EVALUATION OF EFFECTIVE INFINITE CONDUCTIVITY FRACTURE HALF-LENGTHS ON A GROUP OF WELLS STIMULATED WITH ULTRA-LIGHTWEIGHT PROPPANTS

Doug W. Walser
BJ Services Company, USA

ABSTRACT

Flowing/pumping transient analysis was performed on a group of wells scattered across the Permian basin that had been Stimulated with relatively large volumes of brine and an ultra-lightweight proppant with approximately the same specific gravity as the brine. The results of these analyses are discussed, and effective infinite conductivity fracture half-lengths are reported and compared to offsets that were stimulated with more conventional techniques.

These analyses, along with other parameters that were recorded from several hundred treatments performed, were utilized to develop a set of guidelines for optimum candidate selection. The candidate selection parameters are presented, and practical guidelines for exploiting and optimizing the process are explained.

INTRODUCTION

Beginning in the spring of 2003, a number of stimulation treatments were performed whereby a new class of of ultra-lightweight proppants (ULW proppants) with low specific gravity (S.G. about 1.25) was pumped in various fracturing fluids with substantially unit viscosity. In most cases, the base fluid was 10 ppg brine, so the settling rate of the proppant was very low or negligible. The process has been well documented, and detailed descriptions are available elsewhere in the literature[1,2,3,4,5]. Because the process was new to the industry, early treatments were performed based on the theories behind the process. No production statistics were available to guide in treatment design or in the optimization process during this early stage. Since that time, however, well over 400 treatments have been performed in the Permian Basin, and enough time has elapsed that meaningful conclusions can be drawn, at least with respect to the first 200+ treatments.

Early in 2003, it was recognized that optimization would depend up the assimilation of substantial treatment and production information. A database that facilitated storage and manipulation of statistics was initiated and maintained.

Treatments were performed in a number of productive horizons, but were concentrated in Permian Basin San Andres, Clearfork, Glorietta, and Delaware series. The vast majority were pumped in reservoirs with oil and water as the primary fluids. Treatments were split nearly equally between new wells and re-stimulation of existing completions.

STUDY METHODOLOGY

The first 207 of the 400+ treatments were studied in detail. Treatment data was compiled for each of these. Production data was gathered from multiple sources[6]. When production data came directly from the operator, it was given preference (from a validity standpoint) over public data. Occasionally, such private sources included daily production data, which could then be utilized with more confidence in flowing or pumping transient analysis.

Flowing/pumping pressure transient analysis was performed on several of the wells, using a combination of production data (which generally included oil, gas, and water production rates, tubulars, and gas gravity) and privately obtained miscellaneous data. The private data included the net productive height $\boldsymbol{h}$, estimated [log] porosity ϕ in that same $\boldsymbol{h}$, estimated water saturation S_w, the initial bubble point, and the resolution of any problems with the public data. Transient analysis using the reciprocal of the productivity index (RPI)[7,8,9,10] was employed to analyze the production histories. A Miller-Dyes-Hutchinson[11] plot was the primary setting of the analysis. The linear slope best describing the middle-time or reservoir dominated portion of the well's performance was selected, and the production data (as the bottomhole RPI value versus the square root of time) was plotted (see example,

Figure 1). A Log-Log Agarwal/Gringarten Type Curve was used to plot dimensionless pressure versus dimensionless time in a merger of the Agarwal[12] type curve, which considers finite conductivity fractures, and the Gringarten[13] type curve, which presents the behavior of an infinite conductivity fracture in a bounded, square reservoir (see example, Figure 2). A graph representing RPI values versus time (pseudo-steady state plot) visualized and quantified the linear portion of the production[14]. Performing these three analyses resulted in the generation of a production simulation match, which was compared to actual production data. Values for permeability, effective fracture half-length (at infinite conductivity), and impacted reservoir area were then inferred from the matched values (see example, Figure 3).

After information was databased and analyzed, conclusions were drawn and recommendations for future work and improvements were developed. Many of these improvements were implemented on jobs performed after those treatments performed on the study group.

STUDY LIMITATIONS

Often, internal operator data was limited for any of a number of reasons: 1) data was withheld intentionally, for purposes of protecting the confidentiality of future drilling, completion, or marketing decisions, or, 2) the stimulated zone was often produced into a test tank for only a short period of time, then was produced into a common tank battery and from that point forward, production was allocated, or 3) the operator's internal record keeping process was occasionally so complex that data sharing was not convenient.

Nearly forty of the wells had public production data allocation problems that rendered the public data unusable. These forty were identifiable for several cases: a) offset wells producing into the same tank battery recorded increases in production shortly after the treatment on the well of interest, or b) public reports of produced water often were constant over a period of time, or absent altogether when it was obvious that a substantial volume had been produced, or, c) public reports of produced water were such that the water-oil ratio was exactly constant over an extended period of time.

It is possible that in some cases, when actual or allocated public data had a profile that looked "reasonable", such a profile may have had substantial errors associated with it. Obviously, in such cases, analysis and conclusions drawn about the properties could be in error.

As various treatment and reservoir parameters were gathered, an attempt was made to rank production response on a scale from 1 – 10 (a "one" indicated production response substantially below expectations or below equivalent offsets, and a "ten" was associated with a profile significantly better than expected or better than equivalent offsets). All data involved production profiles of less than 18 months, so no long-term comparisons were attempted. It soon became apparent that the "1 – 10" scale was highly subjective and process-dependent, so the scale was changed such that a "success indicator" with a scale of 1 – 3 was utilized instead. A score of two indicated that results were approximately equivalent to expectations or comparable to offset performance. Comparisons to offsets were normalized for various reservoir parameters (***k***, ***h***, ϕ, ***and*** $P^* - P_{wf}$) only twice; in all other cases global comparisons were made that did not take natural parameter normalization into account.

The high incidence of production allocation difficulties was discouraging, and resulted in the transient analysis being performed on fewer wells than was desired. However, even when allocation problems were substantial, often the operator's verbal responses were unambiguous enough to provide a clear ranking of 1, 2, or 3.

RESULTS

After manipulation and analysis of the database, several trends became evident. The following applied to both new completions and re-stimulation of existing completions:

1. For ranges of volumes pumped, less total proppant resulted in higher average success indicators. It is possible that this phenomena is related to the presence or absence of large exposed surface area propped with a partial monolayer, as described in the literature referenced earlier. Such a partial monolayer could result in significantly higher-than-average fracture conductivity, and could therefore be a contributor to the higher success index.

2. The higher proppant laden liquid volumes were associated with a higher average success indicator. This observation may be associated with effective propped fracture half-length, since it is well known that there is a nominal relationship between pumped volume and created fracture half-length[15].

3. The lower the average proppant concentration, the better the average success indicator (for the ranges of volumes pumped). Reasoning similar to result (1) above.

4. The lower the max prop conc, the better the average success indicator (for the ranges of volumes pumped). Reasoning similar to result (1) above. In addition, there is a possibility that low maximum concentrations may have prevented near-wellbore proppant packing, thereby promoting the likelihood of partial monolayer conditions in the region of the fracture close to the perforations.

5. The longer the observed effective infinite-conductivity fracture half-length L_x (for those properties that were evaluated with flowing/pumping transient analysis), the higher the average success index. Again, this observation is consistent with the literature[15].

6. Higher stimulation pump rate was associated with a slightly higher average success index.

7. When screenouts occurred, they were associated with a lower average success index. In addition, it was noticed that if a particular formation/area had a history of a higher-than-normal screenout rate with conventional fluids, the the screenout rate associated with the ultra-lightweight proppant process was also higher.

8. In shallow (generally < 3,500 ft) zones, when the fracture gradient was less than 9.0 psi/ft, the average success index was higher. It is possible that this observation is related to fracture orientation[16].

The following were observed when considering only re-stimulation of existing completions:

a) A higher average success index was associated with lower average permeability *k* (determined from flowing/pumping transient analysis) when compared to wells with a higher value for permeability. Since *k* is a proportional component of the Darcy portion of the flow equation[12,13], it is assumed that this observation could very well be related to the degree of depletion that existed prior to the re-stimulation attempt.

b) When rolling production history was short, the average success index was higher. As in (a) above, this phenomena may have been associated with degree of depletion prior to the re-frac.

c) The higher the estimated value for productive interval *h*, the higher the average success index. This is consistent with the Darcy portion of the flow equation.

d) Lower cumulative production prior to the re-stimulation attempt was associated with a higher average success index. Degree of reservoir depletion may be an explanation for this observation.

e) Reservoir re-pressurization (generally in the form of waterflooding) had a slightly positive impact on the success index, consistent with the Darcy component of the flow equation. It is possible that the impact may have been greater, but there were a number of wells where injection was relatively close to the well of interest, and high post-stimulation water cuts appeared to lower the average success index.

CONCLUSIONS

When applying the ultra-lightweight proppant fracturing process to the acceleration of reserve recovery in the Permian Basin, there are a particular group or class of properties that have a higher chance of fiscal success. Judicious selection of candidates based on estimated or known naturally occurring parameters (such as k, h, P*-Pwf) can impact the success of the project. Treatment design can take advantage of statistically observed data to improve fiscal success. Pumping/flowing transient analysis can be utilized to categorize existing completions and draw conclusions related to the probability of success of a potential re-stimulation attempt.

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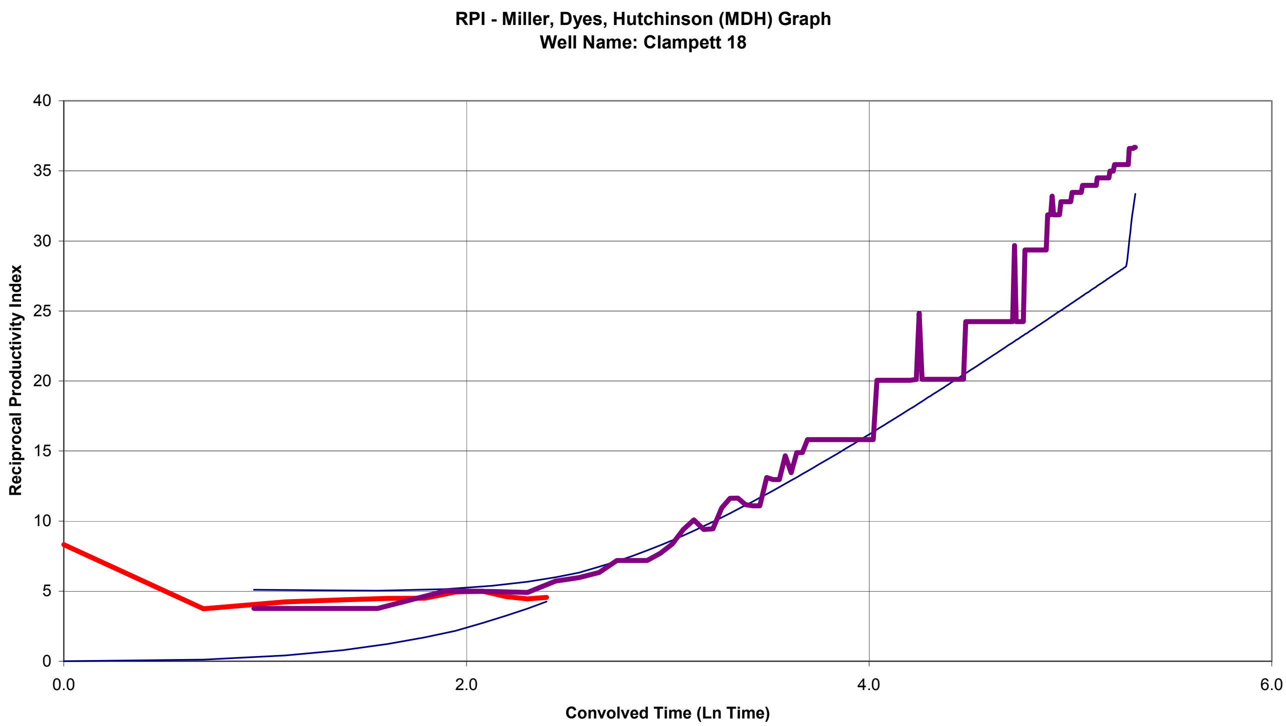

Figure 1 – Typical Miller-Dyes-Hutchinson Plot

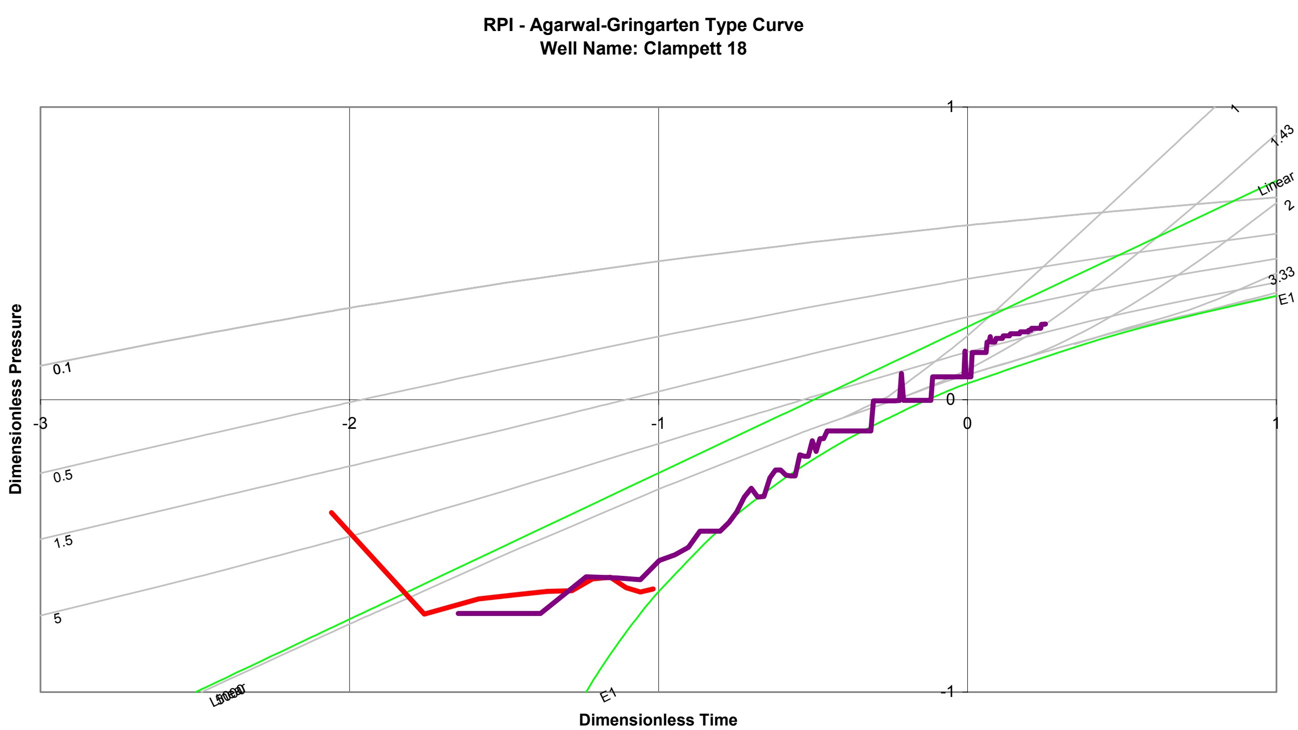

Figure 2 – Typical Agarwal/Gringarten Evaluation

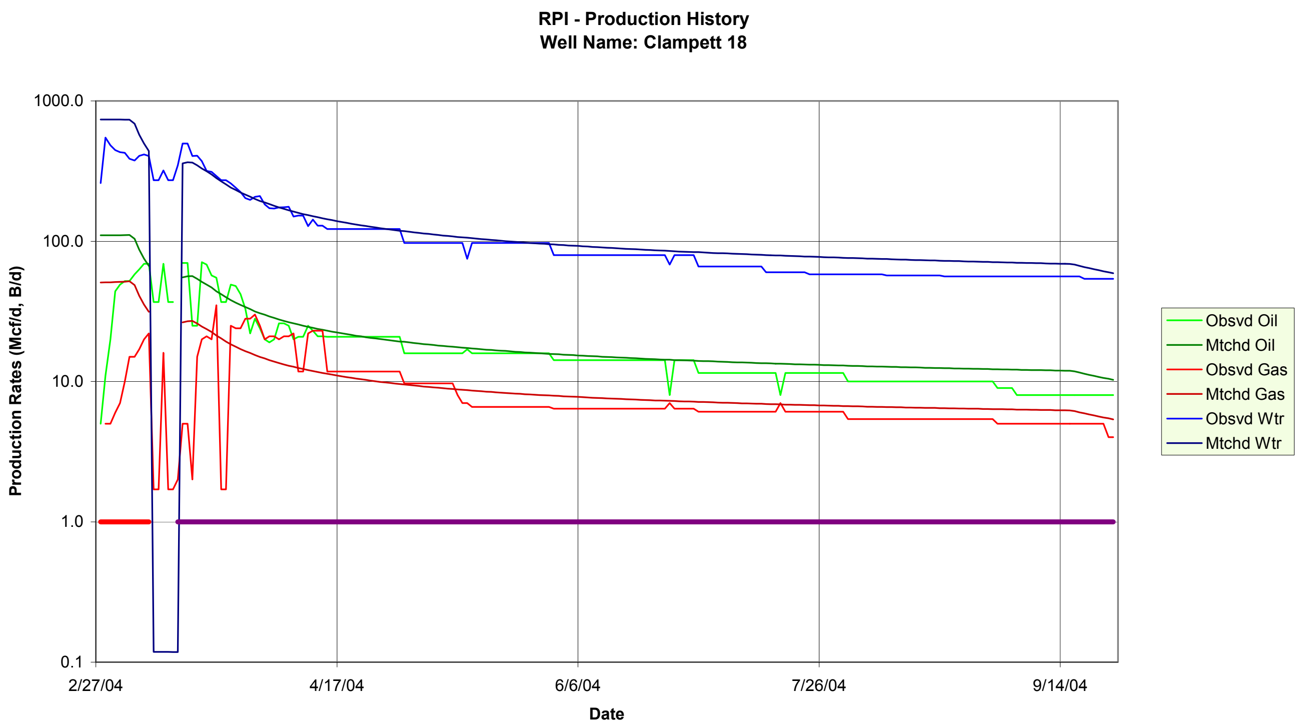

Figure 4 – Typical Production Plot. The evaluation for this well, a San Andres new completion, yielded an effective infinite-conductivity fracture half-length of 608 ft, and a permeability of 0.765 md over 80 ft, with a relatively viscous (4.5 cps @ P*) oil. Typical completions surrounding this well IP @ 20 bopd, and are pumping 3 – 5 bopd within 2 months. The treatment associated with the completion had 5 tanks of 10 lb/gal brine and 18,000 lb of 14/30 mesh ultra-lightweight proppant pumped at 40 bpm down 5-1/2" casing.