管道科技研究中心

PETROCHINA PIPELINE R&D CENTER

Report

AOT Viscosity Reduction Tests in China Using Certain Chinese Crude Oil Samples

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储 运 工 艺 研 究 所

Division of Oil & Gas Storage and Transportation

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INTRODUCTION

Most crude oil produced in China is highly paraffin based, with generally high viscosity in low temperature environment, which presents an extreme hardship for pipeline transportation. For China's oil storage and transportation sector, viscosity reduction has, therefore, been a highly focal issue and one of the most pressing problems that demand for a satisfactory solution.

In 2006, based on the concepts of electrotheology (ER), a new technology to reduce the viscosity of crude oils by a strong electric field was proposed by Professor Rongjia Tao of Temple University. This new technology is now called AOT (applied oil technology) in news media. The comparative advantages of the AOT are reflected in three areas: consuming minimum amount of energy, producing fast effect, and generating significant viscosity reduction results.

In 2011 and 2012, AOT technology and device have been repeatedly tested at Rocky Mountain Oilfield Testing Center (RMOTC) of US Department of Energy. The testing results show that AOT has significantly reduced the viscosity of the crude; with stable flow rate, AOT would significantly reduce the pump pressure, whereas it would significantly increase the flow rate if pump pressure remains stable. Clearly, such testing results would have obvious, meaningful and great potential for commercial application for transporting high viscosity crude oil.

At the beginning of 2012, Beijing Henghe XingYe Technology Development Corporation ("TDC") introduced AOT to PetroChina Pipelie R&D Center, （or CPP in short). AOT has since attracted great attention from experts at CPP, who expressed significant interests in using AOT to conduct laboratory tests in China using Chinese crude oil samples. On such base, TDC has engaged in discussions with Save The World

Air Inc. ("STWA"), the company owns exclusive licensing rights on AOT. TDC and STWA have since made great efforts jointly for such objective. In March, 2012, Mr. Cecil Bond Kyte, the CEO of STWA, visited CPP with his team, and has nailed down the related details on such tests to be conducted.

STWA then specifically ordered the test experiments to be made for tests in China. From July 6 to 15, 2012, Professor Rongjia TAO and his team, working closely with experts from CPP, had carried out a series of tests to investigate the viscosity reduction effect of AOT with Daqing crude oil, Changqing crude oil and crude oil from Venezuela. This report summarized the testing equipment, testing conditions, testing contents, testing results, data analysis and so on.

The report highlights the following basis information:

1). The testing equipment was made by Professor Tao at Temple University in the US, and has been assembled for testing with assistance and coordination from experts at CPP.

2). Labview is used as the testing analysis software.

3). Persons participating in the tests:

Professor Rongjia TAO (Temple University in the US)

DU Enpeng, PHD (Temple University in the US)

MIAO Qing, Senior Engineer (CPP)

GAO Xinlou, Senior Engineer(CPP)

CHEN Zhi, PHD (graduate of Temple University, technology director of TDC)

STWA's CFO, Mr. Gregg Bigger, and COO, Mr. Bjorn Simundson, as well as Mr. ZHAO Ruilin, the GM of TDC, attended to the tests, as well as observed and witnessed the testing process.

I. Testing Equipment

Fig.1 Device for testing Changqing crude oil and crude oil from Venezuela.

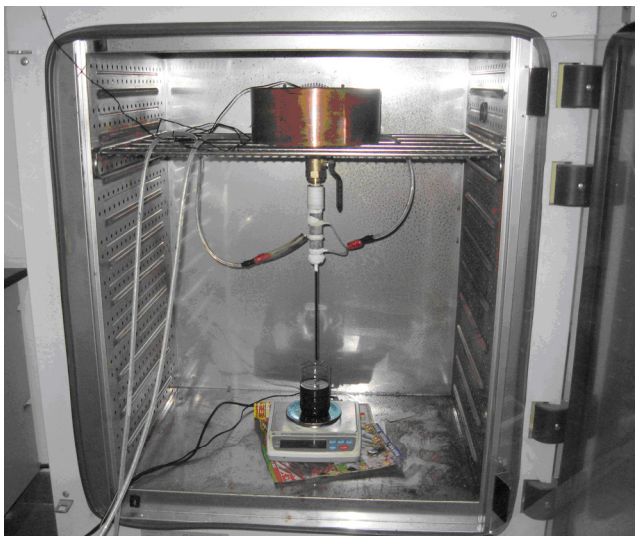

Fig.2 Device for testing Daqing crude oil

The device in Fig.1 is used to test crude oil sample at room temperature or freezing temperature. The device in Fig.2 is specialized for Daqing crude oil, which stops flow and condensed into jell with a finite yield stress at 32℃ and below. Therefore, to test Daqing crude oil, we have to use an incubator to maintain the temperature of the oil sample and device at desirable temperature above 32℃.

II. Methods of Testing

The crude oil sample is loaded in cylindrical container at the top, which serves as the reservoir. Underneath the reservoir, there is a switch. When the switch is open, crude oil flows down under the gravity, passes through three electrodes into a long capillary tube. A cup on a microbalance collects the crude oil down through the capillary tube. The microbalance is connected to a computer, which, with labview software, automatically records the oil mass in the cup as a function of time. Hence we can determine the flow rate. From the flow rate, we can easily determine the viscosity. In this experimental setup,

the pressure gradient due to the gravity remains as a constant. Therefore, the flow rate goes up as the viscosity is reduced.

III. Viscosity Reduction Process

The electrodes are connected to a high voltage power supply. When the power supply is turned on, a strong electric field is produced in the flow direction, forcing the suspended particles inside crude oil to aggregate into streamlined short chains along the flow direction. In this way, the effective viscosity of crude oil is reduced, while no heating or dilution is used here.

IV. Test Results

(1). Daqing Crude Oil

We conducted experiments with Daqing crude oil at 35.1℃, 40℃, and 47.4℃.

Figure 3 is the recorded crude oil mass as a function of time at 35.1℃. The slope of the curve is the flow rate. It is clear that as a strong electric field is applied, the flow rate is increased dramatically.

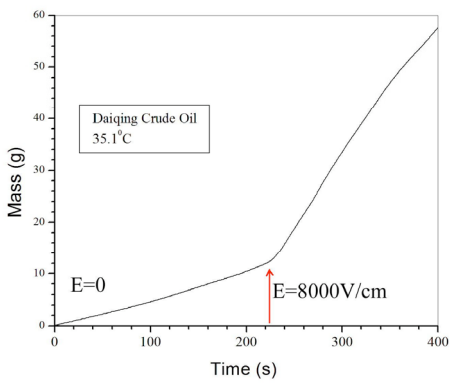

Fig.3 As a strong electric field is applied, the Daqing crude oil flows much faster.

Without electric field applied (at 35.1℃), the flow rate of Daqing crude oil is 0.04182 g/s, corresponding to viscosity 764.5 cp. When an electric field of 7200V/cm is applied, the flow rate is increased to 0.28252 g/s and the viscosity is down to 113.16 cp. In an electric field of 8000V/cm, the flow rate is increased to 0.318095 g/s and the viscosity is down to 100.5cp. The flow rate and viscosity are plotted in Figures 4 and 5 respectively. We note

that it is a factor of 7.61 for the flow rate to be increased from 0.04182 g/s to 0.3181 g/s. This implies that under the same pump pressure, the new technology can increase the flow rate by 761%. The viscosity is also reduced by 86.9%. (Therefore, if we want to keep the same flow rate, then with the new technology the required pump pressure is only 13.1% of the original pressure).

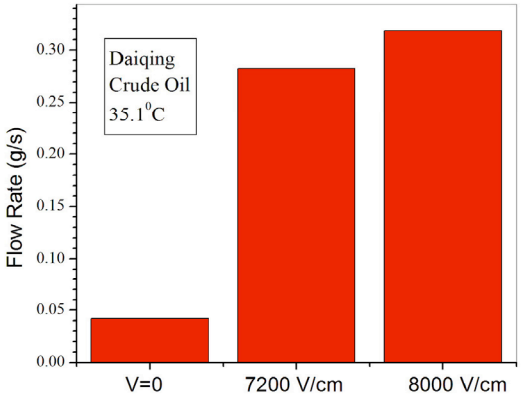

Fig. 4 At 35.1℃ , the Daqing crude oil flow rate is increased more than 6 times when a strong electric field is applied.

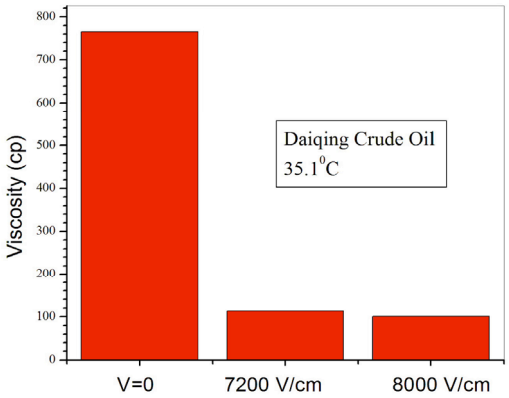

Fig.5. At 35.1℃, the viscosity of Daqing crude oil is reduced significantly when a strong electric field is applied.

Similarly at 40℃, a strong electric field can significantly increases the flow rate of Daqing crude oil and reduces its viscosity. The details are in Figures 6-8. Without electric

field applied, the flow rate of Daqing crude oil at 40℃ is 0.006089 g/s, corresponding to viscosity 464.4 cp. When an electric field of 8000V/cm is applied, the flow rate is increased to 0.045179 g/s and the viscosity is down to 49.12 cp. In an electric field of 9600V/cm, the flow rate is increased to 0.048241 g/s and the viscosity is down to 46.0 cp. It is a factor of 7.92 for the flow rate to be increased from 0.006089 g/s to 0.048241 g/s. This implies that under the same pump pressure, the new technology can increase the flow rate by 792%. (If we want to keep the same flow rate, then with the new technology the required pump pressure is only 12.6% of the original pressure.)

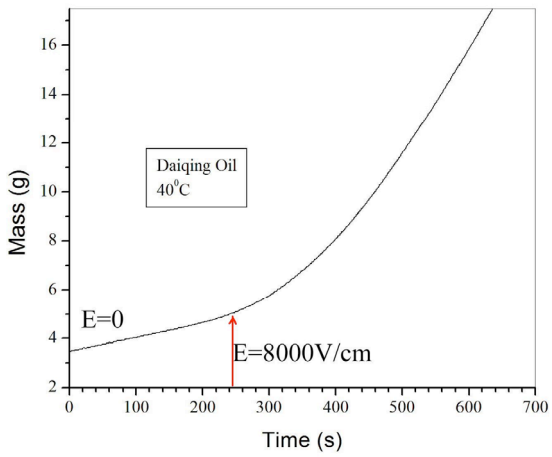

Fig. 6 As a strong electric field is applied, the Daqing crude oil flows much faster.

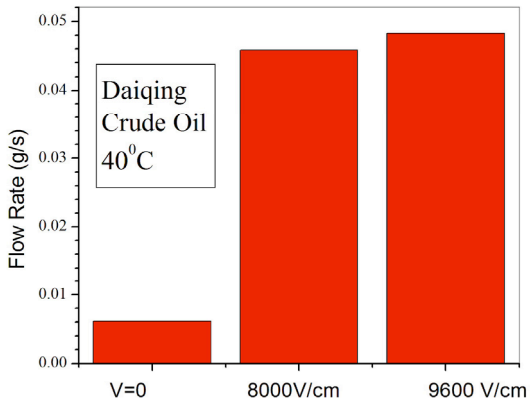

Fig.7 At 40℃ , the Daqing crude oil flow rate is increased more than 6 times when a strong electric field is applied.

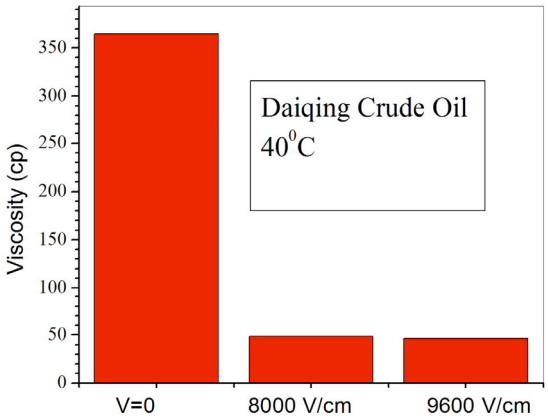

Fig.8. At 40℃, the viscosity of Daqing crude oil is reduced significantly when a strong electric field is applied.

At 47.4℃, a strong electric field can still increase the flow rate and reduce the viscosity significantly. As shown in Fig. 9 to 11 below,

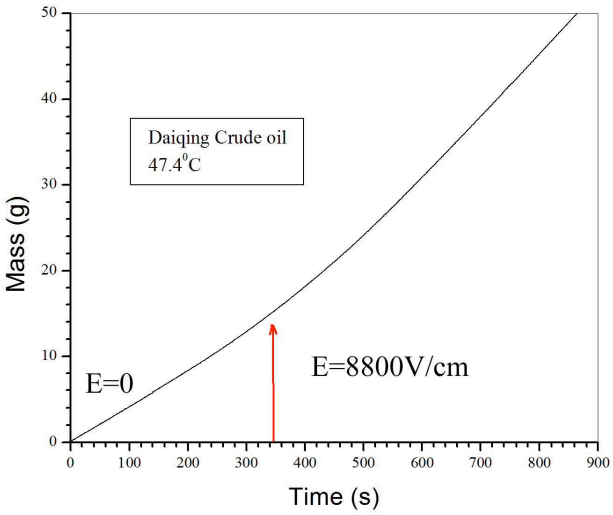

Fig.9 As a strong electric field is applied, the Daqing crude oil flows faster.

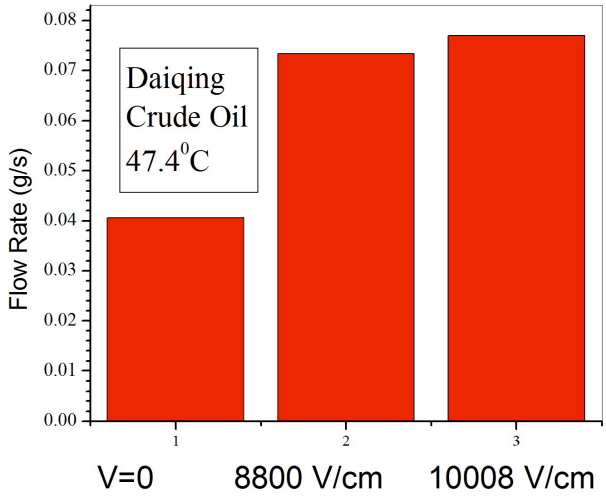

Fig.10 The flow rate is increased as the strong electric field is applied.

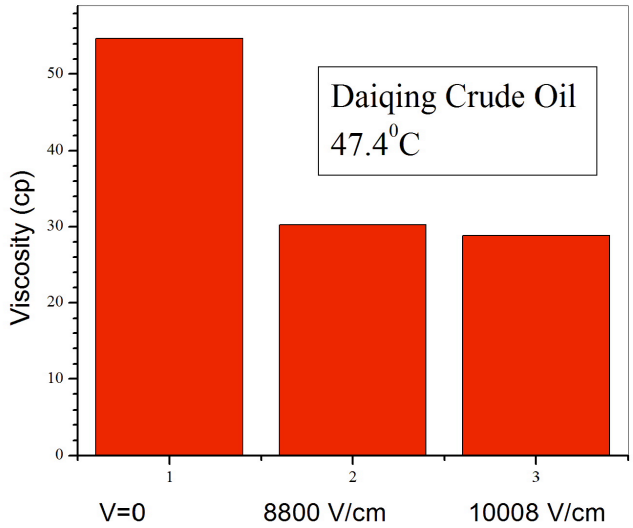

Fig.11 The viscosity is reduced by the electric field.

At 47.4℃ without electric field applied, the flow rate of Daqing crude oil is 0.040613 g/s, corresponding to viscosity 55.61 cp. When an electric field of 8800V/cm is applied, the flow rate is increased to 0.073315 g/s and the viscosity is down to 30.8 cp. In an electric field of 10008V/cm, the flow rate is increased to 0.076894 g/s and the flow rate is increased by 89.3%. The effect is equally remarkable.

CPP scientists also used a rotational viscometer (Physica made in Germany) to measure the viscosity of Daqing crude oil sample. The viscosity at various shear rates for untreated crude oil is in Table 1.

Table 1. Viscosity of untreated Daqing crude oil at 35.1℃

Shear rate (1/s)	10	20	30	40	50	100	150	180
Viscosity (cp)	1500	911	663	527	441	283	219	190

We also collected crude oil in the cup, which is treated by a strong electric field of 8000V/cm. With the same rotational viscometer, we measured its viscosity. The results are in Table 2.

Table 2. Viscosity of Daqing crude oil at 35.1℃ treated with electric field of 8000V/cm

Shear rate (1/s)	10	20	30	40	50	100	180
Viscosity (cp)	524	390	327	287	258	200	186

The same treated oil sample was re-measured again with rotational viscometer 13 hours after the treatment and 26 hours after the treatment. The results are in Tables 3 & 4.

Table 3. Viscosity of Daqing crude oil at 35.1℃, 13 hours after it was treated with electric field of 8000V/cm

Shear rate (1/s)	10	20	30	40	50	80	100	120	160	180
Viscosity (cp)	710	480	385	324	290	220	210	190	135	165

Table 4. Viscosity of Daqing crude oil at 35.1℃, 26 hours after it was treated with electric field of 8000V/cm

Shear rate (1/s)	10	20	30	40	50	80	100	120	150
Viscosity (cp)	693	487	389	332	292	258	242	229	216

As discussed above, the treated crude oil has the suspended particles aggregated into short chains along the flow direction. Therefore, the viscosity is anisotropic. Along the flow direction, the viscosity is the minimum. Along the other directions, the viscosity is higher than that along the flow direction. Therefore, our capillary tube is excellent to determine the viscosity along the flow direction.

Rotational viscometer is not the best to measure such viscosity. As the spindle starts to rotate, the short chains are initially not parallel to the rotational direction. Under the shear force, the short chains are driven to tilt and align along the rotational direction. Once this process is completed, the viscometer will find a low viscosity reading. Comparing Table 1 and Table 2, we see clearly that the treated crude oil has its viscosity reduced.

On the other hand, because some short chains are broken during this driving process, the viscosity measured by the rotational viscometer will be higher than that determined with our capillary tube. Our experiment confirms this analysis. For untreated crude oil, the flow rate of 0.04182 g/s corresponds to shear rate 25.7 (1/s). The viscosity 764.5 cp at such a shear rate is consistent with the data in Table1. For the treated crude oil, the flow rate 0.318095 g/s corresponds to a shear rate 195.47 (1/s). Its viscosity 100.5 cp measured with the capillary tube is much lower than that measured by the rotational viscometer, which is about 180 cp (see table 2), although 180cp is still lower than that of the untreated crude oil.

Comparing Table 3 and Table 4 with Table 1, we are convinced that the viscosity reduction effect lasts more than 24 hours although it is gradually weakened.

During the test, we also note that this viscosity reduction technology consumes very little energy for Daqing crude oil. To treat one barrel Daqingcrude oil, we only need about 0.1 kW-hour electricity.

(2) Changqing Crude Oil

Similar to Daqing crude oil, Changqing crude oil is also a paraffin-base crude oil. Our technology can reduce its viscosity significantly. We conduct the experiment at 26.5℃. As shown in Fig. 12 - 14, a strong electric field can make the crude oil flow much faster. When there is no electric field is applied, the flow rate is 0.21998 g/s, corresponding to a viscosity 178.26cp. In the electric field of 4000 V/cm, the flow rate is increased to 0.4237 g/s and the viscosity is reduced to 92.55 cp. An electric field of 7200V/cm increases the flow rate to 0.6 g/s and reduces the viscosity to 65.35cp. When the electric field is 9600 V/cm, the flow rate is increased to 1.0 g/s and the viscosity is reduced to 38.9 cp. We note that with the electric field of 9600V/cm, the flow rate is increased by 354.6% and the viscosity is reduced by 78.2%.

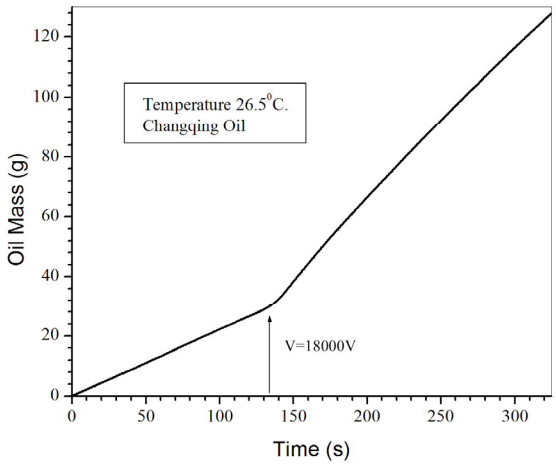

Fig.12 As a strong electric field is applied, the Changqing crude oil flows much faster.

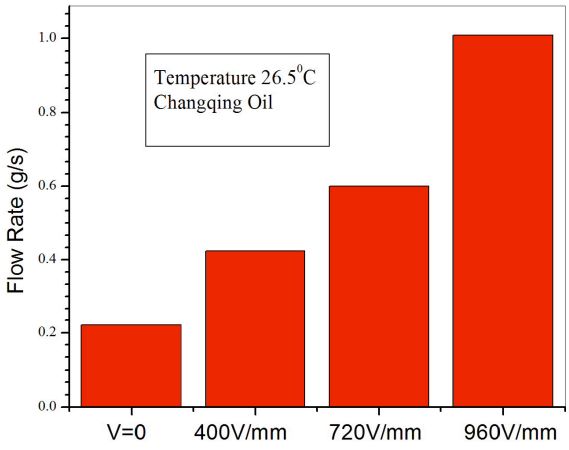

Fig. 13. The flow rate is increased substantially as the strong electric field is applied.

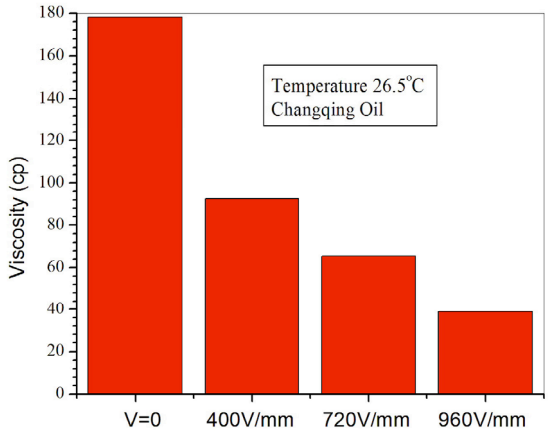

Fig.14 As a strong electric field is applied, the viscosity of Changqing crude oil is reduced significantly.

We also tested Changqing crude oil with anti-freezing additive, the data of which is shown in Fig. 15 and 16.

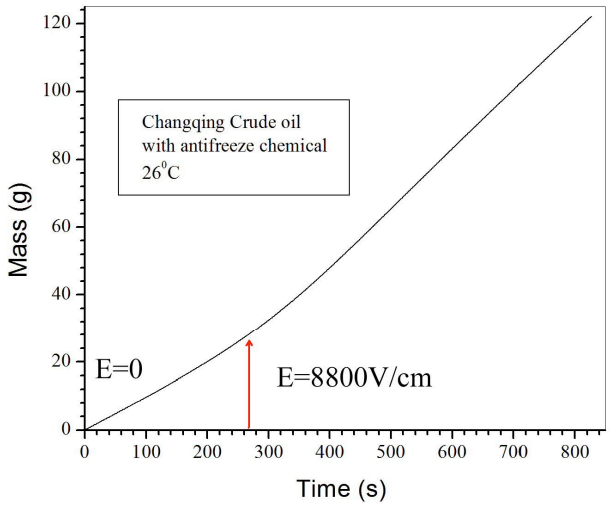

Fig. 15 As a strong electric field is applied, the Daqingcrude oil flows faster.

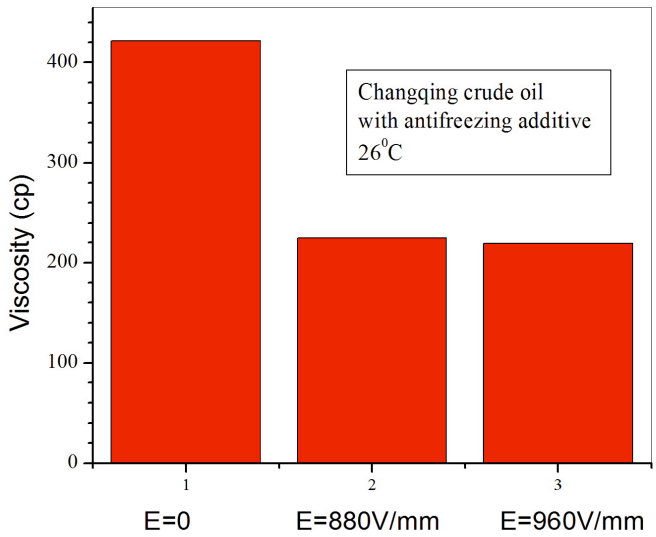

Fig.16 The viscosity is reduced by the electric field.

When there is no electric field, the flow rate is 0.09312 g/s, corresponding to a viscosity of 421.11 cp. A strong electric field of 960V/mm increases the flow rate to 0.17876g/s, increased by 92%. The viscosity is reduced to 219.36 cp. While this viscosity reduction is

not as dramatic as the result for Changqing crude oil sample without the additive, the viscosity reduction is still significant.

During the test, we also note that this viscosity reduction technology consumes very little energy for Changqing crude oil. To treat one barrel Changqing crude oil, we only need about 0.1 kW-hour electricity.

(3) Venezuela Crude Oil

Different from Daqing and Changqing crude oils, Venezuela crude oil is asphalt based. At Temple University in USA, extensive research has done with asphalt-base crude oil. This viscosity reduction technology can effectively reduce the viscosity of asphalt-base crude oil.

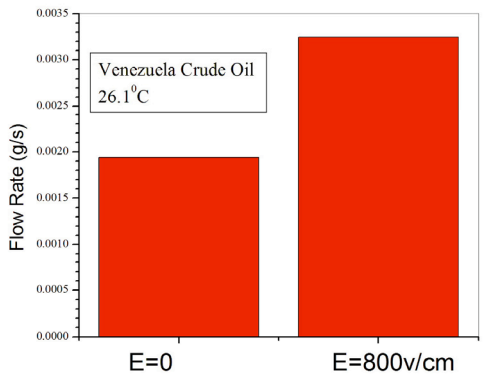

Fig.17 At 26.1°C , with a moderate electric field, the flow rate is increased from 0.00194 g/s to 0.00324 g/s, an increase of 67%.

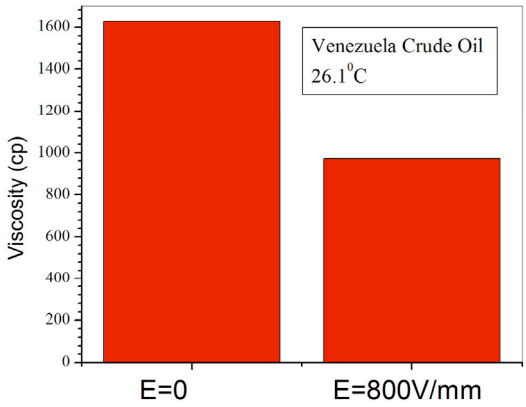

Fig.18 At 26.1°C , with a moderate electric field reduces the viscosity of Venezuela crude oil from 1628.2cp to 971.7 cp, a reduction of 40.32%.

We conducted the experiment at 26.1°C. Without electric field applied, the flow rate of Venezuela crude oil is 0.00194 g/s, corresponding to viscosity 1628.2 cp. When a moderate electric field of 800V/cm is applied, the flow rate is increased to 0.00324 g/s and the viscosity is down to 971.7 cp. The flow rate is increased by 67% and the viscosity is reduced by 40.32%. This is quite significant especially for such a moderate electric field.

During the test, we also note that Venezuela crude oil contains more water than Daqing crude oil and Changqing crude oil. Therefore, the treatment consumes more power than Daqing crude oil and Changqing crude oil. To treat one barrel Venezuela crude oil, we need about 0.3 kW-hour electricity.

Conclusions

The above series of tests show that it is very effective to use AOT to reduce the viscosity of crude oil. We can see that AOT has significantly reduced the viscosity of Daqing crude oil, Changqing crude oil, and Venezuela crude oil, and greatly improved its flow rate.

The test results on Daqing and Changqing crude oil show that AOT has significant effect on reducing viscosity for paraffin based crude oil. For Daqing crude oil, the AOT can reduce its viscosity by 87% at 35℃, and 40℃, and can improve its flow rate by 7 to 8 times. For Changqing crude oil, the AOT can reduce its viscosity by more than 78% at 26℃, and can improve its flow rate by 3 to 4 times.

As to Venezuela crude oil, the tests conducted here show that AOT reduced its viscosity by 42.3%, and improved its flow rate by 67%. Taking into consideration of tests previously conducted by Professor Tao at Temple University, AOT can double the flow rate of Venezuela crude oil, and reduce its viscosity by nearly 50% (See Appendix 3 for relevant data).

The tests also show that the viscosity reduction effect lasts more than 24 hours.

We can clearly see that AOT's viscosity reduction effect is not only remarkable, bust also very fast (producing results in a few seconds), and at the same time it consumes minimum amount of energy.

The experts from both China and US side will work closely to propose solutions that are tailored to China's peculiar crude oil transportation situation.

Division of Oil & Gas Storage and Transportation

Petrochina Pipeline R&D Centre

Dated: June 26th, 2012