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Research paper

Pressure drop reduction of stable water-in-oil emulsions using organoclays

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ABSTRACT

In this study, the influence of organoclays (OC) on the pressure drop of surfactant-stabilized water-in-oil (W/O) emulsions was studied. OC were tested as pressure loss reducing agents for stable W/O emulsions with 0.7 (concentrated) and 0.3 (diluted) water volume fractions. Pressure drop measurements were conducted in horizontal pipes with inside diameters (ID) of 0.0254-m and 0.0127-m. The results showed a significant reduction in the emulsion viscosity with the addition of OC and this effect was enhanced as the concentration increased. In addition, for the case of concentrated W/O emulsions, the addition of OC resulted in 25% reduction in the emulsion pressure drop in both test sections. For diluted W/O emulsion with only 0.3 water fraction, while no pressure drop reduction was observed in the laminar region, it was detected in the turbulent region and such effect was pronounced at high Reynolds numbers and high OC concentration. The observed results were explained in terms of emulsion dispersed phase droplet size. In the laminar regime, the friction factor for stable W/O emulsions was in a good agreement with single phase predictions. However, in the turbulent regime the friction factor for the multiphase system was below the predictions of single phase flow. OC proved to have a good potential as drag reducing agents by producing smaller and stable emulsion droplets hence suppressing the Reynolds' stresses.

1. Introduction

Emulsified acids provide significant benefits in stimulating oil and gas wells by slowing the reaction rate with carbonates and reducing corrosion in the tubular goods. The emulsified acid is essentially a mixture of up to 70% acid emulsified in a 30% continuous diesel phase. However, pumping emulsified acids can result in high friction losses. Such losses limit the matrix acidizing job efficiency by reducing the penetration depth. Therefore, reducing friction pressure loss is an important factor in extending the application of emulsified acids to deeper targets.

Friction reducing agents, or drag reducing additives, have been used to increase the throughput of oil and gas pipelines. Typically a dilute polymer solution is continuously injected into the pipelines resulting in a drag reduction of up to 70% (Al-Yaari et al., 2008, 2009, 2012). For stimulations, water based gels or oil based gels are used not only to increase viscosity for fracture width creation, leak-off prevention, proppant suspension, and diversion, but also are used because of their friction reduction capability. The macro-structure of the polymers dampens the development of turbulence at high pumping rate such that the friction loss is reduced and Reynolds stresses at the wall go down to zero or close to zero.

It is known that the addition of drag reducing polymers (DRP); such as polyethylene oxide (PEO), reduces eddies viscosity; hence reduces turbulence, in high water flow rate (typical to those used in firefighting). Addition of less than 0.5% of PEO to water under turbulent conditions could result in a significant reduction in friction factor. In addition, the use of DRP is a well-known practice in oil transportation.

For surfactant-stabilized emulsions, it has been proved that oil soluble polymers as well as water soluble polymers can be used as drag reducing agents for W/O and oil-in-water (O/W) emulsions at high pumping rates, respectively (Al-Yaari et al., 2013). In addition, pressure drop reduction of stable emulsions can be achieved by decreasing the dispersed phase fraction (Al-Yaari et al., 2014).

New nanomaterials showed high performance in polymer nanocomposites due to their high aspect ratio and the high surface area of the dispersed nano-sized particles. Various nanomaterials are currently being developed; however, clay minerals are the most popular due to their availability (natural source), low cost and more importantly their being environmentally friendly. Of particular interest, organically modified clay mineral showed significant enhancement of a large number of physical properties (Sinha Ray et al., 2005; Sinha-Ray and Bousmina, 2005). The main reason for these improved properties in clay

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Table 1
Properties of the emulsifying agent.

Commercial name	ARMAC T
Common name	Tallowalkylamine acetates
Appearance at 25 °C	Solid
Hydropile–lipophile balance (HLB)	6.8

polymer nanocomposites (CPN) is the high surface area of the organically modified clay mineral particles as opposed to conventional fillers (Chen et al., 2002). Clay minerals generally have layer thickness in the order of 1 nm and very high aspect ratios (length over thickness) in the range 10–1000.

Most of the polymer literature has focused mainly on improvement in mechanical properties of CPN. However, known instabilities associated with polymer flow such as sharkskin and melt fracture (Binding, 1991; Binding and Walters, 1988; Boger, 1987; White et al., 1987) have been significantly reduced and flow rates have increased by the addition of clay minerals.

The impact of nanomaterials on polymer flow was limited to rheological tests. However, Hatzikiriakos et al. (2005) found that clay mineral additives had a significant effect on the extrudate appearance of polyethylene. It eliminated surface instabilities and postponed the critical shear rate for the onset of gross melt fracture to significantly higher values depending on resin type, temperature, and additive concentration (typically 0.05 to 0.5 mass%). The authors observed that the presence of clay minerals suppressed the development of extensional stresses to such high levels that can cause a shift in melt fracture phenomena. Also, it was reported that the combination of clay minerals with traditional processing aids such as fluoro-polymers produces an enhanced processing aid that can increase the critical shear rates for the onset of melt fracture to levels much higher than the individual constituents when they are used independently.

Adesina and Hussein (2012) studied the effect of OC on high density polyethylene (HDPE) rheology and extrusion. It was reported that the addition of $\leq$0.1 mass% of clay resulted in reduction in extensional strain and stress growth of HDPE. Also, the addition of such small amount of OC eliminated the gross melt fracture in HDPE and reduced the extrusion pressure; hence more throughputs were reported. Therefore, they concluded that the addition of platy-like OC can result in melt flow streamlining. They reported that the transient stress overshoot, normal stress difference, zero shear viscosity, onset of shear thinning, and extrusion pressure of polyethylene were reduced by the addition of only 0.05 mass% of the OC and such reduction was for both shear and extensional flows.

Research and experimentation into the application of OC for emulsified acid system may result in a cost-effective solution for reduction of surface treating pressures. Potential applications extend from stimulation treatments to downhole or surface chemical injection wherever emulsified oil–water solutions can exist. For example, in downhole electric submersible pumps or gas lifted well applications, the additional fluid flow friction from emulsion causes excessive back pressure to the system. It is known that the addition of a long molecule reduces single phase turbulence in the flow of a small molecule. Therefore, it is expected to behave like the classical DRP.

This paper aims at exploring the possibility of using OC, for the first time, as drag reducing agents. Here, one can look for reduction of pressure drop in stable W/O emulsions using different pipe diameters. The influence of OC type and concentration on emulsion viscosity and frictional losses was investigated.

2. Materials and methods

All tested surfactant stabilized W/O emulsions were prepared using brine (with 2 mass% NaCl) as the aqueous phase. A type of kerosene, with 780 kg/m^3 density and dynamic viscosity of 1.57 mPa·s, was used as the oil phase. ARMAC T, from Akzo Nobel, was used as the emulsifying agent and its physical properties are presented in Table 1. Forty mass% of the emulsifying agent (solid) was dissolved in naphtha to form the liquid phase. In addition, Cloisite 15A (OC1) and Cloisite 30B (OC2) were used as surface active OC and their physical properties are given in Table 2.

A schematic representation of the flow loop is shown in Fig. 1. The flow loop consists of two small 0.07 m^3 PVC tanks. Two centrifugal pumps were used for low- and high-pump rates. The test sections were made of two acrylic resin horizontal pipes with different ID (0.0254-m and 0.0127-m) that allow visual observation. Flow rate was measured by two OMEGA magnetic flowmeters. The total length of the flow loop was 11 m. Emulsion pressure drop was measured by two smart Rosemount differential pressure transducers manufactured by Emerson Process Management GmbH & Co. The first pressure tap of each pipe was located 8 m away from the entrance, ensuring that the flow is fully developed. In addition, the flow loop contained a conductivity measurement cell that was used to detect the emulsion type and to measure emulsion conductivity while flow takes place in the 0.0254-m ID pipe test section. The conductivity measurements were monitored by a PC through a data-acquisition system. Furthermore, emulsion temperature was maintained at 25 °C by the cooling system illustrated in Fig. 1.

The flowmeters and differential pressure transmitters' information and accuracies are presented in Table 3. All uncertainties were calculated within the 95% confidence level using a method described by Dieck (2007). The uncertainty values summarized in Table 3 represent the combined uncertainties of random and systematic uncertainties.

0.036 m^3 of surfactant stabilized W/O emulsions with 70/30 water to oil volume ratio was prepared by adding the internal phase (water) to the emulsified external phase (oil with 0.6 vol.% emulsifier) at a rate of 0.001 m^3/min (while *mixing* at 8000 RPM (for 30 min) by using high power homogenizer (Ultra Turrax T 50 basic, WERKE IKA, Germany)). Emulsion type was tested by stability drop test where emulsion droplets were injected in a pure phase. If emulsion droplets disperse, the emulsion external phase is the same as the used phase for the test and such results were confirmed by conductivity measurements. Emulsions were then transferred to one of the flowloop tanks. The same procedure was followed for stable W/O with 0.3 dispersed phase volume fraction.

All rheological measurements were conducted using Rheologica Stress Tech rheometer. Steady pressure drop measurements of the prepared emulsion were performed first in both test sections. Then, OC were added to the prepared emulsion in one of the flowloop tanks to produce a specific concentration. After that, emulsion with OC was remixed to get a homogeneous distribution of the OC within the

Table 2
Physical properties of used OC.

Commercial name	Cloisite 15A	Cloisite 30B
Product name	Ditallowdimethylammonium salts with bentonite	Alkyl quaternary ammonium salts with bentonite
Supplier	Southern Clay Products, Inc.	Southern Clay Products, Inc.
Description	Cream powder	Cream powder
Specific gravity	1.6–1.8	1.9–2.1
Solubility	Oil soluble	Oil soluble