Investigating the Possibility of Using only Water and Proppants as Hydraulic Fracturing Fluid to Preventing Environmental Impact of Fracking Additives

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Abstract: Hydraulic fracturing is said to have facilitated the economic production of indigenous unconventional gas reserves in so many parts of the world. However, injecting large volumes of fluid into the subsurface is not without risk, most critical being groundwater contamination. A hydraulic fracturing impact study has been performed, reviewing the geological and Engineering aspects of fracking, the potential environmental impact, and the existing regulatory framework. To counter some of the impacts, the possibility of fracking using only water and proppants has been analyzed using LOT Analyzer and fracpro software to determine the practicality of such a method. Graphs were obtained for a leak off test using normal hydraulic fracturing fluid with a density of 11.79 ppg, a viscosity of 5cp at a flow rate of 0.023 bbl/sec. This gives a leak off the pressure of 765psi, fracture initiation pressure of 850 psi, fracture propagation pressure of 780 psi and instantaneous shut-in pressure of 776 psi. Graph of leak off test using only water with density of 8.34 ppg, a viscosity of 0.89 cp and flow rate of 0.023 bbl/sec gives a leak of the pressure of 730 psi, fracture initiation pressure of 818psi, fracture propagation pressure of 790 psi, and instantaneous shut-in the pressure of 784 psi. This shows the possibility of fracking using only water without additives. Fracking with only water tackles critical effects like groundwater contamination due to toxic additives. However, it presents some challenges like poor proppant transportation. To tackle this issue, the fluid was subjected to turbulence. Fracpro software was used for the two different flow rates (0.023 bbl/sec and 2.8 bbl/sec). A flow rate of 2.8 bbl/sec shows more dispersion of proppants than a flow rate of 0.023 bbl/sec.

Keywords: Hydraulic Fracturing, Fracturing additives, Leakoff, Proppants, LOT Analyzer, Fracfo.

I. INTRODUCTION

Hydraulic fracturing, or 'fracking', is a method used by drilling engineers to stimulate or improve fluid flow from rocks in the subsurface. In brief, the technique involves pumping a water-rich fluid into a borehole until the fluid pressure at depth causes the rock to fracture. The pumped fluid contains small particles known as proppant (often quartz-rich sand) which serve to prop open the fractures. After the fracking job, the pressure in the well is dropped and the water containing released natural gas flows back to the well head at the surface. The boreholes themselves are often deviated away from the vertical, into sub horizontal orientations, to ensure better and more efficient coverage of the targeted shale gas reservoir.

A variety of factors have combined to promote the recent surge in the exploitation of shale gas. Most traditional hydrocarbon reservoirs developed to date have oil and gas located in well-connected pores in the rock. This natural porosity, and related permeability, is often sufficient to allow extraction, but various methods of stimulation have been used over many years to improve the flow rate, including fracking. In shale gas reservoirs, the natural gas is more closely bound to the rock, and sits in a fine scale array of relatively isolated and small pores and cracks. In order to extract this resource, the permeability must be improved by artificial means, and fracking is a popular method.

The aim of this paper is to provide a sustainability assessment of shale gas production, and to examine the overall potentials, paradoxes and challenges of adopting the hydraulic fracturing technology and also proffer solutions to counter those problems. Shale gas fits into the category of unconventional oil and gas that have gained increased importance and value over the last decade as a viable alternative source of energy. Generally, unconventional oil and natural gas are found in sedimentary rocks, such as shales, oil sands, coal bed methane (CBM), biomass based liquid supplies, rather than in reservoir accumulation. Shales are fine-grained sedimentary mud rock, comprising mostly flakes of various clay minerals, and including tiny fragments of quartz, calcite, other minerals and organic material, which are embedded between layers. After drilling into the shale, water is pumped, and the ensuing pressure forces the hydrocarbon particles to be released and collected for processing.

It is no longer news that crude oil is losing its appeal very fast. It has been estimated that by the year 2035, as much as half of the global energy needs will be met by shale gas and other alternative sources of energy. Many countries are planning ahead and poised to gain maximally from what is going to be ages of shale gas.

Fracturing and environment allegations of water quality impacts associated with hydraulic fracturing date back to at least the early 1990s, but hard evidence has gradually begun to surface.

In Nigeria, It has been reported in the news that out of the 388 acreages in the country, 173 had been allocated to 85 companies that are involved in the upstream business, while 215 were yet to be allocated to investors (Anyiam and Onouha 2001).

According to Dr Dave Healy, "Some of the key geological issues with relevance to the potential environmental impacts of fracking are:

- The relatively limited understanding of rock fracture patterns and processes in shales;
- The ability to predict and quantify permeable fracture networks in the subsurface before drilling;
- The accuracy and precision with which the geometry (size or extent, position, thickness) of shale

formations and aquifers in the subsurface can be determined, especially in areas with complex geological histories.

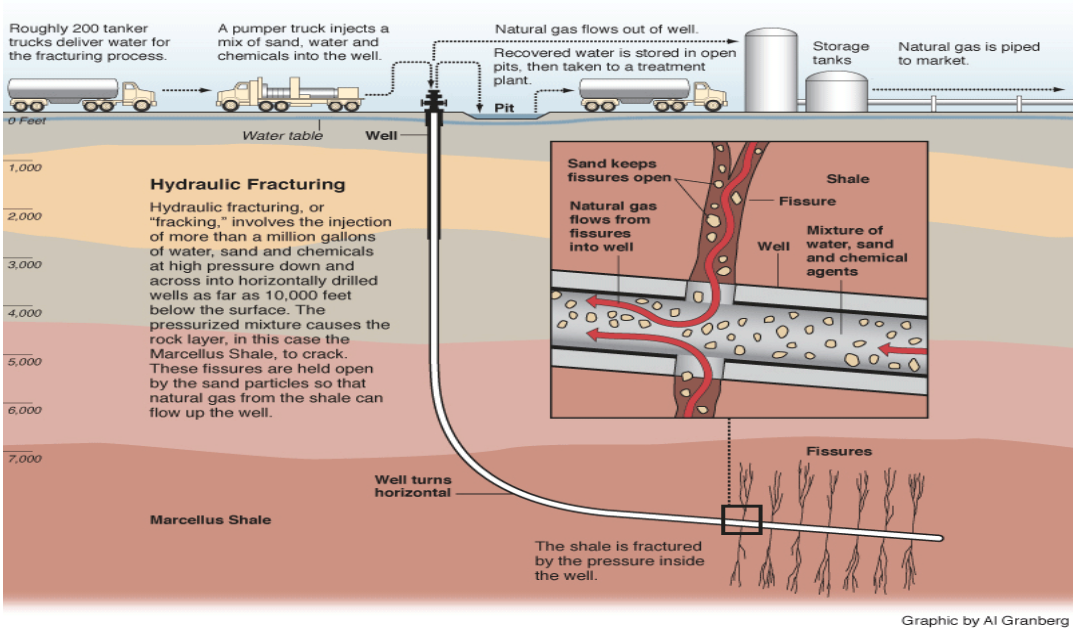

Figure 1: Schematic diagram showing the general features of a fracking operation

The ability of fluids to flow through rock is controlled by a property called permeability, itself a function of porosity. The pore space in rocks is made up of a diverse range of voids in the solid rock matrix and includes cracks induced by stresses. The aim of fracking is to massively improve permeability by creating (or reopening) a locally dense network of open and connected – i.e. hydraulically conductive – fractures.

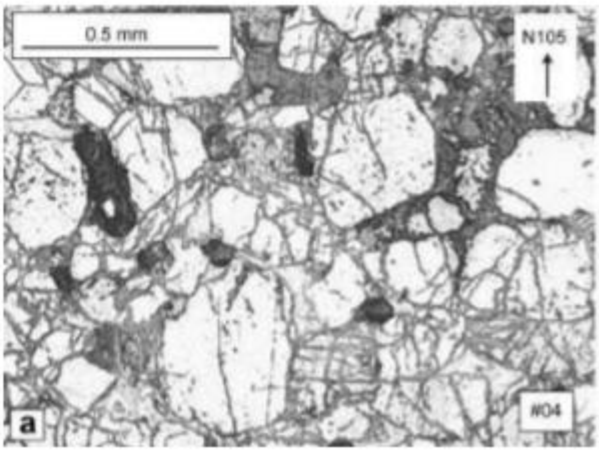

Figure 2: Photomicrograph of a fractured rock showing the intricate network of grains, pores and cracks (Louis et al., 2008.)

Rock Fracture

The nucleation and propagation of hydraulic rock fractures are chiefly controlled by the local in situ stress field, the strength of the rock (stress level needed to induce failure), and the pore fluid pressure (Secor, 1965; Phillips, 1972). Temperature, elastic properties, pore water chemistry and the loading rate also have an influence. Fractures in rock can be classified as tensile, shear or hybrid (a mixture of tensile and shear).

Mechanical anisotropy

A recognised complicating factor in many shale gas formations is that of elastic anisotropy. Many rocks, including common hydrocarbon reservoir sandstones can be considered as elastically isotropic – i.e. their elastic properties, such as Young's modulus and Poisson's ratio, do not vary with direction. This is largely a consequence of the depositional process for granular rocks such as sandstones involving settling, sorting and compaction of more or less equant grains of quartz, each with a random orientation. In contrast, many shales are distinctly anisotropic in their elastic properties, as their constituent clay minerals are platy in form and are then compacted into aligned parallel layers. This gives a measurable and important directionality to their elastic and mechanical response.

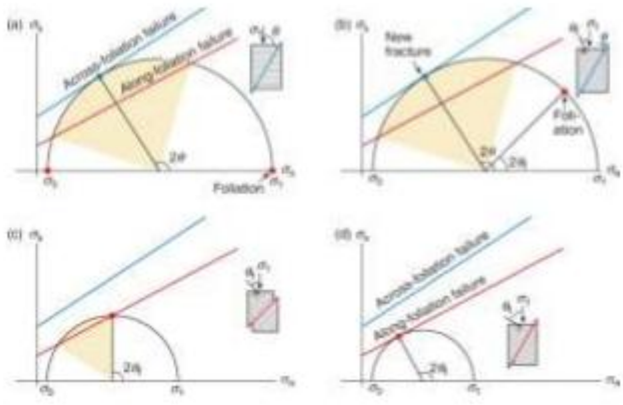

Figure 3.Effect of anisotropy on rock failure. Source: Fossen, 2010.

The precise physical nature of the control exerted by lithology anisotropy on rock fracture is poorly understood; although the effects are well known/documented. Many anisotropic rocks such as shale fail much more easily/frequently along/parallel to their fabric than across it and the orientation of any cross-cutting fractures is different to those orientations predicted for an isotropic rock in the same stress field. These observations have potentially important implications for the connectivity, and therefore permeability, of any fracking induced fracture array in anisotropic shales.

Geological Risks

Fracking inherently involves geomechanical risks – i.e. the injection of large volumes of pressurized water at depth will, by design, alter the in-situ stress state and change the propensity of existing fractures to open or faults to slip, and possibly result in seismic activity (i.e. earthquakes). If the in-situ rock stresses and the pre-existing fracture network are known in advance of the drilling and fluid injection, the geomechanical risks of planned changes in pore fluid pressure can be quantified using methods based on slip and dilatation tendency (Morris et al. 1996; Ferrill et al., 1999). This approach is sometimes employed within the hydrocarbon industry though its predictive capability depends on data coverage and data quality. The stress model and the fault model used as inputs to the predictions need to be as accurate as possible, and any uncertainties need to be quantified. Two recent earthquakes near Blackpool in the UK have been attributed to fracking treatments applied at the nearby Preese Hall 1 well of Cuadrilla Resources (Cuadrilla). Detailed and comprehensive analyses by third parties after the earthquakes has shown that the most likely cause of the seismic activity was slip in a previously unmapped, highly permeable fault zone located near the base of the well (Pater and Baisch, 2011; Geosphere, 2011). Diversion of much of the pumped water into this fault zone eventually led to the relief of sufficient stress to allow the fault to move, on at least two separate occasions, both events occurring shortly after large volume water injections at the well head. It has been pointed out that these fracking induced earthquakes were smaller than many historical events in the same region, attributed to coal mine collapse or natural tectonic processes, and much smaller than naturally induced earthquakes generally reported in the media.

Potential Environmental Impacts

The coverage of the potential environmental impacts of hydraulic fracturing in current times is dominated by material originating from the United States, Europe and Africa. Hydraulic fracturing has a long history in the oil and gas industry. Statistically, the number of proven environmental impacts demonstrated to have been caused by fracking remains small in relation to the volume of fracking activity. According to one estimate, approximately one million oil and gas wells have been drilled and fracked (University of Texas, 2012).

Ground Water Contamination

Ground water contamination is by far the most serious local environmental concern, and probably the most contentious. The potential risk of fracking to ground water comes from two sources:

1- the injected fluid (water plus chemical additives) and
2- the released natural gas. There are alleged cases of both types according to a report(Osborn et al., 2011).

However, a key issue is the exact location and site of this contamination:

1- Leakage from a defective well bore closer to the land surface?
2- Advection (percolation) or diffusion from the hydraulically fractured formation at depth?

Results from a University of Texas study of several incidents of possible contamination around the world shows no confirmed evidence for ground water contamination from the subsurface fracking operation itself, but suggest leakage stemming from fracking-related waste water above ground (University of Texas, 2012).

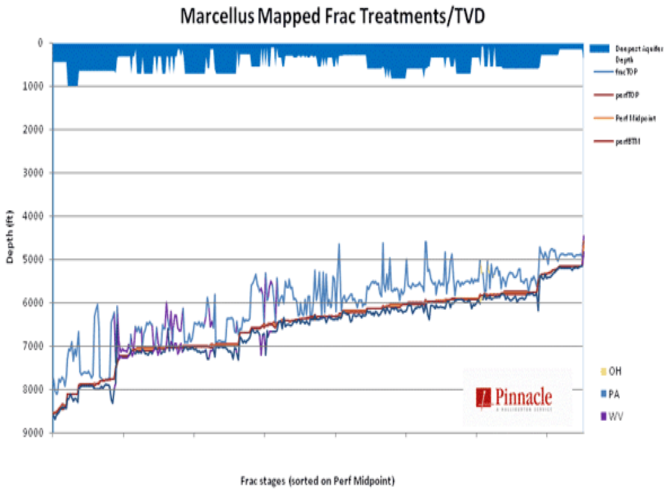

Figure 4. Graphs comparing the depth of deepest aquifers (from well data) and the mapped vertical extent of hydraulic fractures (from microseismicity and tilt meter data) in the Barnett and Marcellus Shale formations in the USA.Source; (Fisher, 2010).

The potential risks identified from some reported incidents of ground water contamination so far include:

i. Overweight (or 'overbalanced') drilling mud causing leakage of drilling fluids from the well bore into near surface aquifers;
ii. Contamination by solid components in the shale entering the flow back fluid;
iii. Poor cement jobs on well bore casing, especially at shallow depths allowing fluid flow to near aquifers.

Chemical additives

To define the level of toxicity of additives used in the fracking should be a relatively simple and quantifiable scientific task, however in some countries like South Africa, fracking companies are under no legal obligation to declare the exact composition of this mixture. In fact, for these companies operating in deregulated market economies there is a clear vested interest in keeping the fluid formula secret for competitive advantage. In order to test for and track potential chemical contamination, agencies responsible for monitoring and regulating the environmental impacts of fracking need to know the chemical composition of substances added to the fracking fluid.

Blowouts

Both Surface and subsurface blow outs have been documented around the world (ProPublica, 2008). If the fluid injected into the well head does not fracture the rock volume around the bottom of the well as intended, then the elevated fluid pressure will drive the fluid into other open and permeable ways. These pathways can include the injecting well bore, but also any other boreholes in the vicinity that are not capped for these high pressures (e.g. other oil and gas wells or artesian wells used for drinking water). Explosive eruptions of drilling fluid and/or oil and gas from neighbouring wells are a direct consequence of pre-existing permeable connectivity at depth. Seepage of any surface spillage from a blow out into the ground could then lead to ground water contamination.

Water Sources

Sourcing thevolumes of water required for the extended fracking program can be tasking, especially in arid or depleted areas. Estimates of water volume required vary widely, with between 90,000 and 13,500,000 litres per well (MIT, 2011). Note that this large range is in part due to the large variation of well 'lifetime', with operations lasting from a matter of days to many years (MIT, 2011). Local extraction of water from small catchments could have an impact on the ecology and hydrology of rivers in these areas. Finding sustainable sources for these volumes of water is clearly a challenge, but related environmental impacts may also develop from transporting water in to the drilling site from further afield.

Fate of the Fracking Fluid

Disposing fracking fluid after use during the fracking process presents further challenges. Some operators have chosen to pond this flow back fluid in man-made pools and then allow it to either evaporate, or be transported away at some day. Evaporation leads to concentration of the chemical additives, increasing the potential for environmental impact if a leak develops. Breaching of these evaporation or temporary ponds (or the related pipe work) due to poor maintenance or poor design has in one instance led to contamination of local habitat and ground water supplies (New York Times, 2011). In Europe, flow back fluid may be formally classified as waste under the European Union Mining Waste Directive, and will then be subject to strict conditions during processing at the surface. At least one operator in the US has successfully reused the flow back fluid in the subsequent fracking operations at the same well head, with no loss in efficiency. However, the costs involved in processing the flow back fluid to remove any contaminants collected during the first cycle may deter wider application (Exploration & Production Magazine, 2010).

Emissions to the Atmosphere from Fracking

An issue related to the fracking fluid is the emission of gas and/or vapour to the atmosphere from the fluid, either of original chemical additives, entrained contaminants from the shale formation or the methane released by the fracking process. There is an ongoing debate about the relative leakage rate of methane into the atmosphere from the exploitation of shale gas in comparison to the emission rate from conventional gas (Howarth et al., 2011; Cathles et al., 2011). This is potentially important because a high leakage rate might mean that methane released by fracking operations into the atmosphere from shale gas extraction could have a higher net greenhouse gas footprint than things like coal. Therefore, Fracking operators should seek to minimize all emissions to the atmosphere, and monitoring processes need to be actively enforced.

Table 1 A summary of frackin fluids with additives used with composition.

Base Fluid	Fluid type	Main Composition
Water Based	Slickwater	Water + sand (+ chemical additives)
	Linear fluids	Gelled water, GUAR<HPG, HEC, CMHPG
	Cross-linked fluid	Crosslinker + GUAR, HPG, CMHPG, CMHEC
	Viscoelastic surfactant gel fluids	Electrolite+surfactant
Foam Based	Water based foam	Water and Foamer + N_2 or CO_2
	Acid based foam	Acid and Foamer + N_2
	Alcohol based foam	Methanol and Foamer +N_2
Oil Based	Linear fluids	Oil, Gelled Oil
	Cross-linked fluid	Phosphate Ester Gels
	Water Emulsion	Water + Oil + Emulsifiers
Acid based	Linear	-
	Cross-linked	-
	Oil Emulsion	-
Alcohol based	Methanol/water mixes or 100% methanol	Methanol + water
Emulsion based	Water-oil emulsions	Water + Oil
	CO_2-methanol	CO_2 + water + methanol
	Others	-
Other fluids	Liquid CO_2	CO_2
	Liquid nitrogen	N_2
	Liquid helium	He
	Liquid natural gas	LPG (butane and/or propane)

II. METHODOLOGY

The method used to achieve the aim of this research work was software simulations. The Softwares used are:

- DrillsWork Lot Analyzer
- Fracpro Software

LOT Analyzer

LOT analyzer was used to determine the leakoff rate of the fracturing fluid.

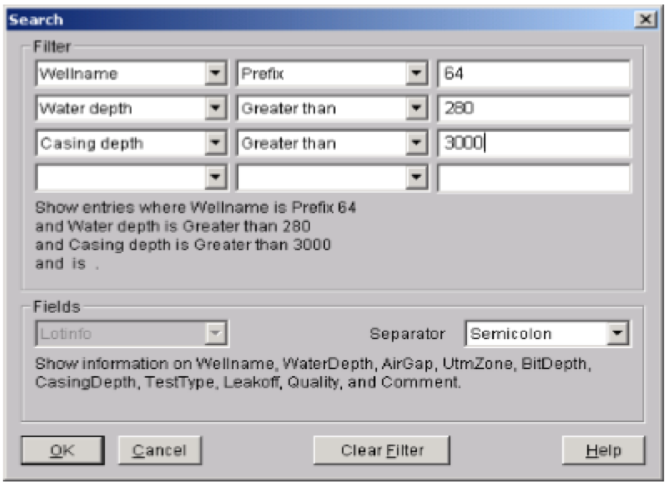

Figure 5: Data input system from LOT analyzer.

Import Test Data

Dialog LOT Analyser – Timedata File was entered. In this dialog, the columns to read was defined, the column separators, the source units and more. The settings depend on the format of the text file that you import.

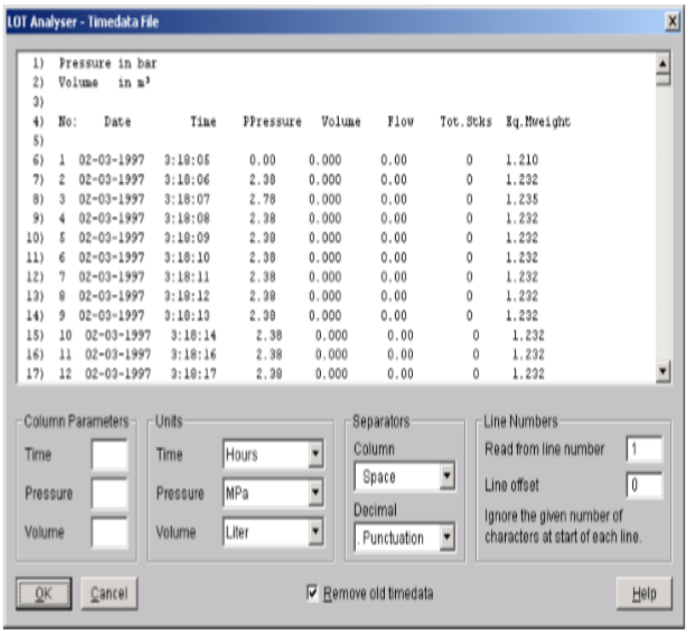

Figure 6.Timedata file from LOT Analyzer.

Leak off Pressure

Interpretation was selected, ->Leakoff from the top menu. On the top bar Left mouse area was seen, clicked and drag. The exact cursor position for the X and Y coordinates was there.

Maximum Pressure

Interpretation was selected, Maximum pressure was given. A horizontal cursor was selected and the maximum point of the curve at approx was clicked.

Propagation Pressure

Interpretation was selected, Propagation Pressure. This value is set with a horizontal cursor. The propagation pressure is found where the curve flats out between the top point C and the drop-down point at D.

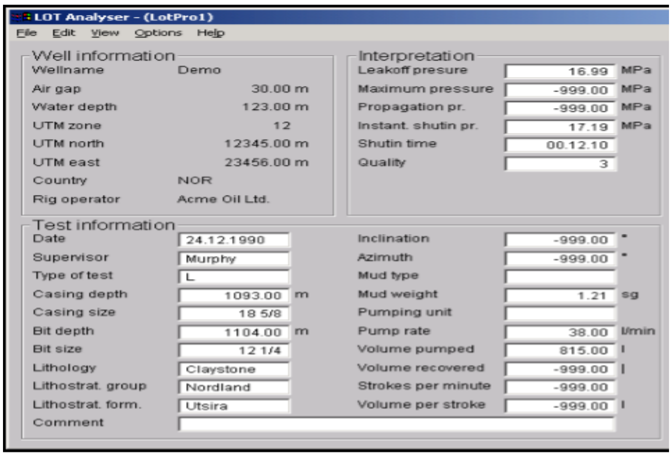

Figure 7: Screenshot of data input from LOT Analyzer

This was done for two different fracturing fluids.

By using the Reynolds number correlation, flow rate to cause turbulence was then determined.

FRACPRO was used to determine the proppant dispersion and carrying ability of water using the flowrate form LOT analyzer, and the calculated flow rate to cause turbulence.

Table 2 Fracturing Fluid Properties Used in the Simulation

Hydraulic fracturing fluid with Water and Proppants only		Hydraulic fracturing fluid with Water, Proppants and additives	
Density	8.34ppg	Density	11.79ppg
Viscosity	0.89cp	Viscosity	5cp
Flow rate	0.023bbl/sec	Flow rate	0.023bbl/sec

III. RESULTS

For leakoff test from Drill works LOT Analyzer for fracking using normal hydraulic fracturing fluid with additives.

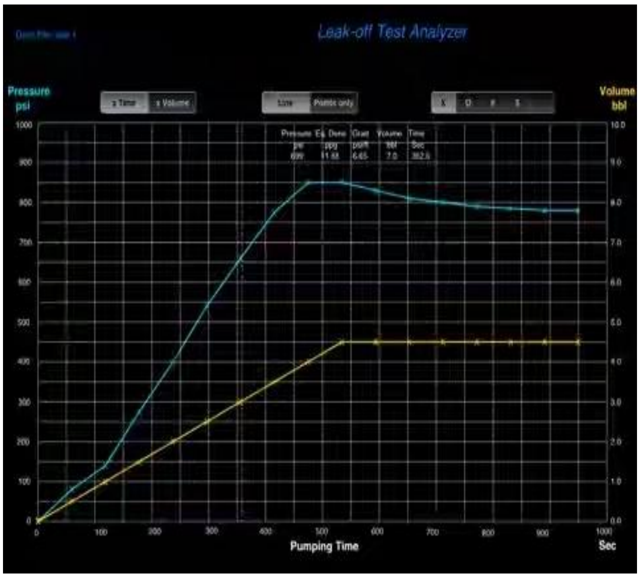

Figure 8: Leak off test result for fracking using water based fracking fluid with additives.

Table 3: Pressure distribution for leak off test using water based fracking fluid with additives.

Pressures	Values(psi)
Leak off point	765
Fracture initiation pressure	850
Fracture propagation pressure	780
Instantaneous shut in pressure	776

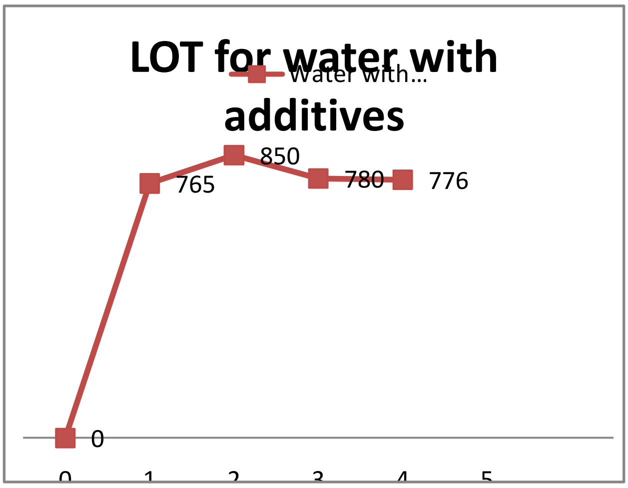

Figure 9: Leak off test result for fracking using water based fracking fluid with additives.

For Fracturing Using Only Water

When only water and proppants were tested as fracturing fluid the leakoff test results are shown below

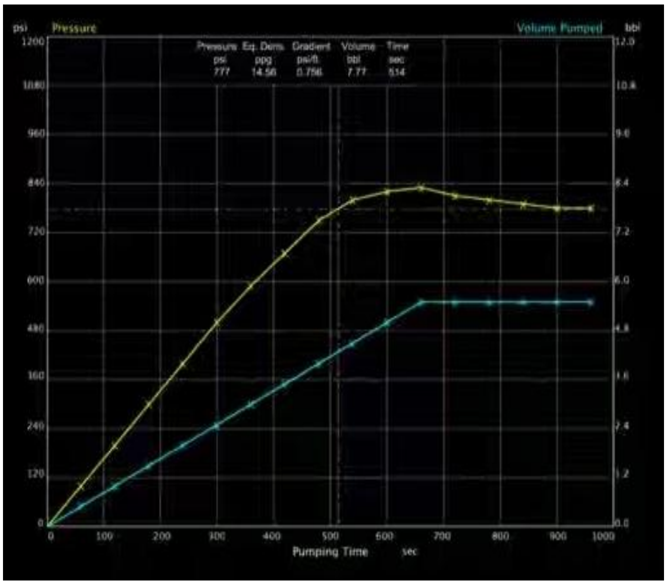

Figure 10.Leakoff test result for fracking using only water.

Table 4. Pressure distribution for leak off test using only water.

Pressures	Values(psi)
Leak off point	730
Fracture initiation pressure	818
Fracture propagation pressure	790
Instantaneous shut in pressure	784

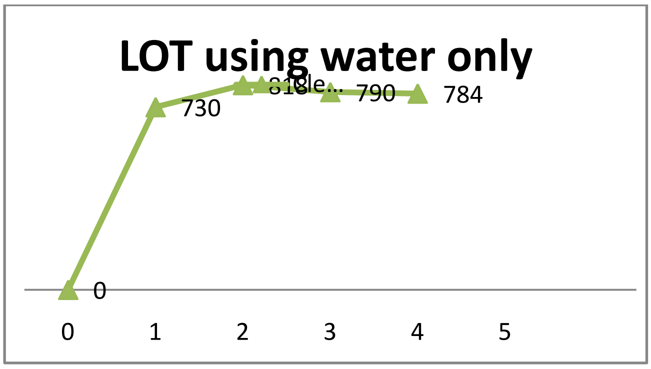

Figure 11. Leak off test result for fracking using only water.

Comparison of the two results

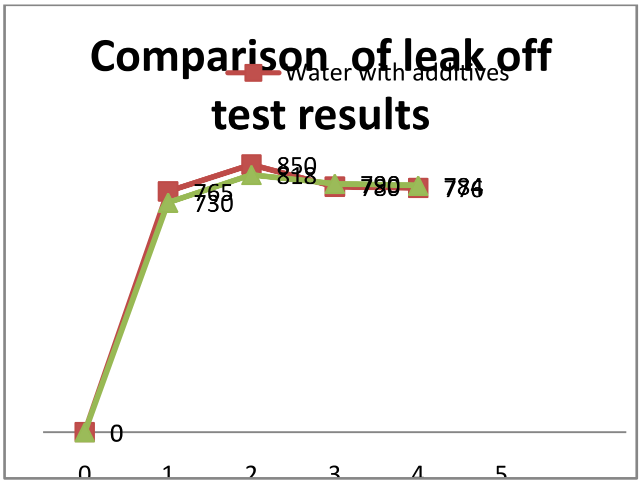

Figure 12. Comparison of Leak off test results for fracking using only water and water base fracking fluid with additives.

Using only water reduces the efficiency of proppants transportation. But subjecting the flow to turbulence helps in carrying the proppants along. Using coiled tubing of 2.5inch inner diameter;

$$Re=\frac{3160\,G.Q}{D.\mu}(1)$$

G= Specific gravity =1

D= Pipe diameter = 2.5inch

μ= Viscosity0.89cp

Re= Reynolds number = 4000

This gives a Flow rate Q of 2.81bbl/sec. Any flow rate greater than this will be turbulent, and will have the ability to suspend sand proppants in water as can be seen below.

For flow rate of 0.023bbl/sec

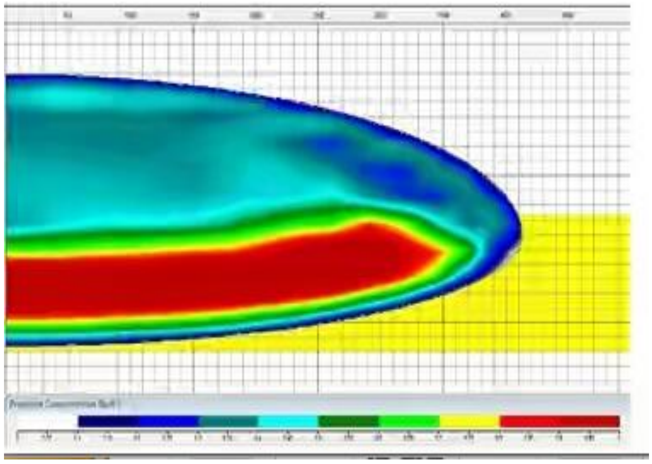

Figure 13. Proppants concentration in fractures using flow rate of 0.023bbl/sec.

For flow rate of 2.81bbl/sec

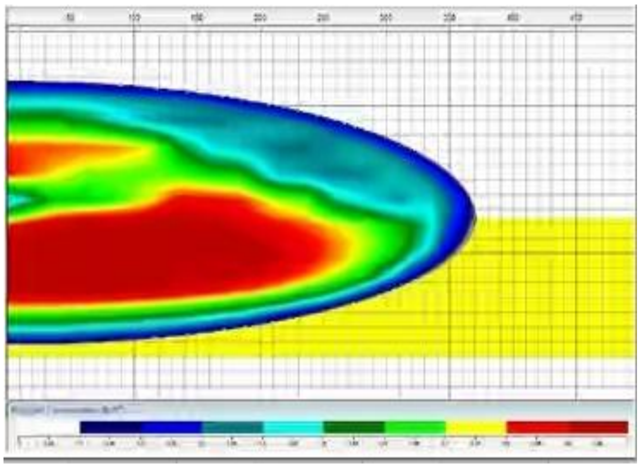

Figure 14. Proppants concentration in fractures using flow rate of 2.81bbl/sec.

IV. DISCUSSION OF RESULTS

Results from the leak off test using the LOT analyzer shows leak off point, fracture initiation pressure, fracture propagation pressure, and instantaneous shut in pressure for both fluids with some additives like viscosifier and using only distilled water as can be seen on figures8, 9 and 10, 11 respectively. This points out to the possibility of frackin subsurface formations using only water with no additives.

Fracking without additives does not come without its own issues. Some of which are;

i. Poor proppants carrying ability.
ii. Corrosion of tubulars.
iii. Higher leak off of water.

However, two solutions were proposed. One is turbulent flow which can keep proppants in suspension as can be seen from figure 13 and 14. Red colored spots show proppants concentration. Figure 13 shows poor proppants carrying ability. Figure 14 for turbulent flow shows more suspension of proppants. And aid proppants transport, and also reduce excessive water loss to the formation.

The next solution is the use of distilled water. This can reduce the tendency of corrosion attack on tubulars. This requires special treatment and storage facilities. Cost considerations can be complimented by the additional cost of additives which is not required.

Note: This procedure followed for making this suggestion cannot serve as a conclusive point on the practicability of frackin with only water. Practical field operations should be done to verify and back this project and determine its practicability.

Next part of the result is the recommended best practice. Recommendations are done based on three headings, monitoring and assessments, materials and resources, and media coverage and public debate. These are expected to provide the best condition possible to prevent problems with regards to hydraulic fracturing.

CONCLUSION

As this research aim to show with regards to shale gas production and the hydraulic fracking technology, however environmental questions must be well understood, anticipated and addressed in order to ensure sustainable shale gas production. As proposals and policies continue to emerge on the desirability of exploring unconventional oil and gas opportunities in Nigeria, it is therefore important to comprehensively examine and address the long-term sustainability potentials of shale gas production from the onset through an integrated and holistic policy frame that addresses its economic, environmental and social impacts. Solutions have been proposed and tested, which can serve as a stepping stone tackling frackin related issues in the future.

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