

## Research Article

# Electric Field Suppressed Turbulence and Reduced Viscosity of Paraffin Based Crude Oil Sample

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### Abstract

Flows through pipes, such as crude oil through pipelines, are the most common and important method of transportation of fluids. To enhance the flow output along the pipeline requires reducing viscosity and suppressing turbulence simultaneously and effectively. Unfortunately, no method is currently available to accomplish both goals simultaneously. Here we show that Electrorheology provides a universal method and efficient solution which was confirmed by SANS and DOE pipeline testing. When a strong electric field is applied along the flow direction in a small section of pipeline, the field polarizes and aggregates the particles suspended inside the base liquid into short chains along the flow direction. Such aggregation breaks the rotational symmetry and makes the fluid viscosity anisotropic. In the directions perpendicular to the flow, the viscosity is substantially increased, effectively suppressing the turbulence. Along the flow direction, the viscosity is significantly reduced; thus the flow along the pipeline is enhanced. Recent laboratory experimental tests and field tests with a crude oil pipeline fully confirm the theoretical results. The technology consumes very little energy and will be very useful for both off-shore and on-shore crude oil production and transportation about three paraffin based crude oil samples, HAW, KHU, NAPD, from Saudi Aramco.

**Keywords:** Crude Oil; Electric Field; Energy Security; Pipeline; Reduce Viscosity; Suppress Turbulence

### Introduction

Pipelines are the foundation of our liquid energy supply. Crude oil has traditionally been collected by pipelines from inland production areas. Crude oil also arrives in the U.S. by marine tankers, often moving for the final leg of that trip from a U.S. port to a refinery by pipeline, too. The United States consumes millions of gallons of crude oil every day. This is especially important because frequently pipelines permit the movement of large quantities of crude oil and product to these areas with little or no disruption to communities everywhere. Pipelines also move crude oil produced far offshore in coastal waters. 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. 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 [1-4]. 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 [5-8] and verified by experimental test and computer simulation [9-13]. In this paper, we will report our finding that the AOT technology (Apply Oil Technology) significantly reduces the viscosity of Saudi Aramco crude oil and increase the flow rate.

### Dr. Tao's Viscosity Theory

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 and found the effective viscosity  $\mathbf{h}$  as follows [14-16],

$$\mathbf{h} = \mathbf{h}_0(1 + 2.5\mathbf{j}) \quad (1)$$

where the small parameter is the volume fraction of the suspended particles. Following Einstein's work, Krieger-Dougherty introduced the intrinsic viscosity for particles of different shapes and generalized it for all volume fractions [17],

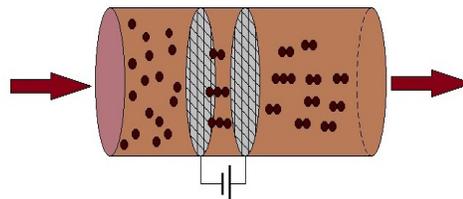
$$\mathbf{h}/\mathbf{h}_0 = (1 - \mathbf{j}/\mathbf{j}_m)^{[\eta]\mathbf{j}_m} \quad (2)$$

Where  $\mathbf{j}_m$  is the maximum value fraction allowed for packing the suspended particles. When  $\mathbf{j}$  is unchanged, the most widely used method to reduce viscosity  $\mathbf{h}$  is to reduce  $\mathbf{h}_0$ , such as raising the temperature. On the other hand, Equation (2) suggests that there is another method: if we change the rheology of the suspension to increase the value of  $\mathbf{j}_m$  and lower intrinsic viscosity  $[\eta]$ , we will reduce the viscosity  $\mathbf{h}$ . The physics is clear: the effective viscosity depends on how much freedom the suspended particles have in the suspension. A  $\mathbf{j}_m$  and low  $[\eta]$  mean high freedom for the suspended particles, which leads to lower dissipation of energy and lower viscosity [18]. The following three mechanisms contribute to the viscosity reduction [18,19]:

(1) Aggregate the nanoscale particles into short chains with their shapes streamlined along the flow direction

- (2) Increase the polydispersity to increase  $\mathbf{j}_m$ .
- (3) Increase the average size of suspended particles.

Our technology is illustrated in (Figure 1).



**Figure 1:** As the crude oil flow passes a strong local electric field from left to right, the suspended particles (brown dots) aggregate along the field direction after the mesh which applied high voltage, and the viscosity along the flow direction is reduced.

The crude oil flows from left to right along a pipe. Initially the nanoscale particles are randomly distributed and the viscosity is high (left side of the tube). When the oil passes a strong local electric field (two parallel metal meshes), the suspended particles are polarized by the electric field. The induced dipolar interaction forces the nanoscale particles to aggregate into micrometer-size short chains once they passed the electric field. 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 which breaks the rotational symmetry, making the viscosity of crude oil anisotropic. Along the field direction, the viscosity is significantly reduced, while the viscosity along the directions perpendicular to the field is actually increased [20]. 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.

### Application of Dr. Tao's Viscosity Theory to Reducing Viscosity

It is clear from the above background that aggregating the nanoscale particles into short chains with their shapes streamlined along the flow direction will reduce the effective viscosity while remains the same. At the same time, it is important to note that after formation of short-chains along the field direction, its molecular alignment parallel to the flow direction which breaks the rotational symmetry, making the viscosity of crude oil anisotropic. Along the field direction, the viscosity is significantly reduced, while the viscosity along the directions perpendicular to the field is actually increased. For most suspensions, this aggregation can be realized

with either electric or magnetic fields. We assume that the particles have an electric dielectric constant  $\epsilon_p$  different from the dielectric constant of the base liquid  $\epsilon_f$ .

In an electric field, the particles are thus polarized along the field direction. The dipole moment is estimated by

$\vec{p} = \vec{E} a^3 \epsilon_f (\epsilon_p - \epsilon_f) / (\epsilon_p + 2\epsilon_f)$ , where  $\vec{E}$  is the local electric field, which should be close to the external field in dilute cases. The dipolar interaction between the two induces electric dipoles is

$U = p^2 (1 - 3 \cos^2 \theta) / (4\pi \epsilon_0 r^3)$ , where  $r$  is the distance between these two dipoles and  $\theta$  is the angle between the joining line and the electric field. If this interaction is stronger than the thermal

Brownian motion, that is  $a = p^2 n / (\epsilon_f k_B T) \geq 1$ , these two dipoles will aggregate together to align in the field direction.

$a = p^2 n / (\epsilon_f k_B T) \geq 1$ , where  $n$  is the particle number density,  $k_B$  is the Boltzmann constant and  $T$  is the absolute temperature. We derive the following critical field

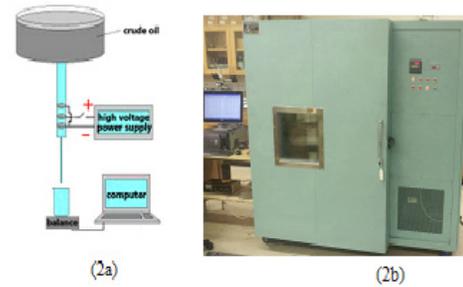
$$E_c = [k_B T / (n \epsilon_f)]^{1/2} (\epsilon_p + 2\epsilon_f) / [a^3 (\epsilon_p - \epsilon_f)] \quad (3)$$

If the applied electric field is weaker than  $E_c$ , the thermal Brownian motion prevents particles from aggregating together. So the applied electric field must be not lower than  $E_c$ . The required pulse duration time is,

$$t = n^{1/3} / v = \rho h_0 (\epsilon_p + 2\epsilon_f)^2 / [e_f n^{5/3} a^5 (\epsilon_p - \epsilon_f)^2 E^2] \quad (4)$$

If the duration of electric field is too shorter than, the particles do not have enough time to aggregate together [2]. Once the e field is turned off, the hysteresis time is  $t = (3a^3 \rho_0) / (K_B T)$  [2].

Our lab device is outlined in (Figure 2a), which is placed in an environment chamber (Figure 2b).



**Figure 2:** Device to test the crude oil samples (2a): The gravity feed crude oil flows through the three electrodes into a long capillary tube which is used to measure the viscosity (2b): the environment chamber.

The chamber provides the desirable and stable temperature for our test. The crude oil sample is loaded in cylindrical container at the top (Figure 2a), which serves as the reservoir. Underneath the reservoir, there are three meshes, serving as electrodes. The electrodes are connected to a low-amperage high-voltage power supply. Using a gravity feed, the crude oil flows through the three electrodes into a long capillary tube. A beaker on a microbalance collects the crude oil below the capillary tube. The microbalance is connected to a computer, which automatically records the oil mass in the beaker as a function of time with LabVIEW software. Using this configuration, we can accurately determine the untreated flow rate. When the power supply is turned on, a strong electric field is produced in the flow direction of crude oil, forcing the suspended particles inside to aggregate into streamlined short chains anisotropically along the flow direction (Figure 1).

In this way, the effective viscosity of crude oil along the flow direction is reduced, while no heating, drag reducing agents, or diluents are used. Because the Reynolds number is low, the crude oil flow inside the capillary tube is laminar. The capillary tube serves as a viscometer. From the flow rate, we can mathematically and precisely determine the viscosity. In this experimental setup, the pressure gradient due to the gravity remains constant. Therefore, the flow rate increases as the viscosity is reduced. Usually, we measure the flow rate without the electric field applied first and obtain the viscosity of the untreated oil. Following the baseline test, we turn on the electric field, measure the new flow

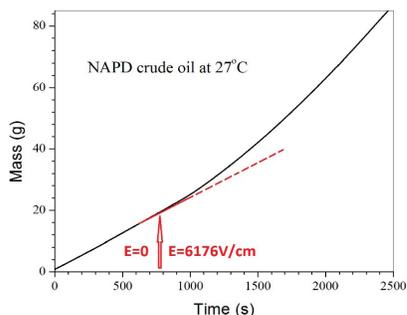
rate, and obtain the viscosity of the electric-field treated crude oil. By adjusting the electric field strength, we can reach the optimal state to reduce the crude oil viscosity. The viscosity reduction and resultant flow rate improvements should significantly improve tariff revenue when this technology is employed commercially. Nuclear method is widely used in soft condensed matter study [21-24]. We also run small angle neutron scattering test at NIST for crude oil samples.

## Results

We conducted the tests at three different temperatures, 27°C, 48°C and 66°C for these three samples to meet various conditions for oil pipelines in Saudi. The results show that the AOT technology can significantly reduce the viscosity of all these three samples effectively.

### Test Results for NAPD Crude Oil Sample

At 27°C, with an electric field of 6176V/cm, the flow rate of the NAPD sample was increased 108.4%. The viscosity was reduced by 52.03% (Figure 3).

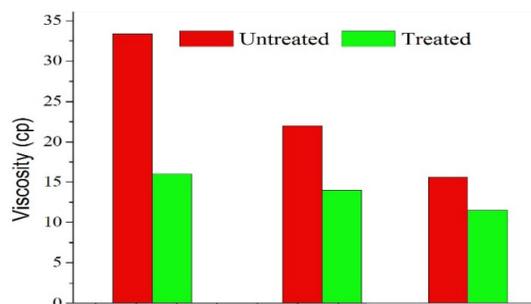


**Figure 3:** At 27°C, with an electric field of 6176V/cm, the flow rate of the NAPD sample was increased 108.4%. The viscosity was reduced by 52.03%.

The typical test results are shown in (Figure 3). The crude oil was tested inside the Environment Chamber (Figure 2b) for temperature stability. Initially, there was no electric field applied and the oil was allowed to flow through the capillary tube. The slope of the curve was the flow rate. Afterwards, the electric field was applied; the curve's slope jumps, indicating that the oil flow rate is increased significantly. The viscosity is reduced effectively. From the flow rates, we calculated the viscosities. The test results are summarized in the following (Table 1) and plotted in (Figure 4).

Test #	Temperature (°C)	Pre-Treatment Viscosity	Post Treatment Viscosity	Electric Field Applied
1	27°C	33.4cp	16.2cp	617.6V/mm
2	48°C	22.0cp	14.0cp	600.0V/mm
3	66°C	15.6cp	11.5cp	608.0V/mm

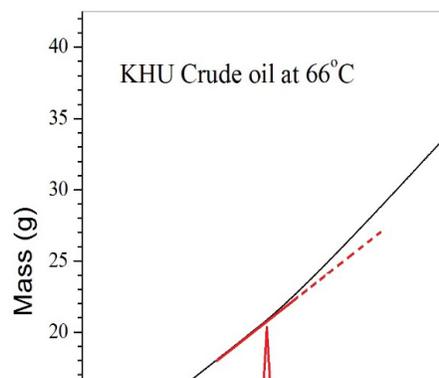
**Table 1:** Test Results for NAPD Crude Oil Sample.



**Figure 4:** The AOT test results for NAPD crude oil sample.

### Test Results for KHU Crude Oil Sample

The AOT technology can significantly reduce the viscosity of KHU crude oil and increase the flow rate, to shows the typical test results (Figure 5).



**Figure 5:** At 66°C, with an electric field of 6040V/cm, the flow rate of the KHU sample was increased 36.5%. The viscosity was reduced by 26.8%.

It is clear that after an electric field is applied, the curve slope jumps up, indicating that the viscosity is reduced significantly. From the flow rates, we calculated the viscosities. The test results are summarized in (Table 2) and plotted in (Figure 6).

Test #	Temperature (°C)	Pre-Treatment Viscosity	Post Treatment Viscosity	Electric Field Applied
1	27° C	14.15cp	11.67cp	806.4V/mm
2	48°C	7.48cp	6.21cp	605.2V/mm
3	66°C	6.39cp	4.68cp	604.0V/mm

Table 2: Test Results for KHU Crude Oil Sample.

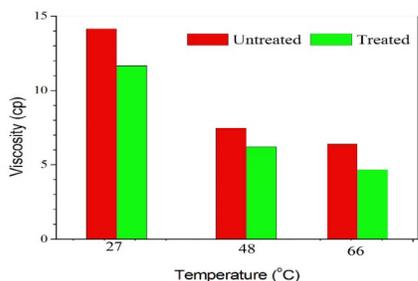


Figure 6: The AOT test results for KHU crude oil sample.

### Test Results for HAW Crude Oil Sample

HAW is a very light crude oil. Its original viscosity is quite small. However, the AOT technology can also significantly reduce the viscosity of HAW crude oil and increase the flow rate. The test results are summarized in (Table 3) and plotted in (Figure 7).

Test #	Temperature (°C)	Pre-Treatment Viscosity	Post Treatment Viscosity	Electric Field Applied
1	27° C	7.81cp	6.51cp	928.0V/mm
2	48°C	3.23cp	2.45cp	618.4V/mm
3	66°C	1.03cp	0.82cp	604.0V/mm

Table 3: Test Results for HAW Crude Oil Sample.

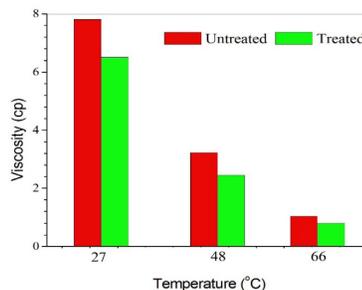


Figure 7: The AOT test results for HAW crude oil sample.

The applied electric field for all these tests is listed in all the three Tables. The electric current used during the tests was about 200  $\mu$ A, indicating that the water content inside the crude oil is moderate. In summary, the AOT viscosity reduction technology significantly reduces the viscosity of NAPD, KHU, and HAW crude oil samples.

### Conclusion

The test results fully confirm the theoretical analysis. On the other hand, in comparison with the theoretical prediction, there is still some room for improvement. This implies that in our electric field treatment, some particles are not aggregated into short chains. If we need to reduce the viscosity further, it is required to find an optimal range of electric field strength and optimal application time to make almost all particles inside the crude oil to aggregate into short chains. Or with mew technology, we can make the electric field even stronger for better effect [25,26].

Naturally, there is a question: How long can such reduced viscosity last after the electric-field treatment? Since the viscosity reduction is the result of aggregated short chains along the flow direction, the viscosity will return to the original value once the aggregated chains are completely dissembled. To answer the above question, we conducted a number of tests. It shows a low viscosity after the short chains are tilted along the flow direction. We have found that the reduced viscosity keeps more than 12 hours. The above results are understandable. The aggregated short chains make the suspension as a viscoelastic fluid. It is well known that to dissemble such viscoelastic chains is very slow. On the other hand, if we deliberately shake the crude oil violently, the chains will be

broken and the viscosity will return to the original value quickly.

## References

1. E Du, X Xu, K Huang, H Tang, R Tao (2017) Bunker diesel viscosity is dramatically reduced by electro rheological treatment. International Journal of Modern Physics B 1850012.
2. E Du, H Tang, K Huang, R Tao (2011) Reducing the viscosity of diesel fuel with electro rheological effect. Journal of Intelligent Material Systems and Structures 22: 1713-1716.
3. E Du, L Cai, K Huang, H Tang, X Xu, R Tao (2018) Reducing Viscosity to Promote Biodiesel for Energy Security and Improve Combustion Efficiency. Fuel 194-196.
4. K Huang, E Du, H Tang, R Tao (2011) Electrorheology improves E85 engine efficiency and performance. Journal of Intelligent Material Systems and Structures 22: 1707-1711.
5. R Tao, H Tang, K Tawhid-Al-Islam, E Du, J Kim (2016) Electrorheology leads to healthier and tastier chocolate. Proceedings of the National Academy of Sciences 113: 7399-7402.
6. K Tawhid-Al-Islam, R Tao, E Du, H Tang, X Xu, et al. (2017) Suppressing Turbulence and Reducing Blood Viscosity to Prevent Heart Attacks and Strokes. Bulletin of the American Physical Society 62.
7. W Zhang, Jiang D, Wang X, Hao BN, Liu YD, et al. (2017) Growth of Polyaniline Nano needles on MoS<sub>2</sub> Nano sheets, Tunable Electro response, and Electromagnetic Wave Attenuation Analysis. The Journal of Physical Chemistry C 121: 4989-4998.
8. F Wu, Yamei J, Dandan L, Yuy Z, Lunan G, et al. (2017) Electro fluid hydrolysis enhances the production of fermentable sugars from corn-cob via in/reverse-phase induced voltage. Bio resource Technology 234:158-166.
9. R Tao, E Du, H Tang (2014) Neutron Scattering Studies of Crude Oil Viscosity Reduction with Electric Field. Fuel 134: 493-498.
10. C Ma, Y Lu, C Chen, K Feng, Z Li, et al. (2017) Electrical Treatment of Waxy Crude Oil to Improve Its Cold Flow ability. Ind Eng Chem Res 56: 10920-10928.
11. R Ibrahim, M Oudah, A Hassan (2017) Viscosity reduction for flow ability enhancement in Iraqi crude oil pipelines using novel capacitor and locally prepared nano silica. Journal of Petroleum Science and Engineering 156: 356-365.
12. S Tada, Y Shen, and Z Qiu. (2017) Modeling and simulation of dielectrophoretic collective dynamics in a suspension of polarizable particles under the action of a gradient AC electric field. Electrophoresis 38: 1434-1440.
13. A Einstein (1905) On the movement of small particles suspended in stationary liquids required by the molecular-kinetic theory of heat. Ann Physik 17: 549-560.
14. Y Dong, B Wang, L Xiang, Y Liu, X Zhao, et al. (2017) Influence of Side Chain Sizes on Dielectric and Electrorheological Responses of Poly (ionic liquid) s. J Phys Chem B 121: 6226-6237.
15. A Einstein (1906) A new determination of molecular dimensions. Ann Physik 19: 289-306.
16. A Einstein (1906) On the theory of Brownian motion. Ann Physik 19: 371-381.
17. E Du (2015) Neutron scattering studies of crude oil viscosity reduction with electric field. Dissertation Abstracts International 76-12.
18. R Tao (2011) Electrorheology for efficient energy production and conservation. J Intell Mater Syst Struct 22:1667-1671.
19. M Miesowicz (1946) s The three coefficients of viscosity of anisotropic liquids. Nature 158: 227.
20. E Du, Y Zheng, D Zhou, Y Zuo, D Yuan, et al. (2005) Study of quadrupole interactions in nano-LaFeO<sub>3</sub> perovskite by time differential perturbed angular correlation. Nuclear Techniques 28: 409-412.
21. S Zhu, T Iwata, Y Xu, Y Zheng, D Zhou, et al. (2004) Experimental verification of heavy ion irradiation simulation. Modern Physics Letters B 18: 881-885.
22. D Zhou, Y Zheng, J Zhu, Y Xu, Z Wang, et al. (2004)  $\beta$ -NMR and  $\beta$ -NQR spectrometer. Atomic Energy Science and Technology 38:111-114.
23. S Zhu, Y Zheng, P Ahmat, Y Xu, D Zhou, et al. (2005) Temperature and dose dependences of radiation damage in modified stainless steel. Journal of nuclear materials 343: 325-329.
24. S Zhu, Y Xu, Z Wang, Y Zheng, D Zhou, et al. (2005) Positron annihilation lifetime spectroscopy on heavy ion irradiated stainless steels and tungsten. Journal of nuclear materials 343: 330-332.
25. T Tan, Wolak MA, Xi XX, Tajima T, Civale L, et al. (2016) Magnesium diboride coated bulk niobium: a new approach to higher acceleration gradient. Sci Rep 6: 35879.
26. C Zhuang, T Tan, A Krick, Q Lei, K Chen, XX Xi (2017) MgB<sub>2</sub> thin films on metal substrates for superconducting RF cavity applications. Journal of superconductivity and novel magnetism 26:1563-1568.