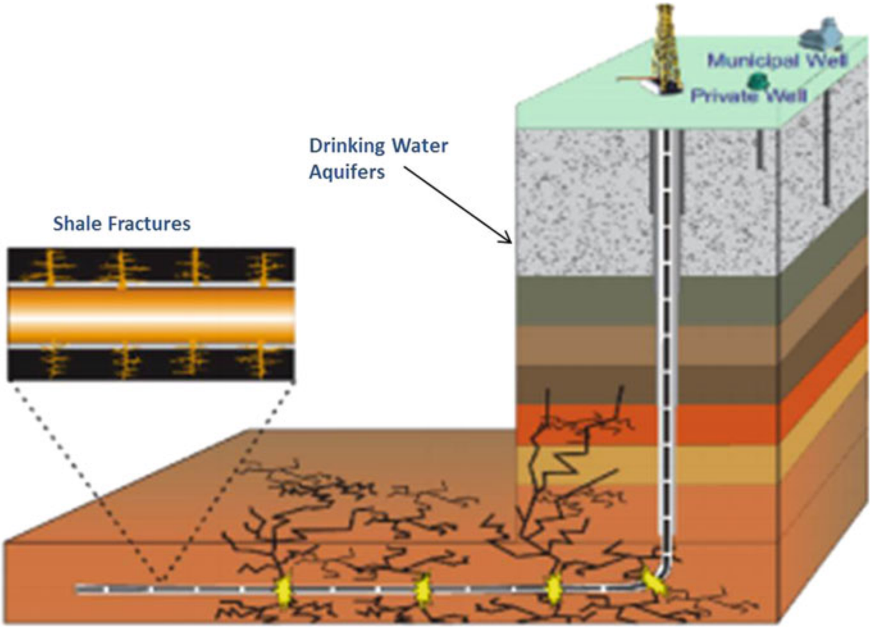

Fig. 1 Diagram of horizontal fracking (*Source* EPA)

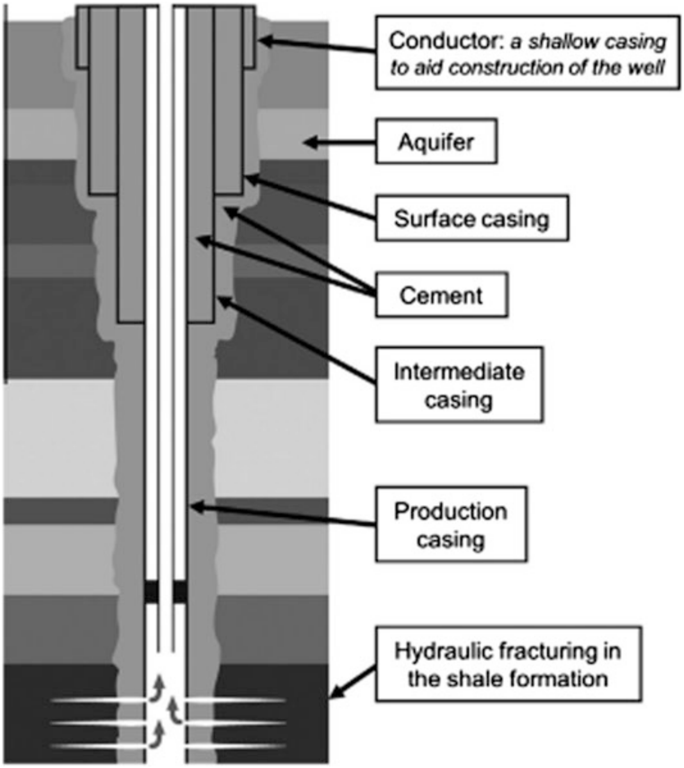

Fig. 2 Typical modern design of shale gas well (based on Cuadrilla design 2012)

> Horizontal drilling is used to provide greater access to the gas trapped deep in the producing formation. At the desired depth, the drill bit is turned to bore a well that stretches through the reservoir horizontally, exposing the well to more of the producing shale;
>
> Hydraulic fracturing is where fluid (water, sand, and other substances) are pumped into the well at pressure to create and increase fractures in the rock. These fractures start at the injection well and can extend a few hundred metres into the reservoir rock. A material such as sand holds the fractures open, allowing hydrocarbons to flow into the reservoir rock. Between 15 and 80 % of the injected fluids are recovered at the surface. Fluid that returns to the surface is captured, treated and disposed of and gas that flows to the surface is captured and used for electricity generation or is put into the mains supply. It is also possible to 'frack' a well several times in its lifetime to increase yield.

In shale gas extraction, the injected fracturing fluid which is usually water-based with small amounts of silica (sand) or similar particulate matter are normally introduced into the source bed (target formation) so as to prop open the fractures. The fractures may be in order of a few micrometers in width and usually limited in length to a few tens of meters. Upon creation of an artificial fracture, individual molecules of shale gas that are far away from the well can find their way to the fractures, and once there, can migrate quickly through the fractures to the wellbore

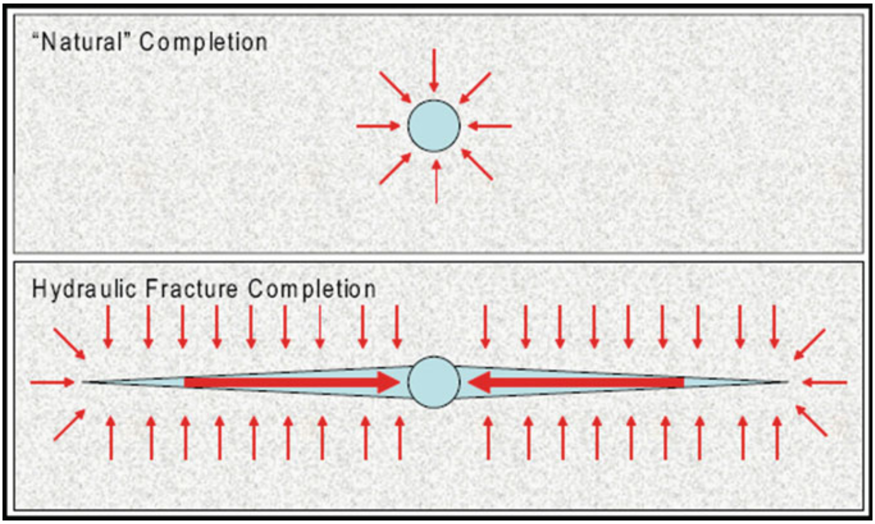

Fig. 3 Illustration of a fractured and a nonfractured well. The *top portion* of the figure shows "traditional" nonfractured well, where the *red arrows* represent the flow of fluid to the circle which represents the well. The *bottom part* depicts that by creating an artificial fracture, individual molecules that are a long distance from the well can find their way to the fracture, and ultimately travel quickly through the fracture to the well (API Guidance Document HF1, 2009)

(Fig. 3). Further details of hydraulic fracturing operations can be found in API Guidance Document HF1 (2009).

Effects of Hydrofracking Process

The resulting effects of the operations involved in shale gas extraction on man and ecosystems as well as groundwater systems depend on certain factors. The most important of these is the chemical composition of the source rocks (shales). Source composition is also dependent on the depositional environments ranging from continental through lacustrine to marine environments. For instance, marine shales are likely to be richer in sulfur than lacustrine shales; and this will have a significant effect on the fracturing environment and ecosystems. Thus, the compositions of shales and resulting shale gas could vary widely. Hydraulic fracturing fluid compositions and the manner in which the resulting wastewater is managed and disposed are other key factors. The overall management of all the phases involved in shale gas extraction, development, and production is also critical. These factors may cause hydrofracking operations to pose serious problems to man, ecosystems, and groundwater systems.

Although hydraulic fracturing has been described as an established technology (The Royal Society and the Royal Academy of Engineering 2012), concerns have been expressed that the extraction of unconventional gas through this process may be detrimental to both the environment and local communities (Tyndall Centre 2011). A number of possible environmental impacts have been identified and these are discussed below.

Environmental Impacts Related to Water Used in Shale Gas Operations

It has been reported that shale gas development requires large volumes of water (e.g., Tyndall Centre 2011). It follows that in the regions where the water resource is not readily adequate shale gas exploration may put the resource under pressure. As the technology for shale gas development is being exported to the developing countries where in most cases water supply is grossly inadequate, the activity may further reduce the volumes of water available to people for their various daily needs. Access to water sources is likely to become more of a constraint for operators in arid regions in particular facing growing depletion of water resources, and in areas where water flows and availability follow seasonal variations (Stark et al. 2012).

Environmental impacts associated with water and drilling operations include cross-contamination of underground aquifers due to poor borehole construction when the integrity of wellbore casing is compromised; pollution from an unexpected release of gas or fracturing fluids (especially surfactants, biocides, and mineral acid for acidizing process) into other parts of the water environment can adversely affect animals and ecosystems due to their toxic nature; and surface contamination from the uncontrolled disposal of liquid (wastewater) or solid waste containing potentially harmful substances; and abstraction of uncontrolled volumes of water which could lead to an unacceptable impact on the water environment and its ecosystems.

According to Stamford and Azapagic (2014), although the impacts of fracking fluids on groundwater system is still a matter of debate in the literature, the impacts from fracking fluid are centered on the potential contamination of groundwater owing to accidents and/or malpractice. This could involve contamination with fracking fluid components or naturally occurring substances that have been mobilized by the extraction process, such as heavy metals (Stamford and Azapagic 2014).

Environmental Impacts Related to Induced Seismic Events

The fracturing operations for shale gas exploration have also been suspected to be related to the occurrences of low magnitude seismic events such as earthquakes. A good example in this regard was a recent report produced for the Department of

Energy and Climate Change (DECC) in 2012 which concluded that the seismic events recorded at Preese Hall in Lancashire were directly connected to the fracturing operations. Stamford and Azapagic (2014) also reported that in the UK, low-intensity earthquakes (measuring 2.3 and 1.5 on the Richter scale) were observed in April 2011 due to fracking in North West England which led the government to suspend shale gas extraction nationally from May 2011 to December 2012, because there was an impression that the seismic event was attributable to hydraulic fracturing. Though real data evidences are to yet be provided by the researchers or seismologists in this field, presupposed induced seismic events could cause damage to facilities and even death depending on the severity of the events.

Environmental Impacts Related to Greenhouse Gas Emissions

Shale gas exploitation and production activities have a potential for increased greenhouse gas emissions from fugitive releases. The role of methane gas in greenhouse and global warming phenomena is often underrated compared to carbon dioxide. However, methane could be a more potent greenhouse gas than carbon dioxide. It has been reported that fugitive releases of methane during shale gas operations is higher than those of conventional gas but less than from coal, and this observation awaits empirical data to substantiate it (EU Report for European Commission 2012). Related to this is the impact of the shale gas compositions. Shale gases containing appreciable amounts of sulfur or hydrogen sulfide and nitrogen can be oxidized into respective acids thereby causing havocs to facilities especially if they are designed by not taking this factor into consideration. In addition, if these gases are dissolved in or exsolved into the groundwater, they are capable of contaminating the water or increasing the acidity of the aquifer systems. Finally, if they find their way into the Earth's atmosphere they play a role of greenhouse gases in the form of oxides of sulfur (e.g., SO_2) and nitrogen (e.g., NO_2).

Remediations

In order to nip the environmental impacts of shale gas exploitation, development, and production in the bud, the environmental impact assessment (EIA) of the shale gas development on sites is critical. It is the role of the host government and its agencies, and other relevant stakeholders in environmental-related matters to request for the EIA Reports from the companies licensed with shale gas plays at an early exploration stage before actual development and production commence. These government agencies should mandate the shale gas operators to disclose the chemicals of the fracturing fluids. This is already a common practice in the United States of America and some European countries (e.g., Poland now makes fracking fluid chemicals disclosure mandatory). Although currently not obligated, operators in South Africa are committed to voluntarily disclose the chemicals used in hydrofracking and it is expected that in the near future, many other countries especially China and Argentina shall embrace some level of disclosure (Stark et al. 2012).

An adequate knowledge of the chemical composition of the shale deposits is very paramount to prediction of the compositionally related impacts of shale gas exploitation on man, ecosystems, and groundwater systems and this has to be established. The shale gas fields should be put into the regional geology context in order to understand the depositional environment of the shale source beds. This should also be approached through chemical analysis of the shale formations. The analytical results from the chemical analysis also have certain implications for shale gas development such as shale gas well design and completion.

With respect to the disposal of excess fracturing fluid and residual fluids produced during shale gas production, wastewater ponds should be discouraged while closed metal tanks should be made available for temporary storage of wastewater before it is treated for disposal or reuse. This is because the wastewater ponds and open pits can lead to local environmental damage should the pits overflow in the event of heavy rainfall (POSTNOTE 374 April 2011). Closed metal tanks are now made compulsory for temporary storage of wastewater in the UK (The Royal Society and the Royal Academy of Engineering 2012). It is currently agreed that shale gas extraction process requires huge quantities of water. In order to lessen this burden on public water supply, researchers should continue to advance the technology (hydraulic fracturing) for shale gas exploitation to reduce its water requirement. Appropriate legislation and regulation should be put in place to deter fugitive emissions which are potential greenhouse gases during drilling and production of shale gases. Finally, the governments, academia, shale gas prospectors, energy operators, and non-governmental organizations (NGOs) should support and fund researches on the possible linkage between shale gas exploitation activities and seismic events.

Conclusions

This chapter appraised hydraulic fracturing as an emerging technique for shale gas exploitation and development and the effects of the overall processes on the local inhabitants, man, ecosystems as well as surface and groundwater systems. The identified effects of hydrofracking include pressure on public water supply and surface water, groundwater pollution or contaminations from wastewater and residual fracking fluids, release of fugitive gases which are potential sources of greenhouse gases into the Earth's atmosphere, and seismic events.

It is suggested as a remediation measure that the environmental impact assessment (EIA) should be carried out by the companies licensed to develop gas shale deposits and their reports submitted at an early exploration stage to the host government or relevant agencies, and this has to be concluded before actual development and production of shale gas begins. Legislation and regulation and safety guidelines for drilling and production of shale gas such as chemical in fracking fluids disclosure should be enforced. Researches should be supported by various stakeholders such as governments, academia, shale gas prospectors, energy operators, and non-governmental organizations (NGOs) to understand the chemical constituents of shale deposits and shale gases, monitor the influence of shale gas exploitation on the groundwater system, and determine possible connection between hydrofracturing and seismic events. It is believed that with dogged researches to review and advance the current hydraulic fracturing technique, better technologies which are more environmentally friendly to exploit gas shale assets will soon emerge.

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