ACID FRACTURING OF CARBONATES NO LONGER RATE RESTRICTED

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ABSTRACT

One of the most effective methods of carbonate stimulation is acid fracturing. Development of fracture geometry sufficient to allow etched penetration to provide economic production increases is dependent upon several factors, one of which is pump rate. High rates and/or lower hydraulic horsepower requirements can be critical to success to one of these projects.

Many times wells lack the integrity or flexibility to be treated down casing. Treating down tubing affords highly viscous fluid's opportunity for rate restrictions due friction pressure. In addition, fluids of high viscosity based on the crosslinking of polymers using zirconium are known to have shear limitations, and, therefore, high rates have been unattainable.

Laboratory testing and case histories are presented regarding the evaluation and usage of zirconium crosslinked hydrochloric acid systems in the acid fracturing of several carbonates utilizing tubulars of 2-7/8 and 4-1/2 inches in O.D.

BACKGROUND

Stimulation of carbonate reservoirs is typically the result of a need for restoration or enhancement of production to a more economic level. Acid Fracturing is the most widely used technique for stimulating limestone or dolomite formations.[1] Fracture acidizing originally was conducted using non-reactive fluids as pads to create a fracture in a dolomite or limestone formation.[1] Acid was then injected into the fracture to react with the formation to produce flow channels, after closure. During the 1970's, various techniques and new acid systems were developed.[2,3,4] The fluid systems were designed to provide better penetration through leak-off control, fracture geometry control and reaction retardation of the hydrochloric acid. In general, leak-off control and retardation are found to be the two most significant parameters in achieving success in vugular and natural fractured dolomites.

The gellation of hydrochloric acid (HCl) for use in the oil industry began in the mid-1970's. Since, the distance reactive acid will penetrate along a fracture normally will increase as the flow velocity along the fracture is increased the higher the rates generally the better the treatment.[1] Higher pumping rates were possible using gelled acid blends allowing for better acid fracturing of carbonates. The viscosity of the acid reduced the overall spending of the acid on the formation allowing for deeper penetration of etched width. Residual acid viscosity resulted in removal of formation materials, released by the acid but not dissolved, from the well. Less acid volume overall could be pumped to get the same stimulation results. The 1980's saw the advent and usage of several crosslinked acid gels in the stimulation of carbonate reservoirs.[5,6]

Crosslinked acid gels utilized a transition-metal ion to effect crosslinking of synthetic copolymer chains. Transition-metal polymer bond is very sensitive to shear and high shear irreversibly degrades transition-metal crosslinked fluids.[7] The high shear region of smaller diameter tubulars with high pump rates was therefore a restriction for stability. In addition, significantly higher friction pressures in these smaller diameter tubulars using the high viscosity transition-metal crosslinked fluids prohibited usage in wells with wellheads rated to lower pressures.

The proppant fracturing of formations has experienced similar problems. Fluids, of similar chemistry to that used in crosslinked gelled acid system, have been modified to create a delay in the time to achieve full crosslink. This paper will present results of such a delay mechanism being utilized in the acid fracturing of carbonates with a transition-metal crosslinked fluid. Specifically, the friction pressures and the shear stability will be addressed.

EXPERIMENTAL

Laboratory Crosslink Delay Evaluation. A crosslink delay time equal to 1/2 - 3/4 of the pipe is normally desired. It is essential the fluid be crosslinked prior to entering the formation. Crosslink delay times are normally conducted with a rheometer (R1 spring, B2 bob, at 100 rpm's) and a heat cup**.**

1. Allow the base gel to age for four hours or the anticipated time the gel is expected to age on location prior to pumping before testing.

2. Add the base gel to the blender cup and agitate. Start a timer, add the delaying chemical and stir for 5 seconds. Add the zirconium transition-metal crosslinker. Shut down the blender when vortex closure is observed. (Normally 5 – 10 seconds). Record vortex closure time. (Do Shear Past Closure.
3. Immediately transfer fluid to rheometer. (R1 spring B2 bob) Record dial readings at 100 rpm's in 1-minute increments. A dial reading of 25 represents crosslink.

Rheological Properties. Rheological data was generated using an automated Fann-50 Rheometer with a R1B5 Rotor Cup/Bob configuration. Tests were run under 400-psi nitrogen pressure. Samples were conditioned at a 101 sec^{-1} Shear Rate (100 RPM). At 10-minute increments, a "sweep" or "ramp" reading was performed. During this event, the shear was reduced in 20-RPM increments down to 35 sec^{-1} (40 RPM). The new RPM was maintained for 50 seconds, in order to stabilize the fluid. The "sweep" is used to calculate the n' and k constants which are used to characterize a power law fluid.

Fluid Shear Stability Evaluation. A test was created to evaluate the effects of shear on the stability of the acid crosslink system. The decision was made to conduct the test at approximately 1500 sec^{-1} for two minutes. Fluids were prepared by blending acid, corrosion inhibitor, crosslink delay agent and then the zirconium transition metal crosslinker. The fluid was allowed to develop ultimate viscosity. Eight liters of the acid system were loaded into a positive displacement duplex pump. The fluid was pumped through 200 feet of 0.1875 inch O.D. stainless steel tubing. The wall thickness was 0.035 inch giving an I.D. an of 0.1175 inch. Samples were caught throughout the experiment in 5-minute increments. The shear rate and shear stress were measured on a rheometer of the crosslinked fluid before shearing and after were measured. The sheared fluid was also placed into a water bath at150F and shear rate and shear stress rechecked.

RESULTS

Laboratory Crosslink Delay Evaluation. Data is presented in Figures 1, 2 and 3 illustrating some of the typical pre-treatment testing to determine delayer concentration. Figure 1 is typical of tests on 15% hydrochloric acid at 62°F, while Figure 2 is based on an 80°F temperature at point of crosslink. Data in Figure 3 was measured on 20% hydrochloric and heated in simulation of going down hole, from a 60°F environment to 80°F at crosslink downhole. As expected it has been found that the higher the temperature of the acid at the surface more delayer is required. In addition, the higher the acid concentration the more delayer is also needed.

Rheological Properties. Figure 4 illustrates the effects on viscosity as a result of the delaying agent. Ultimate viscosity is reduced as the crosslinked system is delayed, however not below what is sufficient to allow the fluid to function as a fracturing fluid in place of a viscosified water based fracturing fluid.

Fluid Shear Stability Evaluation. A comparison of Shear Stress versus Shear Rate for a 15% hydrochloric acid blend crosslinked using four gpt delayer and eight gpt zirconium transition metal crosslinker is presented in Figure 5. The three graphs represent before shearing, after shearing and after shearing but heated to 150°F. The viscosity of the fluid reduced after the shearing but when heated returned to pre-sheared value.

Field Friction Pressure Comparison. Friction pressure data has been collected from wells over the last year where treatments using the delayed system have been employed. Figures 6 through 8 graphically reflect results for a treatment down 2.875-inch O.D. tubing. Figures 7 and 8 illustrate the effect of delaying the crosslink vividly. The rate is held constant and the pressure is increasing as the delayer is decreased. This is a result of the crosslink point moving uphole and therefore the friction generated by the higher viscosity crosslinked fluid providing the pressure increase.

Figures 9 through 11 represent a treatment down 4.5-inch O.D. casing. Figure 9 shows the overall rate and pressure associated with the treatment, while Figures 10 and 11 illustrate the additives pumped to provide the crosslink and the delay in comparison to pressure and rate respectively. This particular treatment did not employ any delay agent in the first stage of crosslink of the acid system. It can be seen that the pressure increase through the time period of displacement of the first crosslinked acid stage without delay resulted in about a 1500-psi pressure increase. The subsequent stages utilizing the delay agent were observed to have an 800 and 500-psi increase respectively.

CONCLUSIONS

1. It has been shown that the incorporation of a delay agent to control the crosslink of a gelled acid system utilizing a zirconium transistion metal can result it reduced shearing degradation of the viscosified fluid.

2. Further it is demonstrated that the utilization of this system allows for precise control of the point of crosslink downhole and therefore the ability to control the surface treating presure to a lower value while allowing for maximum rate devolpment for acid fracturing.
3. Even with delays in maximum viscosity devlopment a significantly viscose fluid can be applied to the rock face to provide fracture propagation.

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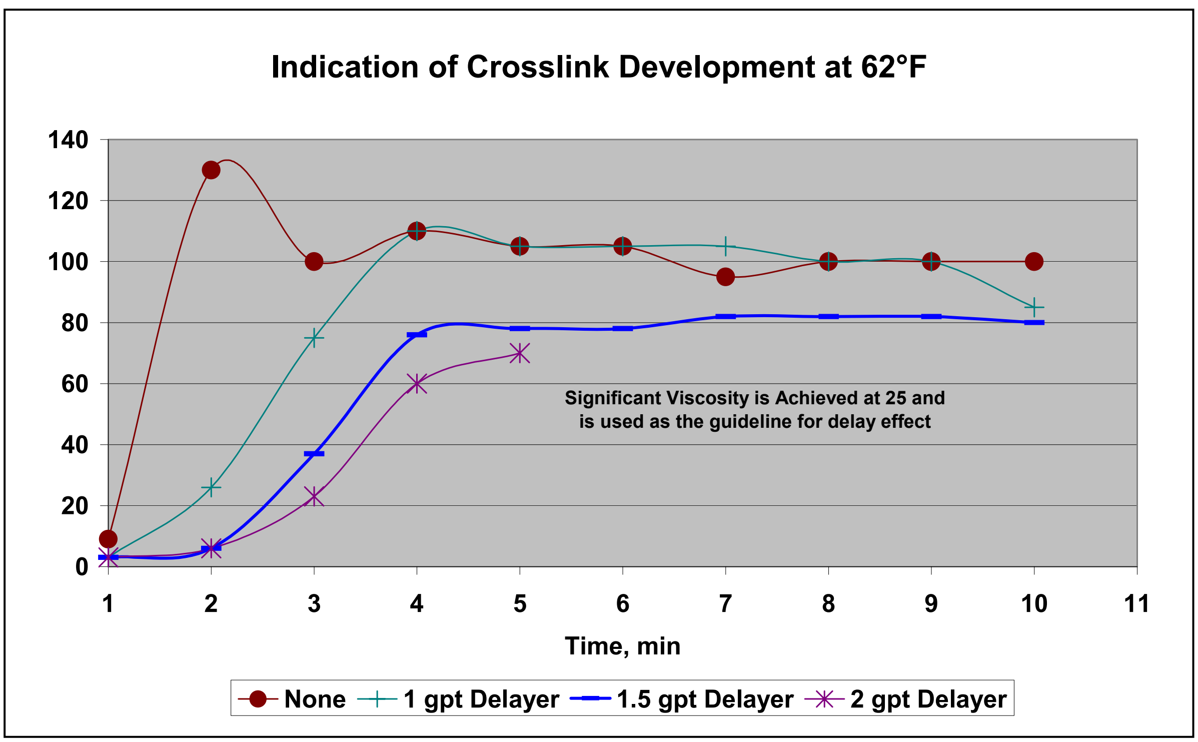

Figure 1 – Effect of Delay on Viscosity at a Fixed Temperature with Changes in Delay Agent Concentration

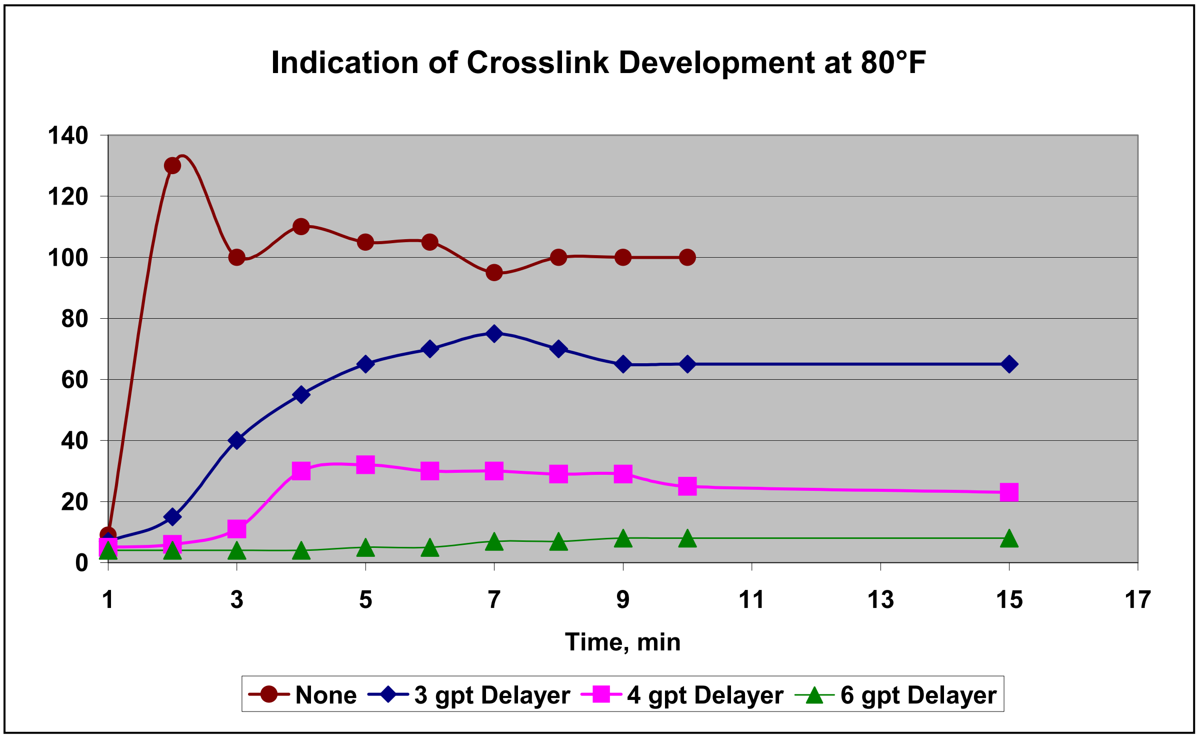

Figure 2 – Crosslink Time Variance at a Constant Temperature with Changes in Delay Concentration

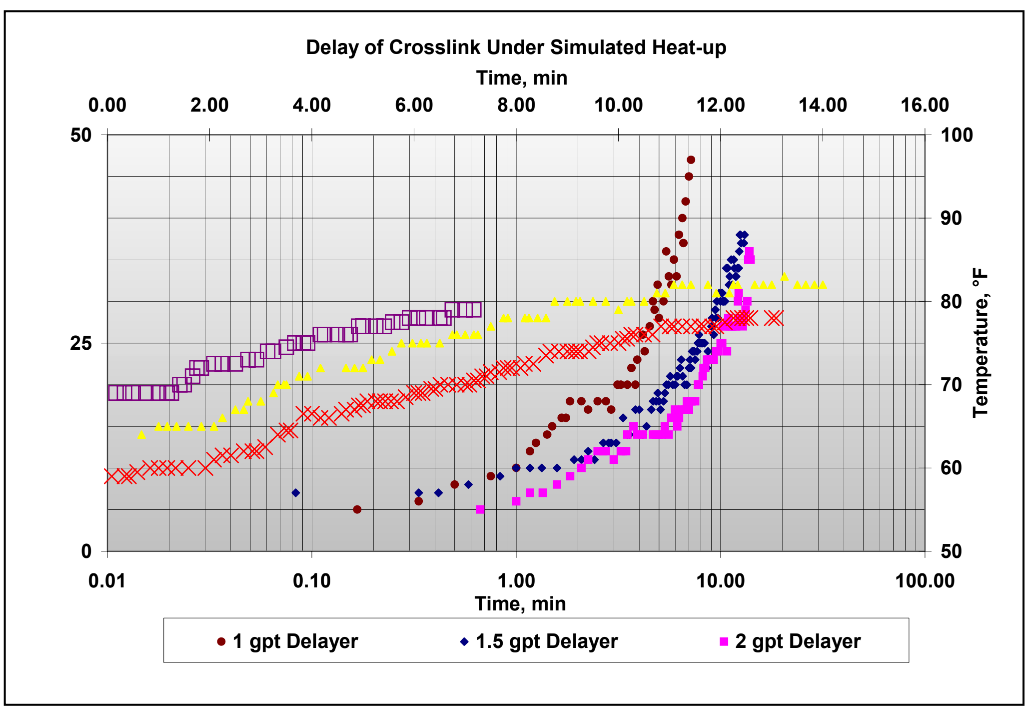

Figure 3 – Comparison of Delay with Respect to Heat Up Associated with Downhole Conditions

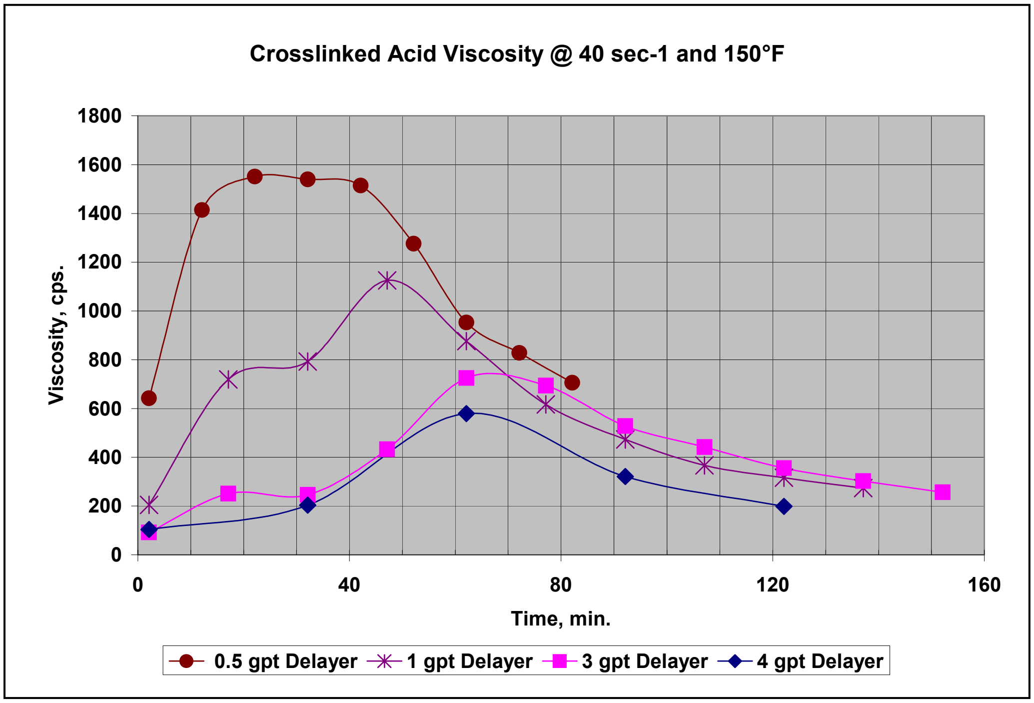

Figure 4 – Fann 50 Comparison of Viscosity of Delayed Crosslinked Hydrochloric Acid

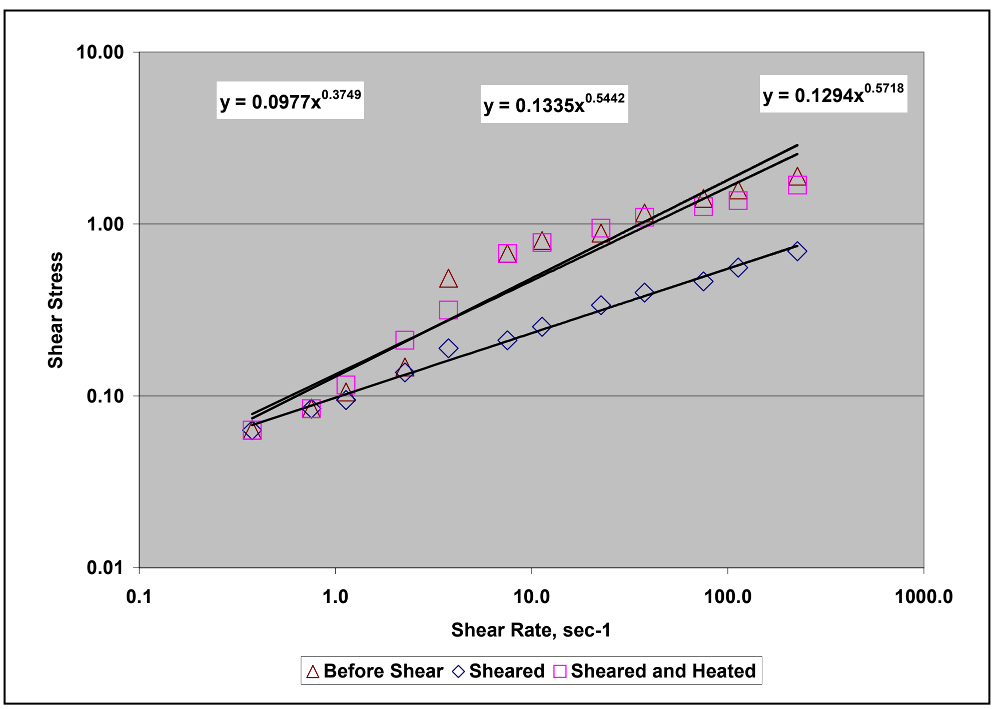

Figure 5 – Comparison of Shear Stress Versus Shear Rate for Fluids Before Shearing at 1500 Sec^{-1} and After

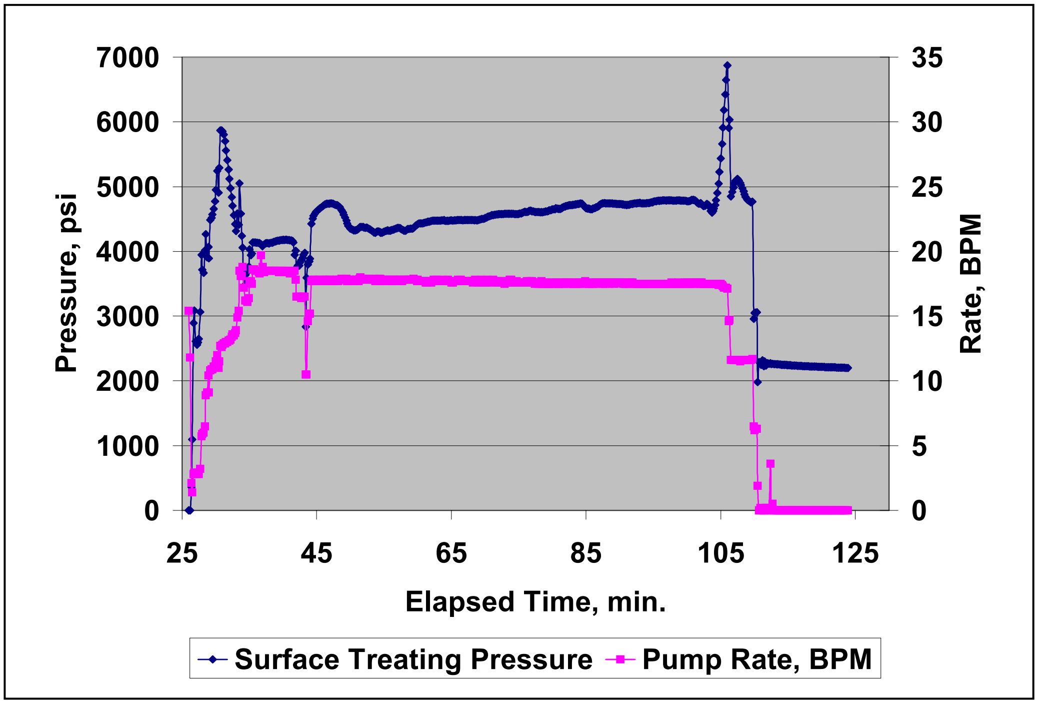

Figure 6 – Rate and Pressure During a Fracture Acidizing Treatment Down 2.875 Inch O.D. Tubing

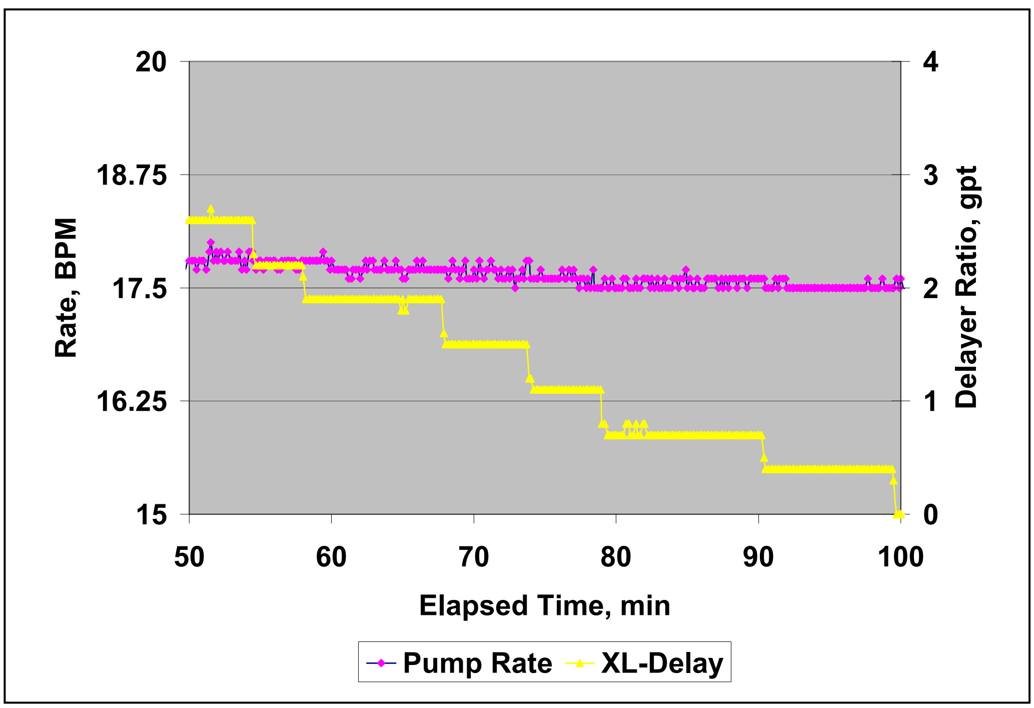

Figure 7 – Demonstration of the Lack of Effect on Pump Rate Utilizing the Delay Agent Down 2.875 Inch O.D. Tubing

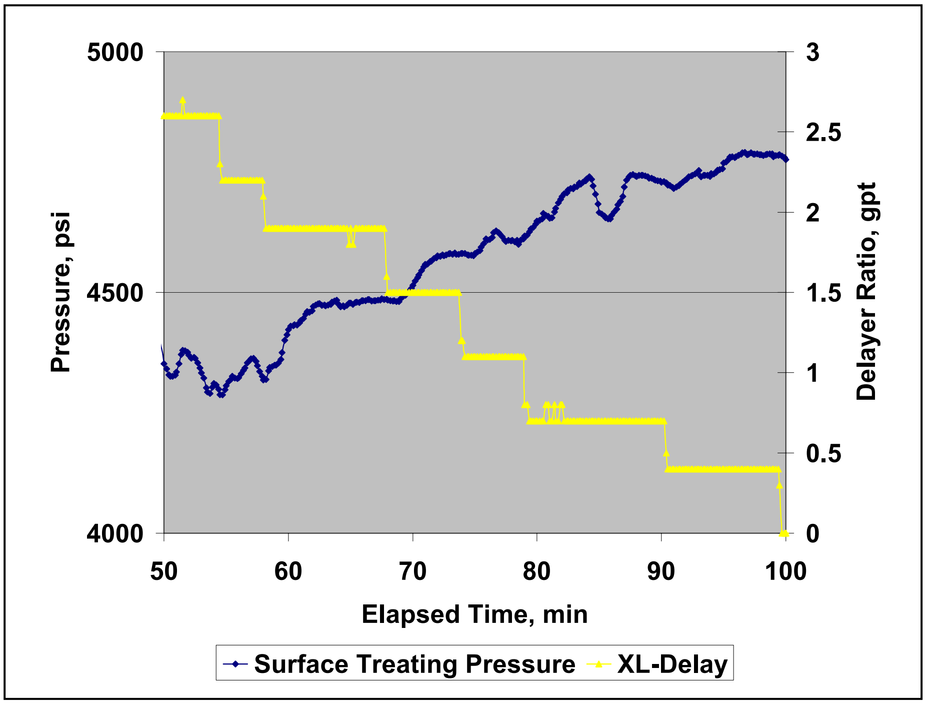

Figure 8 – Effect of Decreasing Delay Agent Concentration on Surface Treating Pressure Down 2.875 Inch O.D. Tubing

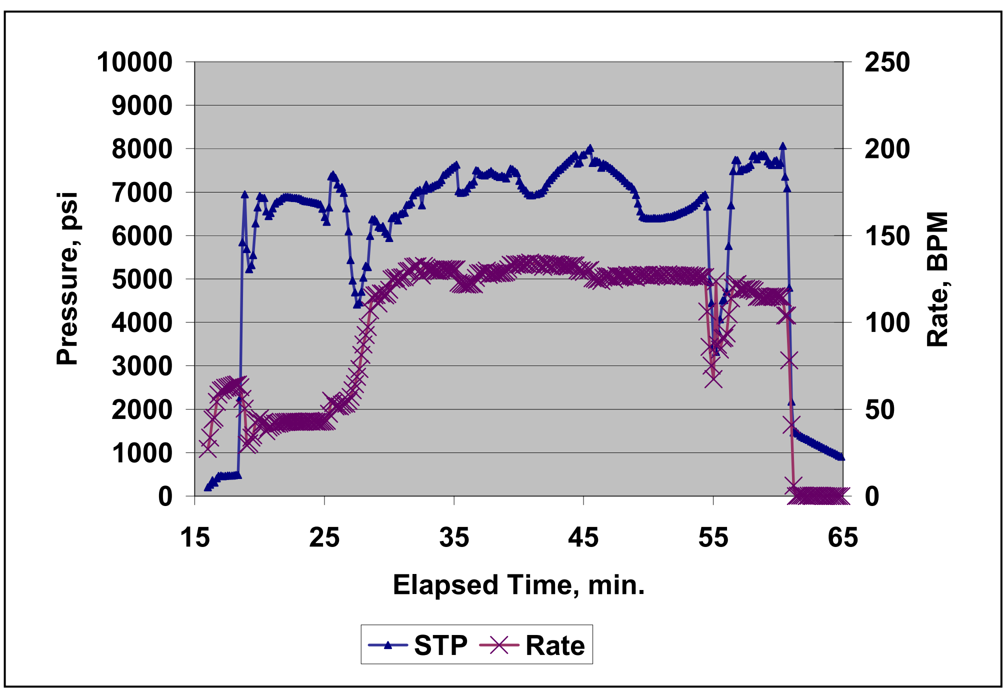

Figure 9 – Rate and Pressure During the Fracture Acidizing Treatment of a Limestone Down 4.5 Inch O.D. Casing

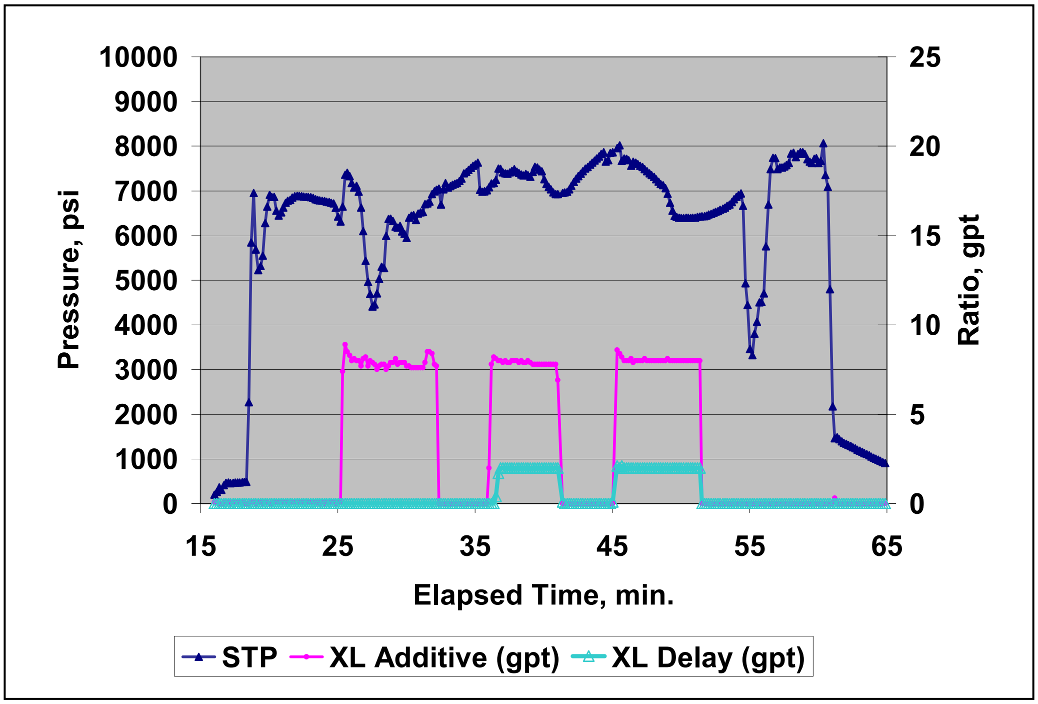

Figure 10 – Pressure and Additive Ratios During Acid Frac Down 4.5 Inch O.D. Casing

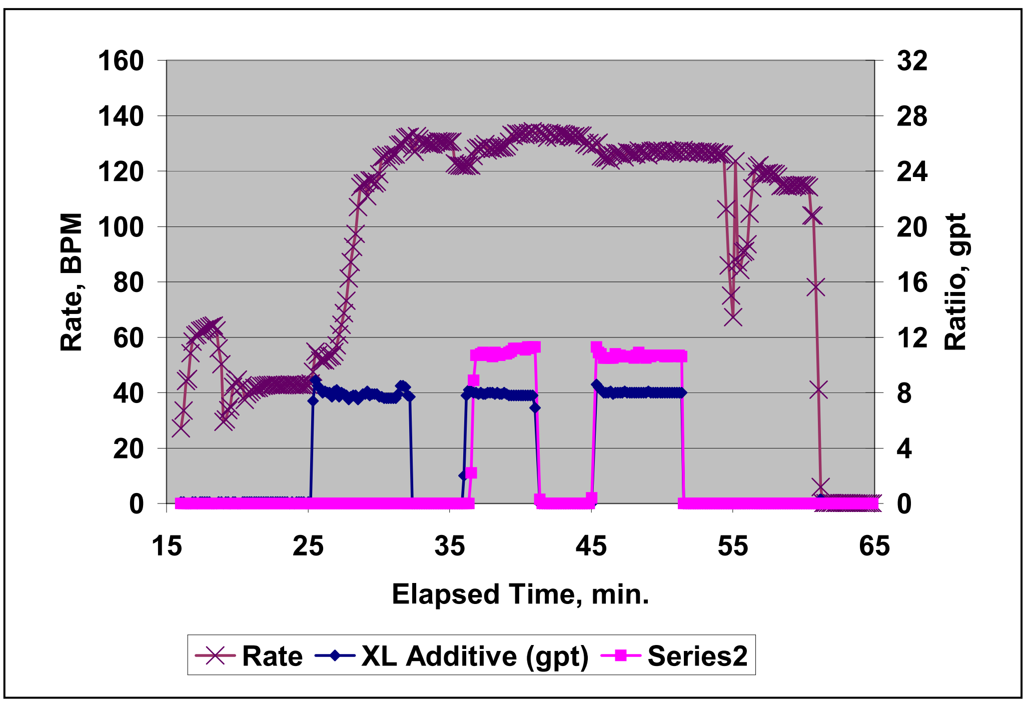

Figure 11 - Rate and Additive Ratios During Acid Frac Down 4.5 Inch O.D. Casing