This research proposal is part of the final project in "Integrated Academic English Skills". In this final project, students have to read journal articles in their own fields and find a gap to propose a research direction.

Developing a Versatile Hydraulic Fracturing Fluid System for Sustainable Shale Gas Production

Group 1

Abstract

Hydraulic fracturing has been utilized as an efficient technique to extract shale gas, however, its high water consumption and toxic residuals during the process is still a complicated issue to be solved. To cope with these problems, the frac fluid, a key element of the process, is of the first priority to be considered. Therefore, we plan to develop a novel frac fluid system which is composed of bio-degradable polymers and nontoxic additives and possess high proppant capacity and high recovering rate along with extremely low waste water disposal to meet the purpose of sustainable energy source production, promising human beings a delight future.

Keywords: Hydraulic fracturing; frac fluid; bio-degradable polymer

Introduction

Hydraulic fracturing (or fracking), a novel technology to drill shale gas from the shale formation, provides additional job opportunities, abundant energy sources, and sufficient raw material for chemical industries (Sovacool, 2014). The main component of hydraulic fracturing, frac fluid, is thought to be a great impact to environment, such as contamination of shale layer (Zhou, Abass, Li, & Teklu, 2016) and toxic flowback and produced water (Jiang, Hendrickson, & VanBriesen, 2014) . Besides, the water consumption is also a critical issue for hydraulic fracturing. Clark, Horner, and Harto (2013) reported that the average water usage per job is of a significant number of 15,000,000 L.

To cope with these drawbacks of conventional fracking fluid, two novel frac fluid systems, energized (Jung et al., 2015) and VES-based fluid (Baruah, Shekhawat, Pathak, & Ojha, 2016; Wang, Liu, & Zhou, 2016; Yan, Dai, Zhao, Sun, & Zhao, 2016), are developed to solve the water consumption and environmental issues, respectively. This proposal aims to develop a versatile fracking fluid system which possesses high proppant capacity and high recovering rate as well as utilizes environmentally friendly materials for greener hydraulic fracturing process. Below, this proposal will firstly provide a review on the process of hydraulic fracturing and the composition of frac fluid, then the comparisons of different frac fluid systems, finally the methodology by four stages for developing a new frac fluid from synthesize to field operation.

Literature Review

In this literature review, there are two parts, background and comparisons of three representative frac fluid systems. In the first part, the mechanism of the hydraulic fracturing and the composition of frac fluid are provided. For the second part, three different fluid systems will be introduced and compared.

Background

From coal, natural gas to petroleum, human's desire on energy resources and carbon-related chemicals is a bottomless pit. Because of the awareness about exhaustion of fossil fuels and the raising environmental concerns, shale gas, presenting higher hydro-carbon ratio and producing less air pollutant (e.g., NOx, Sox…) during combustion process, becomes undoubtedly an transition energy resource between conventional energy and alternative energy resources (e.g., solar energy, wind power...). Trapped inside the shale formation, Shale gas is first developed in 19 centuries in U.S. by using vertical drilling process. However, due to the high cost of drilling, shale gas development have not been put into mass production until 2014, the mature of hydraulic fracturing. (Montgomery & Smith, 2010)

Hydraulic fracturing (so-called fracking) is a modern drilling and excavation method which can be briefly categorized into four steps. (Zemlak, Lemp, & Thiessen, 2002) First step is the well pad construction. Geologists and engineers have to verify whether the shale gas deep inside the shale is abundant, evaluate the commercial value of drilling, and then construct the well pad. Secondly, it comes for constructing pipe lines underneath to rock formation. To make hydraulic fracturing more efficient, there are two ways of drilling applied into hydraulic fracturing, vertical drilling and horizontal drilling. Next step is the rupture of the shale. To obtain the shale gas inside the formation, perforating gun are used to create holes on the shale. After forming holes, fracking fluids, which containing 90% of water, 9% of sand and 1% of mixed chemicals (Waxman, Markey, & DeGette, 2011), is injected into rocks at high pressure to fracture holes to fissures. Then, the injected fluid is recycled via lowering the pressure. The fracking fluid which returned immediately is called the “flowback water”, however, only 25% to 50% of fracking fluid are recovered when a conventional frac fluid system is conducted (Ferrer & Thurman, 2015; Wattenbarger & Alkouh, 2013). The third step is the extraction of shale gas. Due to the remaining fracking fluid in the shale formation, the shale gas is extracted accompanied by the fracking fluid and underground water. These accompanied fluids are long-term mixed with the deep-sited rock, which dissolved in a high concentration of inorganic substances, volatile organic gases and aromatic hydrocarbon, and these accompanied fluid are called “produced water” (Ferrer & Thurman, 2015). Eventually, the oil extraction company would discard or reuse the flowback water and the produced water. (Ferrer & Thurman, 2015)

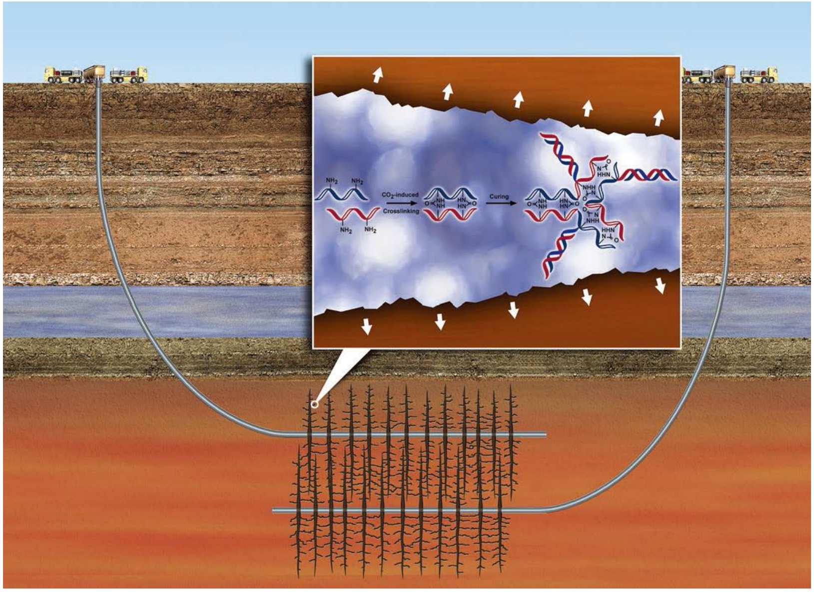

Figure 1. A demonstration of hydraulic fracturing process (Jung et al., 2015).

Due to the fast expansion in shale gas development, the dispute for environmental impact from the production of hydraulic fracturing has been debated for a period of time. There are few points needed to be taken into consideration: the large usage of water (Gregory, Vidic, & Dzombak, 2011), the leakage of methane from pipeline (Liu et al., 2016), the contaminant of the remaining fracking fluid deep in the formation (Zhou et al., 2016), and the deposal of produce water and the flowback water. (Centner, 2013)

Since the environmental concerns are mainly came from the toxicity of a frac fluid, so the components of frac fluid and its by-product becomes very crucial to those disputes. Frac fluid is mainly composed of water and sand (so-called proppant) and a small portion of functional additives (~1%). Generally, the formula of fracking fluid varies from wells to wells and from companies to companies, and most of the detailed chemical structure and component are kept confidential as the trade secret (Waxman et al., 2011). Ferrer and Thurman (2015) summarized the general chemical constituents of a frac fluid by their functions and features as listed in Table 1.

Table 1. General chemical constituents of a fracturing fluid and specific purpose for hydraulic fracturing taken from Ferrer and Thurman (2015)

Components	Chemical composition	Purpose	wt%
Acids	Hydrochloric acid, acetic acid,	Clean and help dissolve minerals and initiate cracks in the rock	0.15
Clay stabilizer	Choline chloride, tetramethylammonium chloride	Prevent swelling of clays found in shale	0.12
Scale inhibitors	Carboxylic acids and acrylic acid polymers	Prevent formation of scale (mineral) deposits in the pipe	0.09
Surfactants	Amido-amines, quaternary amines, phosphate esters, alcohol polyethoxylates, ethylenene glycols, isopropanol	Increase the viscosity of the fluid	0.075
Friction reducer	Polyacrylamide	Minimize friction between the fluid and the pipe, thus allowing to pump at a higher rate	0.07
Breakers	NaCl and KCl	Reverse crosslinking allowing the production gas to flow through	0.06
Biocides	Gluteraldehyde, quaternary ammonium compounds	Prevent bacteria growth in water	0.06
Gels	Guar gum	Thicken the water to suspend the sand and also increases viscosity of the fluid to deliver proppant more efficiently	0.05
pH adjusting agents	Sodium or potassium carbonate	Maintain effectiveness of crosslinkers	0.01
Cross linkers	Borate salts	Maintain fluid viscosity as temperature increases	0.007
Iron control	Citric acid	Prevent precipitation of iron oxides	0.006
Corrosion inhibitors	Amines, amides and amido-amines	Prevent corrossion of the pipe	0.002

Comparisons of Three Representative Frac Fluid Systems

The most efficient way to improve the efficacy of hydraulic fracturing process lies mainly on modifying the properties frac fluid. As Sang et al. (2014) claimed, "it is essential to know how fracking fluid affects the environment in case there is a spill, as this process knowledge is required to design effective ways to mitigate environmental accidents." The main characteristic for a successful frac fluid system is to transport proppants to the fractured crack efficiently. Figure 2 demonstrates how proppant help create a conductive way for shale gas and prevent crack from collapsing. Previous study has suggested that the proppant capacity of a frac fluid system determines the efficacy of shale gas extraction and the usage of water, and it is highly dependent on the viscosity and rheological properties of a system (Barati & Liang, 2014).

Conventional frac fluids thus developed with respect to high viscosity, which is largely contributed by polymer-based gels, are commonly used nowadays. These gels, however, are difficult to entirely cleaned up or recovered from the shale layer (Kang, Huang, You, Li, & Gao, 2016). Zhou et al. (2016) revealed that the remaining frac fluid could permanently damage the permeability of shale layer. Some researchers sought to reduce the environmental impact using enzyme breakers or friction reduced liquids (Barati & Liang, 2014), but these treatments could lower the proppant capacity, and so as the performance of a hydraulic fracturing process. Therefore, developing a versatile frac fluid system with high proppant capacity and high recovering rate is crucial to a process.

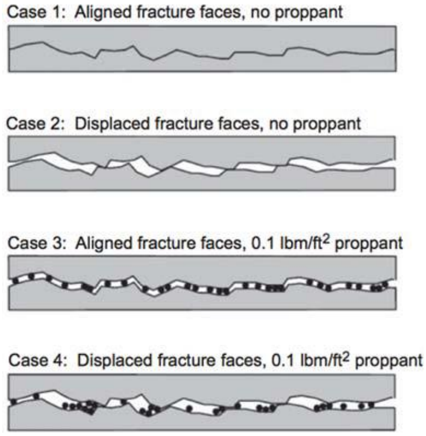

Figure 2. Proppants in a fractured crack in different cases (Barati & Liang, 2014).

Recently, two novel frac fluid systems are developed for this purpose: energized fluids and viscoelastic surfactant (VES)-based fluids. Energized fluids contain mostly gas and small water fractions, and their water requirements are significantly lower than that of the conventional frac fluids. The disadvantages of energized fluids are their complex multiphase issues and higher energy demand and transfer cost (Barati & Liang, 2014). A representative example for utilizing the energized fluid is demonstrated by Jung et al. (2015). They developed a non-toxic polymer-CO_2 mixture system with stimuli-responsive/rheoreversible properties, which helps the frac fluid recover at specific processing conditions (e.g., high temperature or high pressure) and subsequently increase the amount of flowback. This work makes significant progress in introducing the stimuli responsive idea into the developing of energized fluids.

On the other hand, VES-based fluids aim at decreasing the residual chemicals in the shale layer after the process. This type of frac fluid forms viscoelastic fluid with high viscosity because of the enormous micelles composed of high-concentration surfactants, which are easily breakable during the pressure release step. However, the viscosity of VES-based fluid is difficult to maintain because of their sensitivity to mineral ions and working temperature (Barati & Liang, 2014). Baruah et al. (2016) developed a high-viscosity and stable VES-nanoparticle system with surfactant mixture and nanoparticles which improves the stability of apparent viscosity at specific conditions. Yan et al. (2016) developed a reusable VES system with a controllable crosslink mechanism stimulated by pH values, showing good resistance to various factors such as temperature variation and salt concentration.

To conclude, the background of hydraulic fracturing process and three types of frac fluid system are briefly described in this section. From background, the public concerns are of two-fold: high water consumption and environmental issues which are highly dependent on the proppant capacity and the recovering rate of a frac fluid system, respectively. From the comparison of three frac fluid systems, the advantages and disadvantages of each system are summarized as follows: Polymer gel-based fluid possess high proppant capacity but suffer from its low recovering rate; Energized fluid has low water consumption and fair recovering rate but suffer from its high energy demand and transfer cost; VES-based fluid has high recovering rate but the viscosity are difficult to maintain. Therefore, we sought to develop a better frac fluid system which combines the advantages of energized fluid and VES-based fluid to simultaneously achieve the requirement of low water consumption and high recovering rate.

Methodology

The methodology of this proposal is divided into four major stages: (1) synthesizing bio-degradable polymer, (2) creating energized frac fluid, (3) small-scale testing, and (4) field operation. In the first stage, the chemical structure of the bio-degradable polymer is molecularly designed to have good affinity to the target surfactant micelles, then the desired bio-degradable polymer are synthesized through anionic polymerization. In the second stage, the polymer, surfactants, and the necessary chemical additive are mixed with CO_2 gas to form energized fluid. In the third stage, the rheological characterizations of the fluid are conducted according to the target environment of the shale layer (e.g., temperature, pressure, soil conditions…). Thus, the necessary parameters and data bases are created which can be used in the scale-up procedure. In the final stage, the efficacy of the frac fluid can be examined by using it to a practical hydraulic fracturing process.

Expected Results

We expect that the good affinity between bio-degradable polymer and surfactant micelles could significantly improve the undesired viscosity drop during the process, and thus could transport as many of proppants to the fractured crack. During the pressure release step, the viscoelastic micelles are soon decomposed into small surfactant molecules, leading to high recovering rate of flowback. Also, the remaining bio-degradable polymer will degrade because of the surrounding bacteria in the shale formation. The entire process requires low water consumption and significantly lower the cost of the treatment of flowback and produced water. Unfortunately, one thing can be improved is that the cost of creating energized fluid is still high, compensating the cost saved from water usage and treatment. Therefore, we envision that utilizing this novel and versatile frac fluid system will significantly reverse the poor image of the hydraulic fracturing process from people and, most importantly, contribute to the sustainable shale gas production in the future.

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