STUDY ON HYDRAULIC FRACTURING FLUID SELECTION TO MAXIMIZE EFFECTIVE HYDRAULIC FRACTURE LENGTH

by

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Dissertation submitted in partial fulfillment of the requirements

for the Bachelor of Engineering (Hons) Degree in Petroleum Engineering

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CERTIFICATION OF APPROVAL

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Approved by,

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AP Aung Kyaw

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Seri Iskandar, Perak

January 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AINIL IZZYAN NAFFI

ABSTRACT

Effective fracture length is often observed to be only a fraction of created fracture length. The poor fracture performance is consequence of poor recovery of fracturing fluid during flowback. This usually happens when water-based fracturing fluid is used in low permeability reservoir. Unrecovered fracturing fluid stays in formation and creates obstruction for hydrocarbon flow. The residue fluid which has become immobile reduces effective fracture length and thus decreases hydrocarbon production. The problem becomes more severe by the water-wet nature of most tight gas reservoirs.

This study is conducted to evaluate performance of liquefied petroleum gas (LPG) as hydraulic fracturing fluid in order to maximize effective fracture length. The term LPG and propane are used interchangeably in this report, however they are all subject to propane. LPG has demonstrated quick and complete fracture fluid recovery, significant production improvements and longer effective fracture length. This is proven by the application of propane based hydraulic fracturing in McCully Gas Field, New Brunswick, Canada. Once well is drawn down during flow back, a large portion of injected LPG may be produced back as gas. The remaining LPG that remains in created fracture dissolved in formation hydrocarbon during production. For fields that has limited storage and handling facilities, return of LPG fracturing fluids can easily be flared during flowback.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Hydraulic fracturing is a type of well stimulation treatment designed to create a highly conductive fracture to bypass near-wellbore damage and improve flow path from formation to production well. To initiate and expand fractures, hydraulic fracturing fluids are pumped with high pressure into the formation. Once hydraulic fracture created intersects with a natural fracture, fluid will flow normal to the fracture face from the reservoir along the fracture path[2].

Fracturing fluids also serve the mean to transport proppant into the created fractures[1]. Proppants are the substances injected into the formation to hold the fractures open. Following the treatment, well is shut in for several hours to let the fluid viscosity to break and so that proppant can settle inside fracture. Fracturing fluids injected into the formation are then pumped back out of the well, with the proppant left inside to hold the fracture open.

However in practice, created fracture length does not always fully contribute to production. Only a fraction of the created fracture length called effective fracture length will allow gas flow. The difference between created fracture length and effective fracture length is blocked by hydraulic fracturing fluid that cannot be recovered during flowback. In some cases where flowback is highly inefficient, effective fracture length can be as low as 30% of the created fracture length[1].

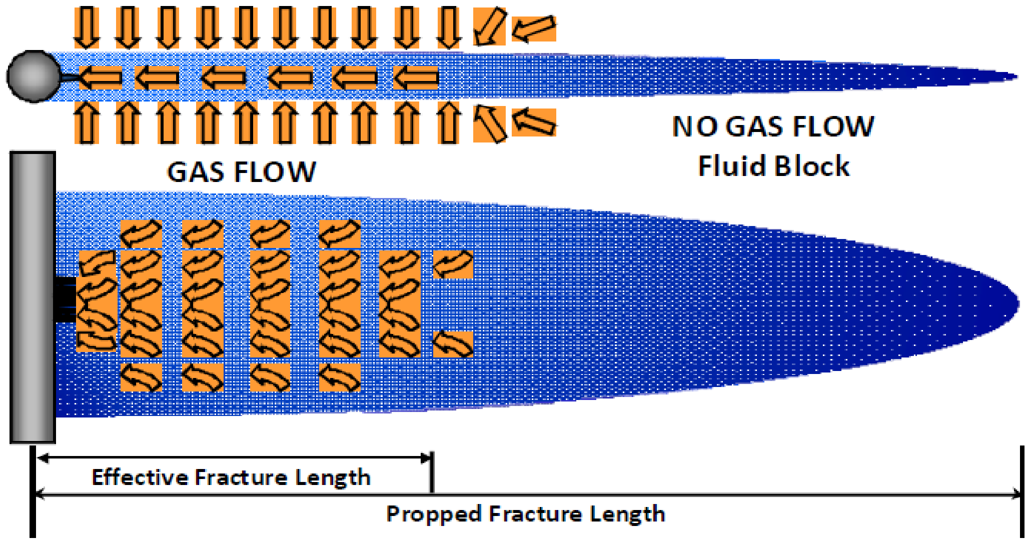

Figure 1 : Effective fracture length in conventional fracturing

Complete removal of hydraulic fracturing fluids is essential as the residue could severely damage fracture conductivity and thus decrease production, or worst, damage the formation. The recovery efficiency of fracturing fluids can be influenced by factors such as fracturing fluid travels beyond the capture zone, leakoff into secondary fractures, check-valve effect, chemical reaction with formation[3] or unsuitable selection of additives.

In order to achieve maximum fracturing fluid flowback, fracturing fluid design and cleanup technique must be understood and studied. Complete flowback of fracturing fluid will contribute to maximizing effective fracture length.

1.2 Factors Affecting Fluid Recovery

In order to achieve optimum result of hydraulic fracturing, fracturing fluids need to be completely removed to maximize effective fracture length. These factors can decrease the efficiency of fracturing fluids cleanup.

1.2.1 Fluid Leak-off

Because of connected fractures and void pore spaces, fluids can leak off from primary hydraulically induced fracture into porous rock. High injecting pressure during fracturing will transport fracturing fluid deep into secondary fractures. These fluid can be trapped in the smaller natural fractures and make it almost impossible to recover. If the gels injected are not completely broken down, this can also causes fluid leak-off into formation and block the pores[3]. Volume of lost fracturing fluid depends on permeability of rocks and surface area of fracture.

1.2.2 Check-valve Effect

Fluids can be trapped by check-valve effect because injectivity index is much higher than productivity index. This occurs when fractures allow fluid to flow when fracturing pressure is high, but later prevent fluids from flowing back as they close after fracturing pressure is low. Check-valve effect usually takes place beyond propped zone or in smaller secondary fractures that has no proppant placed.[3]

1.2.3 Fluid Move Outside the Capture Zone

Capture zone of a well is the part of aquifer that contributes water to the well[3]. High injecting pressure during fracturing forced fracturing fluids into the formation to enlarge and propagate existing fractures. Hydraulic gradients of fluid that flow away from the well during injection are much greater than hydraulic gradient during recovery. This result in some fracturing fluids travel beyond capture zone and not recovered during flowback.

1.2.4 Phase Trapping

Water phase trapping is defined as the permeability reduction process of near wellbore reservoirs and fracture faces when water saturation decreases from initial water saturation to irreducible water saturation and to 100% during the well operation[9]. Phase trapping that is caused by water imbibition when water as wetting phase trapped oil that is flowing. In Figure 2, oil is trapped by water that is the wetting phase from flowing.

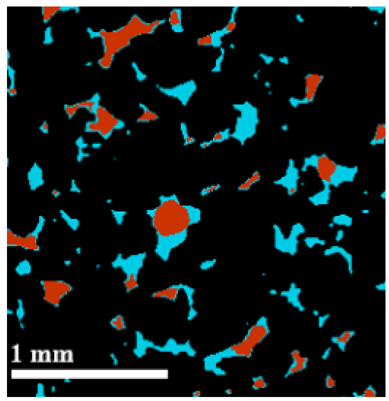

Figure 2: Water phase trapping

1.3 Problem Statement

1.3.1 Problem Identification

Subsequently after fracturing fluid is injected to create fracture and transport proppant, it needs to be completely removed to allow formation fluid to flow through the induced fracture. Complete removal of hydraulic fracturing fluid from created fracture will maximize effective fracture length and thus maximize the efficiency of the treatment. However, fracturing fluids often trapped as residue in the created fracture after the treatment and decrease the effective fracture length.

1.3.2 Significant of the Project

Through this project, studied fluid which is gelled HD-5 propane fracturing fluid has the ability to revert to low-viscosity fluid to allow complete flowback. This will improve effective hydraulic fracture length and thus increase in production operation. Since this method of fracturing is relatively new and only being tested across North America, it has the potential to be conducted in Malaysia especially in shale gas rock formation.

1.4 Objective

- To study the efficiency of gelled HD-5 Propane as fracturing fluid for optimum cleanup in order to maximize effective fracture length

1.5 Scope of Study

The main scope of this study is to study the efficiency of gelled HD-5 Propane as fracturing fluid in order to enhance cleanup to maximize effective hydraulic fracture length. Factors that contribute to decreasing effective fracture length are analyzed to see whether gelled LPG can overcome the barriers. This study focuses on gelled LPG properties and its advantages over other conventional types of fracturing fluid. Fracturing fluid needs to revert to low-viscosity fluid after the treatment to allow complete flowback to the wellbore. The fracturing fluid must be designed not to react chemically with the formation. Appropriate additive must be selected to adjust the properties of fracturing fluid to meet the requirements.

1.6 Relevancy and Feasibility of Study

The study is expected to be relevant and feasible after much deliberation based on the following:

1) Optimum selection hydraulic fracturing fluid is in need as hydraulic fracturing is widely used worldwide to increase oil and gas production.
2) Malaysia is endowed with natural gas reserves that are three times larger than its oil reserves. Hydraulic fracturing using LPG based fracturing fluid is very much applicable in the unconventional gas reservoirs.
3) Application of propane based hydraulic fracturing fluid in McCully Gas Field has shown significant improvement on fracture cleanup.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydraulic Fracturing Fluid

Hydraulic fracturing treatment includes mixing certain chemicals to make fracturing fluid and then pumping it into the formation at high rates and pressures to initiate and extend a fracture. To achieve efficient stimulation, fracturing fluids must have certain chemical and physical properties.

1. It should be compatible with formation material
2. It should be compatible with formation fluids
3. It should be capable to suspend and transport proppants deep into fracture
4. Its viscosity should be capable to create desired fracture width
5. It should have low-fluid loss
6. It should be easy to remove from formation
7. It should have low friction pressure
8. Fluid should be easy to prepare and deliver in the field
9. It should be stable throughout the treatment
10. It should be cost effective[1]

2.2 HD-5 Properties as Hydraulic Fracturing Fluid

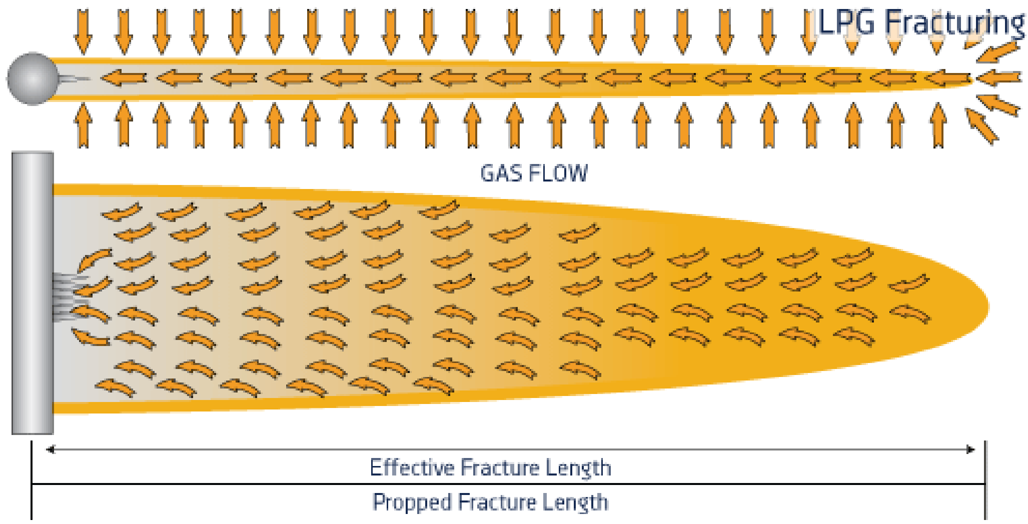

Figure 3 : Effective fracture length in LPG fracturing

HD-5 (Heavy Duty-5**%** maximum allowable propylene content, and no more than 5% butanes and ethane) grade propane is consumer grade propane and is the most widely sold and distributed grade of propane in the market[8]. It is the highest grade propane available to consumers and is what propane companies ordinarily sell to customers. HD-5 propane consists of:

- Minimum of 90% propane
- Maximum of 5% propylene
- Other gases constitute the remainder (iso-butane, butane, methane, etc.)

The HD-5 specification is based on allowable contents. For instance, 99% propane and 1% propylene is considered HD-5 grade propane, the same as 95% propane and 5% propylene is HD-5 propane. Although the product consistency and purity is different, both mixtures are considered HD-5 propane because they fall within the allowable limits.

2.2.1 Pressure and Temperature

Propane has critical temperature of 213°F (100.56°C) which limits its use as fracturing fluid above that temperature. For applications above 213°F, propane is commonly mixed with butane with critical temperature 350°F (176.67°C). At ambient temperature of 70°F, the minimum storage pressure of 125 psi is required to maintain propane as liquid. Propane that is used as fracturing fluid is stored, gelled and proppant blended at a constant pressure of 280 psi within the surface equipment[6]. During fracturing, it will be pressurized with high pressure pump to the required injection pressure.[6]

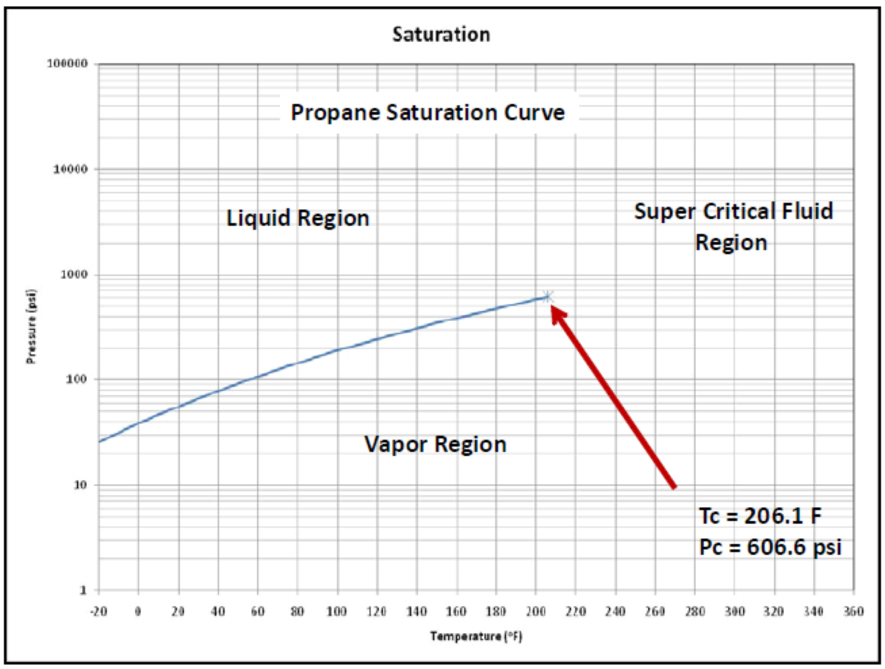

Figure 4 : Propane liquid-vapor saturation curve

After fracturing treatment, as propane which initially in liquid form mixes with the formation hydrocarbon (predominantly methane), the mixture naturally reverts to gas phase. For a reservoir with temperature of 122°F (50°C), minimum 50% of methane-propane mixture is required to flash the propane in the reservoir.

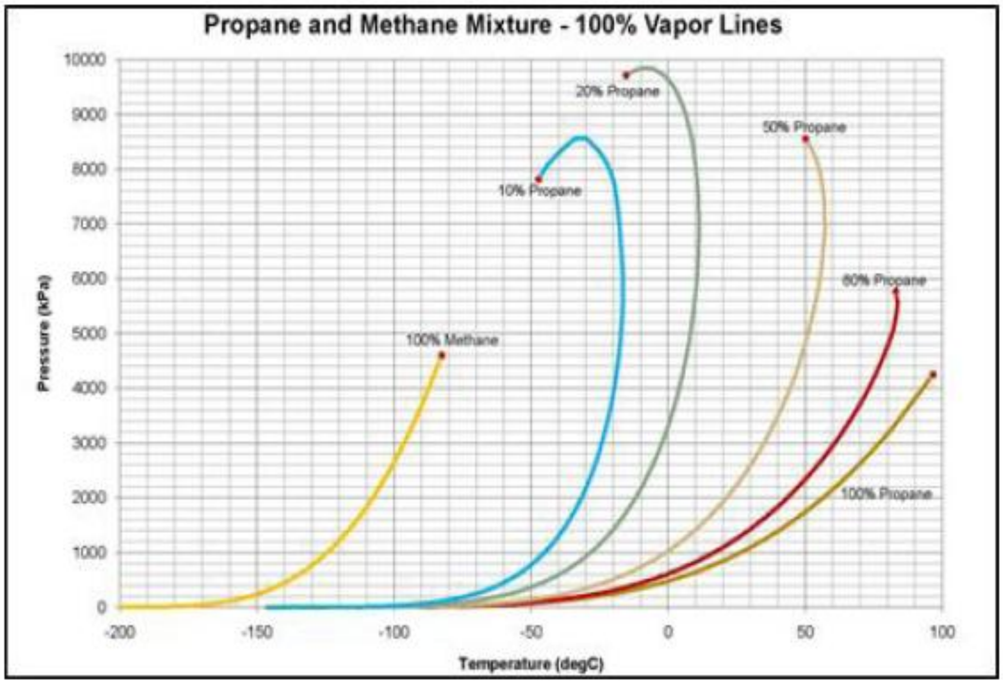

Figure 5 : Propane-methane mixtures phase envelopes

2.2.2 Specific Gravity

Propane has low specific gravity of 0.51 which allows formation to be in underbalanced condition during flowback. As compared with conventional fracturing i.e. using water-based fracturing fluid, incidence of well loading up or dying can be avoided due to its low density. Surface pressure of a well that is load up with propane can be easily drawn up below 100 psi to allow propane to vaporize. This gives the advantage of self regulating flowback without the need of swabbing or gas lifting.[6]

2.2.3 Viscosity

LPG has viscosity of 0.08cps at 105°F. Gelled LPG is made up of 90% propane and a diester phosphoric acid gelling agent to give it sufficient viscosity to proppants. Once the gellation system breaks, viscosity of injected fracturing fluid will reduce to the viscosity of the base fluid. As shown in Figure 5, all fluids thin as temperature increases.

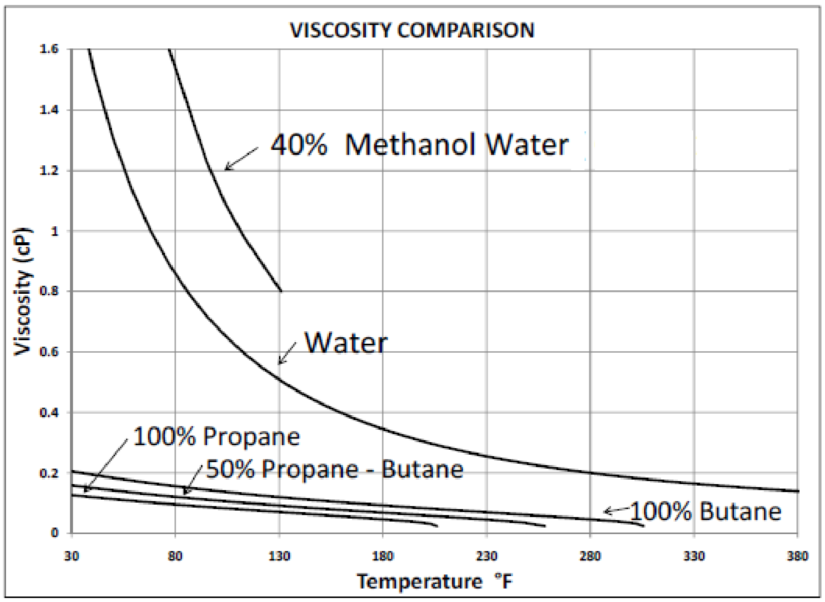

Figure 6 : Comparison of viscosity

Darcy's Law described laminar flow of fluid though porous media as:

$$\frac{\Delta P}{\Delta L} = \mu \frac{V}{k}$$

Where,

P = pressure　　　k = permeability

L = length　　　μ = viscosity

V = velocity

For a constant volume of fluid, a decrease in velocity will result in reduction of pressure required to move it. Based on Darcy's Law, minimizing the needed differential pressure during fracturing will greatly aids fluid clean up. Viscosity of propane and formation hydrocarbon will result in further reduction of required pressure especially if the mixture is in vapor phase.[2]

2.2.4 Surface Tension

This property has impact on capillary pressure once fluid enters the formation. Fluid with low surface tension reduces the pressure needed to move fracturing fluid during flowback.

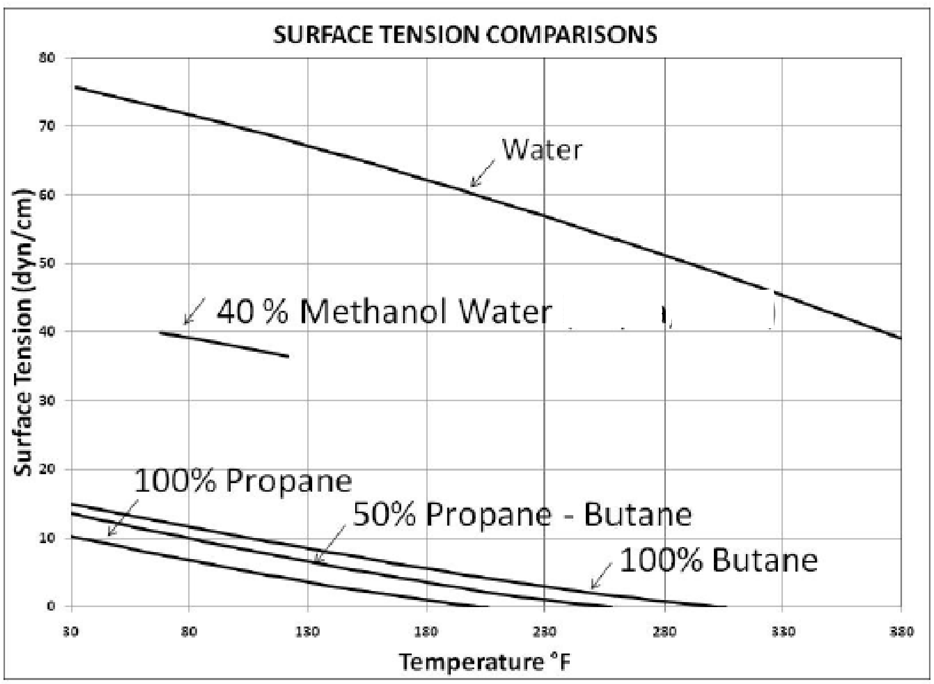

Figure 7 : Comparison of Surface Tension

Capillary pressure of invaded fluid often causes blocking of pores or natural fractures. Blocked pores and fractures can obstruct the flow of formation hydrocarbon into created fracture because trapped fluids are typically almost impossible to remove. The extremely low surface tension of propane eliminates liquid or phase blocking of trapped fluid in pores.

2.3 Gelled LPG

At a moderate pressure of 100 psi, LPG is injected in liquid form and has properties similar to conventional fracturing fluids. It has a consistent viscosity when gelled with chemical gellation technology. The chemical system used to gel LPG is applied as a continuous mixed system and controlled using mass flow meters.[9]

Figure 8 : Gelled HD-5 Propane at atmospheric condition

The gelled LPG is made up of 90 per cent propane and a diester phosphoric acid as gelling agent to give it sufficient viscosity to carry chemicals and sands, show that it the recipe is both safer and far more efficient than water. Depending on the requirement of hydraulic fracturing design, viscosity and breaking time can be adjusted by altering the chemistry composition.

However, gas producers conducting this new approach using propane instead of water to hydraulically fracture the rock are not revealing much of the results data. This is holding back the widespread introduction of the method in the booming shale gas sector.

2.4 Advantages of LPG as Fracturing Fluid

Compatibility

Using LPG as fracturing fluid is highly recommendable for formation that is water sensitive. Conventional water-based fracturing fluid often caused clay swelling in formation and reduces effective fracture length. LPG is completely compatible with formation and formation fluids. Multiple fractures can be conducted without immediate fracture cleanup between treatments due to this.

Soluble in Formation Hydrocarbon

Since LPG comes from natural gas, it is completely soluble with produced hydrocarbons. Injected LPG can be recovered together with production in sales line presents the option to recover propane as sales gas. As nitrogen or carbon dioxide is not used in LPG fracturing, the contaminants are not required be flared prior flowing the return to sales line.

Easy Return Handling

Return of LPG fracturing fluid can be either flared or directed into sales line together with production. In fields with no facilities to store propane return, it can simply be flared especially during early stage of flowback. This is also a great alternative for fields with low water handling facilities that use conventional water-based fracturing fluid.

Readily Available

Natural gas is produced in abundance worldwide. In 2007, Malaysia's production of natural gas averaged 7.01 billion standard cubic feet (bscf) per day. As of January 2008, the natural gas reserve in Malaysia is 88.0 tscf or 14.67 billion barrels, approximately three times the size of crude oil reserves of 5.46 billion barrel[11].

2.5 Limitations

Special considerations

To ensure safety of operations, specialized pumping equipment and LPG storage vessels are requires as well as additional safety procedures including purging of lines with inert gas after pumping.

Limitation on lab equipment

Break test of LPG will require specialized lab equipment which is not many available.

Extra cost

Using LPG as based fluid is can cost 20-40% more than conventional based fracturing fluid. However, this can be recovered by sale of recovered flowback fluids. Elimination of swabbing and reduced flowback time can also make up for the extra cost.

2.6 Field Background

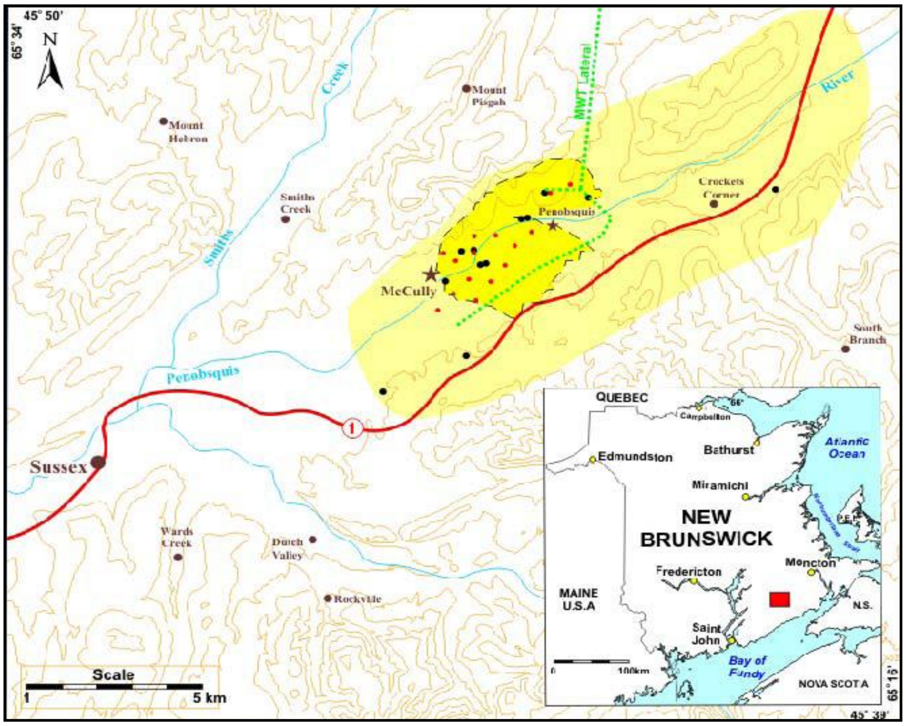

Figure 9 : McCully field location

The McCully gas field in southern New Brunswick was discovered in the year 2000 on a joint drilling exploration venture by Corridor Resources Inc. and Potash Corporation of Saskatchewan. Located about 10 km east of Sussex, the potential field measures about 15 km long by about 5 km wide and is estimated to contain 1 trillion cubic feet of gas in place.

The McCully tight gas filed in New Brunswick, Canada has porosity ranges from 4% to 8% with water saturation ranging from 10% to 30%. The permeability ranges from as low as 0.001md and as high as 1.8md across the field. Reservoir pressure ranges from 2900 psi to 5100 psi with low reservoir temperature of 40°C at depth 7380 ft.[8]

Since the early stage of production, 74 water-based hydraulic fracturing treatments were conducted in 26 of the wells. However, water cleanup has become a problem after the treatment which resulted in changing the alternative to using gelled LPG as fracturing fluid. Gasfrac Energy Services, a small Canadian company in Calgary, Alberta, has developed a technology to gelled propane-based LPG as a substitute for water to carry the chemicals and sand needed to fracture the shale rock. Four wells were initially tested where the fracture characteristic and flowback performance were carefully monitored. The most significant improvement between water and propane fracture treatments was the recovery time of the fracturing fluid. Gelled LPG was recovered within 20 days after the flowback while water-based fluid was still produced even after 1000 days of production.

Nonetheless, despite being used around 1000 times in Canada and the US since first being tested three years ago, little data on the application of the technology has been made publicly available. In such a highly competitive industry, producers do not want to disclose its potential benefits.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Investigation will be conducted to ensure that research went on smoothly. At first, the study on conventional hydraulic fracturing fluid will be conducted to identify all the parameters such as viscosity, fluid loss, filtration time and etc. Intensive study on gelled LPG as fracturing fluid is carried out to certify the suitability of the fluid in maximizing effective fracture length. Series of equations will be used to model the key parameters influencing fracture cleanup.

3.2 Project Activities

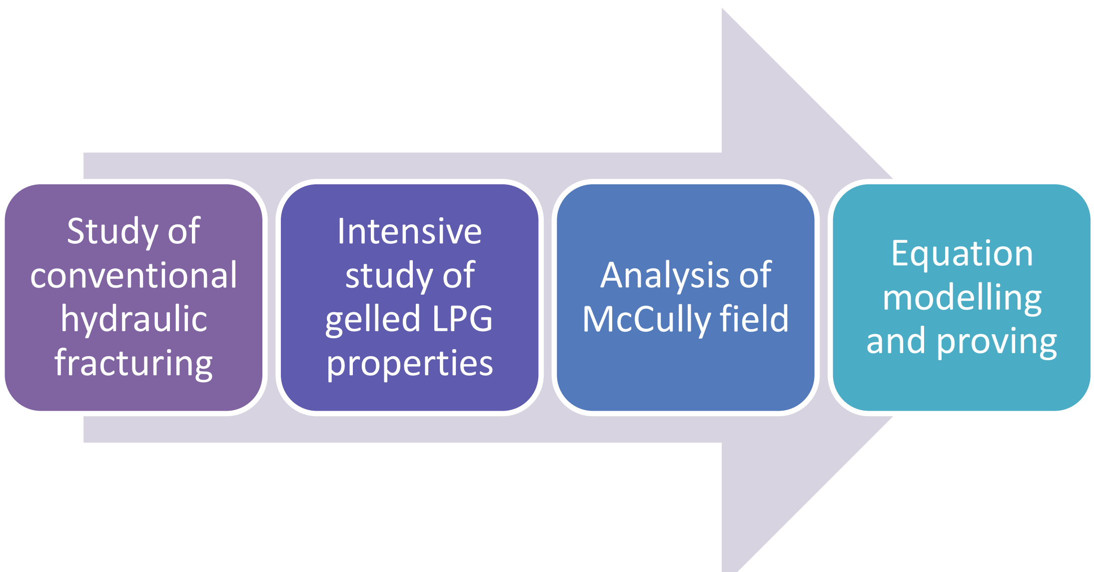

Figure 10 : Project activities

3.3 Gantt Chart

Activities	Final Year Project I (FYP-1)														Final Year Project II (FYP-2)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic selection	■	■																										
Study on conventional hydraulic fracturing system			■	■	■	■																						
Study on factors affecting fluid loss behavior							■	■																				
Study on gelled LPG as fracturing fluid									■	■	■	■	■	■	■													
Determination of simulation method														■	■	■	■											
Single phase flow simulation																■	■											
Two phase flow simulation																		■	■									
Modeling flowback																				■	■							
Analyzing compatibility with formation for flowback																						■	■					
Result and analysis																							■	■	■	■	■	■

Milestone	Final Year Project I (FYP-1)														Final Year Project II (FYP-2)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Completion of study in conventional fracturing fluid design					■	■	■																					
Completion of study of LPG fracturing fluid								■	■	■	■	■	■	■														
Completion of case study analysis																■	■	■	■	■	■	■						
Result analysis																								■	■	■		

CHAPTER 4

RESULT AND DISCUSSION

4.1 Fracture Design

To estimate the required fluid volume, proppant mass and time of injection, the parameters needed are propped width, w, fracture permeability, k_f, assumed fracture halflength, x_f and reservoir permeability, k.

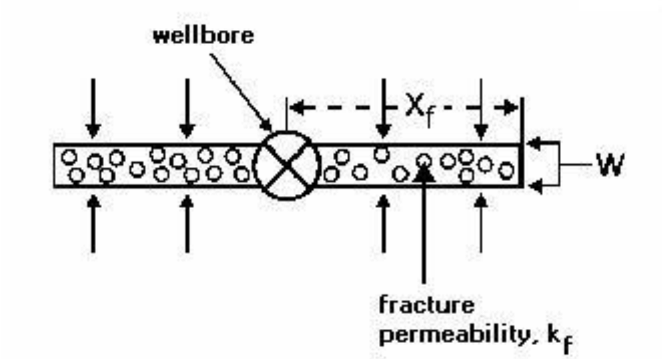

Figure 11 : Hydraulically fractured formation

Fracture conductivity can be determine by

$$F_{cd} = \frac{k_f w}{k x_f}$$

Cinco et al. (1978) relates the dimensionless fracture conductivity, F_{cd} and fracture length with equivalent skin effect, s_f in a plot of Fcd against s_f + l(x_f/r_w). F_{cd} improves over time as hydraulic fracturing fluid is pumped to propagate the fracture.

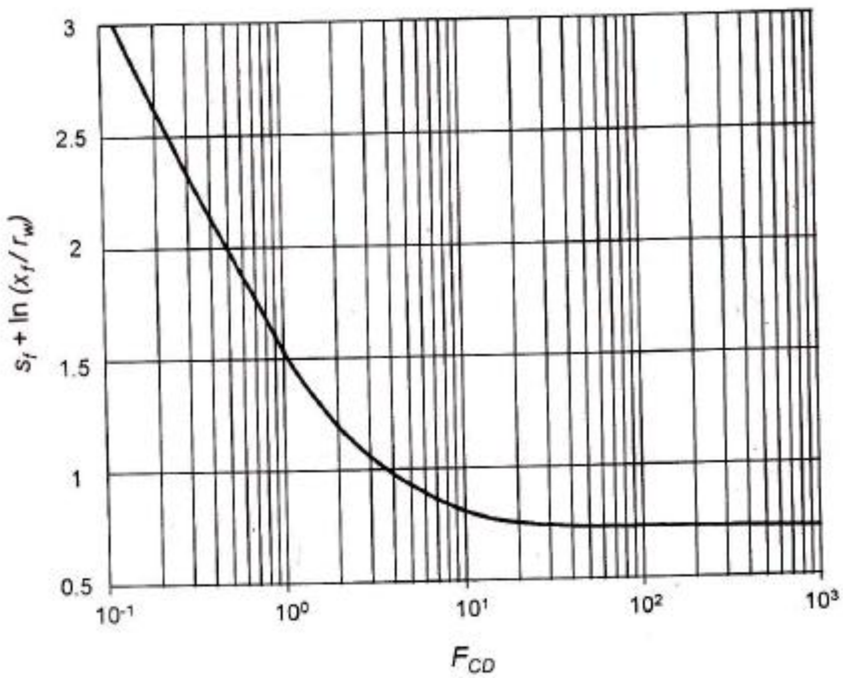

Figure 12 : Equivalent skin effect into a fractured well

Initial test of fracture using water-based fluid showed that F_{cd} reached maximum after three to four pressure cycles of fracture cleanup. The opposite was however observed when gelled LPG is used where no issues of fracture cleanup occurred.

With propane flowback, the initial 24 hours of production from the well has to be flared because it is mostly 100% propane. After the gas specific gravity decline from 1.5 to around 1.0, gas can be directed to the gas plant for processing and sales. In previous cases, it took only around five days for the propane content to drop below 10% after flowback started.

4.2 Initiating Wellbore Fluid Recovery

The initial stage of recovering fracturing fluid starts with fluid that is still in the wellbore which is most likely still in liquid form. If pressurized vessel is not available to accommodate liquid propane, the fluid needs to be vaporized using line heater. A 2MMBTU/hr line heater is typically used to supply the heat for vaporization. Separator temperature and pressure are carefully adjusted to avoid freezing of LPG that can cause build-up in the separator.

If the heat provided is not sufficient, temperature in separator can drop significantly and cause liquid accumulation. This will create potential flow of liquid to flare stack. Furthermore, liquid accumulation in separator slows vaporization resulting in long recovery period. Propane saturation graph is used to check whether propane liquid will accumulate in the separator.

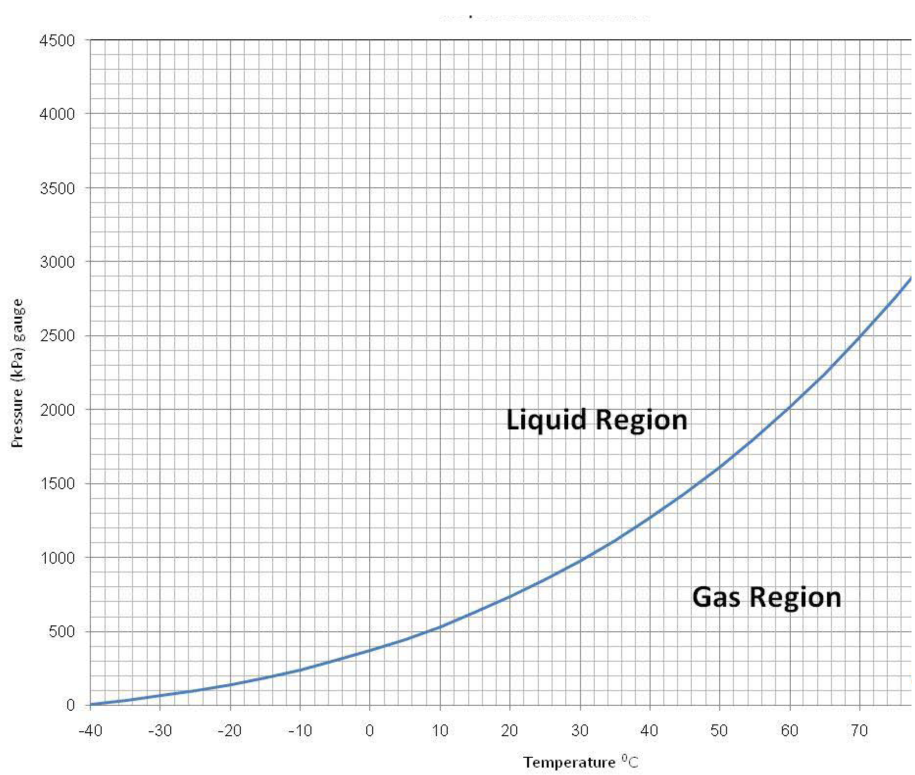

Figure 13 : Propane Saturation Curve

For example, a separator operating at 5°C and 700kpa will face liquid propane accumulation because the intersection falls above the saturation line. For that operating pressure, the operating temperature should be at least 25°C. Note that lowering the operating pressure will normally result in further cooling.

4.3 Calculating LPG Recovery

LPG is often recovered as vapor or gas through separator meter run. Generally, the amount of LPG vapor recovered is determined as follows:

i. Volume of gas flow from separator is measured
ii. The content of LPG in flowback is determined using gas chromatograph analysis or by gas density. For every one cubic meter (1 m^3) of LPG liquid that vaporizes, 272 m^3 gas is created (at 15°C, 101.3 kPa)
iii. Recovery of LPG in both liquid form from pressurized tank and gas are added and recorded to determine the total volume recovered

For example, a hydraulic fracturing treatment is carried out with 100 m^3 of LPG. 100% vaporization of the fracturing fluid will generate 27, 200 m^3 of gas. Complete recovery is said to be achieved when cumulative recovery of the treatment reached that volume. Flowback with gas flow rate of 30, 000 m^3/day ongoing for 15 minutes gives cumulated gas volume of:

$$\text{Gas volume} = 30\ 000\ m^3/\text{day} \times 15\ \text{min} \times 1\ \text{day}/\ 1440\ \text{min}$$

$$= 312\ m^3$$

4.4 Heat Requirement for LPG Vaporization

The industry recommendation for initial propane flowback is 2 m^3/hour. However in some occasions where flowback time needs to be minimized, higher rate is applied which requires properly sized line heater to accommodate the recovery rate. After the fracturing fluid has been pumped to create fracture, well is usually shut in for 48 hours or more to allow mixing of the LPG with reservoir fluids. The mixing of LPG and natural gas will reduce heat requirement for vaporization. The level of mixing however is difficult to predict and recovery of LPG in liquid form should be expected during flowback.

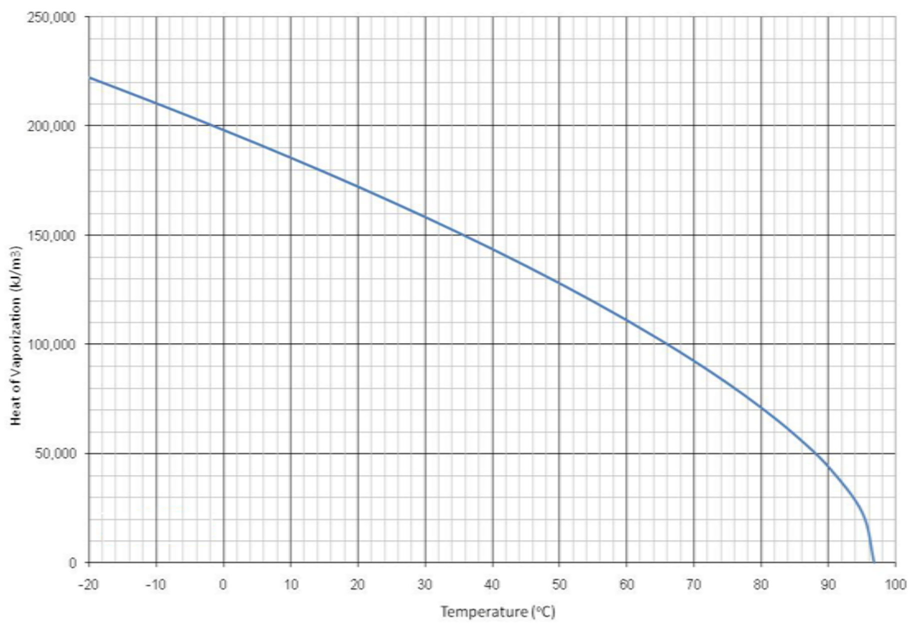

Figure 14 : Propane – Heat of Vaporization Chart

Heat of Vaporization Chart is used to determine the minimum heat requirement. At wellhead temperature of 10°C, intersection line on the curve reads the value of 185, 000 kJ/m^3. For a liquid recovery rate of 2m^3/hour, the heat required is:

Heat required = 2 m^3/hour x 185, 000 kJ/m^3

= 370, 000 kJ/hour

= 370, 000 kJ/hour x 0.94782 Btu/kJ

= 0.35 MMBtu/hr

4.5 Results

Case 1 : Gas formation with permeability 3.29mD

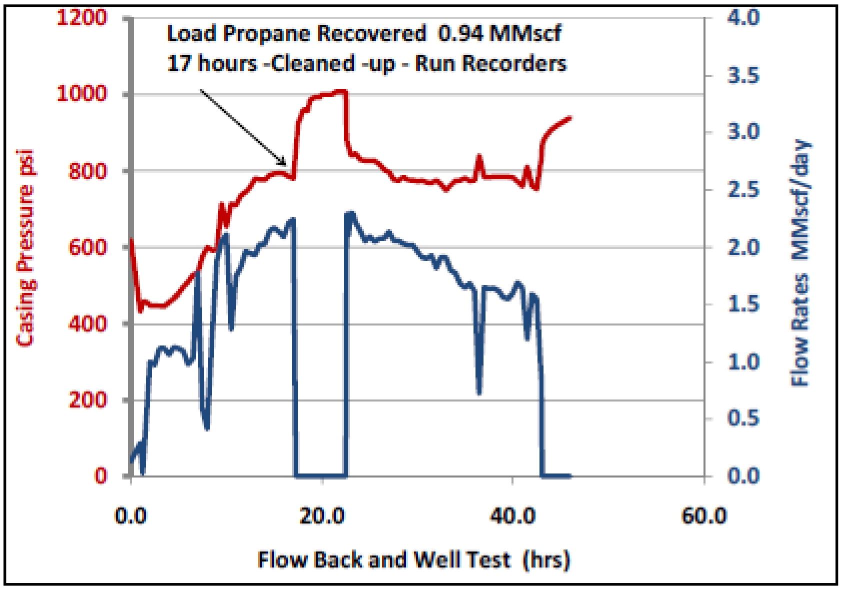

Figure 15 : Case 1, Flowback report

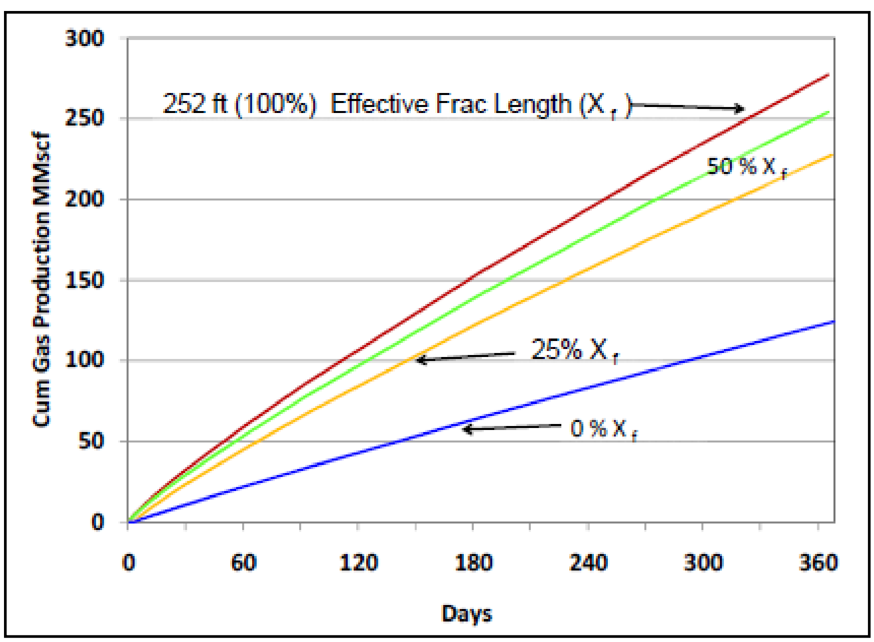

Figure 16 : Case 1, Cumulative production forecast

Case 1 Stimulation Formation	55,000 lb Gelled LPG Fracture Treatment Blue Sky Sand (Gas)	Post Stimulation Results	Case 1
Mode	4-1/2 " Casing	Pay	5.6 ft
Propane Volume (Load Gas) Proppant	612bbl (0.94 MMscf) 55,000 lb 30/50 Ceramic	Perm (K)	2.96 mD
Depth TVD	1308 ft	Skin	-5.94
Bottom Hole Temperature	138 ° F	X_f - Effective Fracture length	252 ft
Average Porosity	14 %	Created Fracture Length (Modeled)	262 ft
Water Saturation	20 %	% X_f/ Created Length	96 %
Bottom Hole Pressure	1,300 psi		

Table 1 : Case 1, Fracture treatment result

Case 2 : Gas formation with permeability 0.10mD

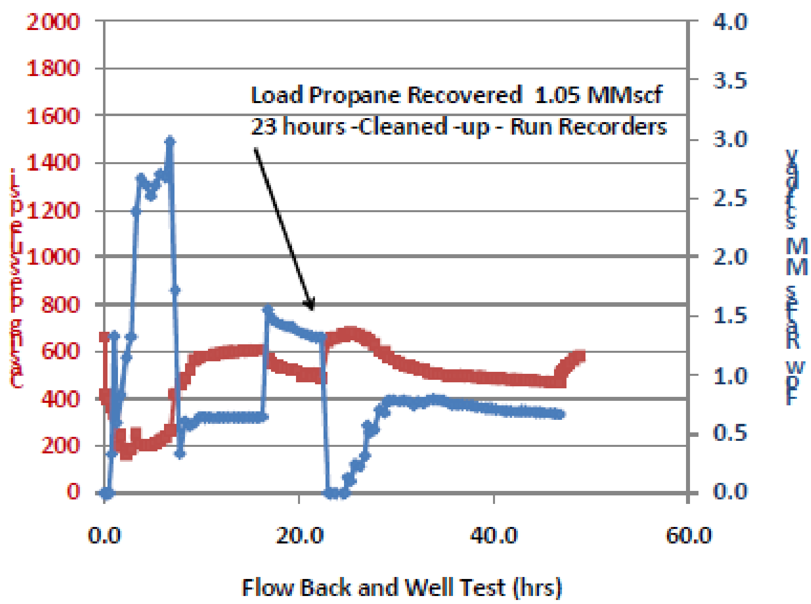

Figure 18 : Case 2, Flowback report

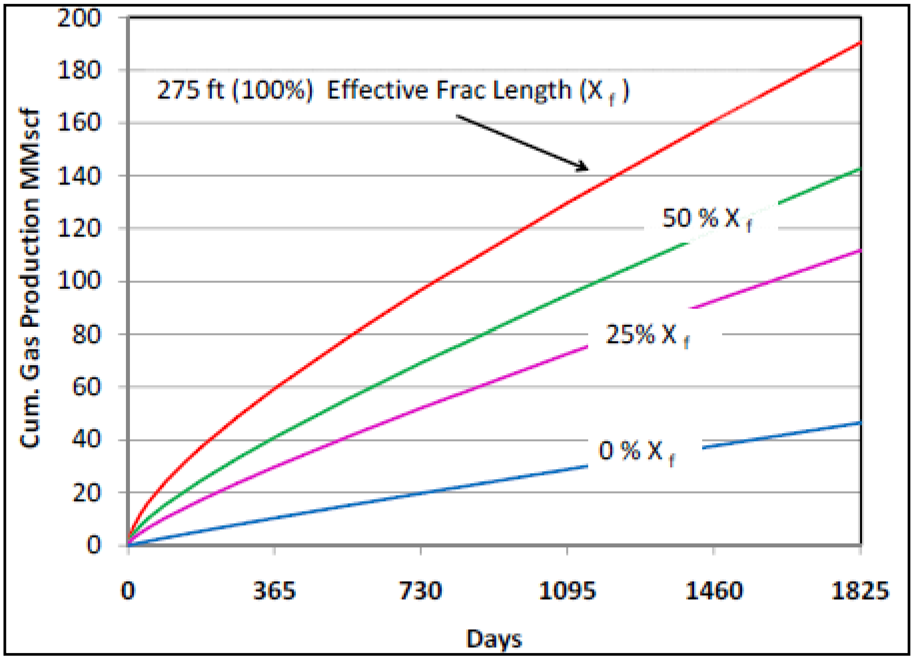

Figure 19 : Case 2, Cumulative production forecast

Case 2 Stimulation Formation	66,000 lb Gelled LPG Fracture Treatment Cardium Sand (Gas)	Post Stimulation Results	Case 2
Mode	4-1/2 " Casing	**Pay**	14 ft
Propane Volume (Load Gas) Proppant	630 bbl (1.05 MMscf) 66,000 lb 30/50 sand	**Perm (K)**	0.10 mD
Depth TVD	4264 ft	**Skin**	-4.66
Bottom Hole Temperature	86 °F	**Xf - Effective Fracture length**	275 ft
Average Porosity	10 %	**Created Fracture Length (Simulated)**	290 ft
Water Saturation	20 %	**% XF/ Created Length**	94 %
Bottom Hole Pressure	1,133 psi	**K fw – Fracture Conductivity**	91.44 mD*ft

Table 2 : Case 2, Fracture treatment result

Case 3 : Gas formation with permeability 0.07mD

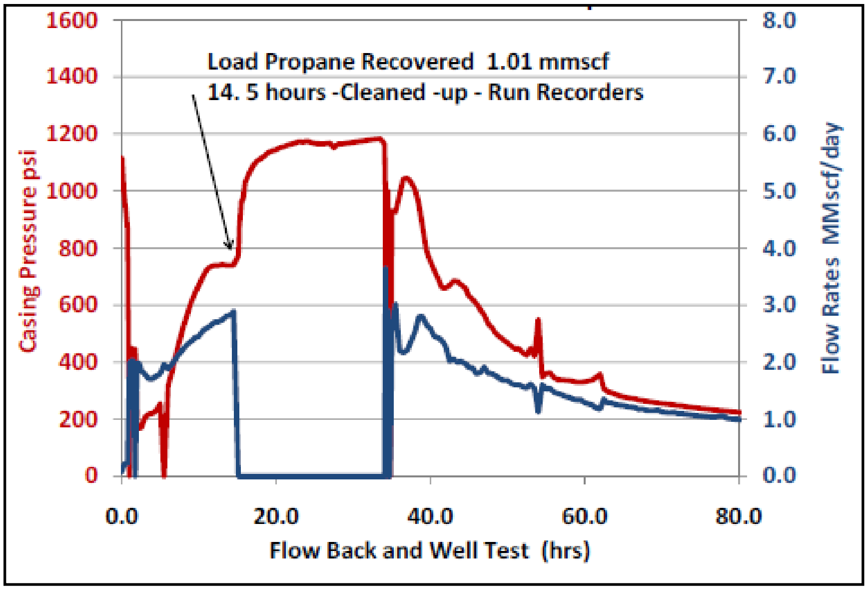

Figure 21 : Case 3, Flowback report

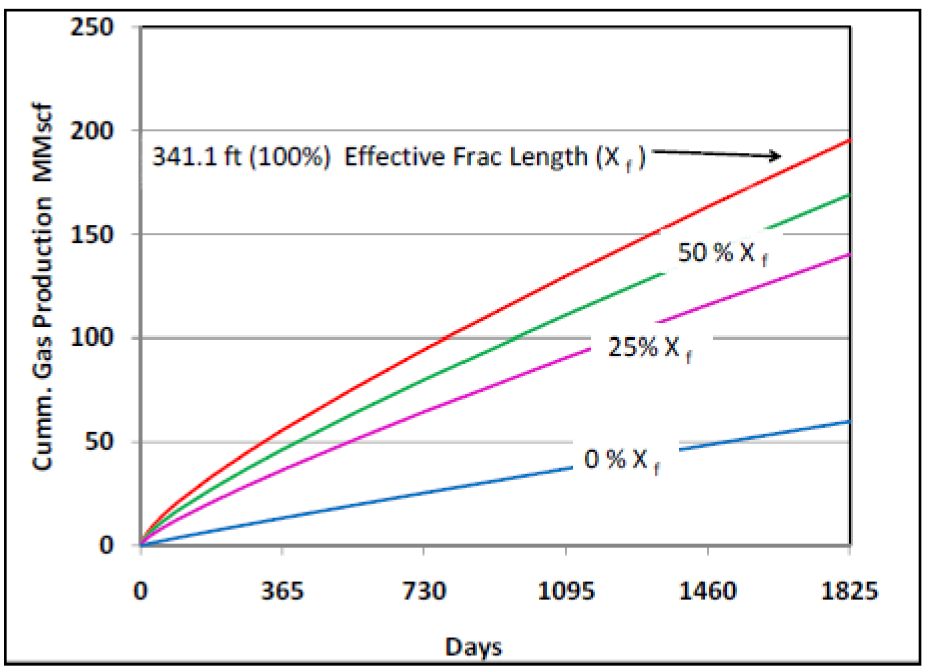

Table 3 : Case 3, Cumulative production forecast

Case 3 Stimulation Formation	46,000 lb Gelled LPG Fracture Treatment Tight Hole Sand (Gas)
Mode	4-1/2 " Casing
Propane Volume (Load Gas) Proppant	664 bbl (1.01 mmscf) 46,000 lb 40/70 RC Sand
Depth TVD	8140 ft
Bottom Hole Temperature	172 ° F
Average Porosity	11.1 %
Water Saturation	20 %
Bottom Hole Pressure	2,570 psi

Post Stimulation Results	Case 3
Pay	7.9 ft
Perm (K)	0.07 mD
Skin	-5.73
Xf - Effective Fracture length	341.1 ft
Created Fracture Length (Modeled)	357 ft
% XF/ Created Length	96 %
K fw – Fracture Conductivity	221 mD*ft

Figure 23 : Case 3, Fracture treatment result

Successful stimulation can be monitored by early indications of rapid fracture fluid recovery and expected initial gas production rates. Figures 15, 18 and 21 illustrates rapid recovery and cleanup after 100% LPG fracture treatment. All cases show complete cleanup within 14 to 24 hours, which is much less than time needed for cleanup compared to fracture treatment using conventional fracturing fluids. Fracture treatment effectiveness and predicted productions rates are then quantify using pressure transient analysis.

In this case study, simulated reservoirs are evaluated by effective fracture length instead of using formation skin. The propped fracture lengths were estimated using fracture propagation simulator calibrated with the history matching pressure response during each treatment. As can be seen from the results, all three cases using gelled LPG fracturing fluid resulted in 94 to 96 percent of effective fracture length.

CHAPTER 5
CONCLUSION

In conclusion, the study is on the right track to meeting its objective. Based on the case study of using gelled LPG as fracturing fluid in McCully fields, the result is proven to successfully maximize effective fracture length and minimize flowback time. This is highly desired in every hydraulic fracturing job conducted to optimize well performance after the treatment. The main characteristic of LPG as fracturing fluid that makes it the desired choice is its compatibility with formation fluid and its ability to revert back to low viscosity fluid after the treatment.

This method is currently being tested across North America and proven to be successful. Since first being tested three years ago, more than 1000 hydraulic fracturing treatment has been conducted using gelled LPG. This clearly shows massive potential of using gelled LPG as substitute to conventional hydraulic fracturing method in order to maximize effective fracture length by complete removal of fracturing fluids. The cost for using gelled LPG is higher than conventional fluid but it can be recovered by sales of flowback fluid, elimination of swabbing cost and significant reduction of flowback time.

The relevancy of this study can be highly improved if hydraulic fracturing software is available. The software StimPlan and F.A.S.T are commonly used in the industry to predict and monitor fracture performance. However, due to unavailability of the software in UTP, this cannot be done. Nonetheless, the author is able to revised samples of result generated from the software as guideline in this study.

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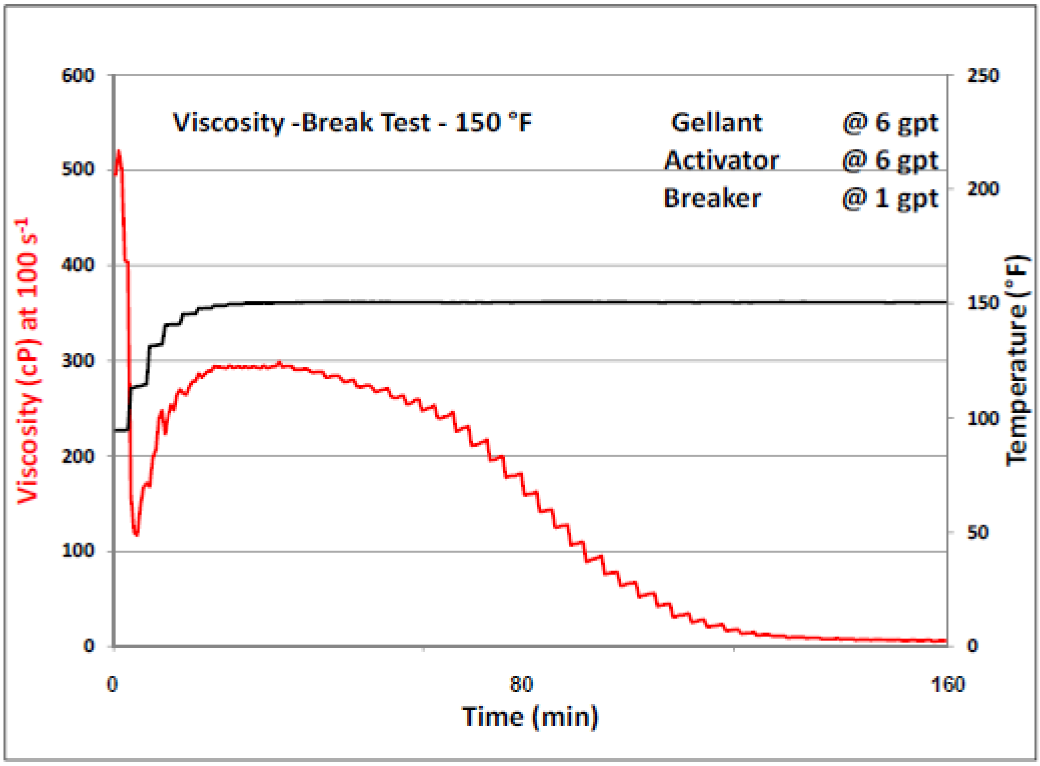
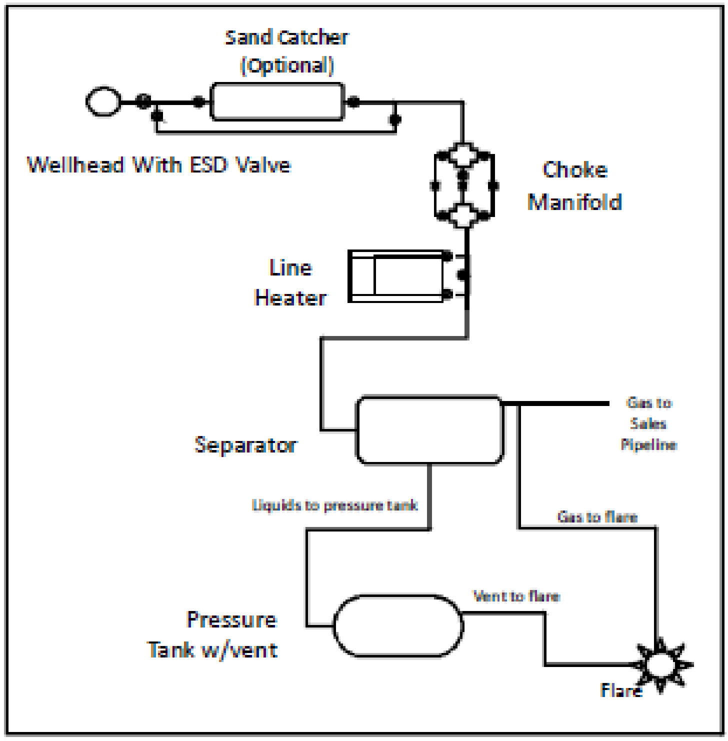
APPENDIX

Typical viscosity and break curve for gelled LPG



Typical equipment setup for flowback of LPG Hydraulic fracturing



McCully reservoir parameters

Reservoir depth	1800m
Gross thickness	Up to 870m
Net pay	Up to 95m
Temperature	40^oC – 60^oC
Porosity	4% - 8%
Water saturation	<10% - 30%
Permeability	0.01mD – 1.8Md
Reservoir pressure	20 Mpa – 35 Mpa

McCully field water based fractures history between 2005-2008

Well (Year Frac'd)	Perm	IP @ 4 days		# Fracs	Frac Size	xf	FCD
	md	mscf/d	$10^3m^3/d$		tonnes	m	-
B-58 (2006)	0.030	1,880	53.2	1	69	46	3
B-58 (2008)	0.073	1,345	38.1	1	60	27	100
C-48 (2008)	0.015	1,400	39.6	2	128	50	0.1
C-57 (2008)	0.15	1,871	53.0	4	149	6	1
C-67 (2005)	0.187	3,717	105.3	2	70	27	2
D-57 (2006)	0.044	1,451	41.1	1	42	26	0.6
D-57 (2008)	0.022	n/a	n/a	1	18	33	2
D-66 (2007)	0.031	2,951	83.6	4	275	27	0.1
D-67 (2007)	0.032	631	17.9	4	181	8	0.1
E-38 (2007/2008)	0.033	n/a	n/a	4	128	3	60
E-57 (2006)	0.063	1,801	51.0	1	56	8	100
F-58 (2007)	0.004	749	21.2	4	70	10	0.5
G-67 (2005)	0.014	976	27.6	2	59	27	0.5
H-28 (2006)	0.015	166	4.7	1	68	8	100
H-76 (2007)	1.763	n/a	n/a	1	77	1	0.5
I-67 (2007)	0.025	592	16.8	3	167	10	0.1
J-38 (2007)	0.04	4,065	115.1	4	309	30	0.1
J-47 (2008)	0.012	7,100	201.0	7	524	40	20
J-66 (2006)	0.095	3,601	102.0	3	164	25	2
J-67 (2006)	0.033	650	18.4	3	158	25	0.1
K-48 (2008)	0.023	500	14.2	2	60	25	0.1
K-57 (2005)	0.04	707	20.0	1	32	5	0.1
K-66 (2006)	0.24	7,441	210.7	1	62	40	1
M-66 (2006)	0.12	9,041	256.0	3	100	10	0.1
N-66 (2008)	0.005	2,000	56.6	4	145	27	0.5
O-66 (2005)	0.117	5,065	143.4	4	108	25	2
P-67 (2008)	0.097	5,068	143.5	3	178	25	0.1
P-76 (2007)	0.062	2,020	57.2	3	102	25	1
Well Average	**0.121**	**2,672**	**75.6**	**74**	**48**	**22**	