Application of SiO_2 Nanoparticle to improve Viscoelastic Property of Waxy Crude Oil for Flow Assurance

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Abstract: After the successful extraction of crude oil from below the earth surface, it is transported through pipelines to the production facilities. Some crude oils are very waxy and can contain high amounts of paraffin which can precipitate and causes many operational problems during transportation especially in cold weather conditions. In this paper, Silicon dioxide nano particle along with crude oil to diesel ratio of 70:30 is used to improve the flow properties of crude oil for its effective transportation through pipelines. Studies were carried out to investigate on different properties such as amplitude sweep, frequency sweep, pour point, shearing rate and viscosity with varying composition of 0.5%, 1%, 1.5%, and 2% of SiO_2 nanoparticle on crude oil. The results show that the prepared Silicon dioxide nano particle act as effective pour point depressants as well as viscosity index improvers.

KEYWORDS: Flow Assurance; Nanoparticle; Viscoelastic Property; Waxy Crude Oil; Pour Point Depressants

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INTRODUCTION

Wax precipitation and deposition is a major flow assurance hazard in the production and transportation of waxy crude oil [1, 2]. Wax precipitation increases oil viscosity and with the added risk of gelation formation it changes the oil flow properties [3]. Crude oil contains paraffins, aromatic hydrocarbons, resins and asphaltenes which is a very complex mixture [4, 5]. When the temperature is high crude oil behaves as Newtonian fluids and the viscosity is low, but in pipelines due to low temperature this property cannot hold as the solubility of long chan paraffins and asphaltenes decrease remarkably, so the viscosity increases, flow decreases and pipelines get blocked [6,7]. Heavy oil is estimated to be at least half of the recoverable oil resources of the world according to Inter Energy Agency (IEA) [8]. Crystallization and deposition of paraffin wax crystals in flow line is one of the main problems during production, transportation and storage which is even more severe in winter [9]. The effectiveness of cross-sectional area of pipeline decreases when viscosity of crude oil increases due to wax crystal formation [10]. Adding requisite amount of flow improver which is also known as drag reducing agents (DRAs) can improve the pour point and rheological properties of the crude. Pour point depressants are long-chain, ultra-high-molecular-weight that reduces the level of turbulence in fluid streams [11]. The use of pour point depressants and flow improvers to mitigate the wax formation will help improve flow properties and reduce the need for expensive remedial operations like pigging [12]. Research aiming for the development of low cost, bio-based, additives for crude oil flow improvement is a growing interest in the oilfield industries [13]. One of the most severe operational problems in oil and gas pipelines is the wax deposition. It is to be noted that chemical methods are the most convenient and economic way for the prevention of precipitation of the wax from waxy crude oil as well as they increase its flow ability at lower temperature. Significant efforts have been made to prevent this flow assurance issue by developing solvents that are used to dissolve the wax deposits or to reduce the viscosity of the fluid. In this work, SiO_2 based nanoparticle is used to effectively improve the viscoelastic properties of crude oil and improve the flow assurance problems. The main focus is to study the various properties such as amplitude sweep, frequency sweep, shear rate vs viscosity etc. Also, the effectiveness of Diesel oil with crude oil is compared with the nanoparticle.

MATERUALS AND METHODS:

The waxy crude oil samples used for this investigation were collected from an oilfield in Assam. Diesel was collected from a regional oil pump station which was properly distilled before using in the experiment. The Anton Paar MCR 102 Rheometer was used for rheological property analysis. Concentric Cylinder was used for the rotational static test to measure viscosity with respect to shearing rate for the samples. Plate Plate (PP) configuration was used for oscillation test to determine the frequency sweep. The samples are listed in Table 1.

Table1. Description of Sample and their composition of crude and nanoparticle

Sample	Composition
A	Crude
B	70/30 (Crude/Diesel)
C	0.5% SiO_2 Nanoparticle 70/30 (C/D)
D	1% SiO_2Nanoparticle 70/30 (C/D)
E	1.5% SiO_2 Nanoparticle 70/30 (C/D)
F	2% SiO_2 Nanoparticle 70/30 (C/D)

RESULTS AND DISCUSSION:

A. Shear rate vs Viscosity

The properties of crude oil were compared with different concentrations of additives, which were: 30% Diesel in 70% crude (70/30, C/D), 0.5% SiO_2 NP in C/D (70/30), 1% SiO_2 NP in C/D (70/30), 1.5% SiO_2 NP in C/D (70/30) and 2% SiO_2 NP in C/D (70/30).

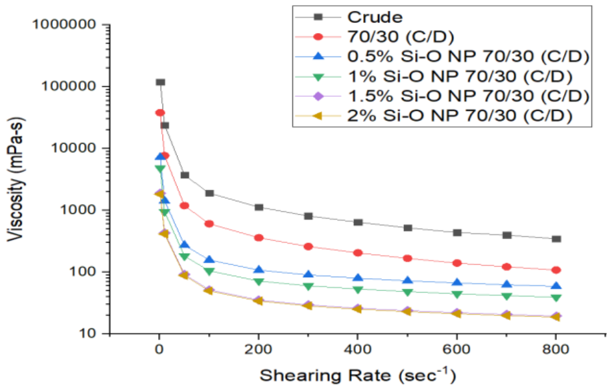

Fig 1: Shear rate vs Viscosity Curves

Here, Fig. 1 shows the changes viscosity with respect to the changes in shearing rate. We can see distinct changes in the graph at three separate regions which are at about 1 sec^{-1}, 300 sec^{-1} and 800 sec^{-1}. The respective values of viscosity oil at these three regions for the raw crude were 119049.45 mPa-s, 810.81 mPa-s and 346.599 mPa-s. The respective values of viscosity oil at these three regions for the crude with different concentration of additives are show in Table 1 below:

Table 2: Shear rate vs Viscosity vales at different concentration of additives

Additives at different concentration	Shear rate at 1 sec^{-1}	Shear rate at 300 sec^{-1}	Shear rate at 800 sec^{-1}
70/30 (C/D)	38079.8	259.35	107.825
0.5% Si-O NP 70/30 (C/D)	4236.957	89.964	58.8
1% Si-O NP 70/30 (C/D)	4824.638	59.976	39.2
1.5% Si-O NP 70/30 (C/D)	1900.839	29.4882	19.4422
2% Si-O NP 70/30 (C/D)	1826.297	28.3318	18.67978

From Table 2, it can be seen that the addition of SiO_2 nanoparticle can significantly reduce the viscosity of the crude oil. The maximum reduction is seen near 1.5% Si-O NP 70/30 (C/D) and 2% Si-O NP 70/30 (C/D) at around 800 sec^{-1} which is approximately 19.45 and 18.68 respectively. Since both are almost same with negligible difference, we can conclude that 1.5% Si-O NP 70/30 (C/D) is more suitable to use as the additive as it requires less concentration. Thus, it can significantly reduce the viscosity of waxy crude oil and help in transportation through pipelines.

B. Shear strain vs Storage modules

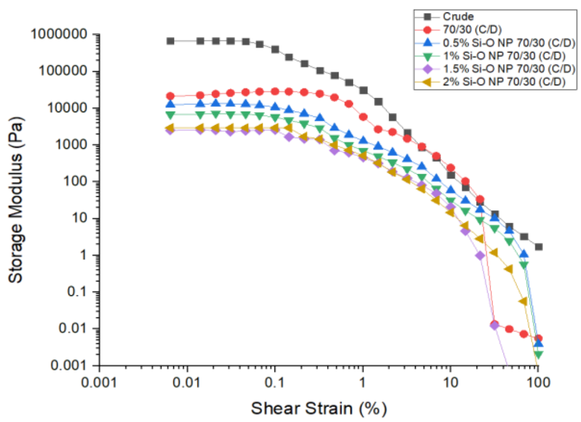

Fig. 2: Shear strain vs Storage modules Curves

Fig 2 show the change in Storage Modulus (Pa) with respect to the change in Shear Strain (%). This graph was obtained by the Oscillation test analysis. The crude sample is kept between two plates residing above and below the sample. While the upper plate oscillates causing certain amount of shear strain in the fluid there is a change in its amplitude. Here the frequency was kept constant.

At the beginning it is seen that the storage modulus remains constant for a while and then it suddenly starts to fall at around 0.1% shear strain and the curves moves downward. This indicates that the fluid has deformed and the storage modulus is reducing. The variation of storage modules with respect to shear strain three distinct points is given in table 3.

Table 3: Storage modulus values for three shear strain points

Additives at different concentration	Shear Strain at 0.01%	Shear strain at 1 %	Shear strain at 100%
Raw Crude	248043.6	31197.72	1.72972
70/30 (C/D)	28436.274	5832.054	0.00559
0.5% Si-O NP 70/30 (C/D)	8903.76	1298.016	0.00396
1% Si-O NP 70/30 (C/D)	7202.26	695.087	0.00212
1.5% Si-O NP 70/30 (C/D)	2513.77	453.348	0.00045
2% Si-O NP 70/30 (C/D)	2940.98	728.483	0.00064

From the above table it can be seen that with the decrease in shear rate the values of waxy crude with additives deviate from the raw waxy crude vales.Hence, it can be concluded that the addition of SiO_2 nanoparticle largely lower the viscosity of the waxy crude oil.

C. Storage and Loss Modulus and Loss Factor vs. Angular Frequency

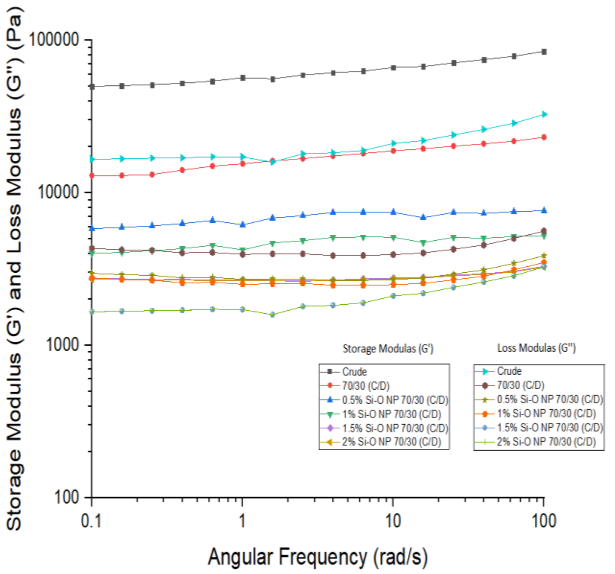

Fig. 3: Storage and Loss Modulus vs. Angular Frequency Curves

Here, Fig. 3 shows the changes in viscoelastic properties for storage modulus and loss modulus with respect to the changes in angular frequency. The test is conducted for all the five concentrations of additives which were 30% Diesel in 70% crude (70/30, C/D), 0.5% SiO_2 NP in C/D (70/30), 1% SiO_2 NP in C/D (70/30), 1.5% SiO_2 NP in C/D (70/30) and 2% SiO_2 NP in C/D (70/30).

At low frequency, the storage modulus is around 49981 (Pa) and loss modulus is around 16627 (Pa) for the raw crude oil sample, and as the angular frequency increases both the storage modulus and loss modulus also increase. The difference between the values of storage modulus and loss modulus remains almost same for both low temperature and high temperature for the waxy crude oil which signifies that elastic property is dominant over viscous property and the crude is a viscoelastic solid. When, the crude sample is treated with additives of different concentration it shows decrease in its values at different degree with respect to their concentrations. Here, from fig.3 it canbe seen that 30% Diesel in 70% crude (70/30, C/D); 0.5% SiO_2 NP in C/D (70/30) and 1% SiO_2 NP in C/D (70/30) show little decrease in its values while 1.5% SiO_2 NP in C/D (70/30) and 2% SiO_2 NP in C/D (70/30) show the most decrease.

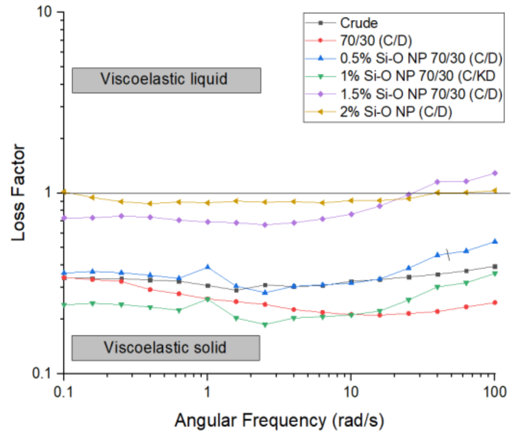

Fig. 4: Loss Factor vs. Angular Frequency Curves

In case of Loss factor (G''/G') vs Angular frequency, 30% Diesel in 70% crude (70/30, C/D); 0.5% SiO_2 NP in C/D (70/30) and 1% SiO_2 NP in C/D (70/30) show similar values of 0.34101, 0.36146 and 0.24098 at low angular frequency of 0.1(rad/s) while 1.5% SiO_2 NP in C/D (70/30) and 2% SiO_2 NP in C/D (70/30) show higher values 0.72976 and 0.94495 respectively at low frequency (0.1 rad/s). With the increase in frequency, the point at which loss factor crosses 1 is called the crossover point and the fluids converts into viscoelastic liquid from viscoelastic solid. In this experiment it is seen that the loss factor remains below 1 for 30% Diesel in 70% crude (70/30, C/D); 0.5% SiO_2 NP in C/D (70/30) and 1% SiO_2 NP in C/D (70/30). While 1.5% SiO_2 NP in C/D (70/30) and 2% SiO_2 NP in C/D (70/30) show higher values 1.28941 and 1.03294 at low frequency (100 rad/s) and crosses the crossover point. Thus, these two concentrations are better suited for improving the pipeline transportation.

D. Temperature vs Viscosity

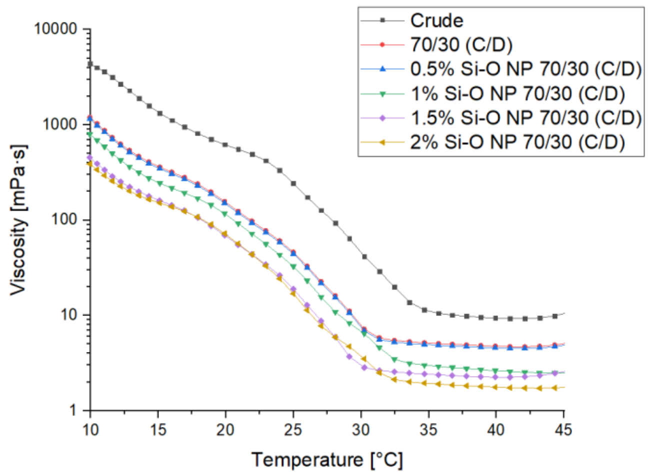

Fig. 5: Viscosity vs. Temperature Curves for pour point approximation

Here, Fig. 5 shows the change in viscosity with respect to temperature for different concentration of additives. Initially the pour point for raw waxy crude oil is seen to be round 34^0C but with the addition of additives it starts to reduce. At 70/30 (C/D) the pour point is around 32^0C; at 0.5% Si-O NP 70/30 (C/D) the pour point is around 31^0C; at 1% Si-O NP 70/30 (C/D) the pour point is also around 31^0C. Both 1.5% Si-O NP 70/30 (C/D) and 2% Si-O NP 70/30 (C/D) show almost similar pour points which is around 29.8 and 30.1^0C. Thus, we can conclude that 1.5% Si-O NP 70/30 (C/D) is more suitable to use as the additiveas good results with less amounts of additive.

CONCLUSION

The results show a drastic change in the viscoelastic properties of crude oil after the use of SiO_2 nanoparticle. The storage capacity of crude also decreased after the addition of SiO_2 nanoparticles. This results in the prevention of back pressure. Also at high frequency, the nature of the crude oil converts from viscoelastic solid to liquid as the loss factor approaches unity. The properties of both 1.5% Si-O NP 70/30 (C/D) and 2% Si-O NP 70/30 (C/D) show good results with minimum differences. Therefore, 1.5% Si-O NP 70/30 (C/D) is more suitable to use as the additive as it shows same results with less concentration of the additive. Thus, it can be said that Silicondioxide nanoparticle is a beneficial additive for the transportation of waxy crude oil through pipelines.

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