NORMALIZED PRODUCTION AND COMPARISON OF STIMULATION PROCESSES FOR A GROUP OF CROCKETT COUNTY STRAWN WELLS

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ABSTRACT

For a number of years, controversy has arisen as to the most efficient way(s) to accelerate the rate of reserve recovery from ultra-low permeability carbonate reservoirs. Efforts were undertaken to locate and study a sufficient number of wells that would be representative of this issue, and that would clearly distinguish naturally occurring reservoir parameters from man-induced processes.

The production from a localized group of Strawn wells in Crockett County, Texas was examined and normalized by permeability, porosity, initial static reservoir pressure, and productive height to establish the impact of various completion methodologies. Flowing pressure transient analysis was performed on each well to determine permeability, effective fracture half-length, drainage area, and aid in the normalization process.

Stimulation of the Strawn was divided into three categories: propped fracture stimulation, crosslinked acid treatments, and all other acid treatments. For each of these categories, average fracture half-lengths and normalized production are compared and contrasted.

INTRODUCTION

In recent years, software and computing tools have become available that expedite the process of normalizing production on large groups of wells[1,2,3,4,5]. The result is that studies of production versus drilling or completion process are much closer to becoming routine, primarily due to lower technical labor requirements.

During the mid-1990's, crosslinked acid systems were developed[6,7,8,9] that showed promise as vehicles to severely retard the spending rate of HCl on carbonate lithologies at elevated temperatures. These systems function by crosslinking a unique polyacrylamide emulsion and preventing turbulent boundary-layer contact with the soluble fracture face. The result is a retarded system that would create longer effective etched fracture half-lengths than the same volume and strength of neat, slick, or gelled acid. Since the development of the system, over 400 treatments have been pumped in the Permian Basin of West Texas.

In early 2003, efforts were initiated to locate and study a group of Strawn wells that were treated with crosslinked acid systems, and compare publicly reported production response with offsets that were stimulated with alternate systems. Because a high percentage of Strawn completions in the southern portion of the Permian basin are commingled with Canyon [sand] production, the search process involved locating an area that focused on the Strawn, to the exclusion of the Canyon. A group of wells in a 20-mile extent of WSW Crockett County was finally selected that included portions of the Whitehead, Sawyer, Seawolf, Read Ranch and Angus Fields.

Active exploitation of the area began in 1976 – 1977. Development (by multiple operators) was sporadic through 1990. Technology employed at the time was consistent with what was known regarding best practices in high-temperature carbonate acid fracturing[10 thru 18]. By the late 1990's and early 2000 – 2001, lower initial reservoir pressures were regularly encountered at new drill sites, indicating that existing well drainage radii was imposing upon the newer wells.

STUDY METHODOLOGY

The study area included 94 wells, 13 of which were stimulated with crosslinked acid, 14 that had propped fracture stimulations, and the balance, which had a variety of slick acid, "retarded acid", and pad-acid treatments. One well had both crosslinked acid and proppant pumped, and so was included in the "proppant" group. Twenty four wells with horizontal trajectories and wells with commingled Canyon and Strawn production were eliminated. One well with nonexistent public treatment information and inadequate private data was eliminated. One well with a recent completion and not enough production data to adequately analyze was eliminated.

Flowing pressure transient analysis was performed on each of the wells, using a combination of public data (which generally included the gas, condensate, and water production, tubulars, and gas gravity) and privately obtained data. The private data included the net productive height $\boldsymbol{h}$, estimated [log] porosity ϕ, estimated water saturation $\boldsymbol{S_w}$, and the resolution of any problems with the public data. It was assumed that publicly reported production data was accurate, and that inherent inaccuracies would be spread relatively evenly across all records. Transient analysis using the reciprocal of the productivity index (RPI)[6,7,8,9] was employed to analyze the production histories. A Miller-Dyes-Hutchinson[19] 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[21] type curve, which considers finite conductivity fractures, and the Gringarten[22] 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[23] (see example, Figure 3). 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 drained reservoir area were then inferred from the matched values (see example, Figure 4).

Best 90-day production of all wells was normalized for $\boldsymbol{h}$, $\boldsymbol{k}$, ϕ, and BHSP. Averages for various process categories were taken and compared, and conclusions were drawn.

STUDY LIMITATIONS

A number of flaws in the study process were observed, and measures were taken to deal with each in the most consistent manner possible:

- 13 of the wells did not have accurate porosity data available. Either operators would not release information, or the location of the information was unknown. In these cases, known offset porosities were averaged and utilized for the well in question.
- 6 of the wells did not have productive height $\boldsymbol{h}$ data available, and the public perforation detail data between top-most and bottom-most perf was unclear. In these cases, known offset heights were averaged and compared to public perforation detail data. Judgmental decisions were then applied for a rational determination of $\boldsymbol{h}$.
- A majority of wells had no data for an estimate of water saturation $\boldsymbol{S_w}$. Fortunately, most of the wells produced from undersaturated zones, so the values for $\boldsymbol{S_w}$ had a high likelihood of being low. When this number was unknown, a field-wide average of 25% was utilized.
- Most wells in the area had publicly reported initial P/Z values available from semi-annual well tests. Initial reservoir pressures (at the time of drilling) were generally estimated from these. A few did not have the information available, and in this case, a variety of methods were used to obtain accurate values. Sometimes the current operator provided details, but occasionally, initial pressures were estimated from an examination of offset transient analysis results. Fortunately, most of the wells without public P/Z data were drilled in the early history of the field, and virgin pressures could safely be assumed.
- The development and implementation of crosslinked acid systems occurred during that portion of field development when new drill wells encountered lower-than-virgin reservoir pressures, and most of these treatments were performed during the recent history of the field exploitation. There did not appear to be any significant difference between fracture gradients in early-history wells and those with drawn-down reservoir pressures, so no attempt was made to adjust for pressure-related hydraulic fracture containment.
- A wide variety of static reservoir temperatures were reported in the public data. It was felt that the huge inconsistencies in the determination of this value were due to differences in calculation methodology. Often, the operator simply reported the Maximum Recorded Logging Temperature, which we were able to confirm by comparing to logs, when they were available. After examining multiple records, it was decided to utilize a common static temperature gradient for the entire area.

RESULTS

After averaging normalized 90-day cummulatives and examining scatter plots for the various categories of stimulated wells, the following results were observed (see Table 1):

- Wells with crosslinked acid systems outperformed wells with conventional acid, slick acid, gelled acid, or pad/acid combinations.
- Wells with propped fractures outperformed wells with conventional and crosslinked acid systems. Reports of screenouts on these wells were frequent. No attempt was made to resolve the additional lost NPV (Net Present Value) associated with the operational cost of screening out over the life of the wells and determine whether or not it approached the value of the additional production.
- Wells stimulated with crosslinked acid systems had longer effective fracture half-lengths than wells that were stimulated wells with conventional acid, slick acid, gelled acid, or pad/acid combinations, by a factor of about 1.4.
- Wells stimulated with propped fractures averaged longer effective fracture half-lengths than conventional acids by a factor of about 1.45.
- Wells stimulated with propped fractures averaged longer effective fracture half-lengths than crosslinked acids by a factor of only about 1.03.
- Generally, the higher the crosslinked acid volume, the higher the best 90-day cummulative. See Figure 5.
- Generally, the higher the pump rate, the higher the best 90-day cummulative. See Figure 6.
- There was not a clear-cut relationship between proppant volume and best 90-day cummulative. See Figure 7.
- There was not a clear-cut relationship between ISDP on crosslinked acid jobs and best 90-day cummulative. See Figure 8.

CONCLUSIONS

For the group of wells studied, there appeared to have been an advantage gained by specifying crosslinked acids over conventional slick acid, gelled acid, or pad acid combinations. Normalized production for wells with propped stimulation was slightly better than for wells with crosslinked acid systems, but it was not determined whether or not the NPV of the additional cost associated with the high screenout rate substantially reduced the overall well performance NPV.

RECOMMENDATIONS

When considering stimulation process(es) for fields similar to the one studied:

- Crosslinked acid systems should outperform slick acids, gelled acids, and pad/acid systems in highly soluble lithologies.
- Propped stimulations could be a viable solution if operational costs associated with screenouts could be forecast and minimized, and as long as the NPV of these costs did not exceed the incremental production gained over production attained when crosslinked acid systems are employed.
- Maximize pump rate for a given available set of tubulars.

ACKNOWLEDGEMENTS

The authors would like to thank the management of BJ Services Company for granting permission to publish this work. Thanks are due to Mr. George Woo, Mr. Henry Lopez, and Mr. Steve Metcalf for their substantial contribution in the development of the crosslinked acid systems. Software from IHS Energy Group and Performance Sciences, Inc., played a significant role in the efficient and timely completion of the study.

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Table 1
Summary of Averages

Data Category	Acid Averages	Prop Averages	Crosslinked Acid Averages
Public Data - Cummulative gas (mscf)	680,556	596,494	175,985
Public Data - Cummulative oil (bbl)	410	825	382
Public Data - Cummulative water (bbl)	1,822	2,448	1,710
RPI transient permeability (md)	0.05	0.04	0.05
RPI transient fracture half-length (ft)	203	296	287
Reservoir pressure at time of drill (psi)	2,877	2,531	2,115
RPI transient drainage (acre)	55	52	51
Porosity (decimal)	0.08	0.09	0.10
Public Data - Best 90-Day gas cum	39,827	59,501	24,721
Public Data - Best 90-Day oil cum	1,107	170	40
Public Data - Best 90-Day water cum	435	151	510
k X h	2.82	2.35	1.74
phi X P* X k X h	476	359	254
90-day gas/phi/P*/k/h	187	283	199

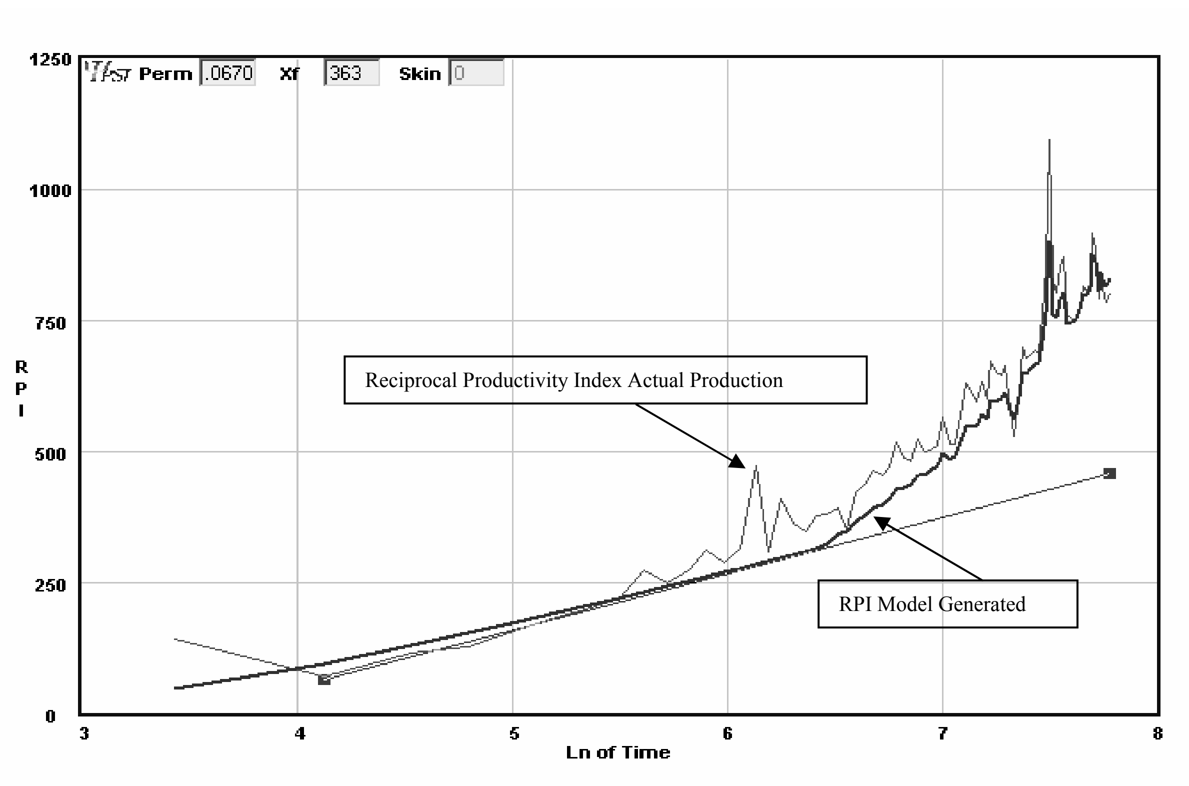

Figure 1 – Typical Miller-Dyes-Hutchinson Plot

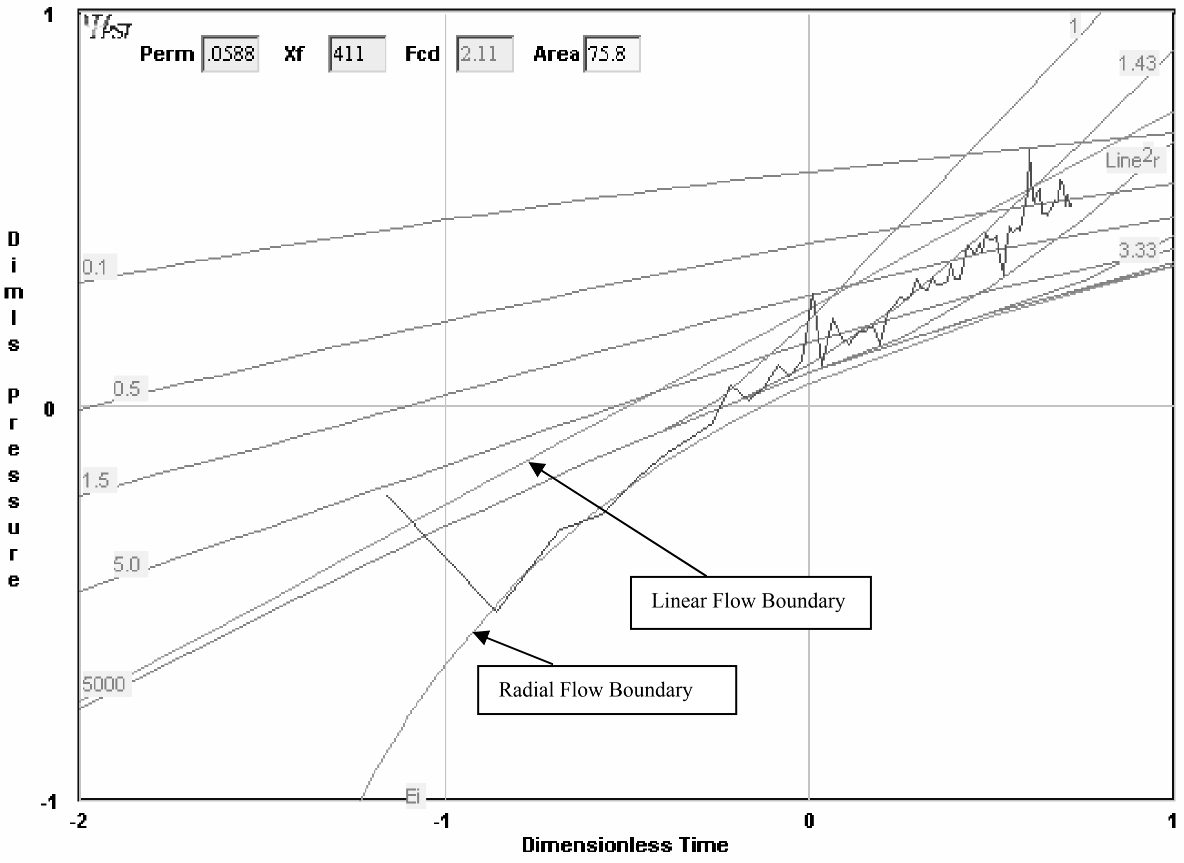

Figure 2 – Typical Agarwal/Gringarten Evaluation

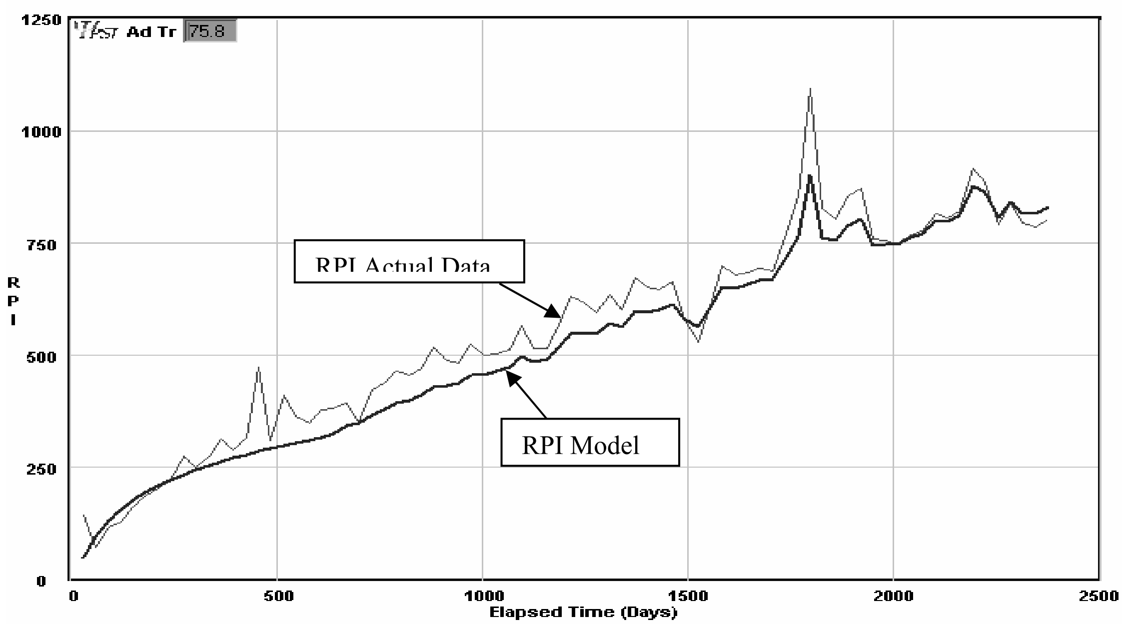

Figure 3 – Typical Pseudo-Steady State Plot

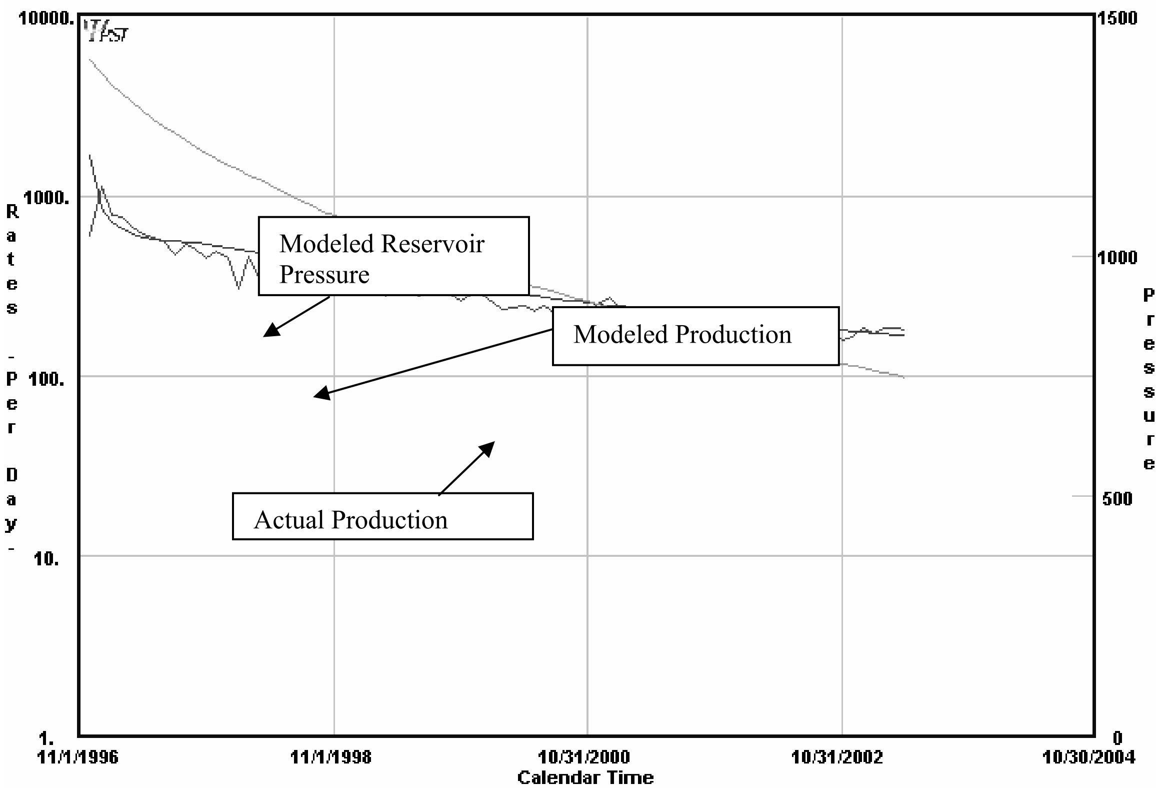

Figure 4 – Typical Production Plot

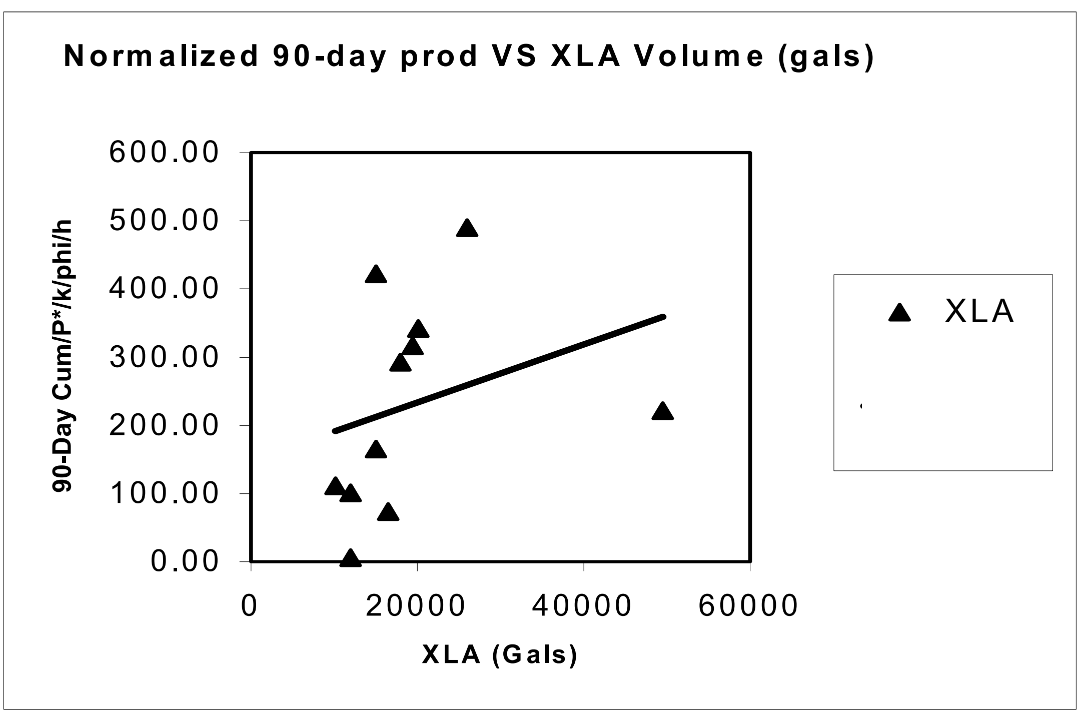

Figure 5

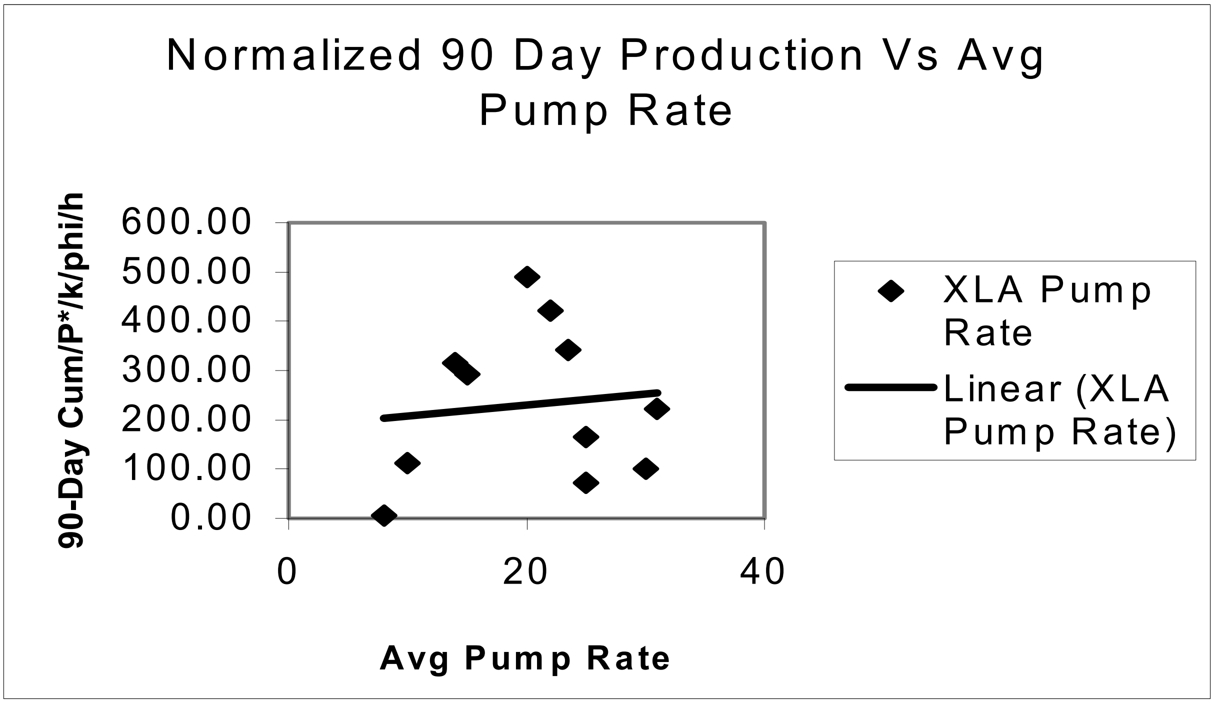

Figure 6

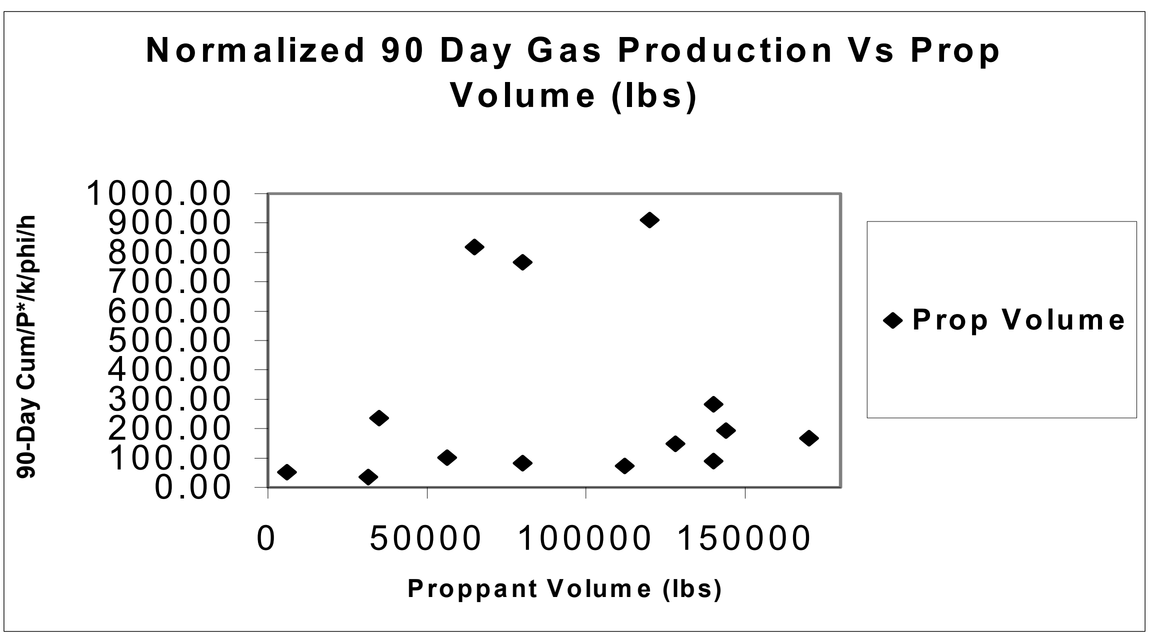

Figure 7

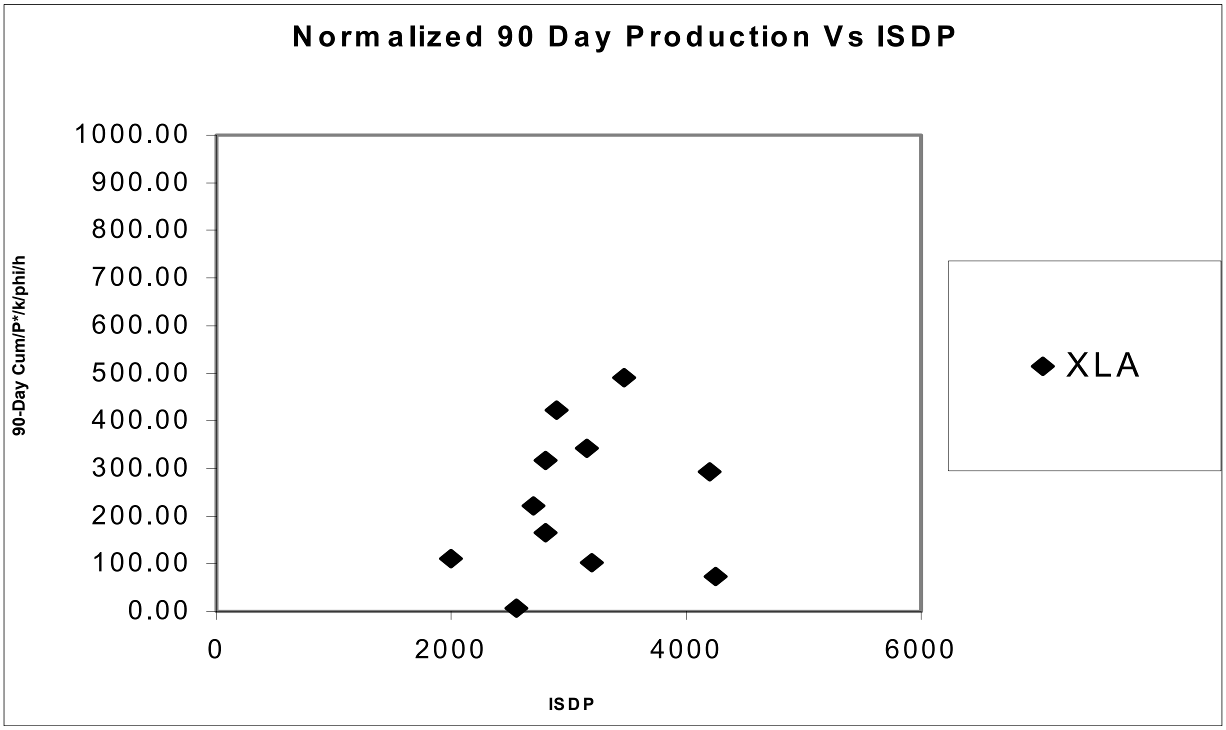
Normalized 90 Day Production Vs ISDP
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0
2000
4000
6000
ISDP
90-Day Cum/P*/k/phi/h
XLA

Figure 8