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Perspectives for use of hydraulic fracturing in oil and gas production

Perspectivas da produção de óleo e gás pelo método de fraturamento hidráulico

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Abstract

Hydraulic fracturing emerges currently, all over the world, as one of the more strategic techniques used by companies in the oil exploitation sector. This technique is characterized by its high productivity and profit in relation to conventional methods of hydrocarbon exploitation. However, in many countries, as is the case of Brazil, there are several divergences considering the employment of this methodology. Many renowned researchers attest that there are several irreversible environmental impacts generated by the use of this methodology. Among the main environmental impacts are the risk of groundwater level contamination, the risk of surface subsidence, and the risk of the environment contamination with fluids used in the process of the oil and gas extraction.

Keywords: hydrocarbons; hydraulic fracturing; exploitation, environment.

Resumo

A técnica de estimulação por fraturamento hidráulico desponta, atualmente, como uma das principais estratégias utilizadas pelas empresas do setor de exploração de petróleo para o aumento da sua produção. Contudo, em alguns países, como é o caso do Brasil, existem discordâncias quanto à empregabilidade desse método, tendo em vista, sobretudo, os prováveis riscos que podem estar associados à utilização do mesmo. Verificou-se que, em relação à questão econômica, as principais vantagens estão relacionadas ao aumento da produtividade. Contudo os pesquisadores salientam que as principais desvantagens em relação a esse método estão relacionadas às questões ambientais. Entre os principais riscos, estão a possibilidade de contaminação da água e do solo, os riscos de subsidência, a contaminação do meio com os fluidos provenientes desse processo, entre outros.

Palavras-chave: *hidrocarbonetos; fraturamento hidráulico; explotação, meio ambiente.*

1. Introduction

The modern society has experienced a constant and inevitable dilemma regarding reduction in use of non-renewable resources and the adoption of cleaner technologies. Thus, the oil industry has invested in new technologies, such as the technique of hydraulic fracturing or fracking in order to reduce financial and labor costs, and maximize the production of hydrocarbons, particularly natural gas. The first references concerning hydraulic fracturing was reported in l947 in a sedimentary rock field of oil in the United States and sometime after (in 1954) in the former Soviet Union. Currently, this methodology is used extensively in several producing fields in order to stimulate hydrocarbon reservoirs (SILVA *et al*., 2002). This technique allows an increase in the productivity of an oil well, doubling or even quadrupling rate of productivity. Data from the United States show that the use of this methodology expanded rapidly after 2005, when the EPA (U.S. Environmental Protection Agency) authorized the use of the hydraulic fracturing. Since this date, there has been a significant increase in the number of wells drilled (WENZEL, 2012). Table 1 shows the evolution of the production of shale gas in the USA in the period 2000-2010.

Year	Shale gas production
2000	0.1
2001	0.2
2002	0.25
2003	0.3
2004	0.4
2005	0.55
2006	0.7
2007	1.3
2008	2.2
2009	3.25
2010	4.3

Table 1
U. S. shale gas production over the last decade (10^{12} ft^3)

Source: WENZEL (2012)

In North America, almost 70% of the natural gas production will be produced by hydraulic fracturing in the near future. Hydraulic fracturing and horizontal drilling apply the most advanced technologies and are economically the most viable in terms of oil and gas recovery from the shale rocks. In the United States, 45% of the domestic production of natural gas and 17% of oil production would not have been recovered (in a period of 5 years) if hydraulic fracturing had not been used. (THE ROYAL SOCIETY, 2012). Shale mineral deposits such as Bakken, Barnett, Montney, Haynesville, Marcellus and some recently denominated ones such as Eagle Ford, Niobrara and Utica have been drilled, completed and fractured using this method (McNutt, 2011). Hydraulic fracturing is being currently used in 90% of oil and natural gas wells in the United States (WENZEL, 2012). Table 2 shows an estimate of mineral reserves (in 1012 ft3) that can be recovered by using hydraulic fracturing technique all over the world.

Country	Reserves technically recoverable by fracking
China	1275
USA	862
Argentina	774
Mexico	681
South Africa	485
Australia	396
Canada	388
Libya	290
Algeria	231
Brazil	226
Poland	187
France	180
Norway	83
Chile	64
India	63
Paraguay	62
Pakistan	51
UK	20

Table 2
Estimate of hydrocarbons reserves technically recoverable by using hydraulic fracturing technique all over the world (in 10^{12} ft^3)

Source: WENZEL (2012)

However, there are many uncertainties about the environmental damage of this methodology and mainly about the harmful effect that hydraulic fracturing may have on the environment as a whole including the surrounding ecosystems (MCNUTT, 2011). According to WELLE (2013) hydraulic fracturing is yet a very controversial theme worldwide. Some European countries such as Ireland, Czech Republic, Romania, Germany and Spain have recently declared a "moratorium" relating to the use of this methodology. In Brazil, the Brazilian Petroleum Agency - ANP- is nowadays monitoring these issues, and several Non-Governmental Organizations (NGO's) are also discussing this theme in their agenda. The non-governmental agency Greenpeace has officially pronounced itself to be against the use of the method.

Hydraulic fracturing is a stimulation technique used to increase the productivity of oil wells which basically consists of injecting a pressurized fluid into the rock formation (around the well) in order to create new pathways to facilitate the hydrocarbon flow in the well.

A key element for successful hydraulic fracturing is a properly constructed well. During the drilling and completion process, appropriate techniques should be used to isolate the groundwater to avoid damages to the reservoir and to the well.

The more critical aspects of a well construction are the selection and application of the appropriate casing and cementation. To provide the necessary protection, three steps are usually taken into account to isolate the well interval of rock that has been penetrated during the drilling process.

In the phase I, a drill hole is made until the base of the soil or unconsolidated material. A steel casing or conductor tube is inserted into the hole and cemented in place. At this stage, an artificial barrier is automatically created to prevent the mixture of fluids, gravels and sands and to avoid the falling of these materials down in the hole. The well is then drilled until the depth defined by the regulatory agencies (EPA in the USA) obeying environmental aspects. This depth is generally below the base of groundwater and in a region of the rock mass with rocks of good quality. In phase II, a second set of steel casing (surface casing) is cemented to the interior of the well throughout the entire perforated vertical interval. In phase III, the well is drilled until the total depth. In some cases, depending on the total depth and azimuth of the well, a set of linear intermediary casing can be inserted and cemented into the well. Once the well is drilled until the depth of the intersection zone containing the hydrocarbon, other steel tubes are inserted into the well. The second (or third) set of tubes is usually cemented in place to isolate the hydrocarbon zone. In some cases, the covering is cemented in place and above the intersection zone to avoid damage to the oil formation. Figure 1 shows an example of the construction of a well for application of the hydraulic fracturing technique.

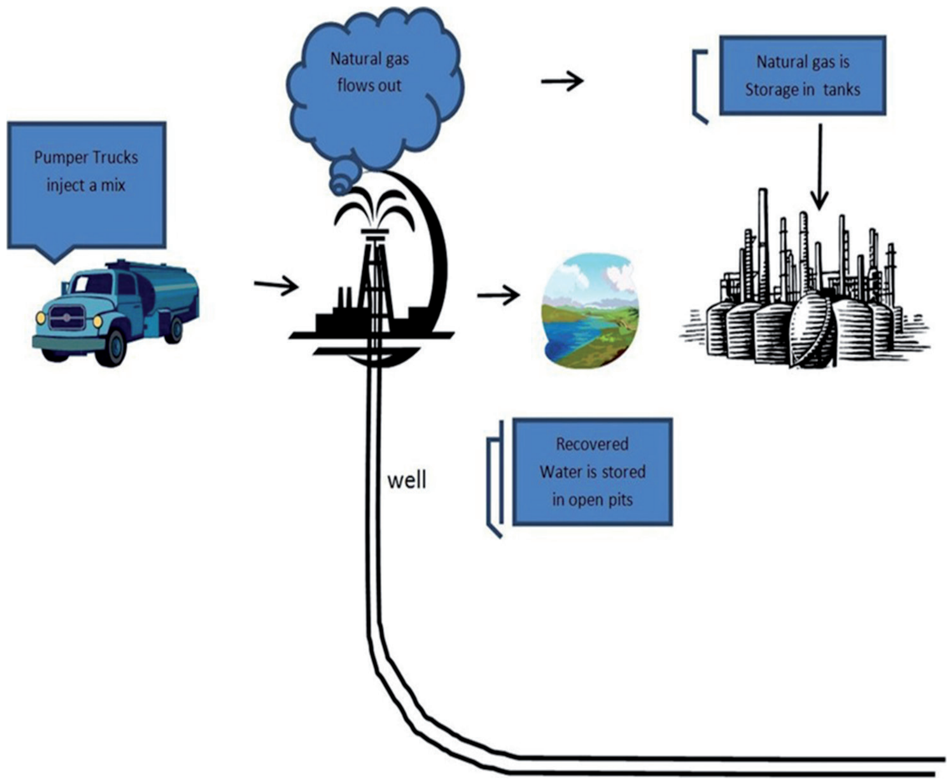

Figure 1
Example of hydraulic fracturing for shale development

During the productive life of an oil well interventions are always necessary to maintain or even improve the productivity. Thus, the technique of hydraulic fracturing has been presented as an exceptional alternative in terms of productivity improvement and costs reduction. In the oil industry stimulation operations such as hydraulic fracturing, are widespread. However, due to the different characteristics of each formation or project, not all wells are suitable to be stimulated. Thus, within the same oil field, wells may be or not may be undergoing this type of operation.

Although the operations of well stimulation are practiced frequently, the problem of selecting wells is still relevant and is increasingly gaining importance in the current mineral scenario. The process of selecting wells for stimulation involves the analysis of various parameters and depends on technological resources. An incorrect interpretation of the parameters of the well or a failure in the planning of the operation may cause serious consequences in the production of an oil field. The use of hydraulic fracturing of a rock formation with success is still a great challenge to mining and petroleum engineers. Several researches has been made in the last decade using artificial intelligence techniques to map existing data and build productive artificial systems in order to try to maximize the results of specific mine operations. Nevertheless, it should be noted that there is still no consensus among specialists regarding the use of this technology.

Many researchers allege that this method can offer various risks to the environment. Experts warn that among the main environmental impacts are contamination of water and soil, risk of explosion because of methane gas release, excessive water consumption, and use of chemical products in the fluids used in the technique. Some technicians also attest that this technique can indirectly induce tectonic movements.

2. Some definitions

Hydraulic fracturing is a stimulation technique used to increase the productivity of oil wells. This technique is the most effective treatment for sandstone layers found in older and consolidated sediments. The main reasons for the increase of productivity of this technique are restructuration of the flow model, improvements in the rock mass permeability and possibility of reaching distant areas with better permeability and more porous conditions. In naturally fractured and lenticular reservoirs, this technique facilitates the interconnection between the parts. The physical principle of this technique consists in an injection of a special fluid at very high pressure in the reservoir rock, changing the state of tension in the rock mass and provoking the opening and or/ expansion of the existing fractures or discontinuities of the original rock mass. To sustain the openings, a supporting agent is injected to maintain the fractures open, creating artificial permeability. This process is done specially in oil fields that have already reached their peak of production or have low permeability, thus presenting a low recovery factor.

The technique is described as follows: a hydraulic fracturing is formed by pumping a fracturing fluid into the well at a pressure high enough to increase the pressure in the well, exceeding the fracture gradient (pressure gradient) of the rock mass. The fracture gradient is defined as the increase in pressure per unit of depth, due to the specific weight of rocks and is usually measured in pounds per square foot or bar per meter. The fracture must be sufficiently permeable to allow the flux of formation fluids into the well. Formation fluids include gas, oil, salt water, fresh water and other fluids introduced into the formation during fracturing. The hydraulic fracturing equipment used in oil fields and natural gas generally consists of a mud mixer, one or more high pressure devices, large-volume pumps and a monitoring unit. Auxiliary equipment includes tanks, one or more units for storage and propellant handling, a chemical additive unit (used to accurately monitor chemical addition), low pressure tubes, and devices to evaluate fluid density and pressure. The fracturing equipment operates over a vast range of pressures and injection rates, and can reach up to 100 MPa (15,000 psi) and 265 liters per second (100 barrels per minute). Due to its high rate of success and financial return, hydraulic fracturing treatments are usually performed as soon as the drilling phase is made and a low permeability of the reservoir rock formation is confirmed.

3. Potential for gas exploration in Brazil

The International Energy Agency (IEA) classifies Brazil in 10th position in the ranking of the world's largest reserves of shale gas.

The Brazilian Agency of Petroleum made a public auction for shale gas exploration on November 28, 2014. On this occasion ANP designated 240 blocks for shale gas exploration in a group of 7 geological basins. The geological basins available in this auction were: Parecis, Parnaíba, Recôncavo, Paraná, São Francisco, Acre and Sergipe. As a result, only 72 blocks were auctioned including 49 to Petrobras.

According to an ANP evaluation, this method can certainly increase the production of natural gas in Brazil, but as yet, it still has high costs and complex operations to be adapted in the country over the next years (WELLE, 2013).

ANP data demonstrate the use of conventional hydraulic fracturing operations in Brazil since 1950. These data reveal that more than six thousand operations were performed using low pressures and flow rates without severe incidents. These data also reveal what the Brazilian experience lacks in terms of high pressures and volumes, as is the case of the USA where shale gas represented more than 20% of the gas production in 2010 (WELLE, 2013).

4. Results

The image profiles are similar to "photographs" of the wall well and are based on the resistive and acoustic characteristics of the rock formations. The analysis of these images generate much information to be used in reservoir characterizations, such as layer inclination, the occurrence of fractures and discontinuities in general, underground landslides, magnitude and direction of in situ stresses, lithology, geological discordances, areas with thin layers, low porosity and underground caves. This information can thus be used in conjunction with other profiles, samples and production reports to model the reservoirs (FÉLIX *ET AL.*, 2008).

LAGE *et al.* (2012) executed a study related to the exploitation of unconventional gas in view of the American experience, and analyzed the perspectives for the market for the Brazilian reality. Based on this study, they concluded that the unconventional reserves mapped in Brazil must play a very important role in the energetic matrix of the country, considering that the reserves are located onshore and can contribute to the gas market, internalizing the use of gas all over the country.

Gomes et al. (2005) described a gel based on non-ionic surfactants used for hydraulic fracturing.

SANTOS AND CORADESQUI (2013) made an analysis of the economic viability of shale gas production based on the case of Fayetteville, in the United States. The authors concluded that the additional costs due the use of hydraulic fracturing can be high. Considering the gas prices of 2013 the profitability of new projects for the production of shale gas in the United States was questioned by the referred authors.

5. Conclusions

There are only a few studies related to hydraulic fracturing as an alternative to conventional exploitation of hydrocarbons in Brazil.

Hydrocarbons frequently accumulate in an oil trap after the geological processes of formation and migration. The reservoir is the portion of this trap containing oil and gas that is hydraulically connected and forms a unified system. The reservoir rock, in principle, can have any origin or nature, but to constitute a reservoir, the rocks must present voids (porosity) and these voids must be interconnected to provide the adequate permeability (SANTOS AND CORADESQUI, 2013). As referred to by the aforementioned authors, conventional reservoirs rocks are porous and permeable reservoirs that contain fluids of low and medium viscosity. Sandstones and limestone are typical examples of conventional reservoir rocks.

High costs and complexity production in the oil industry has stimulated the development of new techniques to substitute the conventional methods. Hydraulic fracturing is an excellent example of an unconventional method because it allows oil and gas extraction from some wells that would be economically unviable by traditional methods.

According to American Society of Petroleum Engineers, around 2.5 million procedures of hydraulic fracturing were done worldwide, of which one million were only in the United States of America. Furthermore, tens of thousands of horizontal wells have been drilled in the last 60 years (WOOD AND ROJAS, 2000).

According to GROTHER (2000) his technique has great economic and social potential for hydrocarbon production in the USA. The main benefits would be more profits for landowners, oil companies and investors, together with the creating of more jobs. (FELIX *ET AL*., 2008).

Most environmentalists believe that the most significant environmental risks are the contamination of groundwater due the opening of an unsuccessful well “blowouts”, generating leaks and spills of wastewater and chemicals. In their defense, oil companies argue that the method of hydraulic fracturing has been used safely for decades (SANTOS AND CORADESQUI, 2013).

Another public concern is the earthquakes. Seismic monitoring is an essential tool to ensure that hydraulic fracturing induces micro-seismic activity (only within the reservoir to be explored). The society's confidence in the safety of hydraulic fracturing would be higher with a systematic seismic monitoring and publication of the results for the inhabitants (SANTOS AND CORADESQUI, 2013). Although the process of hydraulic fracturing creates a large number of micro-seismic events or micro tremors in the earth, the magnitudes of these are too small to be detected at surface. The larger micro-earthquakes have a magnitude of only about 1.6 on the Richter scale (FERNANDES, 2008).

Another important environmental impact is related to the fluids used in the stimulation process. The fluids used in hydraulic fracturing are typically composed of more than 98% of water and sand. The other reagents are chemicals used as thickeners and friction reducers to protect the casing. Preventive measures should be taken to avoid that these chemicals impact surface water and soil during transportation, storage and disposal. The usual percentages of the substances in the stimulation fluid are water and sand (99.51%), and other chemical additives in general (0.49 %) as listed in Table 3.

Table 3
Fluids composition
of the hydraulic fracturing

Solution	Percentage
Water and sand	99.51
Acid	0.123
Petroleum distillate	0.088
Isopropanol	0.085
Potassium chlorid	0.06
Guar gum/hydroxyethyl cellulose	0.056
Ethylene glycol	0.043
Sodium/Potassium carbonate	0.011
Sodium chloride	0.01
Borate salts	0.007
Citric acid	0.004
Dimethyl form amide	0.002
Glutaraldehyde	0.001

Source: DOE & GWPC (2009)

Industries, regulatory agencies and environmentalists believe that these problems can be solved with the use of the best practices of exploration, drilling and exploitation. Thus, researches and investments in new technologies, together with monitoring and strict regulations, are essential. Certainly, the major challenge for all involved in the shale gas and oil production in the coming future will be to ensure the protection of the environment, health and public safety while the shale exploitation increases (SANTOS AND CORADESQUI, 2013). The United States is the best example and has been successfully applying this technique for decades.

The main economic advantages of this method are high productivity, job opportunities, and increased income for the whole society, among others.

6. References

DOE & GWPC: Modern Gas Shale Development In the United States: A Primer. U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory. Ground Water Protection Council. Oklahoma, USA. 2009. http://energy.gov/sites/prod/files/2013/03/f0/ShaleGasPrimer_Online_4-2009.pdf, August, 2014.

DOUGHER, R. Natural gas and America's energy future. http://www.glyfac.buffalo.edu/mib/course/marcellus/natgasenfuturerd.ppt, August, 2014

FELIX, F., NASCIMENTO, E., BORBA, C. Perfis de imagem de poços de petróleo. **Cadernos de graduação – ciências exatas e tecnológicas**, v. 1, n. 16, p. 61-78, 2008.

FERNANDES, A. J. Aquíferos fraturados: uma revisão dos condicionantes geológicos e dos métodos de investigação. **Revista do Instituto Geológico**, v. 29, n. ½, p. 49-72, 2008.

GOMES, D. A. A., NOBREGA, G. A. S., PEGADO, R. M., BARROS NETO, E. L., DANTAS NETO, A. A., CASTRO DANTAS, T. N. Formulação de gel de fraturamento utilizando tensoativos não-iônicos. In: CONGRESSO BRASILEIRO DE ENGENHARIA QUÍMICA EM INICIAÇÃO CIENTIFICA, 6. , 2005, Campinas-SP. **Anais**... Campinas: DEQ/UNICAMP, 2005.

GROTHER, V.P.. **Estudo da filtração de fluidos reticulados em simulações físicas de fraturamento hidráulico.** UNICAMP, Campinas – SP, 2000. (Dissertação de Mestrado em Engenharia de Petróleo).

LAGE, E. S., PROCESSI, L. D., SOUZA, L. D. W.; DORES, P. B., GALOPPI, P. P. S. Gás não convencional: experiência americana e perspectivas para o mercado brasileiro. **BNDS Setorial: Petróleo e gás**, v. 37, p. 33-88, 2012.

MCNUTT, M. **Natural gas hydraulic fracturing-science for a changing world.** USGS, 2011. http://www.shalegas.energy.gov/presentations/Marcia_McNutt_USGS.pdf, August, 2014.

SANTOS, P. R. D., CORADESQUI, S. **Análise de viabilidade econômica da produção de shale gás:** um estudo de caso de Fayetteville. (Monografia de Graduação em Engenharia de Petróleo). Escola Politécnica, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2013.

SILVA, J. C., COSTA FILHO, W. D., NEVES, J. A. C. L. Projeto de fraturamento hidráulico em rochas cristalinas para estimulação de poços e recarga artificial na área-piloto de Samambaia, Custódia-PE. In: CONGRESSO BRASILEIRO DE ÁGUAS SUBTERRÂNEAS, 12, 2002. Florianópolis – SC. **Anais**... Florianópolis: Associação Brasileira de Águas Subterrâneas, 2002.

THE ROYAL SOCIETY. ROYAL ACADEMY OF ENGINEERING. **Shale gas extraction in the UK:** a review of hydraulic fracturing. London, 2012.

WELLE, D. **Brasil quer usar fraturamento hidráulico para explorar gás.** 2013. Disponível em: <http://noticias.terra.com.br/ciencia/brasil-querusar-fraturamento-hidraulico-para-explorar-gas,2c66901143f8e310VgnCLD2000000ec6eb0aRCRD.html> Acesso em 12 de agosto de 2013.

WENZEL, C. B. S. **A case study - hydraulic fracturing geography: the case of the eagle Ford shale, TX, USA.** 2012. (Thesis of Graduate Council). Texas State University-San Marcos, San Marcos, Texas, 2012

WOOD, B., ROJAS, J. C. A new solution for oil-based drilled cuttings disposal. Indirect Thermal Desorption in South America. **Soil Sediment & Groundwater**, Bogota, p. 27-30, 2000.

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