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Evaluation Of A New Friction Reducer for Brines

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Abstract

A new friction reducer was tested in various fluids to measure its performance in both a small-scale flow loop and a field-scale system. The high molecular weight, synthetic polymer was mixed into fresh water and a 1% KCl brine, then pumped through 1½ inch diameter coiled tubing and straight pipe. Drag reduction as high as 84% was achieved in the straight pipe, and as high as 69% in coiled tubing. The optimum polymer concentration in fresh water was 0.06 lb/BBl. In the 1% KCl, similar results were obtained using 0.13 lb/BBl of the polymer.

The study was extended to include determining the polymer performance in several heavy brines, including 7% KCl, 10 ppg NaCl and 11.4 ppg $CaCl_2$. A small-scale flow loop, consisting of ½ inch diameter coiled tubing and straight pipe was used. There was good correlation between the fresh water friction pressures measured in the small-scale flow loop and full-scale system.The heavier brines generally required greater polymer loadings in order to achieve substantial drag reduction. In the 7% KCl, the Polymer A produced reductions in friction of up to 62% in coiled tubing and 77% in straight pipe. In the 10 ppg NaCl brine, the optimum polymer loading was 0.13 lb/BBl, which resulted in a drag reduction of 60%. For the 11.4 ppg calcium chloride brine, a polymer loading of 0.21 lb/BBl produced drag reduction of 49% in straight pipe and 52% in coiled tubing.

Introduction

A new, high molecular weight, synthetic polymer was developed for use in completions, workover and stimulation applications. Early in its field use, it was recognized to have excellent friction reduction properties. A study was conducted with the primary purpose of measuring the capabilities of this polymer in reducing drag, particularly in brine applications.

Friction pressure testing was performed in two distinct apparatus, which differed mainly in scale. The bulk of the testing utilized a lab-scale, ½ inch flow loop, but the rest used a field-scale configuration based on 1½ inch tubing[1]. Both apparatus included pressure drop measurements across coiled tubing, as well as straight pipe.

It was found that pressure losses due to friction increased with brine density and viscosity. Addition of the new polymer reduced friction pressures by up to 70% in coiled tubing and 84% in straight pipe.

Equipment

In evaluating the performance of the friction reducer for oilfield use, it was desirable to make measurements in both straight pipe and in coiled tubing. Two basic equipment configurations were used for this study.

Initial tests were conducted using 1½ inch OD tubing, with an internal diameter of 1.1883 inches, which allowed for data to be gathered which would require the least amount of scale up for field application[1]. Fluid injection was accomplished using a triplex pump. The system was calibrated using fresh water and 1% KCl brine. The polymer was added to the test fluids through the top of a 50 BBl paddle mix tank, and stirred for 15 to 30 minutes in order to allow for complete hydration. Samples were taken for viscosity measurement. The fluid was then injected at rates varying from 30 to 250 gpm. These rates were sufficient to produce Reynolds Numbers of 11,500 to 422,900 in the thickened fluids. The pressure drop was monitored across 160 ft of straight, horizontal pipe and across 1,000 ft of coiled tubing, with allowance made to minimize end effects.

A small-scale flow loop[2] was used for the later tests, which allowed for rapid generation of friction loss data with a minimum amount of waste produced. This consisted of ½ inch OD, stainless steel tubing, with an internal diameter of 0.435 inches. Fluid injection was accomplished using a progressive cavity pump in order to minimize internal noise. The pressure drop was measured separately across the straight and coiled tubing. Fluid temperature and density was measured continuously. Friction measurements were made for the various base fluids prior to the addition of polymer. The polymer was added into the fresh water and to the 7% KCl brine in a 200 gallon paddle mix tank. After full hydration was attained, samples were taken for rheological measurements, and the test fluid was injected through the tubing and directly to disposal. For the saturated NaCl and the $CaCl_2$ tests, the polymer was added to the brine in a 50 gallon mix tank. Because each test required a total volume of approximately 150 gallons, these fluids were circulated through the tubing and back into the mix tank. Except for the initial base fluid test, the fluid was then disposed of and replaced with fresh brine for the next polymer loading. That strategy reduced temperature variations between runs, which minimized effects due to variations in fluid density and viscosity.

Materials and Procedures

The full-scale flow loop tests utilized fresh water and 1% KCl brines as test fluids. The polymeric friction reducer, designated Polymer A, was added at concentrations up to 0.25 lb/BBl. Four fluid systems were evaluated using the small scale flow loop, including 7% KCl, 10 ppg NaCl and 11.4 ppg $CaCl_2$ brines. The fresh water system was also evaluated using the small-scale flow loop in order to provide a comparison of the data based on tubing geometry.

Polymer A is a synthetic, water soluble polymer. It has a molecular weight in the range of 7.5 to 9 MM Daltons. This polymer was chosen for study because of its solubility in a wide variety of brines, its resistance to shear degradation and its excellent thermal stability. The polymer is produced as a dry powder. However, in the full-scale tests, it was added to the base fluid as a particle suspension in a glycol ether. This method provided a means of effectively dispersing and hydrating the polymer particles without the use of a dry additive system.

In the small-scale system, where multiple tests were run in rapid succession, and where both dispersion and hydration could be a problem, two different methods of adding the polymer were used. For the fresh water and 7% KCl fluids, the polymer was applied as a suspension in an isoparaffinic oil in order to promote dispersion and avoid lumping.

In the NaCl and the $CaCl_2$ brines, particle dispersion and lumping is of much less concern, whereas the rate of dissolution and hydration can be slow under ambient conditions. For these tests, a concentrated solution of polymer in the two base fluids was prepared ahead of time. The concentrate was made by weighing the necessary amount of water into a bucket, adding the required weight of salt or $CaCl_2$ to bring the fluid to the correct final density. The polymer was added to produce a final activity of 5 lb/BBl in the brine. The concentrate was mixed until complete dissolution was attained. As in all of the tests, the Polymer A concentrate was added by weight to a measured volume of base fluid in order to assure that the final polymer loading could be accurately determined.

Results in the Full-Scale Flow Loop

Fresh Water

The system was calibrated using fresh water, pumped at rates between 31 and 164 gpm. The pressure drop across the straight pipe varied from 17 to 381 psi/100 ft. (Fig. 1). Across the coiled tubing, the pressure drop reached a maximum of 2,436 psi. Figure 1 shows the very close agreement in friction pressures produced in the two pipe configurations, with only slightly lower pressures produced in the straight pipe than in the coiled tubing. From this data the pipe roughness was estimated to be 3.3 E-04.

The addition of Polymer A resulted in a considerable reduction in friction pressure in the coiled tubing. Figure 2 shows measured friction pressure as a function of pump rate. The addition of only 0.03 lb/BBl polymer reduced the friction pressure across the 1,000 ft of coiled tubing from 2,436 psi for fresh water at 165 gpm to 861 psi. That is a reduction of 1,575 psi. This polymer concentration produced a fluid with a viscosity of 1.6 cP. Figure 2 shows that the maximum amount of friction reduction was attained at a polymer concentration of between 0.03 and 0.06 lb/BBl. The drag reduction (DR) was determined for the various polymer loadings in the fresh water using Equation 1, the results of which are shown in Figure 3. Obtaining ΔP_{base} for this calculation at a given pump rate required curve fitting the friction pressure data of the particular base fluid.

$$DR = 1 - (\Delta P / \Delta P_{base}) \qquad (1)$$

In coiled tubing, the addition of Polymer A reduced drag by as much as 70%. Again, the optimum polymer loading appeared to be in the range of 0.03 and 0.06 lb/BBl. Similar results were obtained in the straight pipe, with drag reductions as high as 83% attained using 0.13 lb/BBl of the polymer.

1% KCl Brine

The potassium chloride brine produced slightly higher friction pressures in the coiled tubing than did the fresh water. At 152 gpm, the 1% KCl produced a pressure drop of 2,203 psi across the 1,000 ft of coiled tubing. At the same pump rate, the fresh water produced 2,149 psi. The addition of 0.13 lb/BBl Polymer A yielded a fluid viscosity of 1.8 cP. The effect of the polymer on friction pressure is shown in Figure 4. At 152 gpm, this concentration of Polymer A reduced the friction pressure across the coiled tubing to 760 psi, or by 65%. In the straight pipe, drag reduction was even more pronounced, ranging from 75% to 81%.

Results from the Small-Scale Flow Loop

Fresh Water

This series of tests were run for the primary purpose of being able to compare data generated in the ½ inch tubing with that from the 1½ inch system. A baseline was run using fresh water, pumped at rates of 3 to 16 gpm, maintaining a line pressure below the 100 psi limit of the equipment. These results are presented in Figure 5. The fresh water consistently produced 21% lower pressure drop in the straight pipe than it did in the coiled tubing.

Addition of 0.06 lb/BBl of the Polymer A to the fresh water yielded a viscosity of 1.7 cP. This produced drag reduction of up to 61% in the coiled tubing and 76% in the straight pipe. Figure 6 shows the drag reduction for this fluid system as a function of Reynolds Number, and compares these values to those obtained for the same polymer loading in the full-scale flow loop. In both flow loops, the fluid exhibited greater drag reduction in the straight pipe than in the coiled tubing. This plot does show that there was very good correlation in the data generated in the ½ inch coiled tubing and that from the 1½ inch coiled tubing, with a close overlap of the data. The polymer produced slightly greater drag reduction in the ½ inch coiled tubing than in the 1½ inch coiled tubing. On the other hand, it showed slightly less drag reduction in the ½ inch straight pipe than it did in the 1½ inch straight pipe.

7% KCl Brine

No baseline test was run for the 7% KCl system. The friction pressure for the base fluid in these test conditions was calculated using the friction factors derived from the Drew et al.[3] correlation for the straight pipe and the Srinivasan et al.[4] correlation for coiled tubing. These correlations produced a good fit to the fresh water data and, because of the close similarity in fluid properties between the 7% KCl and fresh water, were judged to provide an adequate approximation. For the coiled tubing, the friction pressure (psi/10 ft.) was calculated according to Equation 2. For the straight pipe, Equation 3 was used to estimate friction pressure.

$$\Delta P_{CT} = 0.3421\ (\text{Rate})^{1.8063} \quad (2)$$

$$\Delta P_{SP} = 0.3006\ (\text{Rate})^{1.7732} \quad (3)$$

The results of the friction pressure tests in straight pipe for various loadings of Polymer A in the 7% KCl are shown in Figure 7. A significant reduction in friction pressure was achieved using only 0.02 lb/BBl of the polymer. The drag reduction as a function of injection rate and Polymer A loading is shown for the straight pipe in Figure 8. At a concentration of 0.1 lb/BBl, the Polymer A produced a reduction in friction pressure of up to 77% at 20 gpm in the ½ inch straight pipe. This graph indicates that higher loadings of Polymer A were still producing lower friction pressures, and that an optimum loading was not reached in these tests. In the coiled tubing, the spread in data was less, indicating an optimum loading of around 0.06 lb/BBl Polymer A, with a resulting maximum drag reduction of 62% at 20 gpm.

10 ppg NaCl Brine

The sodium chloride brines were mixed in a 50 gallon stirred tank. The polymer was applied as a concentrate consisting of 5 lb/BBl polymer in a 10 ppg NaCl solution. This strategy proved very effective, requiring minimal mixing before complete dispersion was achieved and a homogeneous solution was attained.

The baseline test results for the NaCl brine are shown in Figure 9. The friction pressures in the coiled tubing were distinctly higher than those in the straight pipe. That variation was nearly constant at 21% higher friction in the coiled tubing within the conditions of the test.

Adding polymer to the saturated salt water had the expected result of reducing friction pressures, as shown for the coiled tubing test results in Figure 10. A polymer loading of 0.13 lb/BBl appears to be an optimum loading for these conditions, with minimal additional friction reduction produced with higher polymer concentration. This is confirmed in considering the drag reduction produced at different levels of polymer loading, as shown in Figure 11, where a maximum of 59% drag reduction was attained at 0.13 lb/BBl. In the straight pipe, however, significantly more friction reduction was obtained by increasing the polymer loading from 0.13 lb/BBl to 0.21 lb/BBl, producing a maximum drag reduction of 66%.

11.4 ppg $CaCl_2$ Brine

In testing the calcium chloride brine system, the availability of a pre-hydrated polymer concentrate was very valuable in producing consistent fluid properties and minimizing mixing time.

The baseline test results for the $CaCl_2$ brine are shown in Figure 12. Once again, the friction pressures in the coiled tubing were higher than those produced in the straight pipe. Unlike the NaCl system, however, the variation between the two pipe geometries was not constant, but ranged from 12% higher friction pressures for the coiled tubing at the lower injection rate to 20% at the maximum rate.

The effects of polymer loading on the friction pressure in coiled tubing can be seen in Figure 13. At a rate of 10 gpm, the calcium chloride brine produced a friction pressure of 53 psi/10 Ft, which is 44% higher than that produced by the 10 ppg NaCl brine. Successively higher polymer loadings reduced that friction pressure, with a final measurement of 30 psi/10 Ft for a loading of 0.21 lb/BBl.

This test data for the calcium chloride brines was curve fitted, using a power law model. The calculated drag reduction for the various polymer loadings in the coiled tubing is shown in Figure 14. The maximum drag reduction achieved by this polymer in these tests was 52%, using 0.21 lb/BBl of the new polymer. Slightly less drag reduction was achieved in the straight pipe using this polymer loading, with a DR of 49% attained at the maximum test injection rate of 17.5 gpm. There is no indication that this is an optimum loading, but the data suggests that greater drag reduction might be achieved with higher polymer concentrations.

Conclusions

Friction pressure tests were performed using both field scale and laboratory-scale equipment. There was relatively good agreement in the results obtained from both apparatus for the fresh water tests. That agreement provides some degree of confidence in the ability to scale up the data generated on the smaller equipment for field use. The advantage of the small scale flow loop rests in the ability to quickly run multiple tests, with minimum of material usage and waste generation. Some differences can still be noted from this data, particularly the very close agreement in friction pressure data between the coiled tubing and straight pipe in the full-scale flow loop, as opposed to the constant 21% deviation in the fresh water base line results between the two pipe configurations in the ½ inch flow loop.

The base fluid tests in the small-scale flow loop showed that the heavier brines produce successively higher friction pressures. In comparison to the fresh water, the 10 ppg NaCl brine produced 22% greater friction at a given injection rate. The 11.4 ppg calcium chloride brine produced up to 80% greater friction pressures than the fresh water under the same flow velocities.

The Polymer A was found to be a very effective friction reducing agent in both fresh water and in a number of brines. In fresh water, drag reduction of up to 70% was attained in coiled tubing and up to 83% in the straight pipe, with only 0.06 lb/BBl Polymer A. In the 7% KCl, Polymer A produced drag reduction of up to 62% in coiled tubing and 77% in straight pipe. Increasing the brine density appears to also increase the amount of Polymer A required to produce a given level of friction pressure reduction. Obtaining 60% drag reduction in the 10 ppg NaCl required a concentration of 0.13 to 0.21 lb/BBl Polymer A. In the 11.4 $CaCl_2$ brine, the 0.21 lb/BBl Polymer A achieved 50% drag reduction, but the data indicated that higher concentrations might produce an even greater reduction in friction pressure.

Acknowledgments

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Nomenclature

BBl = barrels
$CaCl_2$ = Calcium chloride
cP = centipoise
CT = Coiled Tubing
DR = Drag Reduction
ft. = feet
gpm = gallons per minute
KCl = Potassium chloride
Lb/BBl = Pounds per barrel
MM = Million
NaCl = Sodium chloride
OD = Outside dimension, inches
ppg = pound per gallon
psi = Pounds per square inch
Q = Injection Rate, gpm
SP = Straight Pipe

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3. Drew, T.B., Koo, E.C. and McAdams, W.H.: “The Friction Factors for Clean Round Pipes,” *Trans.*, AICHE (1932) **28**, 56-72.
4. Srinivasan, P.S., Nandapurkar, S.S. and Holland, F.A.” “Friction Factors for Coils,” *Trans.*, Inst. Chem. Engineers (1970) **48**, Nos. 4-6, T156.

Figures

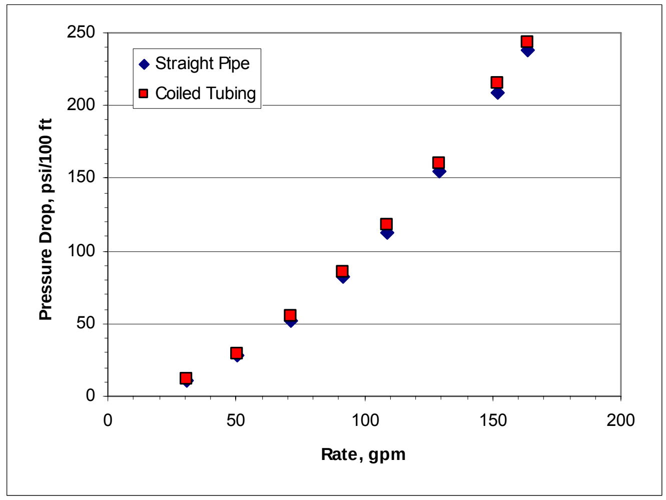

Figure 1 : Fresh water calibration of the 1½ in tubing, showing minimal variation between the straight pipe and coiled tubing.

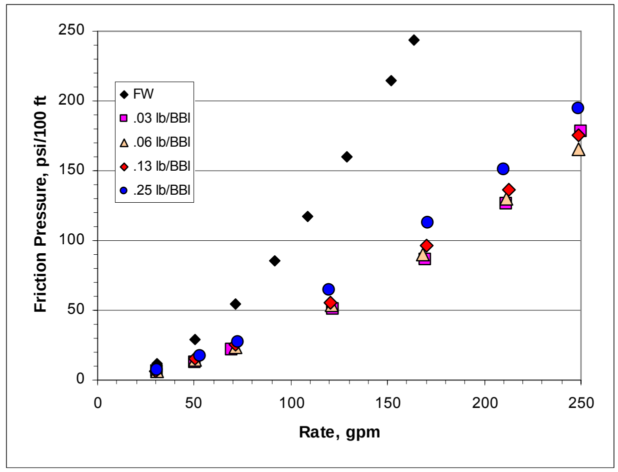

Figure 2 : Friction pressures for fresh water systems in the 1½ inch coiled tubing.

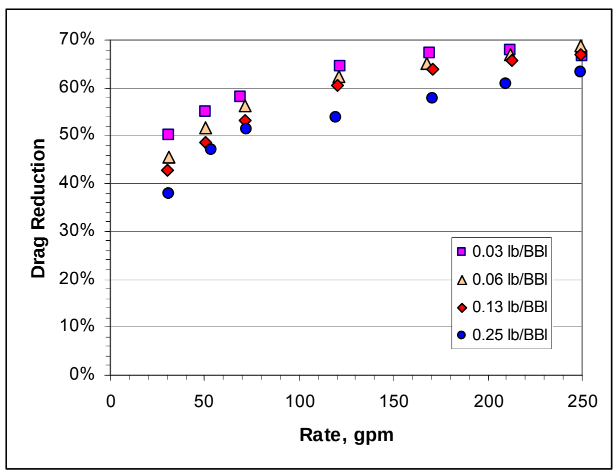

Figure 3 : Drag reduction in 1½ inch coiled tubing for Polymer A in fresh water.

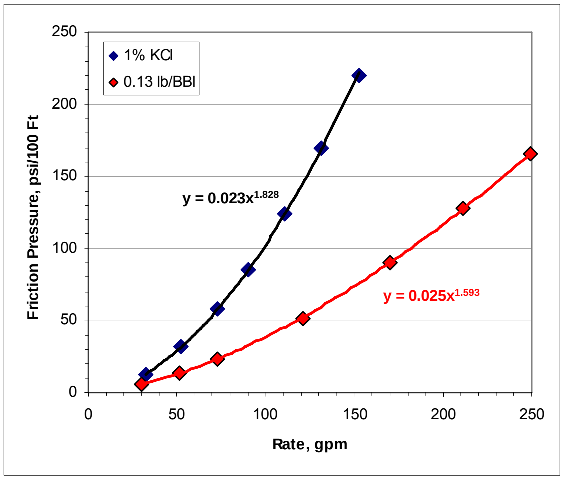

Figure 4 : Effect of 0.13 lb/BBl of the friction reducing polymer on the 1% KCl Brine in 1½ inch coiled tubing.

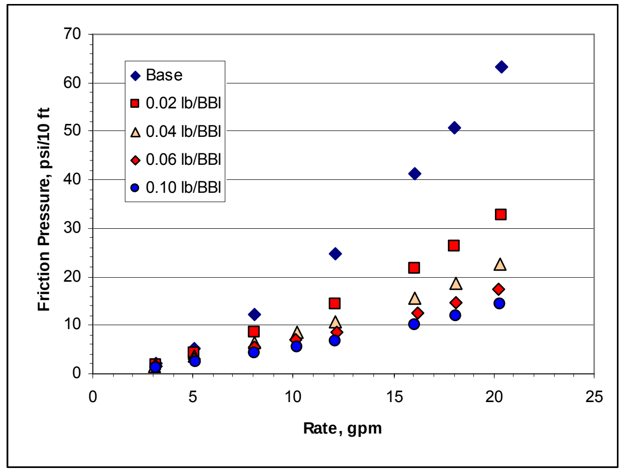

Figure 7 : Friction pressures for 7% KCl in ½ inch straight pipe, with varying loadings of Polymer A.

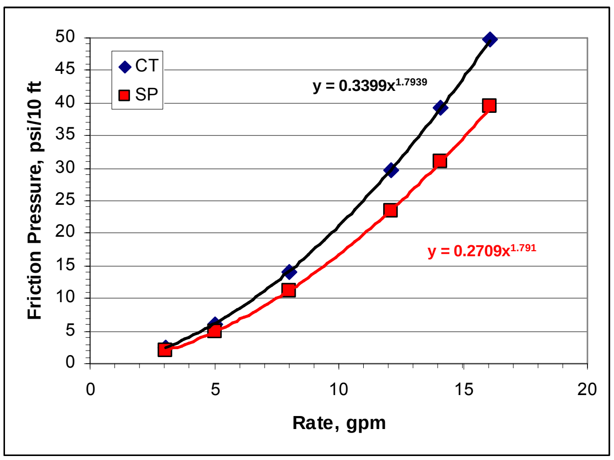

Figure 5 : Fresh water calibration of the small scale (½ inch) flow loop, showing a consistent 21% lower friction in straight pipe than in coiled tubing.

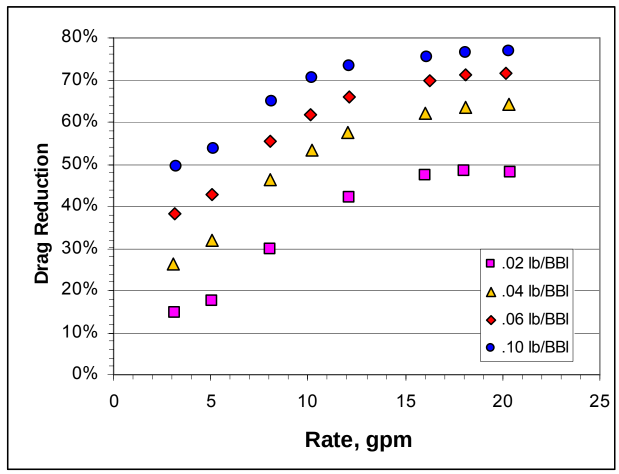

Figure 8 : Drag reduction for Polymer A in 7% KCl in ½ inch straight pipe.

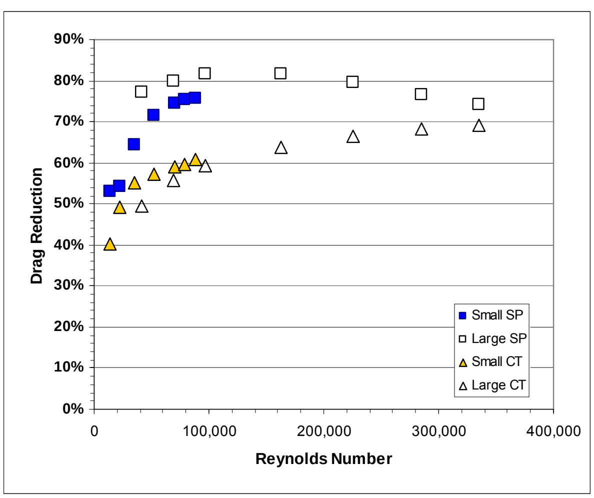

Figure 6 : Drag reduction by 0.06 lb/BBl Polymer A in fresh water in both the large and small scale flow loops. There was good correlation in results between systems for the coiled tubing.

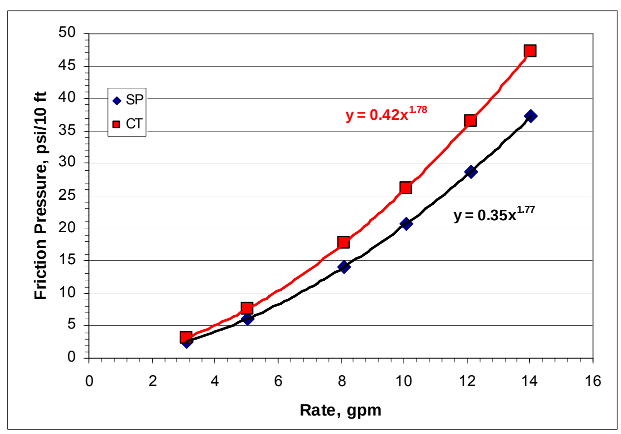

Figure 9 : Base line tests for the 10 ppg NaCl brine. The variation in friction pressure between the coiled tubing and straight pipe was nearly constant at 21%.

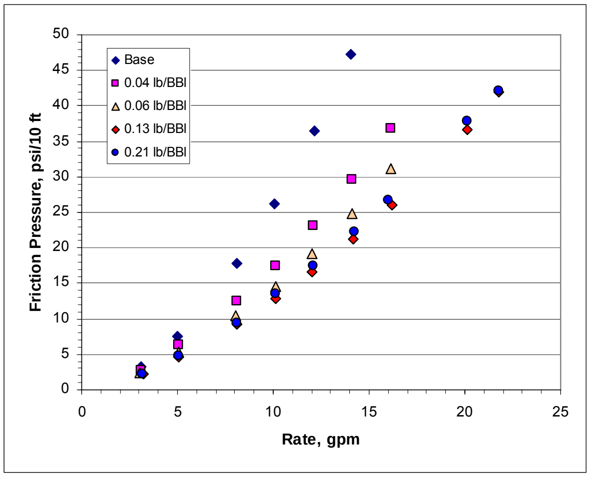

Figure 10 : 10 ppg NaCl brine in ½ inch coiled tubing, with varying loadings of Polymer A.

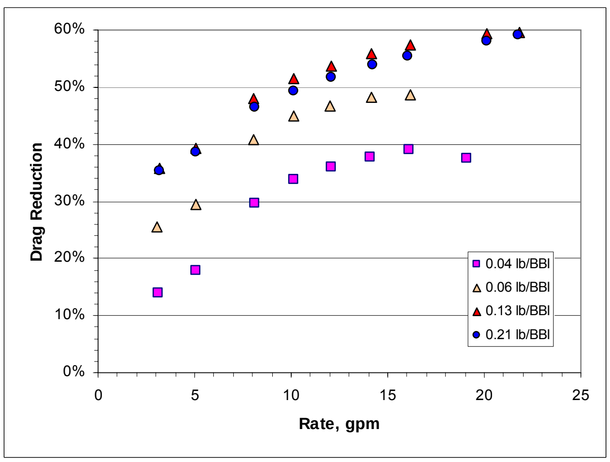

Figure 11 : Drag reduction in coiled tubing for the 10 ppg NaCl brine with varying loadings of Polymer A.

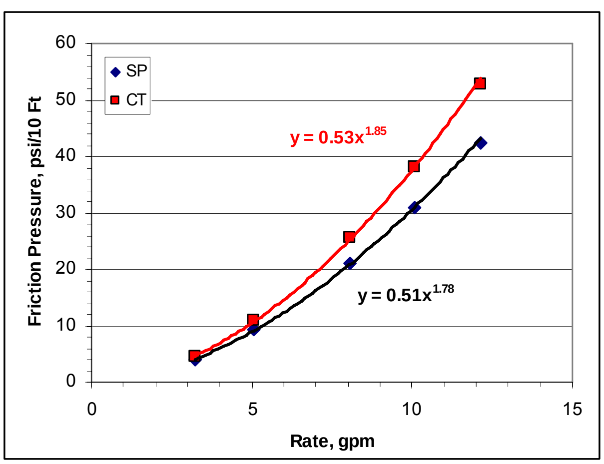

Figure 12 : Base line tests for the 11.4 ppg calcium chloride brine. The difference in friction between the straight pipe and coiled tubing varied from 12% to 20%.

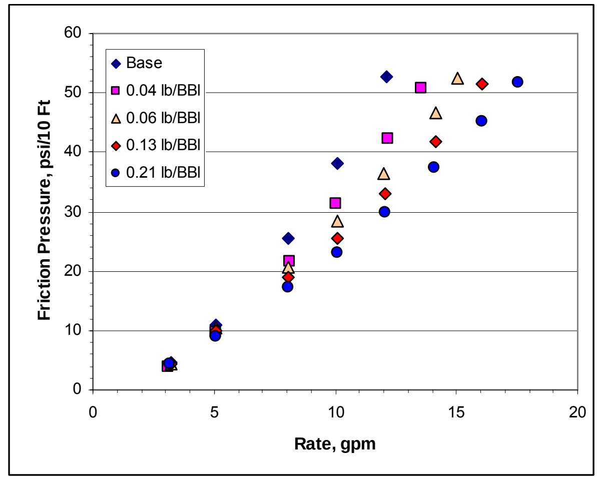

Figure 13: 11.4 ppg $CaCl_2$ brine in coiled tubing, with varying loadings of Polymer A.

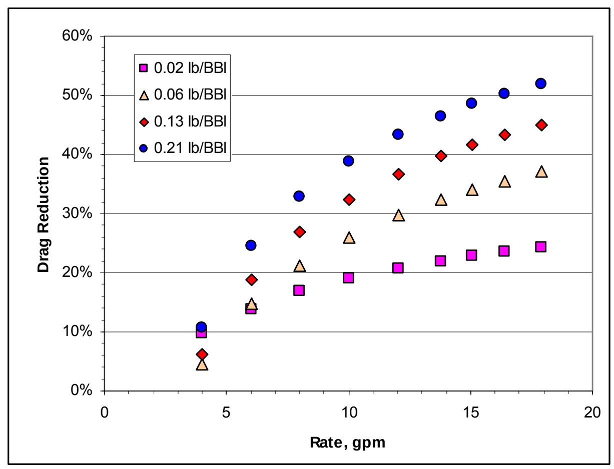

Figure 14 : Drag reduction for 11.4 ppg $CaCl_2$ brine in coiled tubing, with varying loadings of Polymer A.