Alternate Hydraulic Fracturing Fluids

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Introduction

- Overview of the project
- Calculations of flow rates of alternate fluids
- Thermal Effects
- Economics

Overview of Project

- For the spring semester our team is comparing our findings from the fall semester from the data provided by “Triangle Petroleum Corporation,” and use this data to determine the possible application of alternative hydraulic fracturing methods.
- Our team is using data for two wells located in McKenzie County, ND.
- We will compare the feasible methods to the traditional method and determine the best economic choice for our wells.

Hale, Tony. *31 Stage Plug/Perf StackFrac Stimulation Liner Final Job Report*. PackersPlus. Prepared by: Josh Jany. Prepared for: Triangle Petroleum.

Premise

- Looking at liquid carbon dioxide, liquid nitrogen, and liquid natural gas
- In addition we are looking at energized fractures
- To compare the alternative fluids assuming the same fracture efficiencies
- Allow us to obtain flow rates and liquid volumes from the volume of the wings in the original fracture
- This is needed to complete economic analysis

Difficulties With the PKN Model

- Assumptions
- Water loss
- Efficiencies
- Thermal effects

Adaptation of PKN Model

- Last semester PKN assumptions
  - ν
  - G
  - μ

Treatment 5			
	μ, cp= 200		
ν	0.2	0.3	0.4
G, MPa	1.992	1.743	1.494
E, MPa	3.188	2.440	1.792

PKN Analysis

70% Carbon Dioxide 30% Slick Water Flow Rates For Treatment 5										
water viscosity, cp=200										
Treatment 5 for Pois Ratio = .2				Treatment 5 for Pois Ratio = .3				Treatment 5 for Pois Ratio = .4		
ν=	0.20			ν=	0.30			ν=	0.40	
G=	1.99E+08	Pa		G=	1.74E+08	Pa		G=	1.49E+08	Pa
Wmax=	0.02	m		Wmax=	0.02	m		Wmax=	0.02	m
L=	99.36	m		L=	99.36	m		L=	99.36	m
μ=	0.29	Pa*s		μ=	0.29	Pa*s		μ=	0.29	Pa*s
Q=	0.05	m^3/s		Q=	0.05	m^3/s		Q=	0.05	m^3/s
	784.07	gpm			784.07	gpm			784.07	gpm
	18.67	bpm			18.67	bpm			18.67	bpm
water viscosity, cp=470										
Treatment 5 for Pois Ratio = .2				Treatment 5 for Pois Ratio = .3				Treatment 5 for Pois Ratio = .4		
ν=	0.20			ν=	0.30			ν=	0.40	
G=	4.68E+08	Pa		G=	4.10E+08	Pa		G=	3.51E+08	Pa
Wmax=	0.02	m		Wmax=	0.02	m		Wmax=	0.02	m
L=	99.36	m		L=	99.36	m		L=	99.36	m
μ=	0.29	Pa*s		μ=	0.29	Pa*s		μ=	0.29	Pa*s
Q=	0.12	m^3/s		Q=	0.12	m^3/s		Q=	0.12	m^3/s
	1842.89	gpm			1843.00	gpm			1842.62	gpm
	43.88	bpm			43.88	bpm			43.87	bpm

Fenghour, A. Wakeham, W.A. The Viscosity of Carbon Dioxide. *American Institute of Physics and the American Chemical Society.* .J. Phys. Chem. Ref. Data, Vol. 27, No. 1, 1998.

PKN Analysis

70% Nitrogen 30% Slick Water Flow Rates For Treatment 5											
water viscosity, cp=200											
Treatment 5 for Pois Ratio = .2				Treatment 5 for Pois Ratio = .3				Treatment 5 for Pois Ratio = .4			
v=	0.20			v=	0.30			v=	0.40		
G=	1.99E+08	Pa		G=	1.74E+08	Pa		G=	1.49E+08	Pa	
Wmax=	0.02	m		Wmax=	0.02	m		Wmax=	0.02	m	
L=	99.36	m		L=	99.36	m		L=	99.36	m	
μ=	0.16	Pa*s		μ=	0.16	Pa*s		μ=	0.16	Pa*s	
Q=	0.09	m^3/s		Q=	0.09	m^3/s		Q=	0.09	m^3/s	
	1428.31	gpm			1428.31	gpm			1428.31	gpm	
	34.01	bpm			34.01	bpm			34.01	bpm	
water viscosity, cp=470											
Treatment 5 for Pois Ratio = .2				Treatment 5 for Pois Ratio = .3				Treatment 5 for Pois Ratio = .4			
v=	0.20			v=	0.30			v=	0.40		
G=	4.68E+08	Pa		G=	4.10E+08	Pa		G=	3.51E+08	Pa	
Wmax=	0.02	m		Wmax=	0.02	m		Wmax=	0.02	m	
L=	99.36	m		L=	99.36	m		L=	99.36	m	
μ=	0.16	Pa*s		μ=	0.16	Pa*s		μ=	0.16	Pa*s	
Q=	0.21	m^3/s		Q=	0.21	m^3/s		Q=	0.21	m^3/s	
	3357.11	gpm			3357.31	gpm			3356.63	gpm	
	79.94	bpm			79.94	bpm			79.92	bpm	

Fenghour, A. Wakeham, W.A. The Viscosity of Carbon Dioxide. *American Institute of Physics and the American Chemical Society.* .J. Phys. Chem. Ref. Data, Vol. 27, No. 1, 1998.

PKN Analysis

Liquid Natural Gas Flow Rates For Treatment 5										
water viscosity, cp=200										
Treatment 5 for Pois Ratio = .2				Treatment 5 for Pois Ratio = .3				Treatment 5 for Pois Ratio = .4		
v=	0.20			v=	0.30			v=	0.40	
G=	1.99E+08	Pa		G=	1.74E+08	Pa		G=	1.49E+08	Pa
Wmax=	0.02	m		Wmax=	0.02	m		Wmax=	0.02	m
L=	99.36	m		L=	99.36	m		L=	99.36	m
µ=	0.00024	Pa*s		µ=	0.00024	Pa*s		µ=	0.00024	Pa*s
	59.89	m^3/s			59.89	m^3/s			59.89	m^3/s
Q=	949305	gpm		Q=	949305	gpm		Q=	949305	gpm
	22604	bpm			22603	bpm			22604	bpm
water viscosity, cp=470										
Treatment 5 for Pois Ratio = .2				Treatment 5 for Pois Ratio = .3				Treatment 5 for Pois Ratio = .4		
v=	0.20			v=	0.30			v=	0.40	
G=	4.68E+08	Pa		G=	4.10E+08	Pa		G=	3.51E+08	Pa
Wmax=	0.02	m		Wmax=	0.02	m		Wmax=	0.02	m
L=	99.36	m		L=	99.36	m		L=	99.36	m
µ=	0.00024	Pa*s		µ=	0.00024	Pa*s		µ=	0.00024	Pa*s
	140.77	m^3/s			140.78	m^3/s			140.75	m^3/s
Q=	2231249	gpm		Q=	2231385	gpm		Q=	2230931	gpm
	53127	bpm			53130	bpm			53120	bpm

LNG – *Cameo Chemicals*. cameochemicals.noaa.gov/chris/LNG.pdf. Updated 1999. Last accessed: April 27, 2015.

Results of PKN Model

Gardner Denver C-2500 pump at 20,000 psi pumping 191 GPM									
	70% Carbon Dioxide 30% Slick Water			70% Nitrogen 30% Slick Water			Liquid Natural Gas		
Viscosity	200	470	925	200	470	925	200	470	925
# of pumps	5	10	19	8	18	35	5000	11700	23000

"GD-2500 Pump Model." *Stimulation and Frac Pump*. N.p., n.d. Web. 08 Apr. 2015.

Thermal Calculations

- Have been made based on a flow-back report from *Triangle Petroleum*.
- The flow-back report has water temperature leveling off at approximately 170 degrees Fahrenheit.
- By using the specific heat capacities of each fluid type, and comparing that to the temperature change of water, our team has estimated the bottom-hole temperature for each fluid type.
- Although this method is not exact, it is acceptable for this scenario as it uses real production data to estimate temperature.
- This method also has the benefit of giving specific data to apply to viscosity since liquid CO_2 changes with temperature.

Thermal Calculations

- Specific Heat by fluid type:
  - Water – 4480 J/kg*K
  - LNG – 3510.376 J/kg*K
  - Liquid Nit. – 2040 J/kg*K
  - Liquid CO_2 – 2272.72 J/kg*K

- Bottom-hole temperature estimates:
  - Water – 410.928 K
  - LNG – 189.141 K
  - Liquid Nit. – 211.555 K
  - Liquid CO_2 – 315.113 K

Thermal Stresses

- Thermal stress in the formation is calculated using the equation:

$$\sigma = E(1+\upsilon)\alpha\Delta T$$

- υ ~ Poisson's Ratio – 0.3 is an acceptable value for the Bakken
- α ~ Unit temperature change – We use $1 \times 10^{-5}\ K^{-1}$
- ΔT ~ This value is calculated for each fluid type based on its specific heat, and the values we use are:

CO_2 ~ 95.82 K

N_2 ~ 199.37 K

LNG ~ 221.79 K

- The final value used in the equation for thermal stresses is the Modulus of Elasticity.

Enayatpour, Saeid. Patzek, Tad. *Thermal Shock in Reservoir Rock Enhances the Hydraulic Fracturing of Gas Shales.* Center for Petroleum and Geosystems Engineering, The University of Texas at Austin. Presented at: *Unconventional Resources Technology Conference*, 12-14 August 2013.

Modulus of Elasticity

- Our team found discrepancies in the value to use for Modulus of Elasticity. Based on the PKN model, which assumes no water loss, our team calculated a value of 0.2441 GPa for this formation.

- These wells actually lose close to 90% of pumped water to the formation, and as a result the rock appears "softer" then it really is.

- Research has indicated that appropriate values for Modulus of Elasticity in the Bakken are between 5 – 65 GPa

Zeng, Zhengwen. *GEOMECHANICAL STUDY OF BAKKEN FORMATION IN EASTERN WILLISTON BASIN, NORTH DAKOTA*. (n.d.): n. pag. North Dakota. *University of North Dakota*, 31 Dec. 2008. Web. 15 Nov. 2014.
Havens, J. *Mechanical Properties of the Bakken Formation*. Thesis: Colorado School Of Mines. http://geology.mines.edu/Bakken/NETL_DOE/DOE-Student

Calculated Thermal Stresses

	E = 0.2441 GPa	E = 5 GPa	E = 20 GPa	E = 40 GPa	E = 65 GPa
σ_{CO2} (psi)	44.1	903.3	3613.4	7226.7	11,743.4
σ_{N2} (psi)	91.76	1879.6	7518.2	15,036.4	24,434.2
σ_{LNG} (psi)	102.08	2091.4	8365.7	16,731.4	27,181.9

Selection Criteria

- Our formation opening stress is 13,396 psi
- This means that only N_2 and LNG are feasible for our wells.
- These fluids can be used to fracture the wells thermally for Modulus of Elasticity Values above 35.63 GPa for N_2 and 32.03 GPa for LNG.

Economics of Alternative Fracturing Treatment

- Information regarding service company day rates varies
- A contact from Oxbow Energy Services was kind enough to give us a rough estimate
- Most service companies package all fracturing treatment services into a day rate
- While they may vary, a current day rate is generally all inclusive (pump trucks, blenders, chemical pumpers, control van)
- Water disposal is the responsibility of the operator
- $350M per day for 5 stage treatments is currently a good assessment for the industry

Economics of Alternative Fracturing Treatment

- $350M for 5 stages is accurate (plus or minus depending on treatment)
- A 15% premium is a good figure for a CO_2/Nitrogen energized or gas/liquid fracturing treatment
- $403M would be the high end for a day rate
- 3.4MM gallons of water needed for regular “slick water” treatment (this is for the entire fracturing job)
- 119M lbs of proppant per stage=1.8M tons for entire treatment
- Cheaper 40/70 sand used for initial breakdown pressure=$70/ton (only 3100lbs used)
- Carbo-ceramic lightweight ISP 20/40 composes (total cost for all stages=$123MM)
- Purchase freshwater from WAWSA at $20/1000 gallons
- Total job requires purchase of $68.8M in freshwater at industrial rates.
- $0.12-$0.25 per gallon to dispose of wastewater
- Assuming $0.20, at 82M gallons, total cost per stage is $16.4M
- Total wastewater costs for well at $154M for entire treatment
- Total cost per well to perform slick water hydraulic treatment is $2.5MM
- We are not re-injecting water, but this could be a possibility. Environmentally speaking we are going to retreat water based on statues for storage and disposal.

Mian, M.A. *Project Economics and Decision Analysis. Vol 1: Deterministic Models*. 2nd Ed. Penn Well Corporation. Tulsa, OK. 2011.
Propping Agents and Fracture Conductivity. PetroWiki. N.p., 28 Feb. 2014. Web. 17 Nov. 2014. <http://petrowiki.org/Propping_agents_and_fracture_conductivity>.

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Economics of Alternative Fracturing Treatment

- N_2 cost at approximately $0.10 per liquid gallon
- Assumption of 75% flowback performance
- With 70% N_2 hybrid treatment, $24M
- 30% at same disposal/purchase costs gives us $91M in treatment costs
- Service company upcharge for extra pumps and equipment is ascertained to be 20% higher
- Total charge for service is $2.5MM
- Entire cost of hybrid fracturing treatment is $2.75MM

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Economics of Alternative Fracturing Treatment

- CO_2 costs are approximately $40 per ton at wholesale rates
- Translates to $0.18 per gallon
- Extrapolating these figures with a 70/30 hybrid fracturing treatment gives us a total well cost of $2.77MM
- Figures include higher loss rate of CO_2 to formation due to miscibility

Conclusion

- Results of the PKN model
- LNG has best thermal stress
- Energized nitrogen most feasible alternative fluid
- Slick water most economical

Questions?