JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Hydraulic Fracturing in HPHT Wells

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1. Introduction

Hydraulic fracturing fluids are used to initiate and propagate fractures, as well as trans port proppant into fractures in oil bearing formations to increase permeability and enhance oil production. Proppants are and grains or other granular substances that are injected into the formation to hold or "Prop" open formation fractures that have been seated by hydraulic fracturing. Proppants wedged within the fracture serve to increase the permeability of the formation, which promotes oil and gas production. The fracturing Fluids injected into the formation during hydraulic fracturing are subs equity pumped back out of the well in the process of extracting the oil and gas and associated ground water. Some fracturing fluid may remain in the formation due to "Leak off" or due to the fluids being stranded in the formation.

The types and use of fracturing fluids have evolved greatly over the past 60 years. Their composition varies significantly, from simple water and sand, to complex polymeric substances with a multitude of additives. Service companies have developed a number of different oil and ware-based fluids and treatments to more efficiently induce and maintain permeable and productive fractures. Water-based fracturing fluids have become the predominant type of coaled methane fracturing fluids. In some cases, nitrogen or carbon dioxide gas is combined with the fracturing fluids to form foam as the base fluid. Foams perform comparably to liquids, but require substantially lower volumes to transport an equivalent amount of proppant. A variety of other additives (in addition to the proppants) may be included in the fracturing fluid mixture to perform essential takes such as formation clean-up, foam stabilization, leak off inhibition or surface tension reduction.

Based on the availability of the scientific literature, it is evident that hydraulic fracturing fluid performance become a prevalent research topic in the late 1980's and the 1990's most of the literature pertaining to these fracturing fluids relates to the fluids' operational efficiency or human health concerns. There is very little documented research on the environmental impacts that result from the injection and migration of these fluids into subsurface formations, soils and underground sources of drinking water. Some of the existing research does offer does offer information regarding the basic chemical components present in most of these fluids.

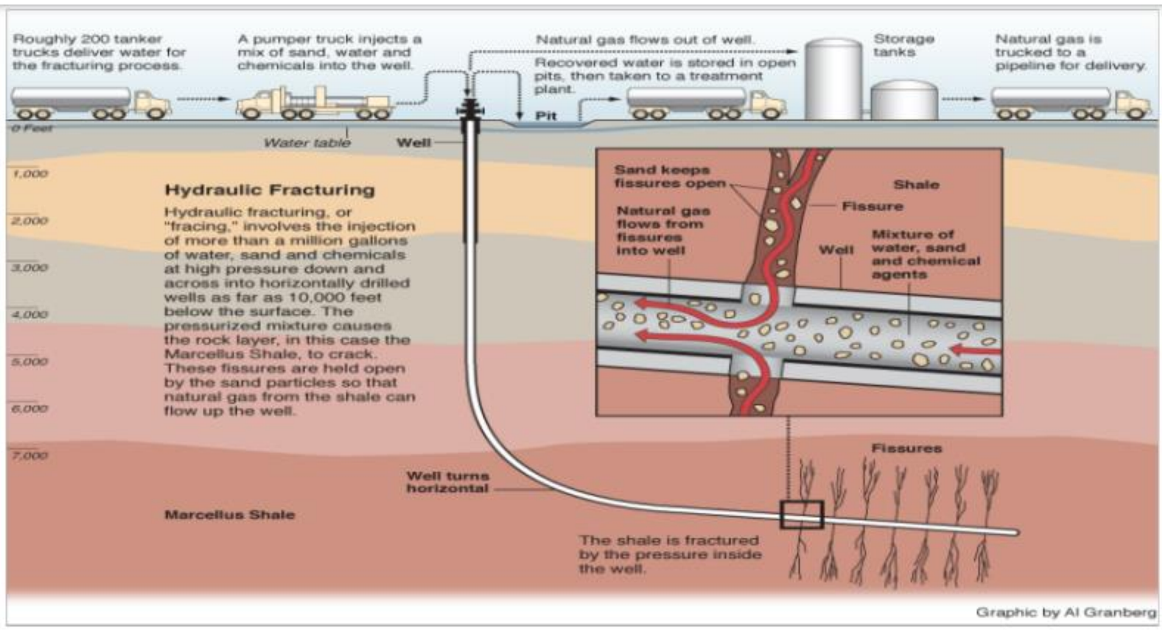


Fig 1: A pictorial representation of fracturing of Marcellus Shale using conventional water-sand mixture.

2. Literature Survey and Current Status

2.1 Chemical composition

The main goal of hydraulic fracturing is to achieve a highly conductive fracture. Fracturing fluids are formulated to provide sufficient viscosity to transport and place proppant into a fracture, and should degrade or "break" into a low viscosity fluid to allow for rapid flow-back and clean up. Breaking of the high viscosity fluid can be facilitated using pre-mixed additives within the fracturing fluid or by injecting breaker fluids into the well after the fracturing process is complete. Specially the following four qualities are desirable:

- ✓ Fluid must be viscous enough the create a fracture of adequate width
- ✓ Fluid must possess characteristics the maximize fluid travel distance to extend fracture length
- ✓ Fluid must be able to transport large amounts of proppant into the fracture
- ✓ Fluid must required minimal gelling agent to allow for easier breaking and reduced cost

Same of the fluids and fluid additives commonly used to create fractures are

- ✓ Linear gels
- ✓ Cross-linked gels
- ✓ Foamed gels

Formation fracturing using fluids has been employed by the oil and gas industry in the United States since the early 1940's (Ely, 1985). Early fracturing fluid technology involved injection of gelled napalm or fuel oil to increase oil and gas well production efficiency (Ely, 1985). These techniques were short-lived due to poor performance and the health hazards generally associated with the chemicals that were used early on. The next step in fracturing fluid evolution involved the use of gelled oils, fatty acids and caustic soaps (Ely, 1985). Because of the excessively high friction associated with these liquids, the Indus try moved toward the use of water without additives (Ely, 1985). However, water alone in not always adequate for fracturing certain formations since its low viscosity diminishes its ability to transport proppant. Higher viscosity fracturing fluids were needed to overcome this problem, so the Indus try developed thickened water starch and then guar-based fluids, also known as linear gels. Guar is a polymeric substance derived from the ground endosperm of the guar plant (Ely, 1985). Guar gum, on its own, is non-toxic and, in fact, is a food-grade product that is commonly used to increase the viscosity and elasticity of foods such as ice cream.

The success of guar-based fluids led to further advances in viscous liquid technology. Different guar derivatives were developed, the most popular being hydroxyl proplguar (HPG) and carboxmethylhyroxpropylguar (CMHPG). One major advance in fracturing fluid technology was the development of cross-linked gels. Cross –linking agents are added to linear gels in order to provide higher proppant trans port performance relative to the linear gels (Ely, 1985, Halliburton inc., Virginia site visit, 2001). Since the introduction of cross-linked fluids, improvements in these fluids have elevated the performance of fracturing treatments.

Another fracturing fluid that quickly gained popularity alongside the use of gelled fluids was foam fracturing. The most popular foam-fracturing fluids employ nitrogen or cartoon dioxide as their base gas. The incorporation of insert gases with foaming agents and water diminished the requirement for large volumes of fracturing liquid The gas bubbles in the foam fill voids that would otherwise be filled by fracturing fluid. Service companies reduce the liquid volume as much as 75 percent by using foams (Ely, 1985; Halliburton Inc., Virginia site Visit, 2001). Foaming agents can be used in conjunction with gelled fluids to achieve an extremely effective fracturing fluid (Halliburton Inc., Virginia Site Visit, 2001).

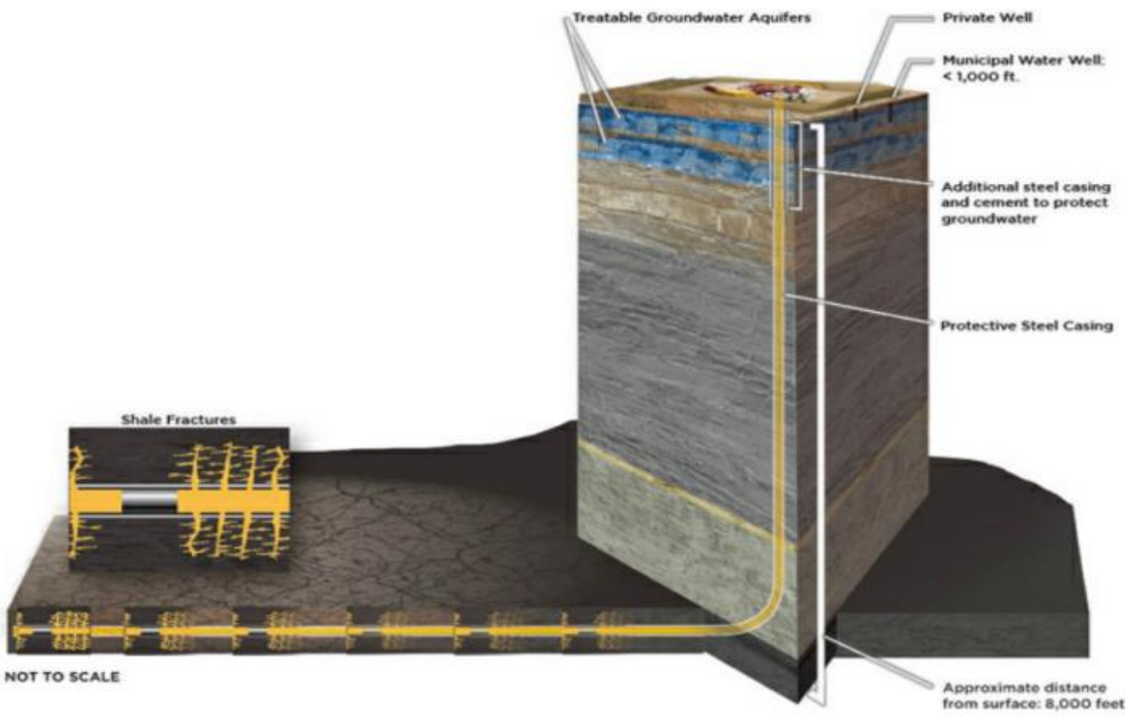


Fig 2: A vertical profile section of shale fracturing treatment

2.3 Rheology of Fracturing Fluids

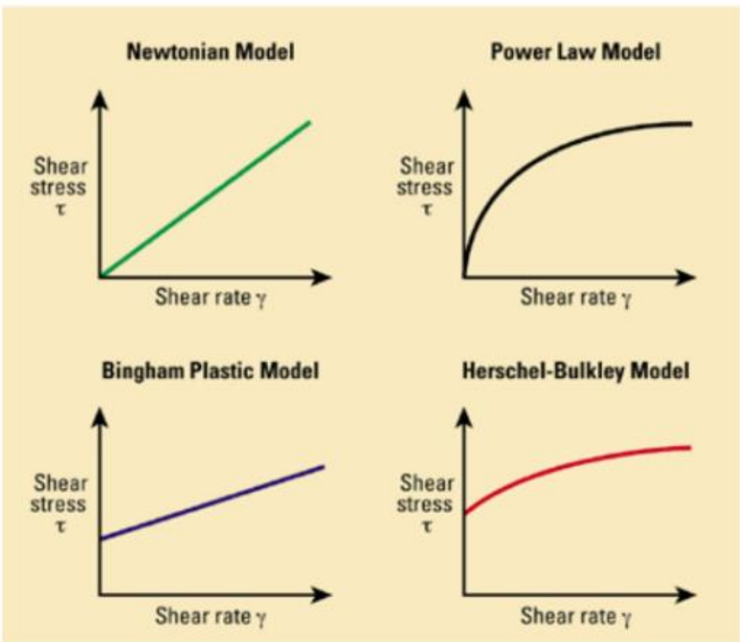
A fluid described by two- parameter rheological model of a pseudo plastic fluid, or a fluid whose viscosity decreases as shear rate increases. Water-base polymer fluids, especially those made with guar or XC polymer fit the power-law mathematical equation better that the Bingham plastic or any two-parameter model. Power-law fluids can be described mathematically as follows:

$$\tau = K(\gamma)^n,$$

Where τ = shear stress
γ = shear rate
n = exponent
K = consistency.

Power-law fluid: Fluids are described as Newtonian or non-Newtonian depending on their response to shearing. The shear stress of a Newtonian fluid (Upper left) is proportional to the shear rate. Some drilling fluids conform to a power-law fluid model(upper right) requiring less stress with increasing shear rate. Most drilling muds are non-Newtonian fluids, with viscosity decreasing as shear rate increases.

Rheological Models



Cross linked fracturing fluids obey power model and a specific fluid formulation is characterized n' and k', which signify the flow behaviour and consistency of the fluid. E.g.

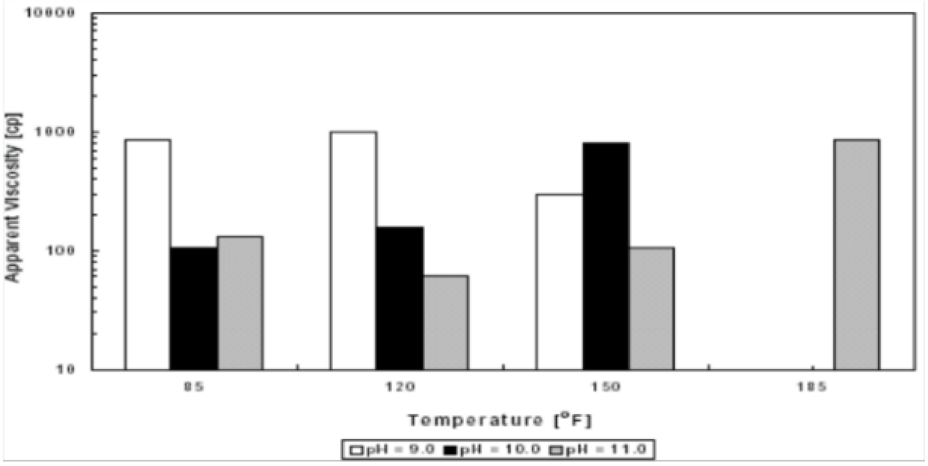


Fig 3: Apparent Viscosity at various pH and Temperatures for Borate Cross linked 35lb/Migal Guar Gel at a Shear Rate 65/s and Shear History of 5 min at 1400/s.

2.4 Types of Fluids:

Water based	Linear Fluids	Gelled Water, HPG, HEC, CMHPG, CMHEC, etc	Short Fractures, Low temperatures.
	Cross-linked fluids	Cross-linker + HPG, HEC or CMHEC, etc.	Long Fractures, High temperatures.
	Surfactant based	Surfactant + Counterion	Low Permeability formations
	Micro Polymer based	Micro polymer + Linking agent	For low and high permeability for moderate temperature

Table 2: Water based fracturing fluids

Each of these fluids is unique in nature, and each possesses its own positive and negative performance traits. Most of these fluids are water-based, however, they can also be oil, methanol, or water/Methanol mixture based as well. Methanol is used in lieu of, or in conjunction with, water to minimize fracturing fluid leak-off and enhance fluid recovery. Methanol is a common winterizing agent in may additives and has been used in the base fluid or many fracturing treatments" Polymer- based fracturing fluids made with methanol usually improve fracturing results, but create a requirement for 50 to 100 times the amount of breaker (Ely, 1985). Methanol breakers are typically acids.

Gelled Fluids

Water gellants or thickeners are used to create linear and cross-linked fluids. Gellant selection is based upon formation characteristics such as pressure, temperature, permeability, porosity, zone thickness etc. Both linear and cross-linked fluid fluids are described in the following sections.

Linear Gels

A substantial number of fracturing treatments are completed using thickened, water based linear gels. The gelling agents used in these fracturing fluids are typically guar gum, HPG, CMHPG, Carboxymethyl guar, Hydroxyethylcellulose (HEC) or other cellulose derivatives Guar, Cellulose and their derivatives are polymeric substances used to increase the viscosity or the fracturing fluid. To formulate a gel fluid, guar powder or concentrate is dissolved into a carrier fluid. To formulae a gel fluid, guar powder or concentrate is dissolved into a carrier fluid so it can create the viscous fracturing liquid. Increased viscosity improves the ability of the fracturing fluid to transport proppant with less need for turbulence. Concentrations of guar gelling agents within fracturing fluids have decreased over the past several years. It was determined that reduced concentrations provide better and more complete breaks in a fracture (Powell et al. 1999).

Hydraulic fracturing gels are typically made up of a gel thickening agent and thickening a carrier fluid. Examples of industrially produced gel thickeners include, hydroxypropylguar blends, guar gum blends, hydroxypropylcellulose, hudroxyethylcellulose, sodium carboxymethylcellulose and cellulose derivatives. In general, these products are biodegradable.

Gel thickeners are slurried into a carrier fluid such as water or diesel fuel. Diesel is frequently used in lieu of water to dissolve the guar powder because its carrying capacity per unit volume is much higher (Halluburton, Inc, 2002). Diesel is common solvent additive, especially in liquid gel concentrates, used by many service companies for continuous delivery of gelling agents in fracturing treatments" (GRI, 1996). Diesel does not enchance the efficiency of the fracturing fluid, it is merely a component of the delivery system (Halliburton, Inc., 2002). Using diesel instead of water minimizes the number of transport vehicles needed to carry the liquid gel to the site (Halliburton, Inc., 2002).

Cross Linked Gels

The first cross-linked gels were developed (Ely, 1985) in 1968. When cross linking agents are added to linear gels, the result is a complex, high-viscosity fracturing fluid Messina, Inc. Website, 2001). Cross – Linking reduces the need of fluid thickener, and extends the viscous life of the fluid indefinitely. The fracturing fluid remains viscous until a breaking agent is introduced to break the cross-linear, and eventually the polymer. Although they make the fluid