Study of Paraffin Wax Effect on Base oil flow Behavior

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Abstract: Some of Libyan crude oils are known to have moderate to high content of paraffin wax. Problems related to paraffin wax are adding to the cost of barrel. In this work, the flow behavior of blends made from two types of base oil (N150, N500) have been experimentally studied, the blends were formulated in order to simulate Libyan waxy crude oils, and to exclude any effects of asphalten, resins and sediments which are normally present in crude oil. The main equipment used in this study is a rotational viscometer, measurements were performed by measuring the rheological properties (shear rate, shear stress, yield stress, and viscosity) of the blends at four different wax concentrations [2%, 5%, 8% and 10%wt] and measurements performed at six different temperatures in the range (15 - 60ºC). The flow behavior of the blends found to vary with temperature ranging from Newtonian to Non-Newtonian flow behavior, the apparent viscosity found to increase with decreasing temperature. Furthermore, the measured yield stress of blends found to increase with increasing wax content and decreasing temperature

Keywords: Waxy oil; Rheology Behavior; Temperature; Yield Stress; Shear rate

INTRODUCTION

The waxy crude oils have been a field of study, due to the severe difficulties that it causes in pipelining, storage. Evaluation of the flow properties of oils containing wax is complex and initially, poor agreement was found between different studies. However, substantial progress has been made thanks to the continues improvement of measuring techniques which made systematic study of the physical parameters affecting the rheology manageable. The role of the shear history on the flow properties is carefully considered. At high temperatures, the crude oils containing linear paraffin's behave like Newtonian. Heated base oil is mixed with wax flaks and carefully homogenized in the bulk of oil. The reason for selecting base oil in this study is to excluded any interference of different materials present in the crude oil. Various studies have been conducted on the rheological properties of different crude oils most of these studies have reported the existence of Non-Newtonian behavior for certain crude oils. (E.G. Barry, 1971) used North Africa oil to investigate the flow behavior, some of these crudes found to behave as Newtonian fluids at higher temperature and as a Non-Newtonian for lower temperature. (AL-Zhrani and AL-Fariiss 1998) investigated the viscosity of Saudi crude oil and has provided a mathematical model described the viscosity. (El-bousiffi, *et al* 2006) reported the flow behavior of Sarir Abu attifel crud oils, some experimental results were obtained on the rheology of Sarir and Abu attifel crude oils. Rotational viscometer is utilized, the temperature dependence of rheological properties and thixotropy of these crudes were investigated.

In this work, two types of base oils are used (i.e, N150, N500) from Azzawiya refinery, mixing with various amount of wax to develop a rheological understanding of these oils.

Experimental: A number of 10 samples were prepared and characterized

Material: Two types of base oils namely (N150 and N500) were used to prepare the blends. The physical properties of the base oils are listed in table (1, 2) paraffin wax flaks (melting point 57°C) were added to the base oil at various concentrations ranging from 2%wt to 10%wt.

Blend Preparation method: The following procedure was followed to prepare the blends:

The paraffin wax was melted in a beaker at 67°C. The temperature was maintained at 10 degrees above the wax melting point (57°C), for 1 h. The base oil

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was then slowly mixed with the melted wax under continuous stirring conditions until a pre-specified concentration was attained. Additions of base oil to the paraffin wax were made on the basis of percentage by weight of paraffin in the mixture. For this work, concentrations of 2, 5, 8, 10wt% of wax in the base oil were selected.

Equipments: Equipments used to measure the physical properties (density (ASTM D 5002) by density meter, pour point by cooling according to (ASTM D 5853), wax appearance temperature by DSC Differential scanning calorimeter (DSC 822 Module)) and the viscosity (Dynamic and Kinematic) are measured by Stabinger viscometer (SVM3000).

RESULTS AND DISCUSSION

Base oil properties: The physical properties measurement for base oil N150 and N500 and blends included: Density, Pour point, Wax appearance

Table 1. Physical properties of the base oil.

Base oil	Density(gm/cm^3) at 15°C	Pour Point (°C)	WAT (°C) Cooling rate=5°C/min	Kinematic viscosity (mm^2/s) at T=40°C
N150	0.8770	-15	-11.14	31.049
N500	0.8880	-12	-11.8	103.31

Table 2. Physical properties of the N150 base oil and blends.

Blend (N150)	Density (gm/cm^3) at 15°C	Pour Point (°C)	WAT (°C) Cooling rate=5°C/min
N150 Base oil	0.8770	-15	-11.14
2%wax	0.8536	-9	18.18
5%wax	0.8514	21	26.51
8%wax	0.8494	27	30.03
10%wax	0.8479	30	32.74

Table 3. Physical properties of the N500 base oil and blends.

Blend (N500)	Density (gm/cm^3) at 15°C	Pour Point (°C)	WAT (°C) Cooling rate=5°C/min
N500 Base oil	0.8880	-12	-11.8
2%wax	0.8860	3	21.06
5%wax	0.8856	24	28.28
8%wax	0.8832	30	39
10%wax	0.8816	36	42

Table 4. The viscosity and density for base oil N150 and blends at T=40°C.

Blend (N150)	Density (gm/cm^3)	Kinematic viscosity (mm^2/s)	Dynamic viscosity (mPa.s)
N150 Base oil	0.8618	31.049	26.757
2%wax	0.8603	30.306	26.071
5%wax	0.8581	29.065	24.942
8%wax	0.856	27.985	23.955
10%wax	0.8544	27.309	23.33

Table 5. The viscosity and density for base oil N500 and blends at T=40°C.

Blend (N500)	Density (gm/cm^3)	Kinematic viscosity (mm^2/s)	Dynamic viscosity (mPa.s)
N500 Base oil	0.8623	40.157	34.626
2%wax	0.8606	37.939	32.652
5%wax	0.8579	35.087	30.101
8%wax	0.8546	31.578	27.14
10%wax	0.8535	31.296	26.713

Table 6. The viscosity and density for base oil N150 and blends at T=60°C.

Blend (N500)	Density (gm/cm^3)	Kinematic viscosity (mm^2/s)	Dynamic viscosity (mPa.s)
N500 Base oil	0.8740	103.31	90.293
2%wax	0.8721	95.262	83.081
5%wax	0.8698	86.326	75.086
8%wax	0.8673	78.56	68.134
10%wax	0.8652	74.132	64.142

Table 7. The viscosity and density for base oil N500and blends at T= 60°C.

Blend (N150)	Density (gm/cm^3)	Kinematic viscosity (mm^2/s)	Dynamic viscosity (mPa.s)
N150 Base oil	0.8496	14.717	12.503
2%wax	0.8476	14.887	12.618
5%wax	0.8458	14.055	11.888
8%wax	0.8439	13.69	11.553
10%wax	0.8423	13.437	11.318

temperature (WAT) and viscosity (Dynamic and Kinematic). (Tables 1, 2, 3, 4, 5,6 and 7). As can be seen from listed properties that the main difference between the two base oils is the viscosity (Dynamic and Kinematic), and density, other properties such as pour point, WAT are almost similar.

Base oil carbon number distribution: The carbon number distribution for both oils N150,and N500, was determined using 3800 gas chromatograph and listed in Table (8) as can be seen N150 consisted of mainly (C_{20}-C_{35}) however N500 consisted mainly of (C_{25}-C_{35}) and this explains the increase in viscosity of base oil N500 compared with N150.

Furthermore, the percentage weight of C_{30} and higher in N500 base oil are in higher values than corresponding components in N150.

Flow behavior of base oils N150, N500: The flow behavior of base oils (N150, N500) are determined and graphically presented in Fig. 1 to Fig. 4, the flow behavior of base oils found to be Newtonian. Which is represent by constant viscosity as shown in Fig. 3 and Fig. 4.

Flow behavior of base oils N150, N500 blends: The flow behavior of blends (2%, 5%, 8% and 10%wt) prepared from N150, and N500 are determined and graphically presented in Fig. 5 to Fig. 28. Blends were made from base oil N150 are placed at the lift side of the page while blends mad from base oil N500 are placed at the right side of the page. From Figs. 5, 6 the shear rate vs. shear stress ,the magnitude of yield stress is increasing with wax concentration in all blends made from (N150 and N500), as can be seen from the Figs. 5, 6 the magnitude of yield stress at low shear is appeared as a Peak (i.e. maximums shear stress), but this peak was increasing as wax concentration increased at T=15ºC ,where the maximum shear stress for the blend (10%) wax is significant for blends made from (N150 and N500) and as can be shown in the Figs. 5, 6 for the two types blends of shear stress is disappearing with wax concentration decreasing, then the curve is declining with increasing shear rate until to shear rate of (7.5 1/s for 8% and 10% wax) after this value of shear rate the magnitude of shear stress as shown become stable even with increasing shear rate in Figs. 5, 6.

In other hand, the flow curve of the blends in this study can be dividing into two parts:-

1. Flow curve without (maximum yield stress).
2. Flow curve with (maximum yield stress).

Flow curve without (maximum yield stress): In this part, the measurement results of the base oils and 2%wt wax are graphical presented as a straight line, passing through the origin point of the graph which indicates base oils and blends with 2%wt wax for N150; N500 behaves as a Newtonian at temperatures considered.

Flow curve with (maximum yield stress): Blends with 8%wt and 10%wt wax prepared from N150 and N500 exhibited a maximum shear stress at shear rate higher than 0 1/s and at temperatures less than 30ºC.

Yield stress of blends: For blends made from base oil N150 and N500 the yield stress is found to increase with increasing wax concentration in the blend. Regarding the effect of temperature on yield stress, where the yield stress is decreasing with increasing temperature of the blends (Figs. 29 & 30).

Tables 9 and 10 below list the yield stress at minimum and maximum shear rate at (0 and 100 1/s) and maximum stress.

Table 8. carbon distribution for base oil N150, N500 blends.

Component	Base oil N150	Base oil N500	Paraffin wax
C_{20}	5.31	-	0.154
C_{21}	5.097	-	0.688
C_{22}	5.727	-	2.033
C_{23}	4.861	-	4.21
C_{24}	9.081	-	7.671
C_{25}	8.067	2.883	10.767
C_{26}	9.314	3.132	14.769
C_{27}	9.685	6.254	15.01
C_{28}	7.255	2.897	14.559
C_{29}	9.589	7.675	11.829
C_{30}	6.458	12.608	8.398
C_{31}	3.447	9.418	5.37
C_{32}	2.349	13.982	2.772
C_{33}	2.011	8.727	1.191
C_{34}	1.037	17.129	0.517
C_{35}	0.32	10.283	0.029

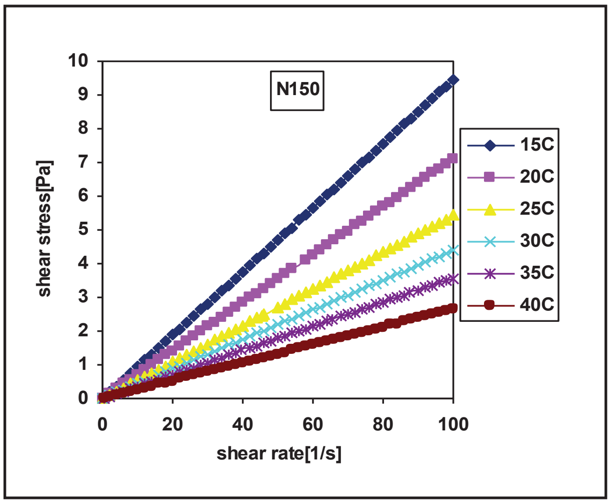

Fig. 1. Shear rate vs. shear stress for base oil N150 at different temperature.

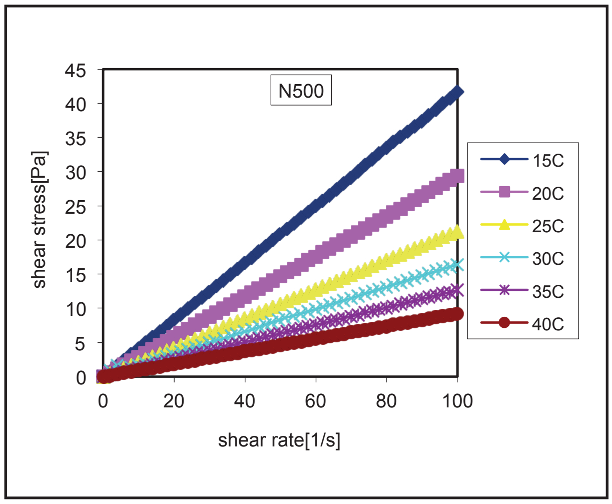

Fig. 2. Shear rate vs. shear stress for base oil N500 at different temperature.

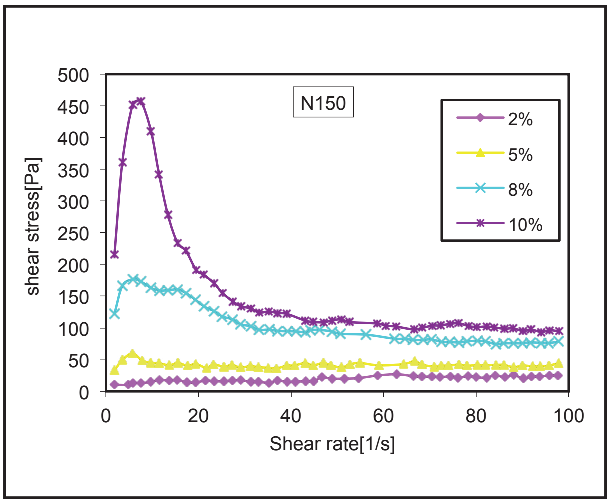

Fig. 3. Shear rate vs. apparent viscosity for base oil N150 at different temperature.

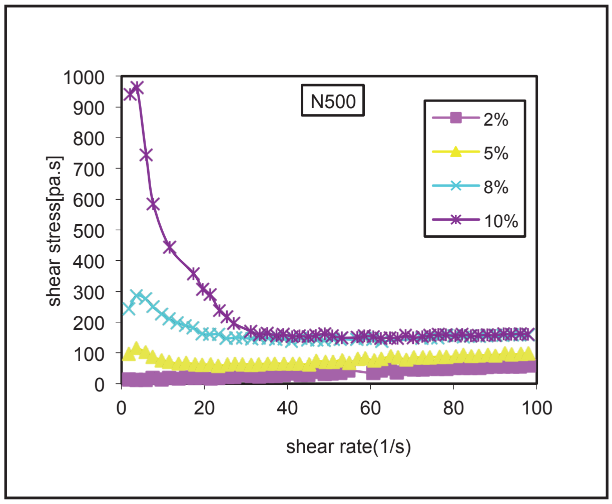

Fig. 4. Shear rate vs. apparent viscosity for base oil N150 at different temperature.

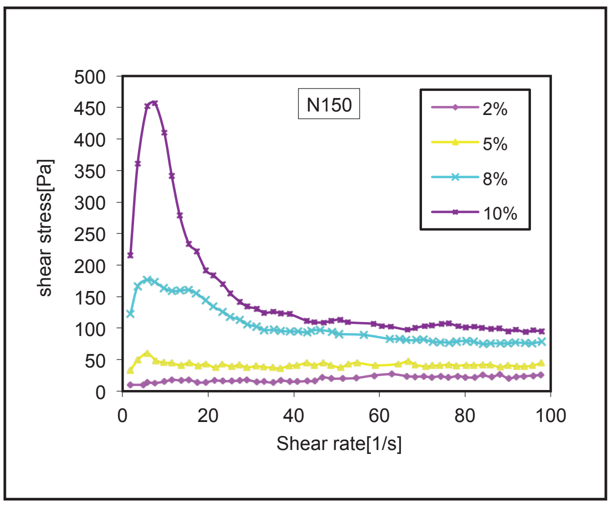

Fig. 5. Shear rate vs. shear stress for N150 blends, at T=15°C.

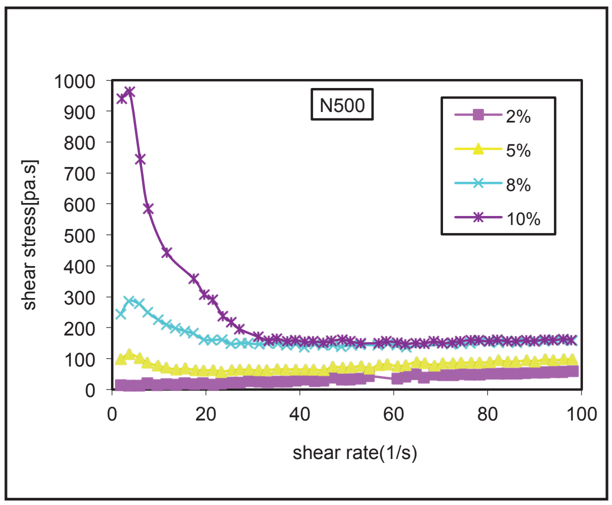

Fig. 6. Shear rate vs. shear stress for N500 blends, at T=15°C.

Table 9. Yield stress for N150 blends at different temperature and wax content.

Temperature	Wax content	Yield stress [Pa]	Shear stress at 100 [1/s]	Shear rate at Max. shear stress [1/s]	Max. shear stress [Pa]	Type of behavior
15°C	2%	10.2	25.22	-	-	Newtonian
	5%	32	44.5	5.73	60	Non-Newtonian
	8%	122.4	78.72	5.76	176.6	Non-Newtonian
	10%	215.2	94.72	7.522	457.2	Non-Newtonian
20°C	2%	0.825	7.92	-	-	Newtonian
	5%	6.2	21.4	-	-	Non-Newtonian
	8%	69.04	57.51	7.395	101.4	Non-Newtonian
	10%	122.1	82.48	7.4	323.3	Non-Newtonian
25°C	2%	0.067	5.22	-	-	Newtonian
	5%	1.236	10.2	-	-	Non-Newtonian
	8%	15.67	19.3	13.87	22	Non-Newtonian
	10%	66.81	28.85	3.956	96.55	Non-Newtonian

Table 10. Yield stress for N500 blends at different temperature and wax content.

Temperature	Wax content	Yield stress [Pa]	Shear stress at 100 [1/s]	Shear rate at Max. shear stress [1/s]	Max. shear stress [Pa]	Type of behavior
15°C	2%	11.65	58.9	-	-	Newtonian
	5%	115	98.04	3.57	114.9	Non-Newtonian
	8%	285.8	158.2	3.56	285.8	Non-Newtonian
	10%	962	160.1	3.7	962.2	Non-Newtonian
20°C	2%	2.57	31.75	-	-	Newtonian
	5%	33	65.3	-	65.44	Non-Newtonian
	8%	113.3	102.9	3.5	126.8	Non-Newtonian
	10%	253.8	136.2	5.76	321.5	Non-Newtonian
25°C	2%	0.4164	19.98	-	-	Newtonian
	5%	4.821	35.82	-	-	Non-Newtonian
	8%	48.15	52.76	1.967	48.15	Non-Newtonian
	10%	126	64.17	1.963	126	Non-Newtonian

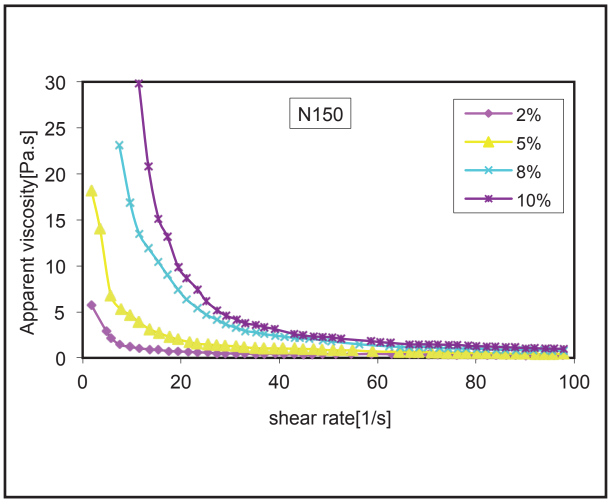

Fig. 7. Shear rate vs. apparent viscosity for N150 blends, at T=15°C.

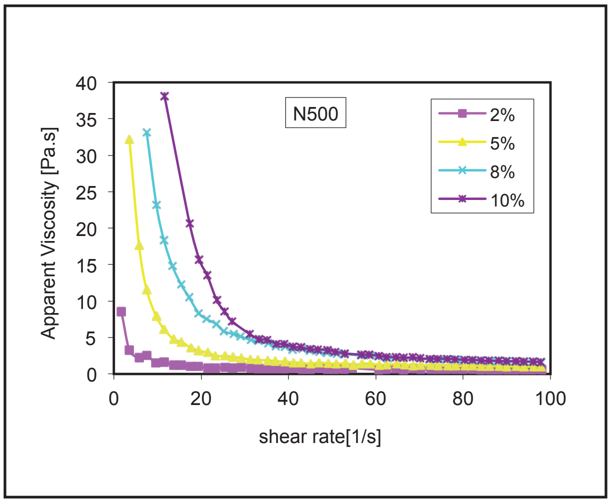

Fig. 8. Shear rate vs. apparent viscosity for N500

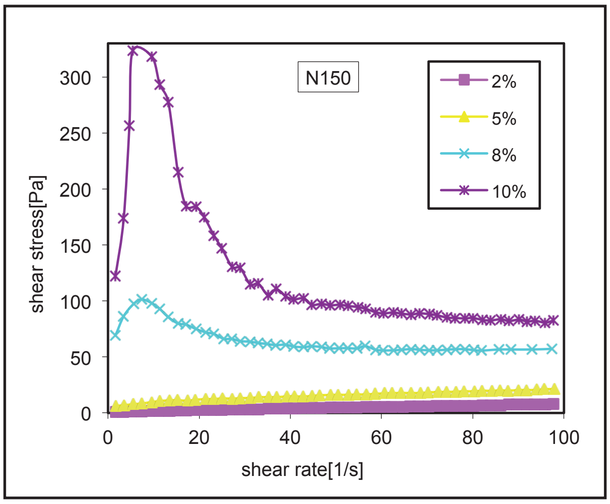

Fig. 9. Shear rate vs. shear stress for N150 blends, at T=20°C.

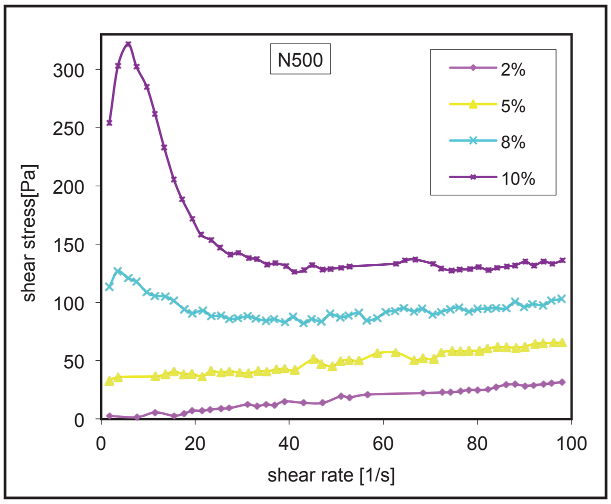

Fig. 10. Shear rate vs. shear stress for N500 blends, at T=20°C.

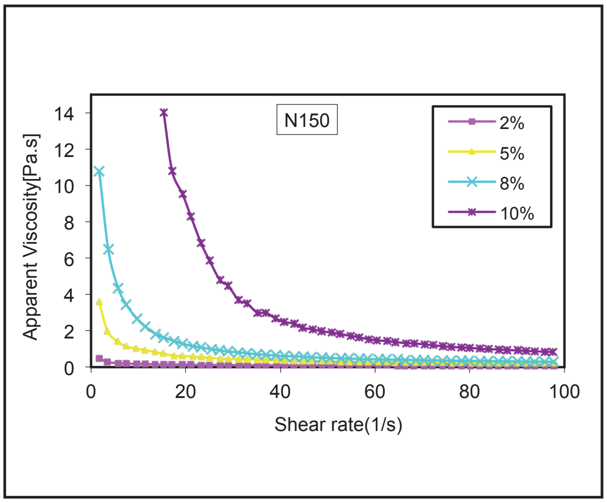

Fig. 11. Shear rate vs. apparent viscosity for N150 blends, at T=20°C.

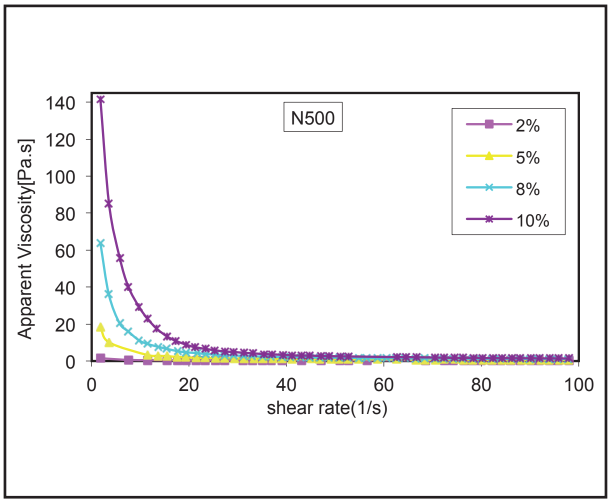

Fig. 12. Shear rate vs. apparent viscosity for N500 blends, at T=20°C.

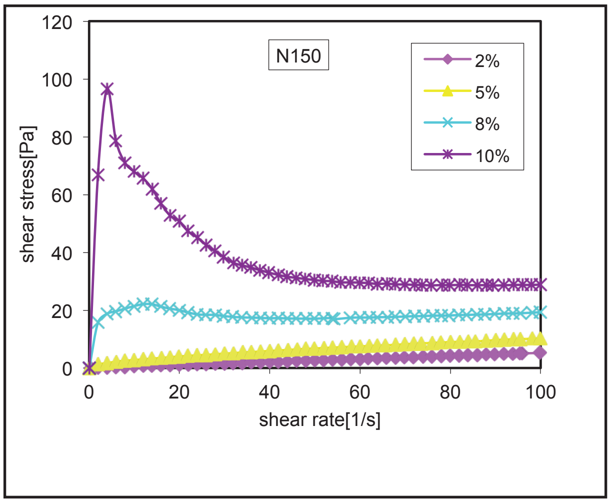

Fig. 13. Shear rate vs. shear stress for N150 blends, at T=25°C.

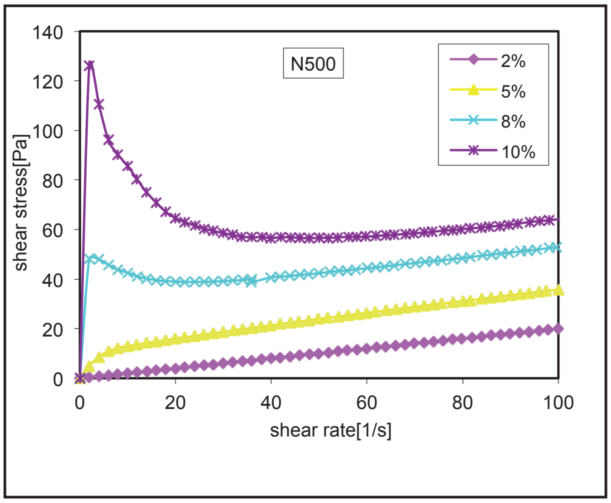

Fig. 14. Shear rate vs. apparent viscosity for N500 blends, at T=25°C.

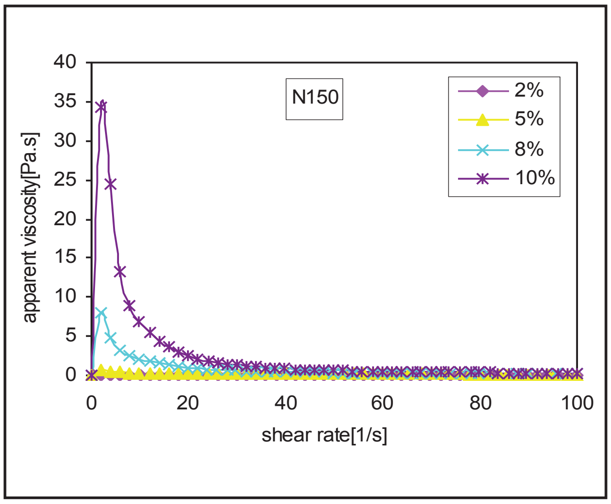

Fig. 15. Shear rate vs. apparent viscosity for N150 blends, at T=25°C.

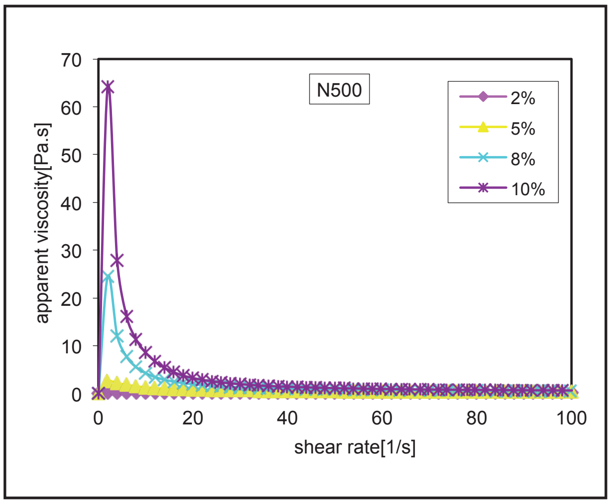

Fig. 16. Shear rate vs. apparent viscosity for N500 blends, at T=25°C.

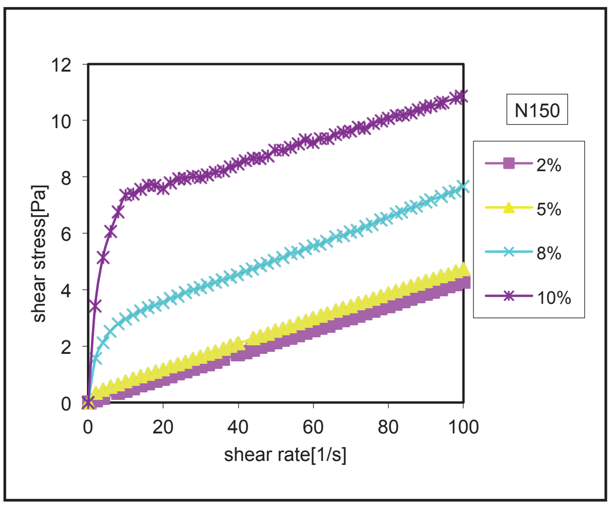

Fig. 17. Shear rate vs. shear stress for N150 blends, at T=30°C.

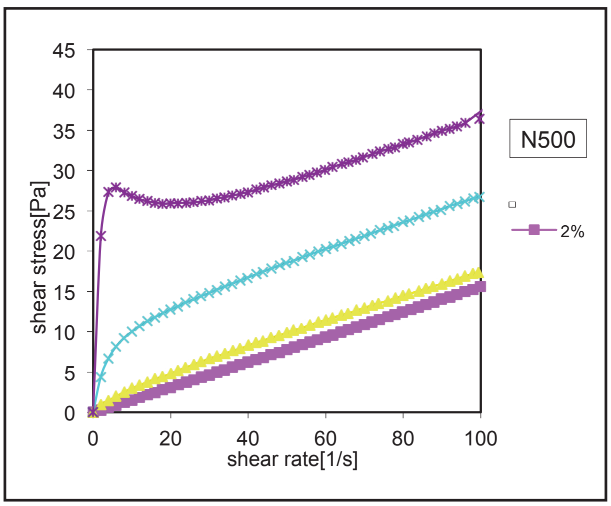

Fig. 18. Shear rate vs. shear stress for N500 blends, at T=30°C.

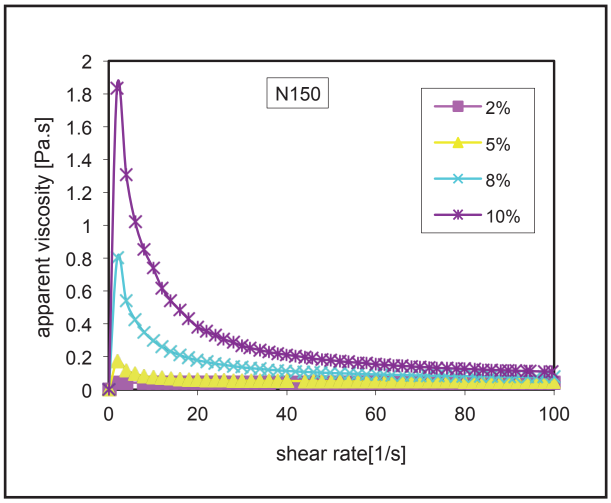

Fig. 19. Shear rate vs. apparent viscosity for N150 blends, at T=30°C.

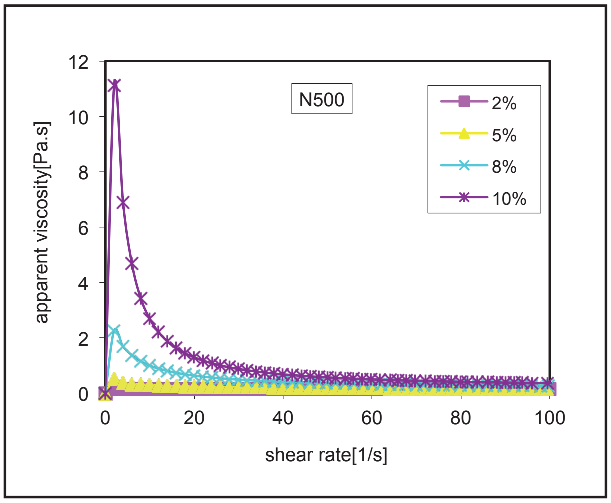

Fig. 20. Shear rate vs. apparent viscosity for N500 blends, at T=30°C.

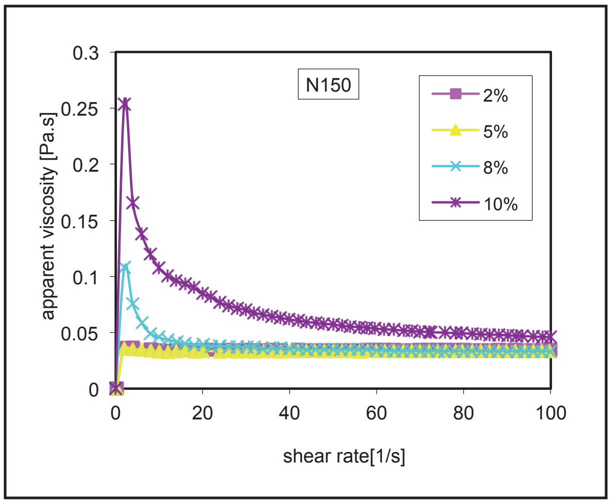

Fig. 21. Shear rate vs. shear stress for N150 blends, at T=35°C.

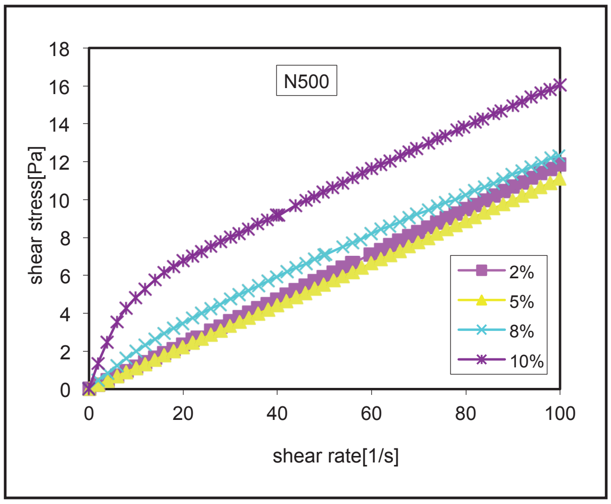

Fig. 22. Shear rate vs. shear stress for N500 blends, at T=35°C.

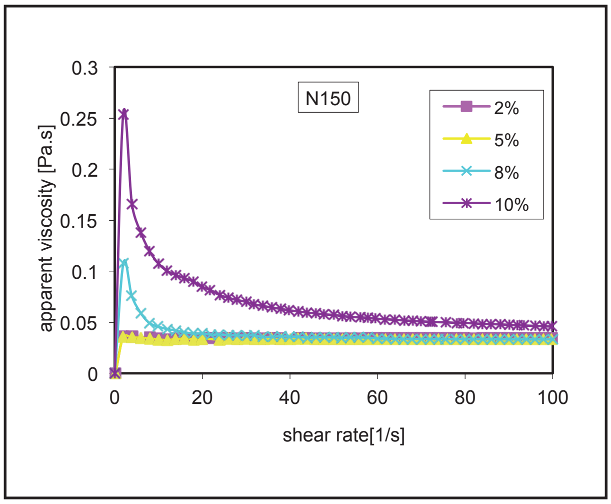

Fig. 23. Shear rate vs. apparent viscosity for N150 blends, at T=35°C.

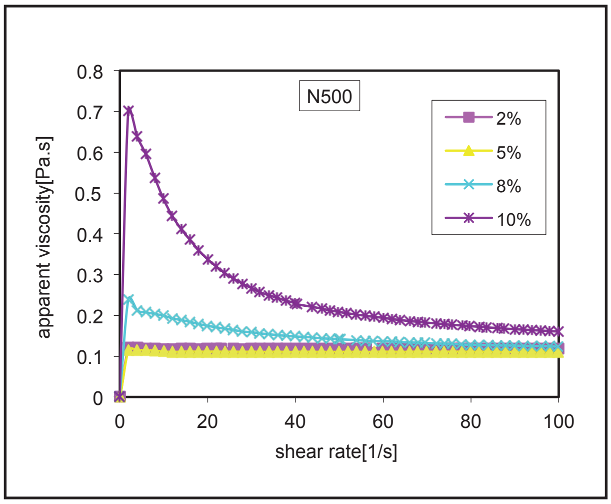

Fig. 24. Shear rate vs. apparent viscosity for N500 blends, at T=35°C.

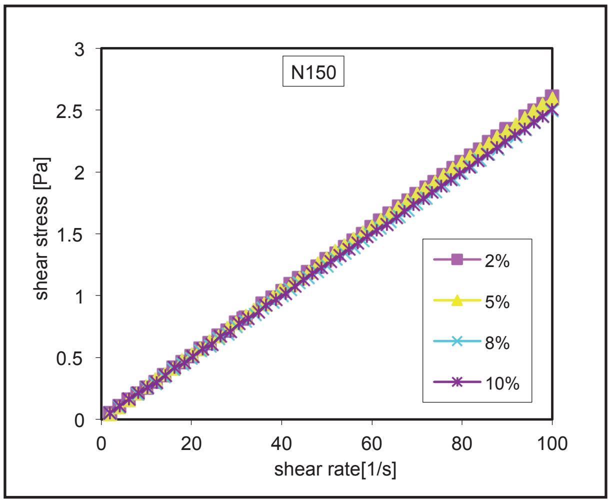

Fig. 25. Shear rate vs. shear stress for N150 blends, at T=40°C.

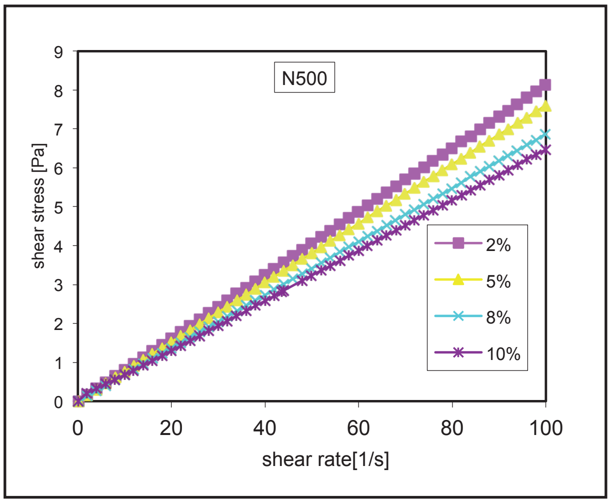

Fig. 26. Shear rate vs. shear stress for N500 blends, at T=40°C.

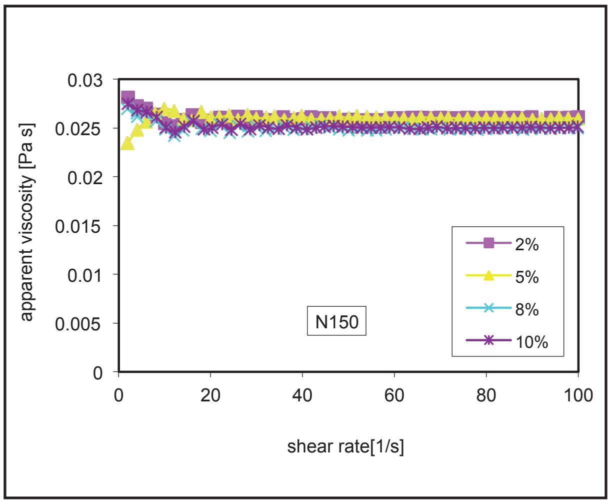

Fig. 27. Shear rate vs. apparent viscosity for N150 blends, at T=40°C.

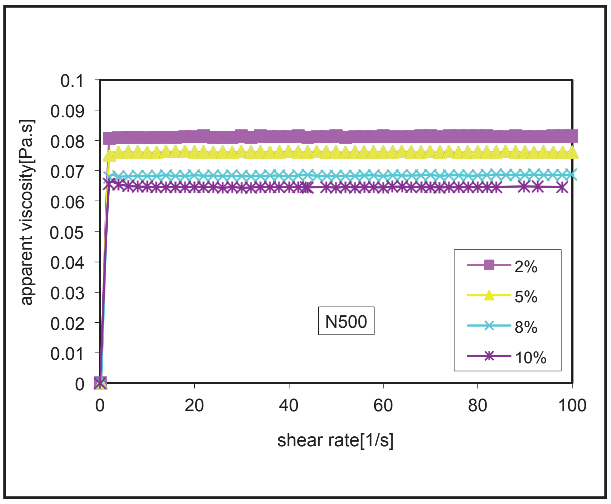

Fig. 28. Shear rate vs. apparent viscosity for N500 blends, at T=40°C.

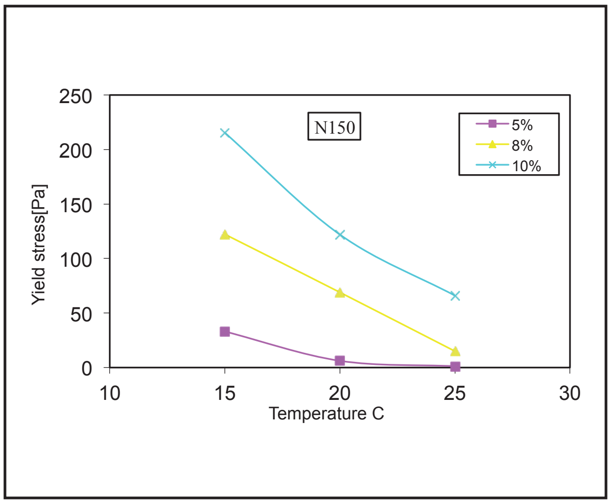

Fig. 29. Yield stress at different temperature for N150 blends

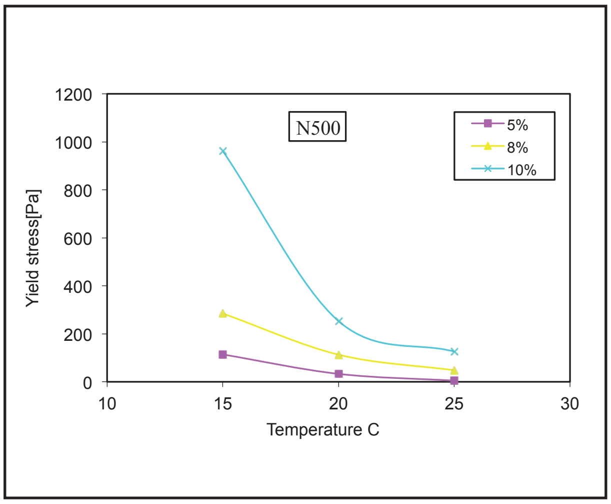

Fig. 30. Yield stress at different temperature for N500 blends

CONCLUSIONS

- Blends from base oil and wax flaks were prepared with wax content ranging (2-10 %wt). Simulating waxy crude oils.
- The flow behaviors of the produced blends were measured using rotational viscometers at temperature (15-60°C).
- The increase of wax content found to alter the flow behavior from Newtonian to non Newtonian with yield stress specially at low temperatures.
- Experimental results indicate that wax content and temperature are the main parameters affecting the viscosity and flow behavior.

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