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Reducing viscosity of paraffin base crude oil with electric field for oil production and transportation

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HIGHLIGHTS

- The reduction of crude oil viscosity is substantial.
- The new technology consumes little electricity.
- The viscosity reduction lasts more than 11 h.
- Important for both off-shore and on-shore oil production and transportation.

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ABSTRACT

Reducing the crude oil viscosity is important for the oil production and transportation. The micro–nanotechnology of viscosity reduction associated with electric field is found to be universal, working for all kinds of crude oil, including asphalt base crude oil and paraffin base crude oil. Especially at low temperature, the electric field is extremely efficient: in a couple of seconds after the electric field is applied, the viscosity is reduced substantially, making the flow rate in a pipeline more than double. The technology consumes very little energy and will be very useful for both off-shore and on-shore crude oil production and transportation.

1. Introduction

The recent reports by Rocky Mountain Oilfield Testing Centre (RMOTC) of US Department of Energy show that the new micro–nanotechnology, reducing viscosity of crude oil with electric field, is energy efficient and feasible on pipelines [1–3]. All these greatly accelerate the technology progress in the energy area and present more challenges for the science research.

Currently hydrocarbons remain the leading energy source. While the amount of conventional light crude oil becomes less and less available, more and more heavy crude oil and off-shore crude oil are needed. High viscosity of these oils becomes a critical issue. Not only the heavy crude oil has a high viscosity, the off-shore crude oil also has very high viscosity because the deep water temperature is very low, around 1.5–1.6 °C. The high viscosity makes the pressure required to pump crude oil via pipeline very high and creates much difficulties in oil extraction, too.

The importance of this issue, reducing the crude oil viscosity, called the attention more than 30 years ago. However, the current dominate methods remain heating and dilution of crude oil with gasoline or diesel. The heating method is slow and energy-consuming and raises concerns about its environmental impact, too. Moreover, for the off-shore crude oil, it is very difficult to utilize the heating or dilution methods. Some people use the drag-reducing agent (DRA), which are additive of polymer chains. DRA suppresses the turbulence, but has little effect on laminar flow. In addition, DRA is expensive and raises concerns at refinery.

In 2006, based on the concepts of electrorheology (ER), a new micro–nanotechnology to reduce the viscosity of crude oils by a strong electric field was proposed [4–6]. Comparing to the heating method, this technology consumes much less energy and is very fast and, therefore, much more efficient. Afterwards, the technology has developed very fast [1–3]. Recently the Keystone project decides to adapt this technology for its pipeline.

In 2006, it was also reported that magnetic field might be useful to reduce viscosity of paraffin base crude oil but had almost no effect on asphalt base crude oil [4]. However, recent experiment by a Brazil group, showing that magnetic field has effect for some kind of paraffin base crude oil, but has little effect on other kind of paraffin base crude oil [7]. This is related to the paraffin molecule structure. If the paraffin molecule has ring structure, the paraffin is diamagnetic; then the magnetic field has effect on the crude oil. If the paraffin molecule's hydrocarbon chain has no ring

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structure, the paraffin is not sensitive to magnetic field; then the magnetic field cannot reduce the crude oil's viscosity.

The electric field has found to be effective in reducing the viscosity of asphalt base crude oil [4]. The work by the Brazil group raises an important question: Is the electric field also effective enough to reduce the viscosity of paraffin base crude oil? This issue is very important as paraffin base crude oil is one of the most important kinds of crude oil.

Paraffin base crude oil has two critical temperatures: (1) the wax-appearing temperature (WAT); (2) the pour point, which is a temperature lower than the WAT. When the oil's temperature is above the WAT, paraffin is in molecule format, the viscosity is usually low. When the oil's temperature is going below the WAT, more and more paraffin crystallizes into nanoscale particles and the oil's viscosity increases sharply. When the temperature further goes down and more and more paraffin wax is crystallized, the crude oil will reach its pour point, below which the crude oil stops flowing. At a temperature slightly above the pour point, the crude oil will have very high viscosity. It is thus clear that to reduce the viscosity of paraffin base crude oil at low temperature is critically needed.

In this paper, we will report our finding that the micro–nanotechnology associated with electric field is universal, working for all kinds of crude oil, including asphalt base crude oil and paraffin base crude oil. Especially at low temperature, the electric field is extremely efficient in reducing the crude oil viscosity. Our test shows that in a couple of seconds after the electric field is applied, the viscosity is reduced substantially, making the flow rate in a pipeline more than double. The technology also consumes very little energy. After one treatment, the viscosity reduction effect lasts more than 11 h. All these findings prove that the technology will be very useful for both off-shore and on-shore crude oil production and transportation.

2. Methods

Crude oil is a mixture of many different molecules. Gasoline, kerosene, and diesel, the liquid made of small hydrocarbon molecules, have very low viscosity. If we treat the rest large molecules, paraffin particles, and asphalt particles etc. as suspended particles in such low viscosity base liquid made of gasoline, kerosene, and diesel, crude oil is a liquid suspension. These suspended particles are typically of nanoscale. The theory about liquid suspensions thus provides the physics basis for our new method to reduce viscosity of crude oil.

Einstein first studied a dilute liquid suspension of non-interacting uniform spheres in a base liquid of viscosity η_0 and found the effective viscosity η as follows [8–10],

$$\eta = \eta_0(1 + 2.5\phi), \tag{1}$$

where the small parameter ϕ is the volume faction of the suspended particles.

Following Einstein's work, Krieger–Dougherty introduced the intrinsic viscosity $[\eta]$ for particles of different shapes and generalized it for all volume fractions [11],

$$\eta/\eta_0 = (1 - \phi/\phi_m)^{-[\eta]\phi_m}, \tag{2}$$

where ϕ_m is the maximum value fraction allowed for packing the suspended particles. When ϕ is unchanged, the most widely used method to reduce viscosity η is to reduce η_0, such as raising the temperature. On the other hand, Eq. (2) suggests that there is another method: if we change the rheology of the suspension to increase the value of ϕ_m and lower intrinsic viscosity $[\eta]$, we will reduce the viscosity η. The physics is clear: the effective viscosity depends on how much freedom the suspended particles have in the suspension. A high ϕ_m and low $[\eta]$ mean high freedom for the suspended particles, which leads to lower dissipation of energy and lower viscosity [4].

The following three mechanisms contribute to the viscosity reduction [4,5]:

(1) Aggregate the nanoscale particles into short chains with their shapes streamlined along the flow direction. (2) Increase the polydispersity to increase ϕ_m. (3) Increase the average size of suspended particles.

Our technology is illustrated in Fig. 1. The crude oil flows from left to right along a pipe. Initially the nanoscale particles are randomly distributed and the viscosity is high. When the oil passes a strong local electric field, the suspended particles are polarized by the electric field. The induced dipolar interaction forces the nanoscale particles to aggregate into micrometer-size short chains. They have high polydispersity and large size. In addition, the most important is that they are of streamline shape with low $[\eta]$ along the flow direction as the electric field is parallel to the flow direction.

It is also important to note that after formation of short-chains along the field direction, similar to the flow of nematic liquid crystal with its molecular alignment parallel to the flow direction, the viscosity is minimized along the field direction, while the viscosity along the directions perpendicular to the field is actually increased [12]. This fact is very important and very useful as it does not only improve the flow along the field direction, but suppresses the turbulence inside the pipeline.

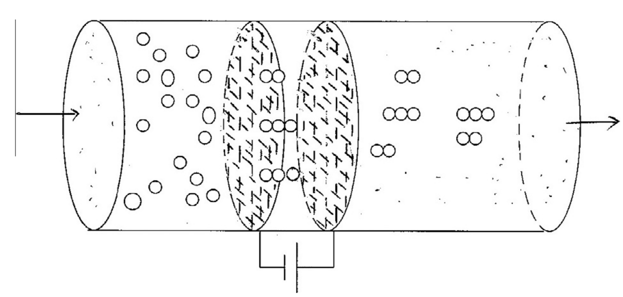

Fig. 1. As the crude oil flow passes a strong local electric field, the suspended particles aggregate along the field direction, and the viscosity along the flow direction is reduced.

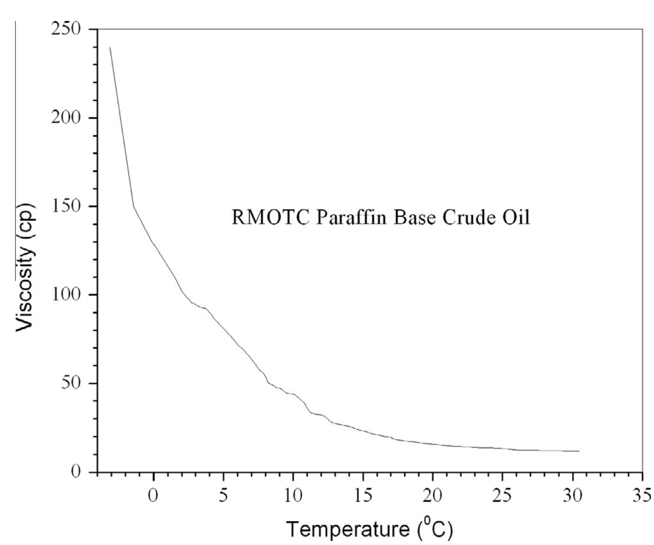

Fig. 2. The viscosity of untreated crude oil versus temperature.