AADE-12-FTCE-49

Lubricants and Drag Reducers for Completion Fluids – An Analysis of Similarities and Differences

Hui Zhang, Arvind Patel and William Foxenberg, M-I SWACO

Abstract

Lubricants, when dissolved or dispersed in completion fluids to reduce mechanical frictions, are often confused with drag reducers, which are polymers acting to reduce hydraulic friction. From the perspective of molecular structure and chemical properties, this paper illustrates the similarities and mainly the differences between brine soluble (or dispersible) lubricants and hydraulic drag reducers from the perspective of chemistry, molecular structure, surface activity, and evaluation methodology.

A unique and very effective lubricant is presented which is soluble in brines and acts to reduce metal-to-metal friction. Also presented is a drag reducer that effectively reduces the hydraulic friction of completion fluids including both low and high density applications for both monovalent and divalent brines.

Introduction

The oil and gas industry has used brines for well completions and workovers for many years. Commonly used brines include seawater, formate brines, monovalent and divalent halide brines, as well as their combinations. The operations employing these brines include, among others, running production tubulars/screens, wellbore cleanup, and coiled tubing operations. As extended-reach, high-angle and deepwater wells are drilled, high friction is one of the major problems that must be addressed. Additives can be applied to the brines to reduce the friction. However, to select the proper treatment and optimize the effectiveness, the root cause of the friction has to be analyzed and understood. Is it the mechanical friction between two surfaces, or is it hydraulic pressure loss which is determined by fluid and tubing characteristics?

To control hydraulic friction pressure loss, a drag reducer can be added to the fluids. When proper drag reducer is applied in the pipeline fluid, even with only a trace amount of treatment, reduction in the pressure drop over some length of a pipeline will be observed. Drag reduction was defined by Savins[1] as the increase in pumpability of a fluid caused by the addition of small amounts of another substance, such as high-molecular-weight polymers, to the fluid. Adding a small amount of drag reducer to a fluid may alter the rheological properties and drastically reduces the friction pressure of the fluid. Savings and a number of others[1-7] have discussed several mechanisms for friction reduction in polymer solutions under turbulent flow conditions. These theories include boundary layer thickening and viscosity gradient, i.e. viscoelasticity.

If the high friction is caused by mechanical friction between tubular equipment run into the well and the wellbore surface, using a lubricious fluid (i.e., a fluid with a low coefficient of friction) or imposing lubricity on the fluid through the use of lubricants can play an important role in controlling torque and drag during well operations. Mechanical friction between solid surfaces increases torque and the power required to run the tubular into the hole. Friction also increases stress on the tubular that can lead to twist-off of the pipe or interfere with running the pipe in and out of the hole. Therefore, obtaining and maintaining low torque-and-drag factors can be the difference between a successful or not-successful operation.

When high friction is encountered in well operation, identifying the root cause is the first step to solve the problem. That is, should the treatment be a lubricant or hydraulic drag reducer or both. A lubricant (sometimes referred to as a "lube") is a substance (often a liquid) introduced between two moving surfaces to reduce the friction between them, improving efficiency and reducing wear. A hydraulic drag reducer is long-chain polymer chemical that when injected into a pipeline reduces the frictional pressure drop along the pipeline length. However, both lubricants and hydraulic drag reducers are often referred to as friction reducers, and thus leads to confusion on their identification and application. In the following discussion, a distinct difference between brine lubricants and hydraulic drag reducer will be discussed from the perspective of molecular structure, surface activity, measurements, etc. Applications will be focused on completion and workover brines.

Brine Lubricants and Hydraulic Drag Reducers

Molecular Structure

There are many hydraulic friction reducers available on markets. Some are nonionic or cationic in nature, and others are anionic. Many publications describe the behavior of friction reducers in water or low-density fluids and their flow properties in the oil industry.[2-14] In well completions and workovers, polymers are the most often studied and used systems. Several typical water-soluble polymer drag reducers include polyacrylamide, Guar gum, Xanthan gum, polyethylene oxide, hydroxyethyl cellulose and carboxy-methyl cellulose. As a rule of thumb, the higher the molecular weight (MW), the more effective a given polymer is as a drag reducer. Polymers with a MW below 100,000 seem to be ineffective. It has been confirmed that the extension of the polymer chain is critical for drag reduction. The most effective drag-reducing polymers are essentially linear in structure, with maximum extensivity for a given molecular weight. Polyacrylamide, polyethylene oxide and polyisobutylene are typical examples of linear polymers. Polymers without linear structure, such as gum arabic and the dextrans, are ineffective for drag reduction.

Many lubricants are also available on the market. However, the majority of oilfield lubricants were originally developed to be used with drilling fluids - both oil- and water-based drilling fluids. The liquid form of the lubricant normally contains 90% base oil (which can be mineral oil, vegetable oils, polyolefins, esters, etc) and 10% additives which are usually material with surface activity. In recent years, the rigorous environmental regulations in many parts of the world have required fundamental changes in lubricant chemistry. In the past, hydrocarbons and fatty acids were the primary effective lubricant additives. However, the industry has recently tended to use more environmentally acceptable lubricant alternatives such as esters and naturally occurring vegetable oils.[15,16] These lubricious materials can significantly reduce metal-to-metal and metal-to-rock coefficients of friction in water-based fluids. Foxenberg[17] reported the successful use of a phospholipid lubricant in completion brines, including high-density calcium chloride and calcium bromide. Surfactant-type lubricants, which are soluble in brines, have a much smaller molecular weight than typical drag-reducing polymers.

The active component in hydraulic drag reducers is a high-molecular-weight polymer which can be purchased as dry product. But more commonly, drag reducer product is packaged in a liquid format as a concentrated particle suspension in order to reduce dusting, speed hydration and enhance field handing. The pre-hydration/dispersion in suspension format allows the polymer to disperse readily in aqueous fluids and allows metering the polymer in continuous mix applications, such as slick-water fracturing treatment. The carrier for the suspension can be hydrocarbon oil such as iso-alkane oil, or a glycol ether such as butyl carbitol. The latter is desirable for operational areas where specific environmental factors or regulations preclude the use of hydrocarbon base oil. Because the glycol ether is miscible in water, no sheen is formed. Suspensions using base oil as the carrier fluid can achieve a lower pour point and better performance in severe winter conditions than suspensions using glycol ether as the carrier.

Liquid drag reducer product usually has a milky or emulsion look (Fig. 1a). Brine lubricants, on the other hand, usually are liquid with a transparent look (Fig. 1b).

Lubricants containing water (or a glycol) solution of surfactants is common for the application in completion and workover brines. These surfactants have much a smaller molecule than a typical drag reducer polymer, so they can dissolve in water or brine and form a true solution.

a b

Fig.1 – Drag reducer (a) and brine lubricant (b).

Surface Activity

When high-molecular-weight polymers are applied to completion brines to reduce hydraulic friction, the polymers do not have surface activity and do not coat on pipe surfaces. They remain in the fluid, entangle and interact with the flow to reduce the turbulence and therefore reduce the friction pressure drop. When applied at low dosage, the viscosity of brine does not increase substantially either. Therefore the chance of entrapping air and cause foam is not a concern.

The mechanism for a lubricant to work, however, depends on their surface activity. They coat the metal or rock surfaces to increase the lubricity of the surface. But due to their surface activity, they can also reduce surface tension and stabilize the air-water interface, thus promoting the formation of foam. Fluids treated with surfactant lubricants, such as phospholipids, have high foamability and usually need a defoamer to control the foam.

Measurement

The effects of lubricant and hydraulic drag reducer are evaluated with totally different methodology. Lubricity of brine fluids is evaluated by coefficients of friction. The lower the coefficient of friction, the higher the brine lubricity. As an example, an OFI lubricity tester is utilized to measure the metal-to-metal coefficient of friction when exposed to a variety of brine fluids (Fig. 2). Outcome of the measurement is Coefficient of Friction (CoF) which is a unitless number. Table 1 gives the CoF of seawater and KCl brines. Without adding brine lubricant, their CoF is around 0.3. With the treatment of 0.5% Lubricant A, the brine lubricity increased and CoF is lowered to 0.13. Lubricant A is a solution of phospholipid surfactant.

Fig. 2 – OFI Lubricity Tester.

Table 1 – Impact of Lubricant A on Coefficients of Friction

Fluids	CoF without Lubricant	CoF with 0.5% Lubricant A
Deionized water	0.34	
Seawater	0.35	0.13
3%KCl	0.34	0.13
9.0-lb/gal KCl	0.31	0.13

In evaluating the performance of a hydraulic drag reducer, flow loop tests with either straight pipe or coiled tubing are used.[11,18] A picture of a small-scale flow loop using straight pipe as the test section is shown in Fig. 3. This set-up consists of stainless steel tubing with an ID of 0.305 inch and length of 195 inches. Fluid injection is accomplished using a triplex pump. The pressure drop, fluid temperature and fluid density are measured continuously. The drag reducer is added to the brine in a 6-gal mix tank then circulated through the loop. Direct outcome of this measurement is flow rate versus pressure drop along the test section that is captured by the sensors equipped at the inlet and outlet of the pipe. Table 2 gives an example of the results measured with seawater. At a given flow rate, by comparing the pressure loss with and without drag reducer, the percentage of friction reduction can be calculated, which reflects the effectiveness of the treatment as a hydraulic drag reducer. In Table 2, Drag Reducer A (DR A) reduced the hydraulic friction drag by about 60% at the loading of 0.05 vol%. DR A contains an acrylamido-methyl-propane sulfonate (AMPS)-type polymer.

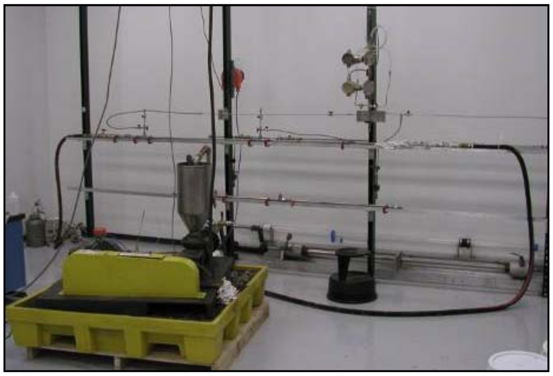

Fig. 3- Flow Loop (straight pipe) for hydraulic drag testing

Table 2 – Impact of Hydraulic Drag Reducer A on Friction Pressure Loss

Flow Rate (gal/min)	Pressure Loss (psi)		Drag Reduction (%)
	Seawater blank	With 0.05 vol% DR A	
2	9.1	4.1	54.7
3	18.2	6.5	64.3
4	29.8	9.7	67.6
5	43.8	13.6	68.9
6	59.9	18.4	69.4
7	78.1	23.9	69.4
8	98.3	30.2	69.3

Lubricity and Drag Reducing Characteristics of Different Brines

Depending on the type of salt, lubricity characteristics may be quite different. Table 1 and Table 3 present the coefficients of friction for different brines. As shown, seawater and 3% KCl had coefficients of friction similar to that of deionized water (0.34). As the salt concentrations in KCl brine increases, the coefficients of friction decreases. For example, 9.7-lb/gal KCl brine has a CoF of 0.28 whereas the 9.0-lb/gal KCl has a CoF of 0.31. NaBr brines show similar lubricity characteristics to those of KCl and NaCl. As the concentration increases, the CoF reduces. $CaCl_2$ and $CaBr_2$ are more lubricous than the potassium and sodium-based brines. As shown, the 10.4-lb/gal $CaCl_2$ brine has a CoF of 0.19 and the 11.6-lb/gal $CaCl_2$ brine has a CoF of 0.13. $ZnBr_2$-containing brines appear to be naturally lubricous. All the brines tested showed good lubricity characteristics. In general, brine lubricity increases with salt concentration or as density increases.

Table 3 – Impact of Brine on Coefficient of Friction

Monovalent Brine	CoF
3% KCl	0.34
9.7-lb/gal KCl	0.28
10.0-lb/gal NaCl	0.26
11.0-lb/gal NaBr	0.30
12.5-lb/gal NaBr	0.22
Divalent Brine	
10.4-lb/gal $CaCl_2$	0.19
11.6-lb/gal $CaCl_2$	0.13
14.2-lb/gal $CaBr_2$	0.12
15.5-lb/gal Zn-$CaBr_2$	0.13
15.5-lb/gal ZnBr/CaBr/$CaCl_2$	0.08

Hydraulic drag (or pressure loss), on the other hand, increases as brine density increases. As shown in Table 4, when circulating in the same pipeline at the same flow rate, pressure loss increases as brine density increases. For example, at a 3-gal/min flow rate, seawater caused an 18-psi pressure loss while the 11.0-lb/gal $CaCl_2$ caused a 30-psi pressure loss when flowed through the straight-pipe test section. For brines with the same density, e.g. 9.0-lb/gal $CaCl_2$ brine seems to cause higher pressure loss than the KCl brine does. As the density of brine increases from 9.0 to 11.0 lb/gal, the pressure loss increased significantly – about 1.5 times. For every brine, as the flow rate increases, the pressure loss increases dramatically, implying that friction-induced pressure loss is closely related to the turbulence of the flow.

Table 4 - Friction Pressure Loss of Different Brines in Straight-Pipe Flow Loop

Flow Rate (gal/min)	Friction Pressure Loss (psi)			
	Seawater	9.0-lb/gal KCl	9.0-lb/gal $CaCl_2$	11.0-lb/gal $CaCl_2$
3	18	19	20	30
7	78	81	86	126

Table 5 illustrates the measurement from a flow loop consisting of coiled tubing (20-ft long x 0.18-in. ID).[11] Data show that as the flow pipe become narrower and curved, hydraulic friction increases significantly.

Table 5 - Friction Pressure Loss of Different Brines in Coiled-Tubing Flow Loop

Flow Rate (gal/min)	Friction Pressure Loss (psi)		
	10.0-lb/gal NaCl	11.0-lb/gal $CaCl_2$	14.2-lb/gal $CaBr_2$
2	198	225	290
3	380	470	590

Compatibility with Brines

For both lubricants and hydraulic drag reducers, the purpose of inclusion in completion and workover operation is to smooth the operation and reduce energy consumption. The solubility or dispersion characteristics in brines are very important for their efficiency. High salt content, low free-water activity, and diversified ionic type and strength can diminish the effectiveness of a lubricant and drag reducer.[7-12] Before choosing the friction reducing additives, their compatibility with brine should always be checked.

For example, Fig. 4 illustrates the compatibility of a treatment with 11.0-lb/gal $CaCl_2$. In Fig. 4a, Lubricant A and DR A were used at 0.5 and 0.05 vol% respectively. Both Lubricant A and DR A have good compatibility with calcium brines, therefore the brine remained clear and transparent. DR A has excellent performance in calcium brines. Unlike many other drag reducers on the market which are only effective in low-density and monovalent brines, DR A provides excellent drag reduction in calcium brines (Table 6 and Table 7). Data were generated with the flow loop using a straight-pipe test section.

Fig. 4b illustrates 11.0-lb/gal $CaCl_2$ brine containing 0.1 vol% DR B and Lubricant B, which are not compatible with the brine. These additives cannot be well dispersed in divalent brines. When precipitate or “cottage-cheese” type incompatibility happens (which is not uncommon when additives commingle in brines), not only is there no reduction in friction, but also formation permeability can be impaired.

Fig. 4 – $CaCl_2$ brines containing both lubricant and drag reducer. Note that the combination on the left is soluble/dispersible in brine; and a different combination on the right is not dispersible in brine and shows “cheesing”.

Table 6 – Friction Pressure Loss of 9.0-lb/gal $CaCl_2$ in Straight-Pipe Flow Loop

Flow Rate (gal/min)	Pressure Loss (psi)		Drag Reduction (%)
	9.0-lb/gal $CaCl_2$ blank	With 0.025 vol% DR A	
2	9.9	5.3	47
3	19.9	9.2	54
4	32.7	13.7	58
5	48.1	19.3	60
6	65.9	25.9	61
7	85.9	33.4	61
8	108	41.8	61

Table 7 – Friction Pressure Loss of 11.0-lb/gal $CaCl_2$ in Straight-Pipe Flow Loop

Flow Rate (gal/min)	Pressure Loss (psi)		Drag Reduction (%)
	11.0-lb/gal $CaCl_2$ blank	With 0.2 vol% DR A	
2	14.9	6.1	59.4
3	29.8	10.9	63.3
4	48.6	16.6	65.8
5	71.0	22.9	67.7
6	96.8	29.9	69.1
7	126	37.4	70.3

Conclusions

Lubricants and hydraulic drag reducers can both be applied to completion brines to reduce energy consumption caused by friction and to ease the operation difficulty. Both lubricants and drag reducers are often referred to as friction reducers. Therefore, their distinct difference in function and chemistry are often confused. This paper illustrated that lubricants and drag reducers differ in chemistry, surface activity, and methodology of evaluation. Also, lubricity and hydraulic friction characteristics are different with various brines.

Lubricants are used to reduce the friction between two moving surfaces so as to reduce torque and wear. As the salt density increases, the CoF of the brine decreases.

Hydraulic drag reducers are used to reduce the frictional pressure drop along the pipeline length and therefore improve pumpability of fluid. As the brine density increases, the pressure loss increases for the same flow rate. As the flow rate increases, the pressure loss increases dramatically.

Acknowledgments

The authors thank the management of M-I SWACO, A Schlumberger Company for permission to publish this paper.

Nomenclature

$CaCl_2$	= *Calcium chloride*
$CaBr_2$	= *Calcium bromide*
CoF	= *Coefficient of friction*
DR	= *Drag reducer*
KCl	= *Potassium chloride*
NaBr	= *Sodium bromide*
psi	= *Pounds per square inch*
$ZnBr_2$	= *Zinc bromide*

References

1. Savins, J.G.: “Drag Reduction Characteristics of Solutions of Macromolecules in Turbulent Pipe Flow.” SPE 867, *SPE Journal* (September 1964) 203.
2. Virk, P.S.: “Drag Reduction Fundamentals.” *AIChE Journal*, vol. 21 (July 1975) 625.
3. Tandon, P.N., Kulshreshtha, A.K., Agarwal, R.: “Rheological Study of Laminar-Turbulent Transition in Drag-Reducing Polymer Solutions.” *Encyclopedia of Fluid Mechanics,* Vol. 7, 459.
4. Sitaramaiah, G. and Smith, C.L.: “Turbulent Drag Reduction by Polyacrylamide and Other Polymers.” SPE 2405, *SPE Journal* (June 1969) 183.
5. Rodriguez, J.M., Zakin, J.L. and Patterson, G.K.: “Correlation of Drag Reduction with Modified Deborah Number for Dilute Polymer Solutions.” SPE 1678, *SPE Journal* (September 1967) 325.
6. Sifferman. T.R. and Greenkorn, R.A.: “Drag Reduction in Three Distinctly Different Fluid Systems.” SPE 8722, *SPE Journal* (December 1981) 663.
7. Pruitt, G.T., Simmons, C.M, Neill, G.H. and Crawford, H.R.: “A Method to Minimize the Cost of Pumping Fluids Containing Friction-Reducing Additives.” SPE 997, SPE 39th Annual Fall Meeting, Houston, October 11-14, 1964. 8. Acharya. A. R.: “Drag Properties Used to Estimate Friction Loss of Fracturing Fluid.” *Oil & Gas Journal* (June 12, 1989) 35-38.
9. Willingham, J.D. and Shah, S.N.: “Friction Pressures of Newtonian and Non-Newtonian Fluids in Straight and Reeled Coiled Tubing.” SPE 60719, SPE/ICoTA Coiled Tubing Roundtable, Houston, April 5-6, 2000.
10. Hoyt, J.W.: “Drag Reduction.” *Encyclopedia of Polymer Science and Engineering*, Vol. 5 (1986).
11. Ke, M., Qu, Q., Stevens, R.F., Bracksieck, N., Price, C. and Copeland, D.: “Evaluation of Friction Reducers for High Density Brines and Their Application in Coiled Tubing at High Temperature.” SPE 103037, SPE Annual Technical Conference, San Antonio, September 24-27, 2006.
12. Shah, S.N. and Zhou, Y.: “An Experimental Study of Drag Reduction of Polymer solutions in Coiled Tubing.” SPE 68419, SPE/ICoTA Coiled Tubing Roundtable, Houston, March 7-8, 2001.
13. Dunn, M.D., Crane, L.R. and Thomas, R.L.: “North Slope Drilling Practices – Ever Adapting to New Challenges.” AADE-05-NTCE-07, AADE National Technical Conference, Houston, April 5-7, 2005.
14. Farmer, P., Miller, D., Pieprzak, R., J., and Woods, R.: “Exploring the Subsalt.” *Oilfield Review* v. 8, No.1, (Spring 1996) 50 – 64.
15. Knox, D. nand Jiang, P.: “Drilling Further with Water-Based Fluids-Selecting the Right Lubricant.” SPE 92002, SPE International Symposium on Oilfield Chemistry, Houston, February 2-4, 2005.
16. Ke, M.J. and Foxenberg, W.E.: “Lubricity of Brine Completion and Workover Fluids.” SPE 130679, SPE/ICoTA Coiled Tubing and Well Intervention Conference, The Woodlands, Texas, March 23-24, 2010.
17. Foxenberg, W.E., Ali, S.A., Long, T.P. and Vian, J.: “Field Experience Shows That New Lubricant Reduces Friction and Improves Formation Compatibility and Environmental Impact.” SPE 112483, SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, Louisiana, February 13-15, 2008.