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Designing of Hydrofracturing Operation for Shale in Indian Conditions.

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Summary

This paper discusses planning and design processes leading to successful execution of hydrofrac treatments in a typical shale reserve of India. The peculiarities of shale which greatly influence the design of hyrofrac job is highlighted and an optimized pumping schedule guideline is laid down keeping in mind certain constraints in Indian environment.

Keywords*: Hyrofracturing, shale, slickwater, proppant transport and pumping schedule.*

Introduction

Hydrofracturing is one of the most leveraging completion technologies. This technology has unlocked tremendous potential in unconventional gas wells viz Coal Bed Methane, Shale gas. However soon after the first commercial treatment was performed in 1947 using gasoline based napalm gel frac fluid two conclusions were drawn: Firstly fractures created by hydrafracs tended to heal unless a propping agent were placed and secondly, frac fluids required elevated viscosity to create adequate width and proppant transport and to minimize leak off(Howard and Fast 1970).

Nearly 20yrs later, guar based crosslink fluids were introduced and along with their synthetic counterpart became the mainstay of fracturing fluids(Veatch et al.1989). By 80s it was pretty common to place massive hydraulic fractures in excess of 2 million llb of proppant, using 60 pptg guar crosslinked gel(Pearson et al 1988). However operations in Cotton Valley Sand in East Texas provided a breakthrough in hydraulic fracturing. Unlike fracturing using cross linked fluids there slickwater fracturing was used in the tight gas reserves. Since then slickwater is primarily employed for hydrofracturing shale or tight gas reserves.

Understanding Slickwater Fracs

In shale gas formations conventional fracturing treatments are uneconomical due to cost of polymers used to create viscosity in fracture fluids and also due to lower productivity arising from the damage caused by polymers in such low permeability formations.

The goal of slickwater frac as defined by Schein as "a fracture treatment that utilizes a large volume of water to create an adequate fracture geometry and conductivity to obtain commercial production from low permeability large net pay reservoir (Schein 2005).
Slickwater is used for the following reasons:-

- Shale can have thousands of microfractures or laminations- minimizing frac fluid viscosity increases leakoff into crevices and enlarge the channel to flow.
- Increased contact area is produced by very large volumes of water and low matrix permeability that keeps vast majority of water in fractures.
- Quicker cleanup times after fracture.

Other commonly used frac fluids in shale formations include foam liquid with and without proppant, both CO2, and nitrogen gas(without proppant), gels, viscoelastic gels and a variety of hybrid fracs.

Proppant transport problems in Slickwater fracs

- One of the biggest concerns with slickwater fracturing is proppant transport away from the wellbore and placement into the smaller secondary fractures. As frac fluid capacity(roughly

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equated to viscosity) decreases, the settling velocity increases, thus for slickwater fracs, the sand settling may occur soon after entering the fracture, building up to a height related to the velocity of the water moving into the frac across the top of the dune. The first sand used in the job probably ends up closest to the well bore, while the last sand pumped ends up farthest.

- SLW fracs produce narrower fracs during pumping than gelled fracs. However proppant transport in slickwater frac is dune development and the propped part of slickwater frac may not close or lose much width as pressure is released.
- Vertical coverage of hydraulic frac with proppant is critical to transport, but may not occur due to proppant settling that forms dune formation.

The slurry physical properties are fluid viscosity, size, specific gravity of both fluid and proppant. The testing, model development, and calculations are provided in papers SPE 95675, SPE 106312. Although some calculations were made to simplify the data analysis and calculations the process has been proven to provide a very good prediction of proppant settling behavior as assessed from both from both complex alternative predictive models, proppant settling test methodologies and calculated propped fracture lengths from production analysis of fractured wells.

Parameter	Desired Result
Dehydration Effect(S_w)	< 40% S_w
Gas Composition	Low CO_2, N_2 or H_2S
Gas-Filled Porosity(Bulk Gas Volume)	> 2% Gas Filled Porosity
Mineralogy	>40% Quartz or Carbonates
	<30% Clays
Permeability	<100 nanodarcy
Poisson's Ratio	<0.25
Pressure	>0.5 psi/ft
Thickness	>30 m
Total Organic Content	>2%

Table 1: This table provides a brief idea of the screening criterias for a shale reserve undergoing undergoing hydrofracturing operations.

Field Overview

The oil field in study is a well in Damodar Valley Basin. This basin is part of the "Gondwana" basins of India characterized by their mostly non-marine sedimentary fill and narrow graben structures. Although filled with mostly Late Permian to Triassic terrestrial sediment, there is a significant thickness of a marine shale known as the Barren measures, so called as it is barren of coal. The technically recoverable resources from this shale are estimated to be 7 Tcf. The geological age is Permian-Triassic and the shale formation is barren. The prospective area is 1080 mi2. The depth interval lies from 3280-6560 ft. while the maximum thickness interval is 2100 ft. The reservoir is moderately overpressured. The average TOC(in wt %) is 4.5 and thermal maturity(in %Ro) is 1.20. the shale reserve has also pretty high clay content.

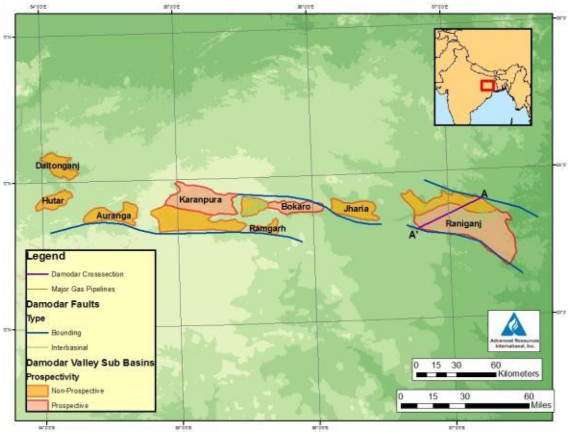

Figure 2: Geology of reserve (Advanced Resources International)

The lithological data is provided in Table

Layer	TVD (ft)	Closure Stress Grad (psi/ft)	Lithology	Permeability (md)	Formation Name
1	0	0.620	Sandstone	0.0001	
2	4166.7	0.720	Bitum Coal	0.1	
3	4206.0	0.850	Shale	0.00001	
4	5200.0	0.850	Shale	0.00001	
5	***5661.0***	***0.780***	***Silty Shale***	***0.0001***	***BARREN***
6	5815.0	0.850	Shale	0.00001	BARREN
7	5900.0	0.620	Sandstone	0.0001	
9	6000.0	0.850	Shale	0.00001	
10	6500.0	0.850	Shale	0.00001	

Table 2: Lithological parameters.

Top of perforations is 5663 ft(TVD) and bottom is 5679ft(TVD) with total number of perforations being 98.

Proppant Selection

For proppant selection it is very important to have clear idea about proppant transport in shale gas formation. Discussion on proppant transport in fluid begins with stroke law. This law estimates the settling velocity of a single particle in a static fluid. While stroke's law has many simplified assumptions that prevent it from calculation of actual settling velocity of a proppant in fracture some points woth consideration are as follows:-

- As the viscosity of fluid decreases, the settling velocity increases. When fluid viscosity is sufficiently high as in case of cross-linked fluids, a perfect suspension can be assumed.
- When viscosity is small as in case of slickwater fracs, the only way to reduce settling velocity to zero is to have a proppant having same density as that of the fluid. In other words, unless the proppants are neutrally buoyant in the fluid, proppant would settle.
- As particle diameter increases, settling velocity increases exponentially.

This factor is often overlooked. Many designers believe proppant density to be primary factor for proppant transport and thus they go on for ultralight proppants. However though proppant density is surely important, proppant size have greater role in proppant transport. Many would not think to pump a relatively dense proppant like bauxite as they would assume that settling problems would be severe and sand dune formation leading to premature screenout would occur.

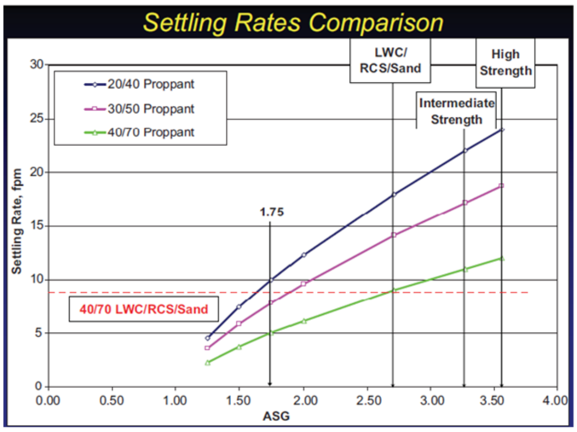

Figure 2: Single particle settling velocity rates for various proppant sizes and densities in 2% KCl at 60o F(Schlumberger i-Handbook)

However, settling rate of 20/40 sand is 50% greater than 40/70 bauxite. In fact the latest trend is to use 100 mesh size sand as proppant. The larger sizes, notably 40/70, 30/50 and 20/40 have been used where conductivity is important.

In our case Jordon 4060 is chosen. Its bulk density is 95.90 lbs/ft3, specific gravity 2.65, has a diameter of 0.011'' resulting in a packed porosity of 42%.

Scheduling of Hydrofracturing Job

Shale in general requires higher pumping rate. This is more pertinent in fracturing by slickwater. Slickwater owing to very low viscosity have minimal proppant carrying capacity. Thus higher pumping rates prevent proppant from settling down. Generally 20bpm is used as the minimum and then rate is increased in small steps as it helps in opening natural fractures. To account for lesser proppant settling, the highest proppant concentration should be pumped in highest rates.

One more thing to take care that maximum surface pressure should not be controlled if possible below 10000 psi considering Indian X-Mas Treeconditions. If that is not possible it should be limited till 15000 psi which could be accommodated by Tree saver.

It is seen that multiples stages of pad each at successively higher rates is beneficial in increasing the propped length, width significantly. Thus a two staged pad is applied in the above case. The use of acid as a frac breakdown aid has been demonstrated in most shales, even when there was little or no acid reactivity in the formation. Using acid in an area where calcite cementation or fill is common in the fractures is well recognized but can lead to plugging problems with excessive amounts of calcite cement and acid. In other areas, the ability to inject any aqueous fluid into a rock may lower its strength and promote fracturing. This is a commonly-known rock mechanics fact: wet rock is weaker than dry rock. Although most shales have moderately water saturations, adding water, regardless of salt content, seems to reduce rock strength. Hydrochloric acid is commonly used at 10% to 15% concentration as breakdown fluid because it is inexpensive, works well and spends gradually on acid soluble material.

The scheduling is done based on the above constraints and is provided in Table 3 below

Stage #	Clean Volume		Slurry Volume		Rate		Proppant		Fluid Type	Proppant Type
	(kgal)	(m3)	(kgal)	(m3)	(bpm)	(m3/min)	(ppg)	(g/L)		
1	2500	9463.53	2.50	9.46	22.00	3.50	0.00	0.00	SLICKWATER	
2	1000	3785.41	1.00	3.79	24.00	3.82	0.00	0.00	SLICKWATER	
3	2000	7570.82	2.03	7.67	22.00	3.50	0.30	35.95	SLICKWATER	Jordan4060
4	2500	9463.53	2.55	9.63	22.00	3.50	0.40	47.93	SLICKWATER	Jordan4060
5	1566	5927.96	1.60	6.06	25.00	3.97	0.50	59.91	SLICKWATER	Jordan4060
6	1600	6056.66	1.66	6.28	29.00	4.61	0.80	95.86	SLICKWATER	Jordan4060
7	2200	8327.91	2.30	8.70	33.00	5.25	1.00	119.83	SLICKWATER	Jordan4060
8	2390	9047.13	2.54	9.60	35.00	5.56	1.35	161.77	SLICKWATER	Jordan4060
9	4183	15834.38	4.47	16.91	35.00	5.56	1.50	179.74	SLICKWATER	Jordan4060
10	3760	14233.15	4.06	15.36	35.00	5.56	1.75	209.70	SLICKWATER	Jordan4060
11	1840	6965.16	1.84	6.97	35.00	5.56	0.00	0.00	SLICKWATER	
12	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	SHUT-IN	

Table 3: Schedule of Hydrofracturing in the Shale Reserve

The fracture geometry obtained based on the schedule is:-

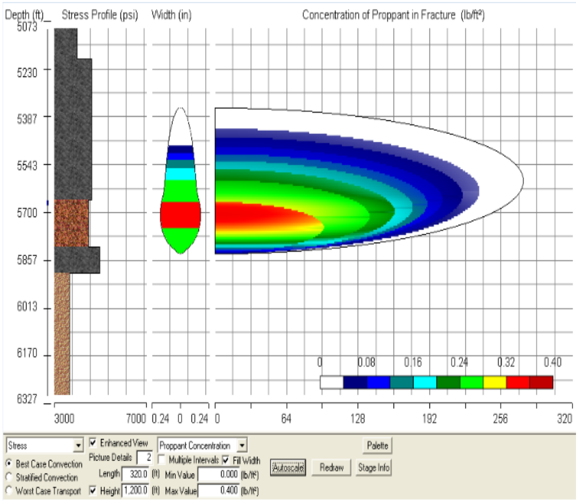

Figure 3:Fracture Dimensions obtained by the schedule. The software used is Fracpro.

Total Summary

Model has run until (min)	112.20 min
Min Surface Pressure (psi)	5306.73 psi
Max Hydraulic Power (hp)	8543.47 hp
Total fluid (bbls)	614.54 bbls Max
Surface Pressure (psi)	9971.38 psi
Average Hydraulic Power (hp)	5936.65 hp
Total proppant (klbs)	22.44 klbs

Summary for Fracture at 5663 (ft)

Fracture length (ft)	276.44 ft
Fracture upper height (ft)	312.91 ft
Fracture lower height (ft)	165.67 ft
Max width at well (in)	0.35 in
Dimensionless Cond. Ratio	1238.18
Total fluid (bbls)	614.68 bbls
Propped length (ft)	222.37 ft
Propped upper height (ft)	219.45 ft
Propped lower height (ft)	165.54 ft
Average proppant concentration (lb/ft2)	0.15 lb/ft2
Fracture efficiency	0.93
Total proppant (klbs)	22.32 klbs

Conclusions

- Fracturing in shale requires use of ultra low viscosity frac fluids like slickwater
- Slickwater due to low viscosity has proppant transport issues.
- Small size proppants like 40/70 or 100 mesh size are used to overcome proppant settling.
- Pumping rate is generally kept high with low proppant concentrations.

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