

CHAPTER-IV-I

TESTING OF SYNTHESIZED POLYMER ADDITIVES ON GANDHAR FIELD CRUDE OIL

4.1. Physico-chemical Properties of Gandhar crude oil :

Gandhar crude oil is light to medium density oil. The sample taken here is combined from many wells and is taken from GGS. Commercially Gandhar crude is very good as seen from distillation characteristics of the oil. But it highly waxy in nature as it has nearly 28% of wax and pour point is 33°C which is not a bigger problem in summer season but when temperature goes down to 20°C it become difficult to handle. The physical properties of Gandhar crude oil are given in Table 29 .

Table 30 shows the distillation behavior of the Gandhar crude oil from zero to 300°C temperature. The initial boiling point (IBP) of the crude oil is 46°C which is quite low.

Sr. No.	Properties	Unit	Result
1	Density	g/cc	0.8130
2	Specific gravity	g/cc	0.8135
3	API ¹ gravity	Degree	42.5
4	Pour point	°C	33
5	Wax content	% wt	28.75
6	Saturates	% wt	84.64
7	Aromatics	--	10.42
8	N,S,O	--	4.94
9	Asphaltene	% wt	0.18
10	Cloud Point	°C	54
11	IBP ²	°C	46.00

Table 29 Geo-Chemical Characterization of Gandhar crude oil

¹ American Petroleum Index

² Initial Boiling Point

Distillation: Volume taken = 100 ml,
Initial Boiling Point (IBP) = 46 °C

Sr. No.	Temperature (°C)	Volume of oil (ml)
1	46-75	04
2	75-100	08
3	100-125	15
4	125-150	23
5	150-175	29
6	175-200	34
7	200-225	42
8	225-250	49
9	250-275	55
10	275-300	67

Table 30 Distillation characteristics of Gandhar crude oil

Temperature °C	Viscosity cps	Yield stress Pa
20	1803.6	258.6
25	1313.4	139.3
30	1226.2	132.5
33 (pour point)	1159	129.8
35	915	20.36
40	102.9	8.407

Table.31 Viscosity and Yield stress at different temperatures of Gandhar Neat oil

4.1.1 Gandahr wax deposit sample

S.No	Parameter	Unit	Results
1	Water Content	% Vol	2
2	Wax Content	% Wt	81.2
3	Asphaltene Content	% Wt	0.12
4	Oil Content	% Wt	9.63
5	Inorganics	% Wt	5.1
6	Resin content	% Wt	1.95
7	M.P of waxes	°C	92
8	M.P of Deposit	°C	94

Table 32 Analysis of Deposit Sample of Gandhar

4.1.2 Pour Point study results with the selected doses⁵: Samples of crude oils of the selected field were arranged with the courtesy of Oil Laboratory RGL,ONGC,Baroda and tested there itself.

Name of the Chemical additive code

n ABA = Diester of Poly(n-alkyl acrylate-co-maleic anhydride)dibenzylate

nOA n = Diester of Poly(n-alkyl oleate-co-maleic anhydride)dialkylate

BAUn = Diester of Poly(n-alkyl undecylenate-co-maleic anhydride)dialkylate

MBA-n = Diester of Poly(n-alkyl methacrylate-co-maleic anhydride)dibenzylate

S. No	Additive code	Pour point of neat Gandhar oil (°C)	Pour point of additive treated crude oil (ppm)						Extent of depression in pour point (°C)
		Doses -	500	1000	1500	2000	2500	3000	500-3000
1	8 ABA	33	30	30	30	30	30	30	3
2	10 ABA	33	30	30	30	30	30	30	3
3	12 ABA	33	33	33	33	33	33	33	-
4	14 ABA	33	27	27	27	27	27	27	6

5	16 ABA	33	33	33	33	33	33	33	-
6	18 ABA	33	24	24	24	24	24	24	9
7	8 OA 8	33	30	30	30	30	30	30	3
8	10 OA 10	33	33	33	33	33	33	33	-
9	12 OA 12	33	24	24	24	24	24	24	9
10	14 OA 14	33	27	27	27	27	27	27	6
11	16 OA 16	33	18	18	18	18	18	18	15
12	18 OA 18	33	15	15	15	15	15	15	18
13	22 OA 22	33	15	15	15	15	15	15	18
14	6 MBA	33	30	30	30	30	30	30	3
15	8 MBA	33	33	33	33	33	33	33	-
16	10 MBA	33	33	33	33	33	33	33	-
17	12 MBA	33	33	33	33	33	33	33	-
18	14 MBA	33	27	27	27	27	27	27	6
19	16 MBA	33	30	30	30	30	30	30	3
20	18 MBA	33	21	21	21	21	21	21	12
21	BAUn 8	33	30	30	30	30	30	30	3
22	BAUn 10	33	36	36	36	36	36	36	-3
23	BAUn 12	33	33	33	33	33	33	33	-
24	BAUn 14	33	24	24	24	24	24	24	9
25	BAUn 16	33	21	21	21	21	21	21	12
26	BAUn 18	33	18	18	18	18	18	18	15

Table 33 Pour points of polymeric additive treated Gandhar crude oil

4.1.3 Rheological study results:

Sr. No	Additive code	Additive Concentration ppm	Temperature °C	Viscosity cps	Yield stress Pa
1	8 ABA	500	30	569.9	37.71
2	8 ABA	1000	30	414.8	27.55
3	8 ABA	1500	30	353.2	17.95
4	8 ABA	2000	30	311	14.74
5	8 ABA	2500	30	291.1	8.84
6	8 ABA	3000	30	265.7	8.04
7	10 ABA	500	30	561.9	36.37
8	10 ABA	1000	30	410.2	27.05
9	10 ABA	1500	30	350.1	17.77
10	10 ABA	2000	30	309.1	14.70
11	10 ABA	2500	30	290.2	8.79
12	10 ABA	3000	30	263.7	8.02
13	12 ABA	500	33	1119.8	51.33
14	12 ABA	1000	33	1102.3	39.47
15	12 ABA	1500	33	822.5	35.21
16	12 ABA	2000	33	785.3	28.45
17	12 ABA	2500	33	689.4	25.95
18	12 ABA	3000	33	632.8	24.61
19	14 ABA	500	24	56.43	17.49
20	14 ABA	1000	24	59.24	15.73
21	14 ABA	1500	24	55.98	3.96
22	14 ABA	2000	24	53.39	3.078
23	14 ABA	2500	24	51.66	0.050
24	14 ABA	3000	24	50.79	2.543
25	16 ABA	500	30	1109.8	50.53
26	16 ABA	1000	30	1101.2	39.19
27	16 ABA	1500	30	821.5	35.19
28	16 ABA	2000	30	782.3	28.15
29	16 ABA	2500	30	687.1	25.92

22	12 OA 12	2000	27	55.10	3.96
23	12 OA 12	2500	27	54.64	3.75
24	12 OA 12	3000	27	53.88	2.59
25	16 OA 16	500	18	14.53	0.568
26	16 OA 16	1000	18	14.35	0.451
27	16 OA 16	1500	18	14.01	0.448
28	16 OA 16	2000	18	13.97	0.388
29	16 OA 16	2500	18	13.47	0.339
30	16 OA 16	3000	18	10.31	0.338
31	18 OA 18	500	15	19.62	0.329
32	18 OA 18	1000	15	18.50	0.327
33	18 OA 18	1500	15	8.58	0.254
34	18 OA 18	2000	15	8.52	0.250
35	18 OA 18	2500	15	8.51	0.250
36	18 OA 18	3000	15	8.40	0.244
37	22 OA 22	500	15	19.87	0.339
38	22 OA 22	1000	15	18.71	0.323
39	22 OA 22	1500	15	8.69	0.267
40	22 OA 22	2000	15	8.59	0.259
41	22 OA 22	2500	15	8.54	0.255
42	22 OA 22	3000	15	8.41	0.251

Table 35 Viscosity data of n OA n treated Gandhar crude oil

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress(Pa)
1	8 MBA	500	33	1106.2	51.54
2	8 MBA	1000	33	990.7	39.08
3	8 MBA	1500	33	830.2	36.09
4	8 MBA	2000	33	791.2	29.49
5	8 MBA	2500	33	694.5	26.60
6	8 MBA	3000	33	642.1	25.28
7	10 MBA	500	33	1104.1	51.02

8	10 MBA	1000	33	998.9	38.99
9	10 MBA	1500	33	829.2	35.59
10	10 MBA	2000	33	790.5	29.42
11	10 MBA	2500	33	695.2	26.65
12	10 MBA	3000	33	641.2	25.28
13	12 MBA	500	33	1102.2	50.12
14	12 MBA	1000	33	998.3	38.97
15	12 MBA	1500	33	829.0	35.56
16	12 MBA	2000	33	788.5	29.16
17	12 MBA	2500	33	694.7	26.61
18	12 MBA	3000	33	640.5	25.18
19	14 MBA	500	27	58.43	17.58
20	14 MBA	1000	27	59.57	5.77
21	14 MBA	1500	27	55.98	4.96
22	14 MBA	2000	27	55.12	3.96
23	14 MBA	2500	27	51.64	3.73
24	14 MBA	3000	27	53.76	2.98
25	16 MBA	500	30	561.0	34.28
26	16 MBA	1000	30	421.2	28.11
27	16 MBA	1500	30	350.5	17.98
28	16 MBA	2000	30	314.9	14.84
29	16 MBA	2500	30	291.5	14.84
30	16 MBA	3000	30	291.5	8.81
31	18 MBA	500	21	19.65	0.91
32	18 MBA	1000	21	19.35	0.86
33	18 MBA	1500	21	18.59	0.81
34	18 MBA	2000	21	14.59	0.51
35	18 MBA	2500	21	14.40	0.53
36	18 MBA	3000	21	14.39	0.50

Table 36. Viscosity data of n MBA polymer treated Gandhar crude oil

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress (Pa)
1	BAUn 10	500	30	571.2	36.88
2	BAUn 10	1000	30	429.9	28.91
3	BAUn 10	1500	30	366.5	18.28
4	BAUn 10	2000	30	329.8	14.88
5	BAUn 10	2500	30	293.9	8.82
6	BAUn 10	3000	30	262.4	8.22
7	BAUn 12	500	36	1788	140.3
8	BAUn 12	1000	36	1621	91.8
9	BAUn 12	1500	36	1489	75.98
10	BAUn 12	2000	36	1364	70.68
11	BAUn 12	2500	36	1363	70.65
12	BAUn 12	3000	36	1320	69.36
13	BAUn 14	500	33	1112.2	50.47
14	BAUn 14	1000	33	992.3	39.47
15	BAUn 14	1500	33	844	36.56
16	BAUn 14	2000	33	794.4	29.98
17	BAUn 14	2500	33	695.5	26.75
18	BAUn 14	3000	33	651.2	26.28
19	BAUn 16	500	24	18.12	3.299
20	BAUn 16	1000	24	18.11	1.529
21	BAUn 16	1500	24	12.67	1.139
22	BAUn 16	2000	24	12.24	1.123
23	BAUn 16	2500	24	17.74	0.939
24	BAUn 16	3000	24	11.73	0.894
25	BAUn 18	500	21	19.45	0.918
26	BAUn 18	1000	21	19.35	0.869
27	BAUn 18	1500	21	19.04	0.868
28	BAUn 18	2000	21	14.57	0.569
29	BAUn 18	2500	21	14.41	0.532
30	BAUn 18	3000	21	14.29	0.505

31	BAUn 22	500	18	15.23	0.5592
32	BAUn 22	1000	18	14.95	0.5412
33	BAUn 22	1500	18	14.40	0.4542
34	BAUn 22	2000	18	10.34	0.3419
35	BAUn 22	2500	18	10.37	0.3389
36	BAUn 22	3000	18	10.33	0.3385

Table 37 Viscosity data of BAUn n treated Gandhar crude oil

4.1.4 Rheological studies on TA AR500 Rheometer⁹²: Rheological studies are the backbone of this research work and the work is carried out at RGL, ONGC. Baroda

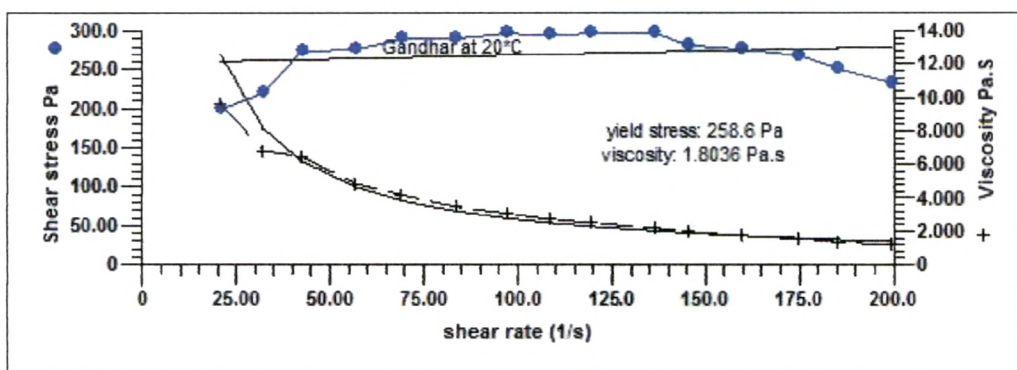


Fig 46 Rheogram Gandhar neat at 20°C

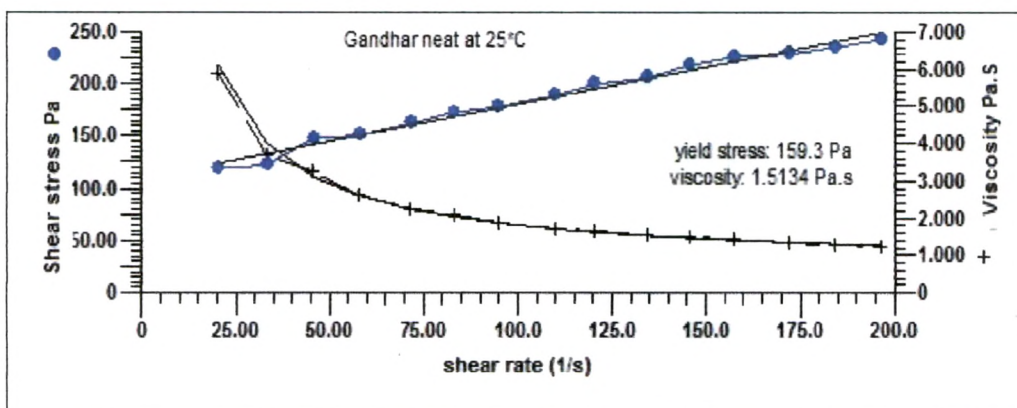


Fig 47 Rheogram Gandhar neat at 25°C

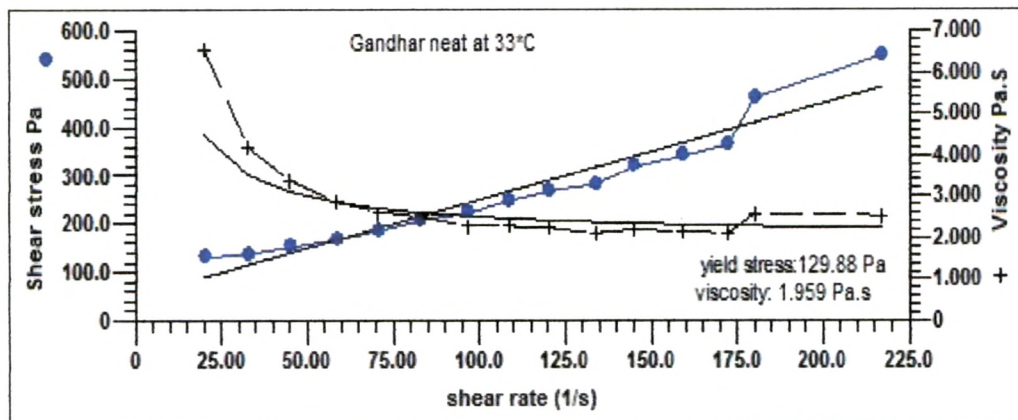


Fig 48 Rheogram Gandhar neat at 30°C

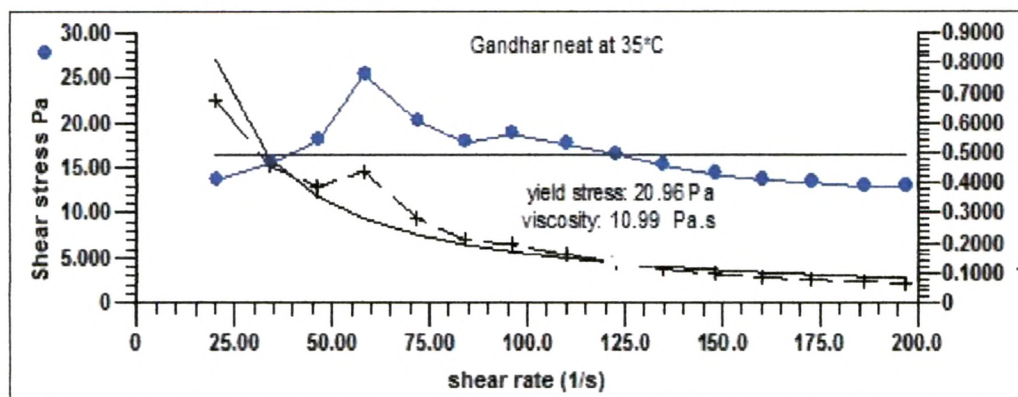


Fig 49 Rheogram Gandhar neat at 35°C

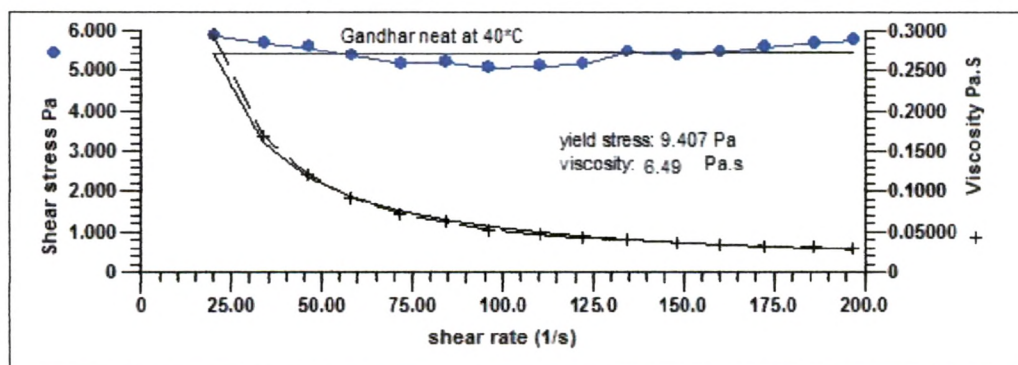


Fig 50 Rheogram Gandhar neat at 40°C

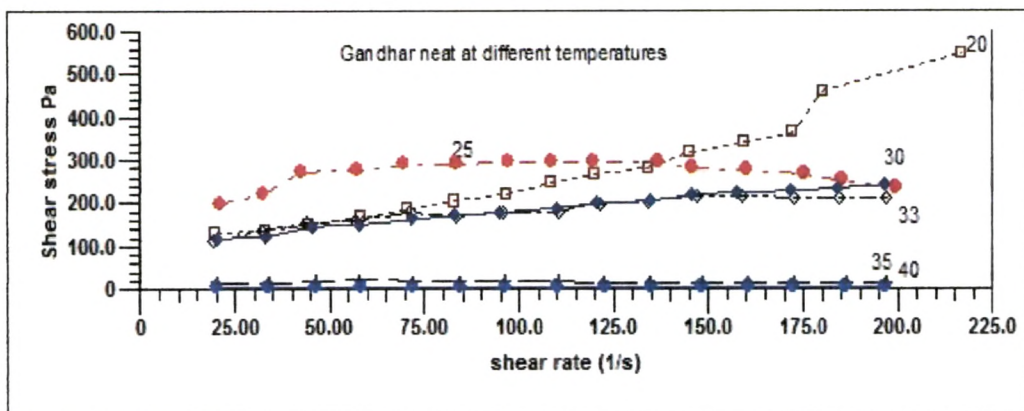


Fig 51 Comparison of shear stress at different temperatures

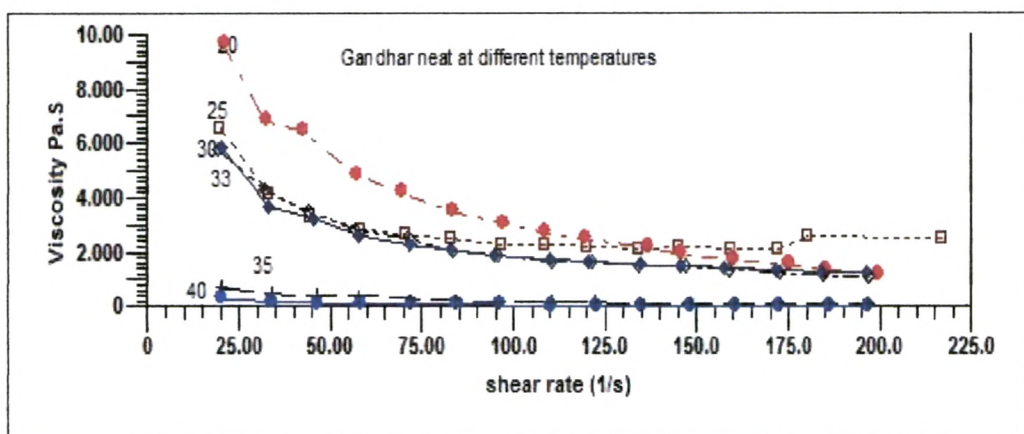


Fig 52 Comparison of Viscosity at different temperatures

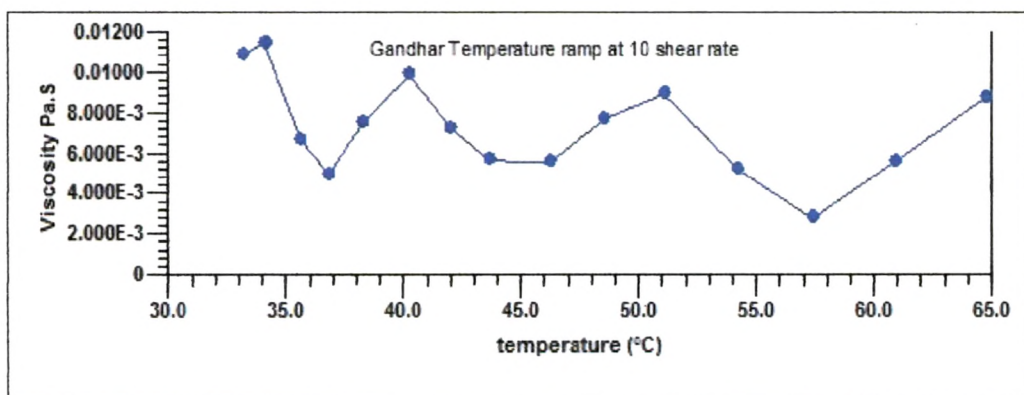


Fig 53 Temperature ramp of Gandhar

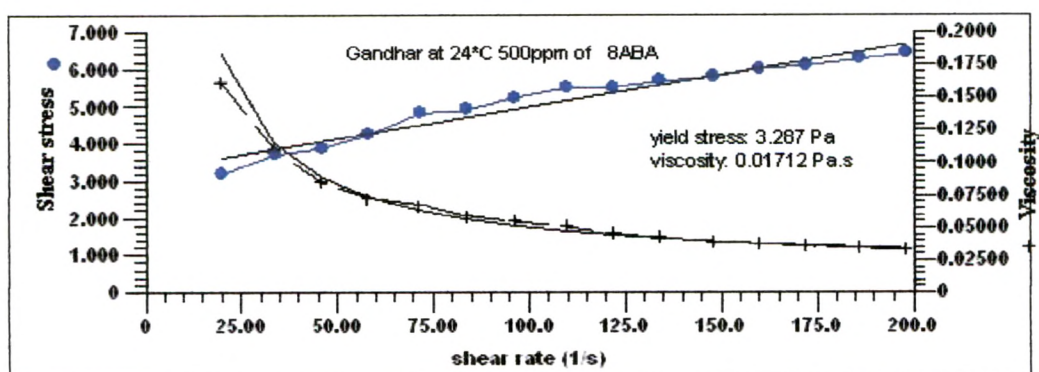


Fig 54 Gandhar 500ppm of 8ABA

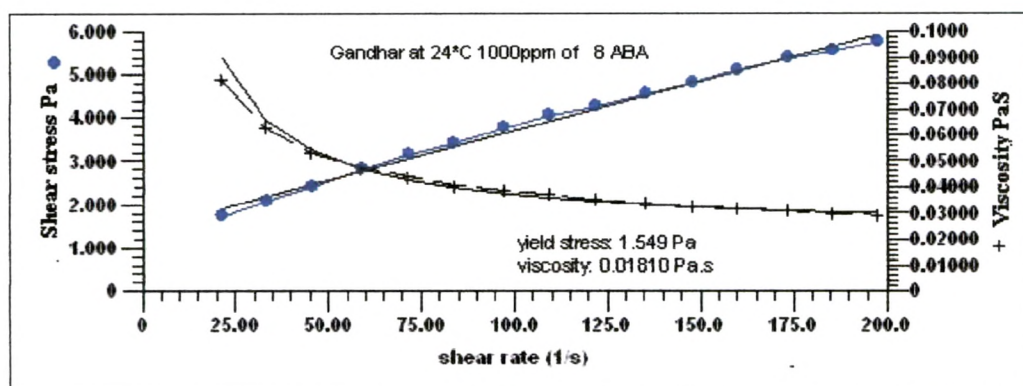


Fig 55 Gandhar 1000ppm of 8ABA

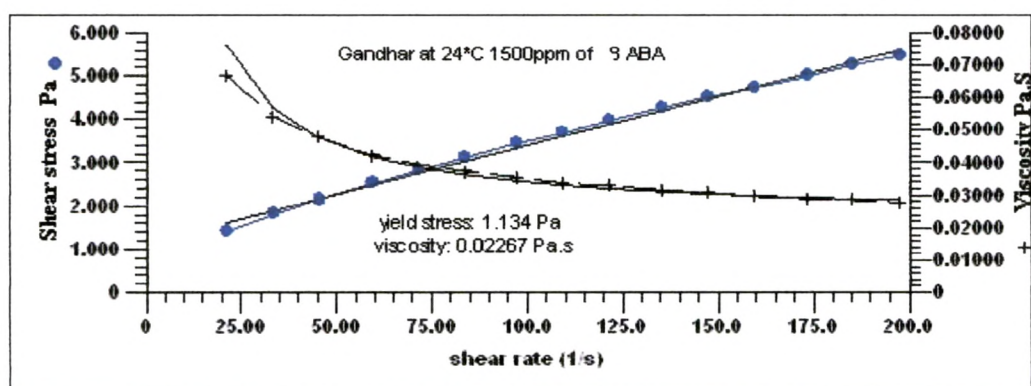


Fig 56 Gandhar 1500ppm of 8ABA

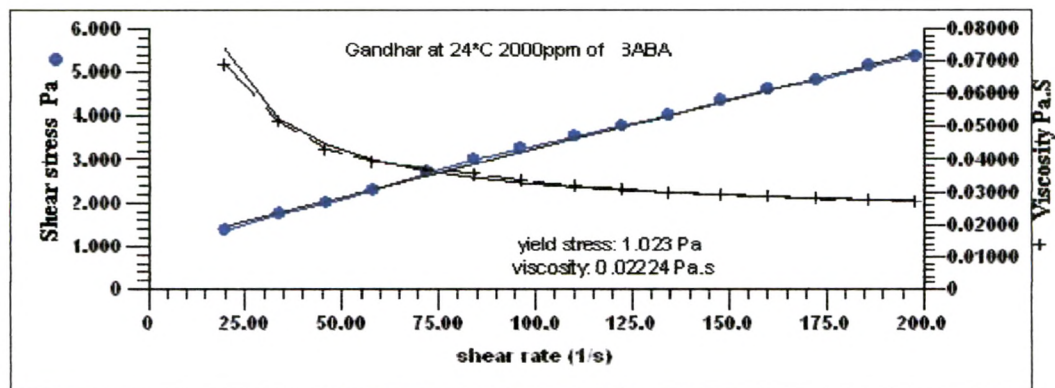


Fig 57 Gandhar 2000ppm of 8ABA

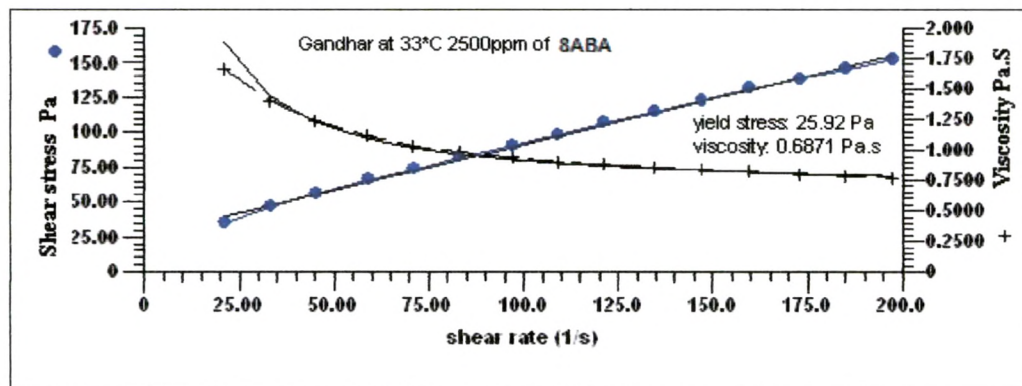


Fig 58 Gandhar 2500ppm of 8ABA

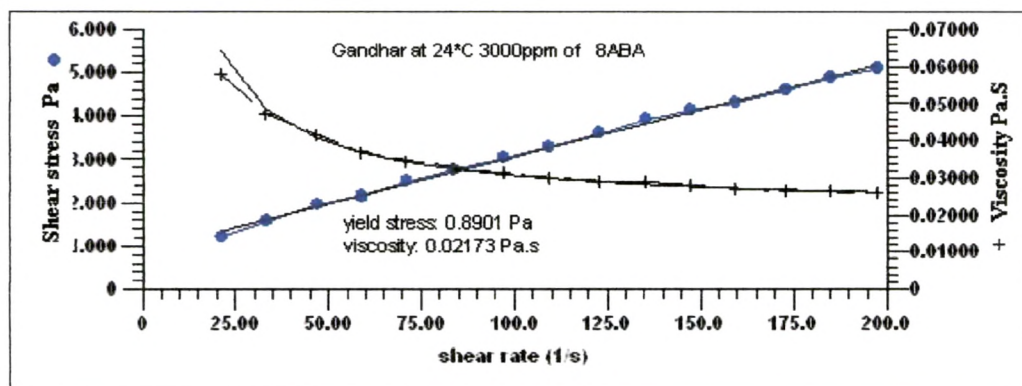


Fig 59 Gandhar 3000ppm of 8ABA

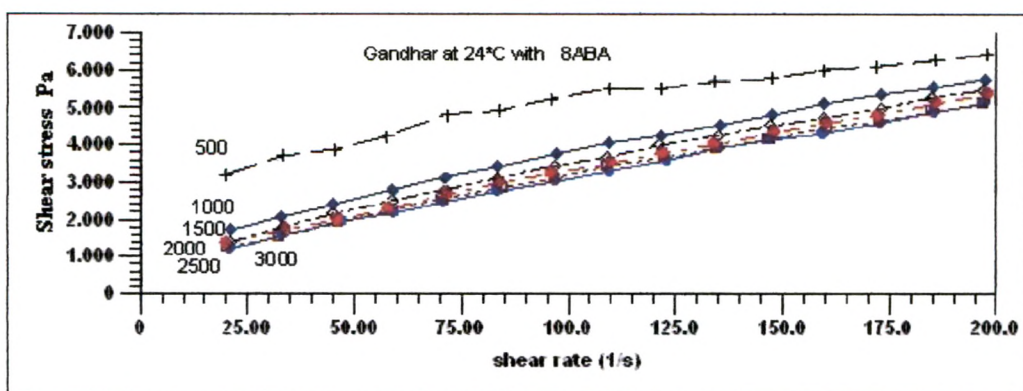


Fig 60 Comparison Gandhar with doses of 8ABA

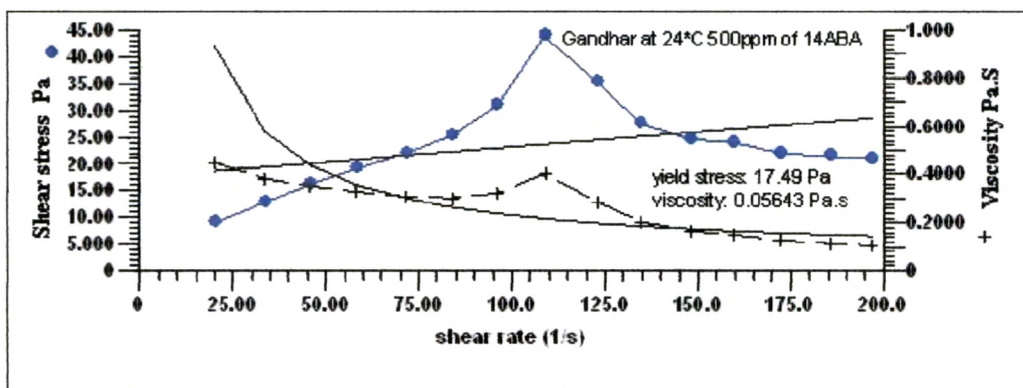


Fig 61 Gandhar with 500ppm of 14ABA

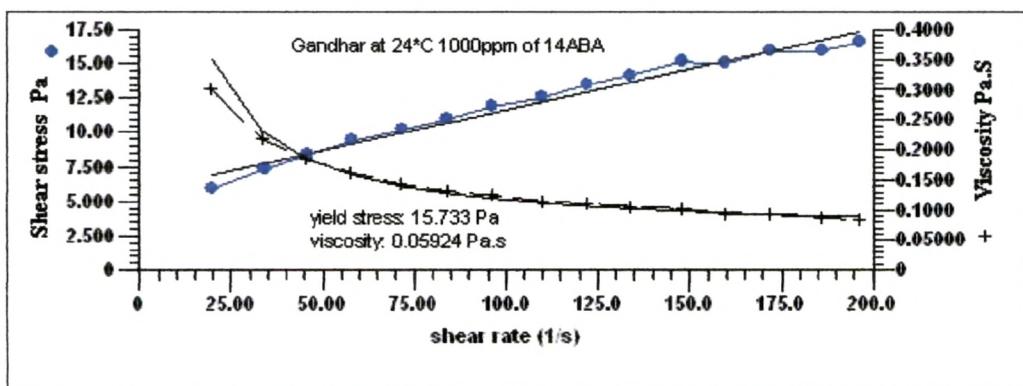


Fig 62 Gandhar with 1000ppm of 14ABA

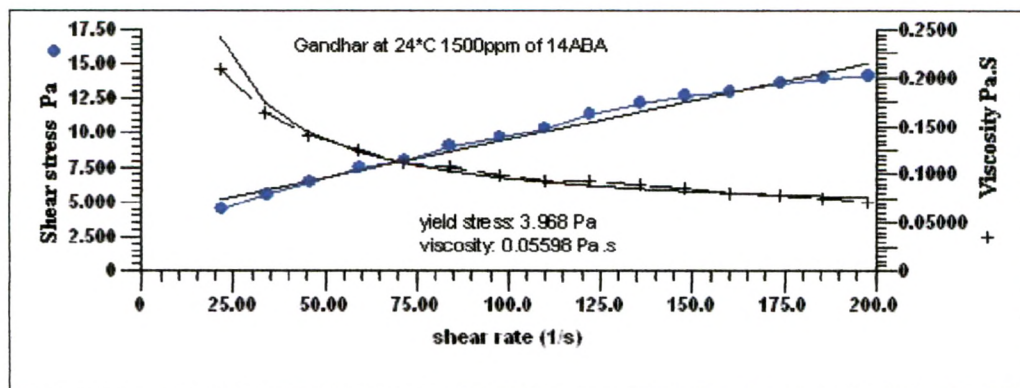


Fig 63 Gandhar with 1500ppm of 14ABA

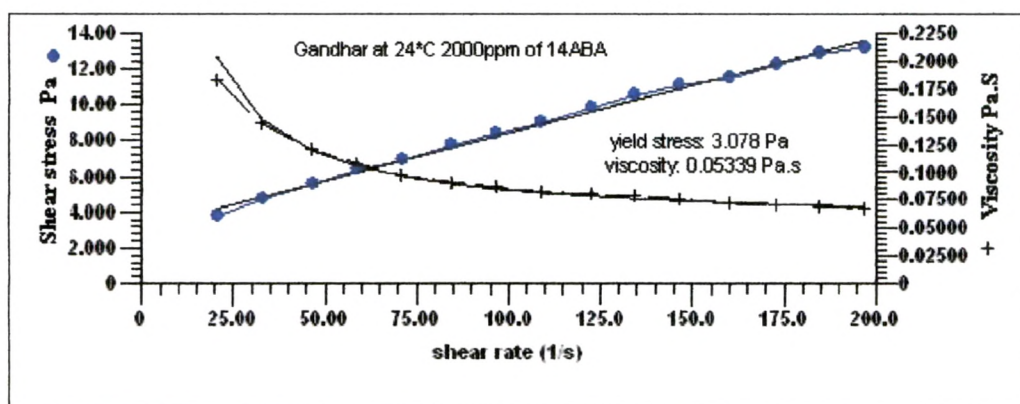


Fig 64 Gandhar with 2000ppm of 14ABA

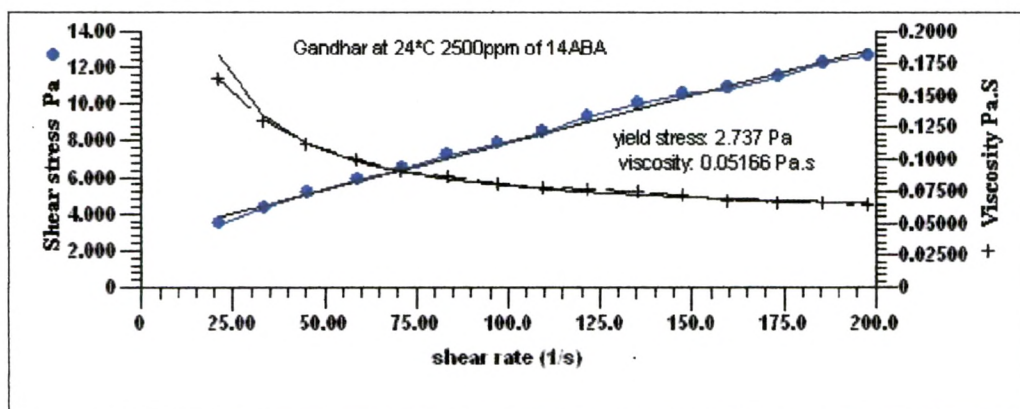


Fig 65 Gandhar with 2500ppm of 14ABA

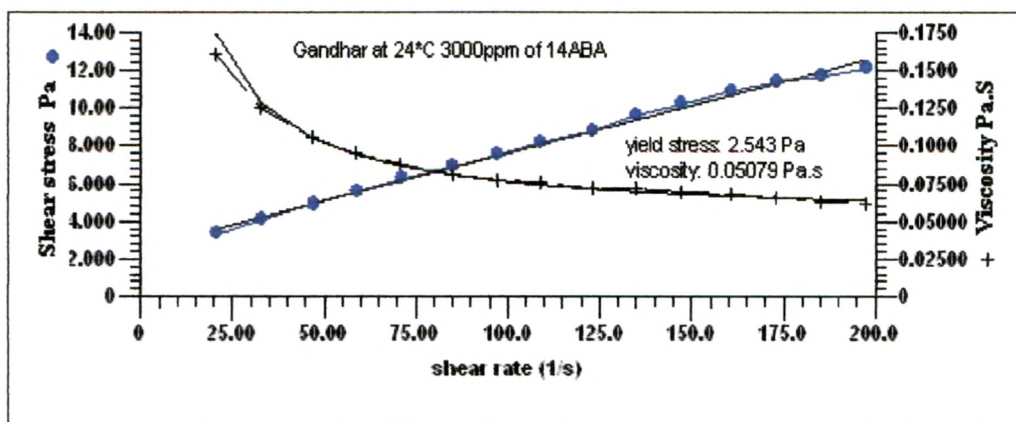


Fig 66 Gandhar with 3000ppm of 14ABA

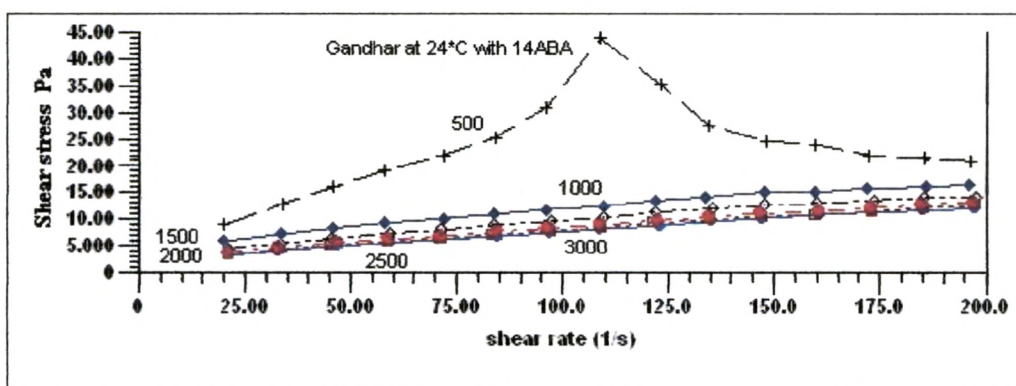


Fig 67 Comparison Gandhar with doses of 14ABA

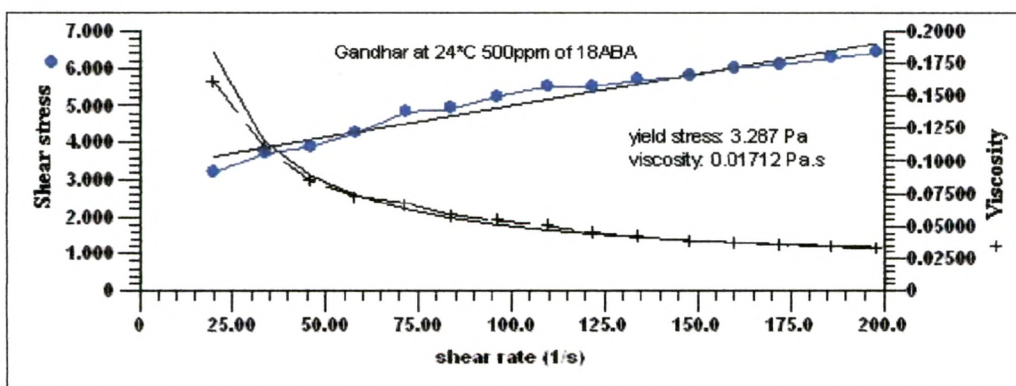


Fig 68 Gandhar with 500ppm of 18ABA

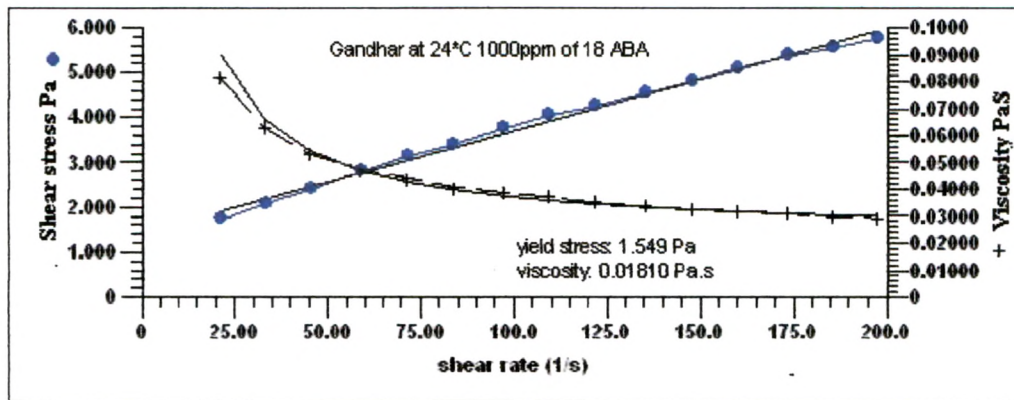


Fig 69 Gandhar with 1000ppm of 18ABA

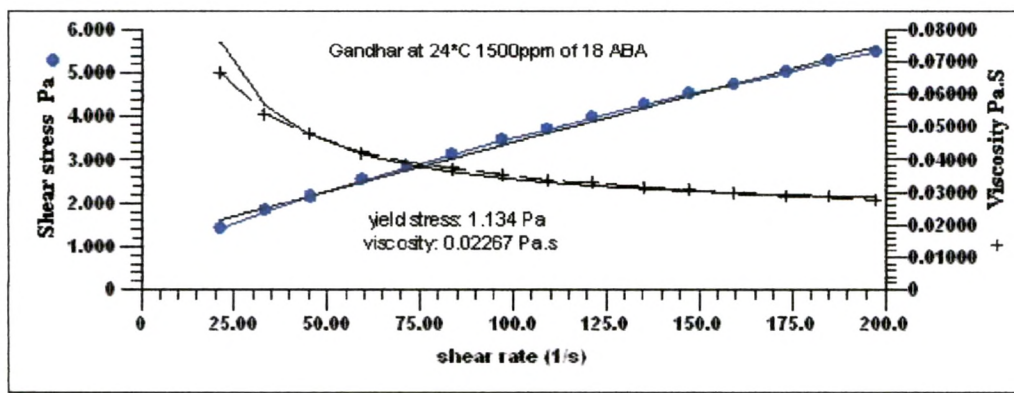


Fig 70 Gandhar with 1500ppm of 18ABA

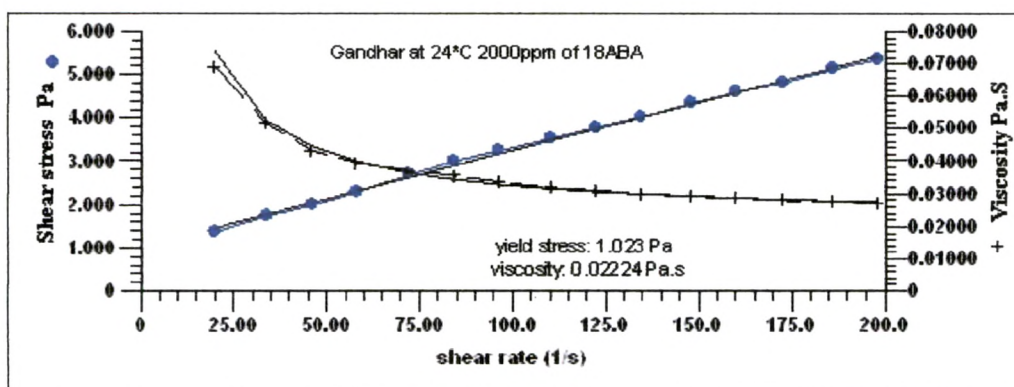


Fig 71 Gandhar with 2000ppm of 18ABA

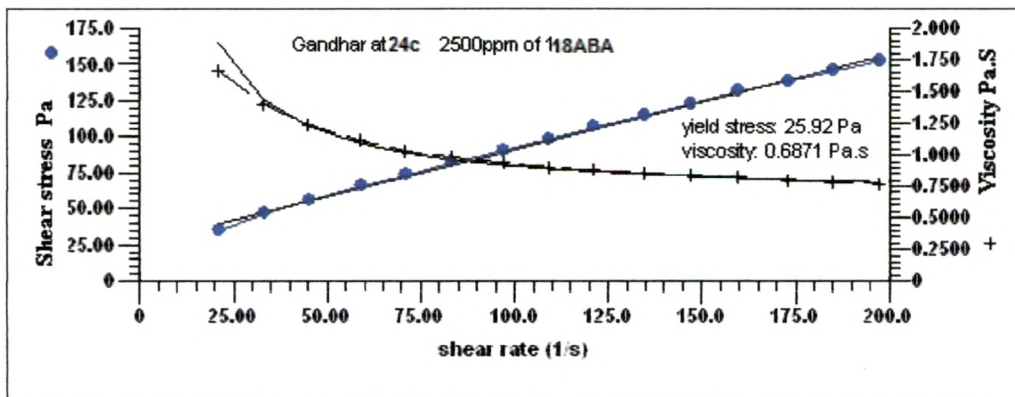


Fig 72 Gandhar with 2500ppm of 18ABA

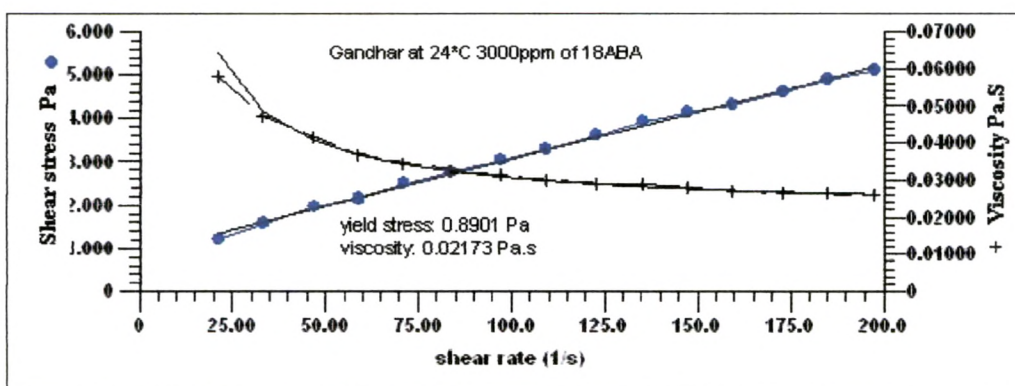


Fig 73 Gandhar with 3000ppm of 18ABA

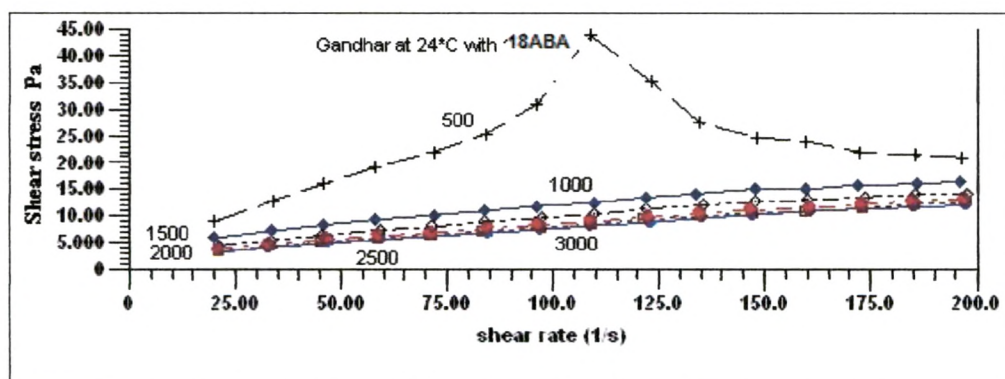


Fig 74 Comparision Gandhar with doses of 18ABA

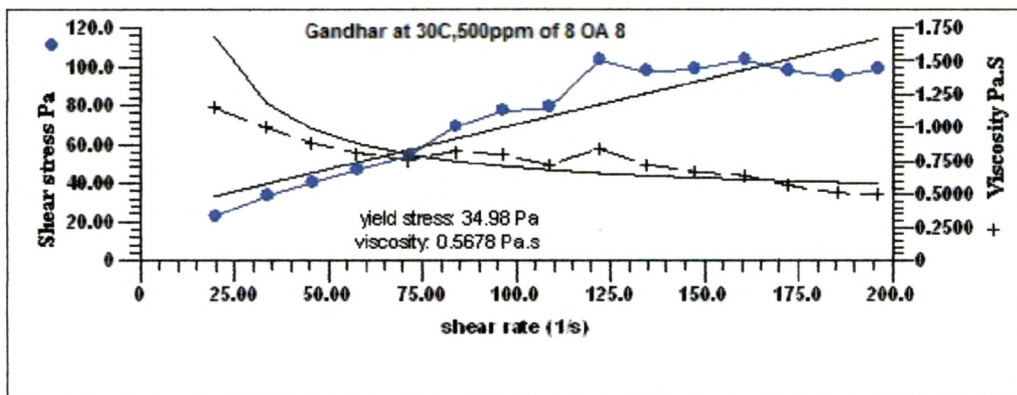


Fig 75 Gandhar with 500ppm of 8 OA 8

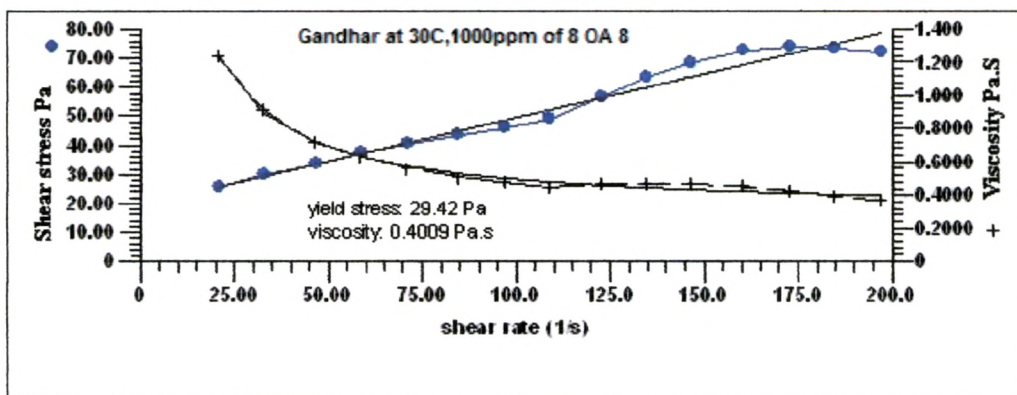


Fig 76 Gandhar with 1000ppm of 8 OA 8

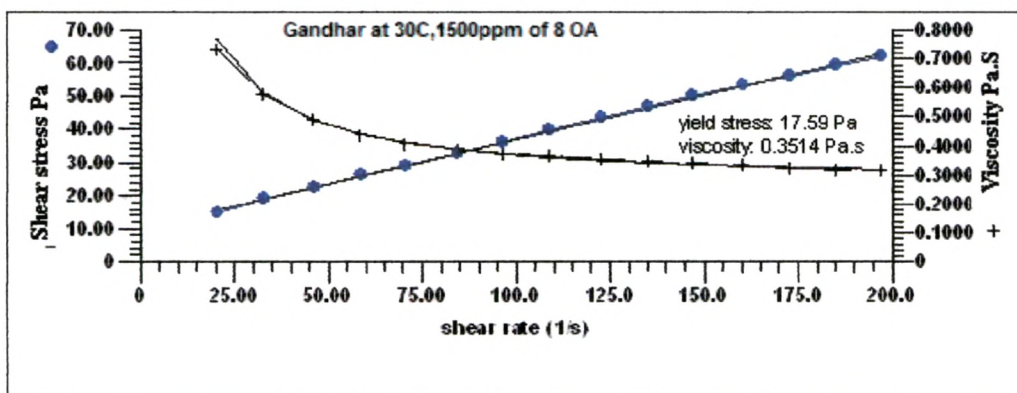


Fig 77 Gandhar with 1500ppm of 8 OA 8

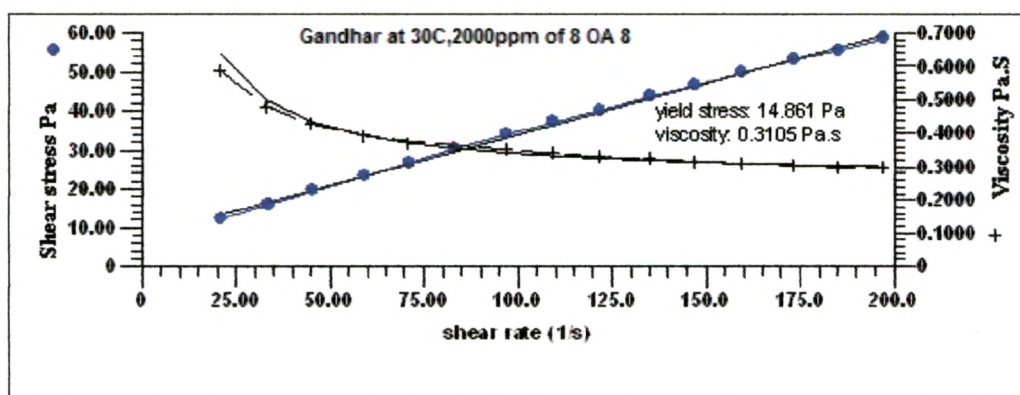


Fig 78 Gandhar with 2000ppm of 8 OA 8

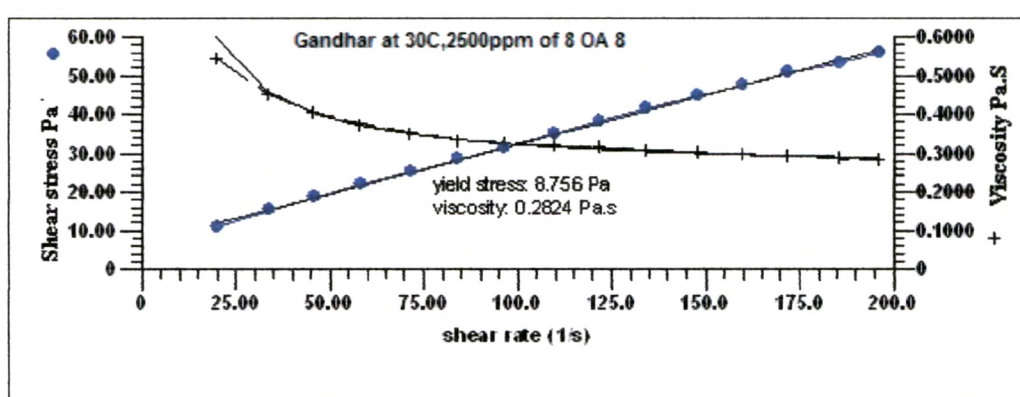


Fig 79 Gandhar with 2500ppm of 8 OA 8

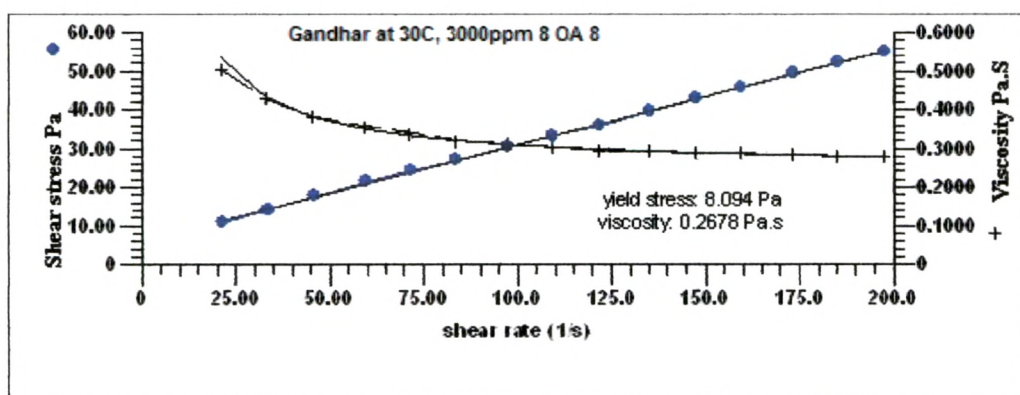


Fig 80 Gandhar with 3000ppm of 8 OA 8

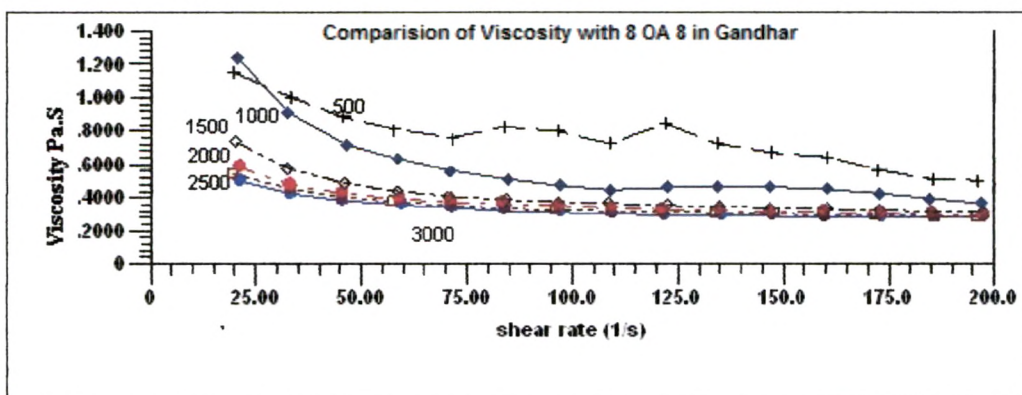


Fig 81 Comparison of Gandhar viscosity with doses of 8 OA 8

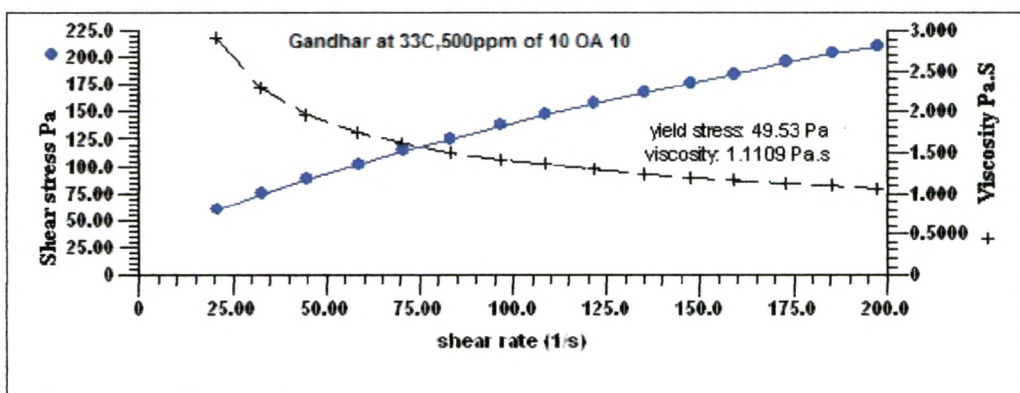


Fig 82 Gandhar with 500ppm of 10 OA 10

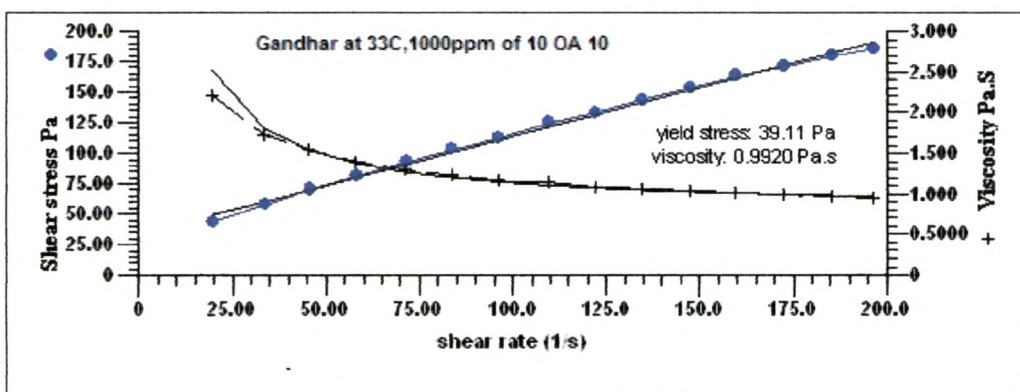


Fig 83 Gandhar with 1000ppm of 10 OA 10

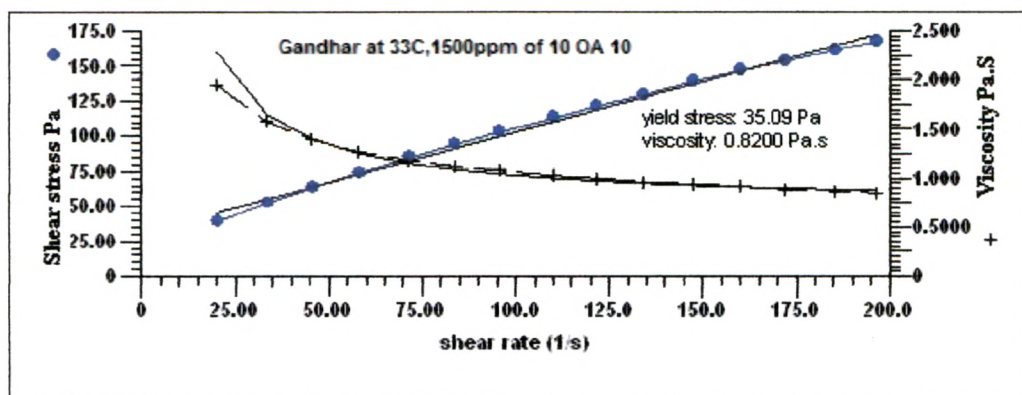


Fig 84 Gandhar with 1500ppm of 10 OA 10

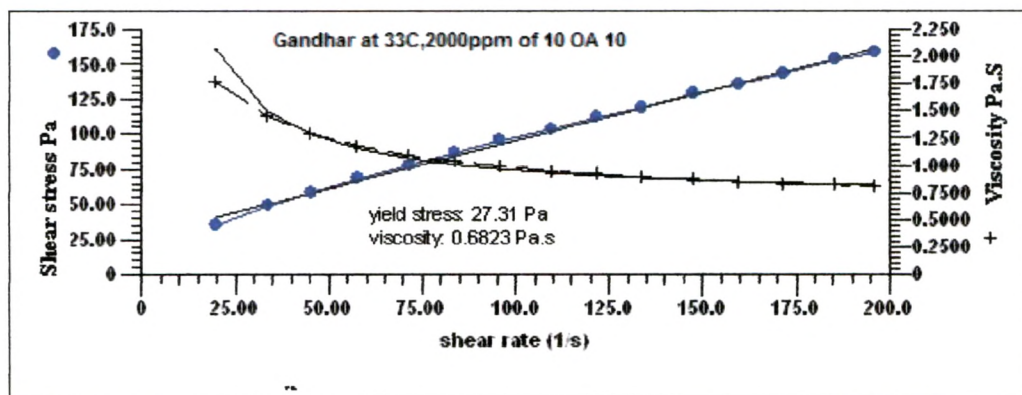


Fig 85 Gandhar with 2000ppm of 10 OA 10

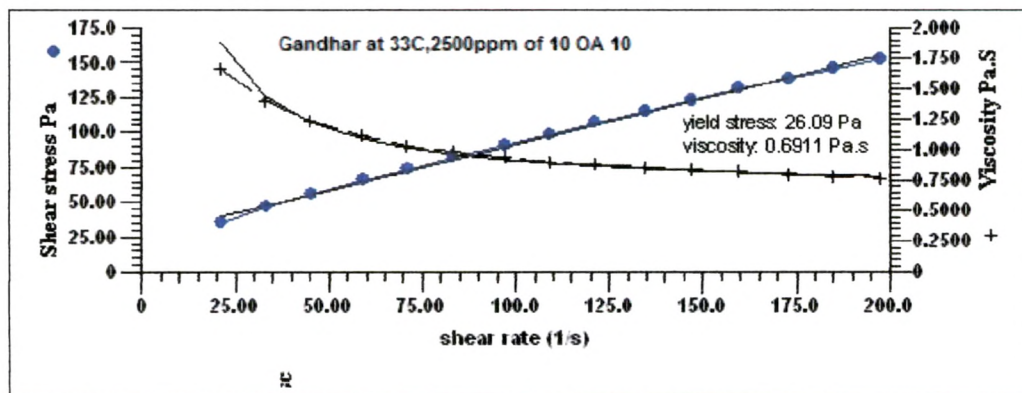


Fig 86 Gandhar with 2500ppm of 10 OA 10

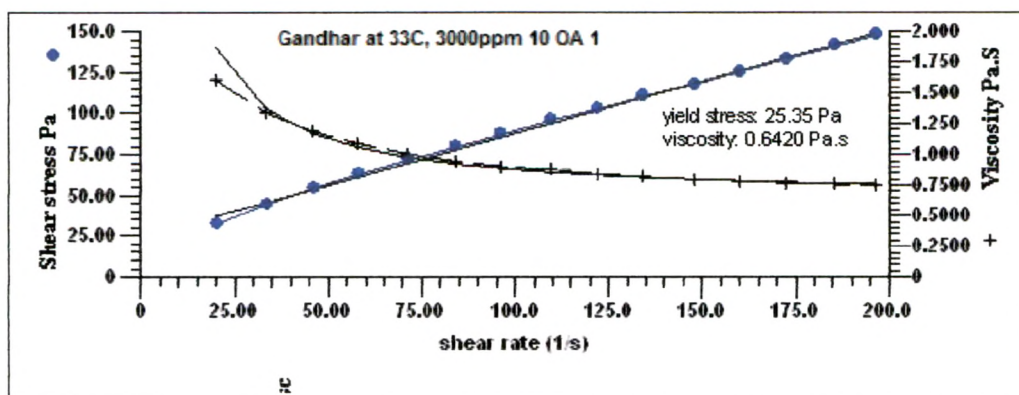


Fig 87 Gandhar with 3000ppm of 10 OA 10

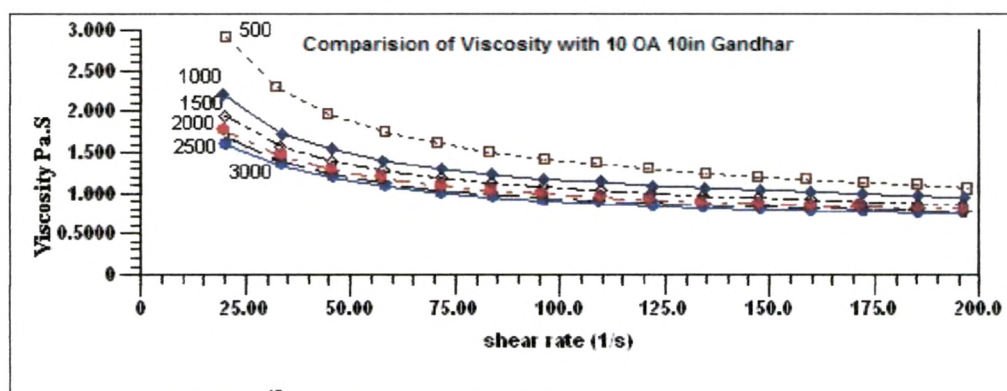


Fig 88 Comparison of Gandhar viscosity with doses of 10 OA 10

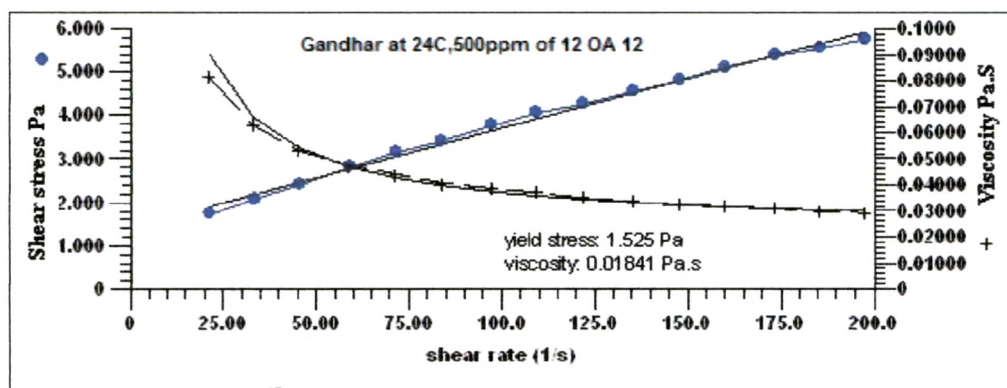


Fig 89 Gandhar with 500ppm of 12 OA 12

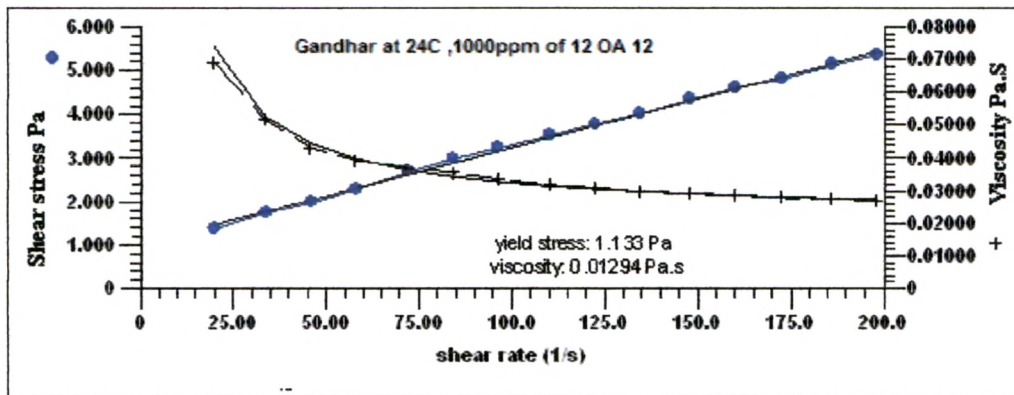


Fig 90 Gandhar with 1000ppm of 12 OA 12

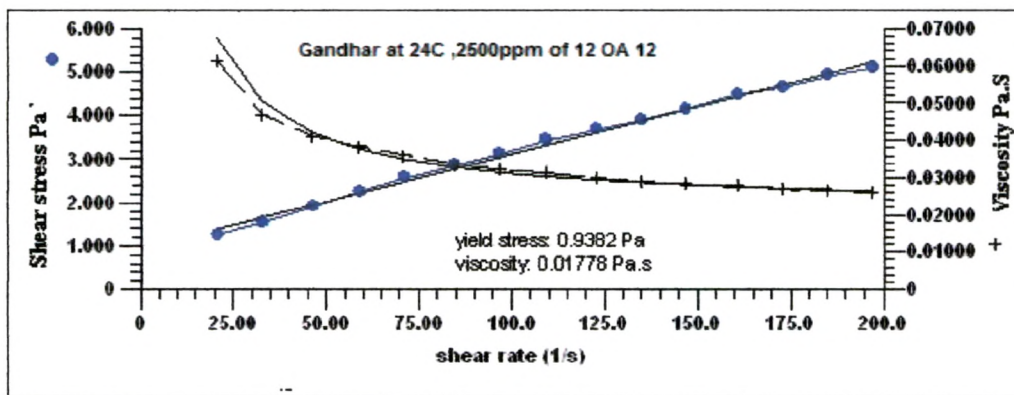


Fig 91 Gandhar with 2500ppm of 12 OA 12

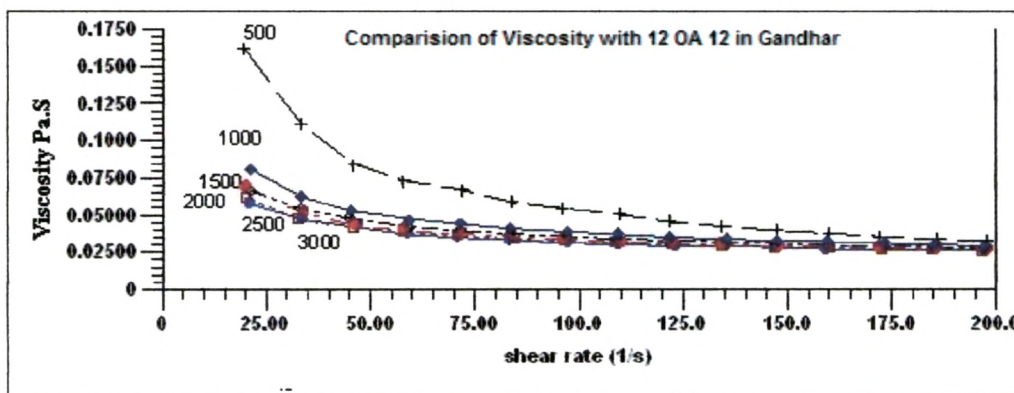


Fig 92 Comparison of Gandhar viscosity with doses of 12 OA 12

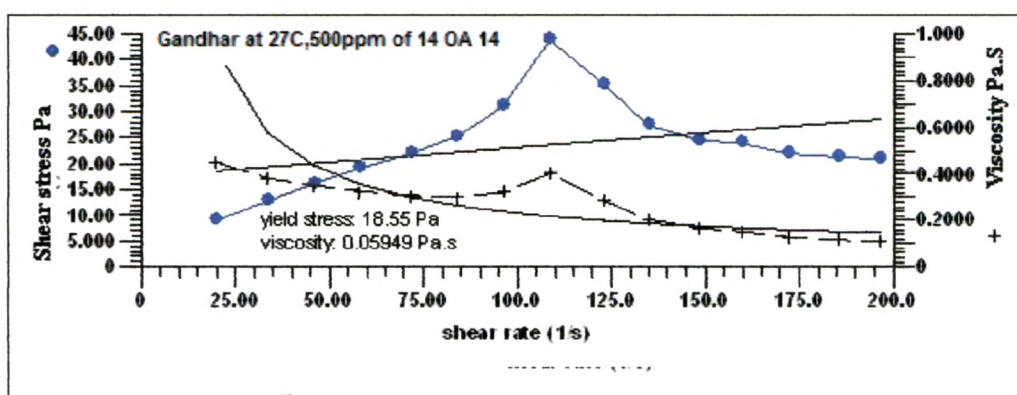


Fig 93 Gandhar with 500ppm of 14 OA 14

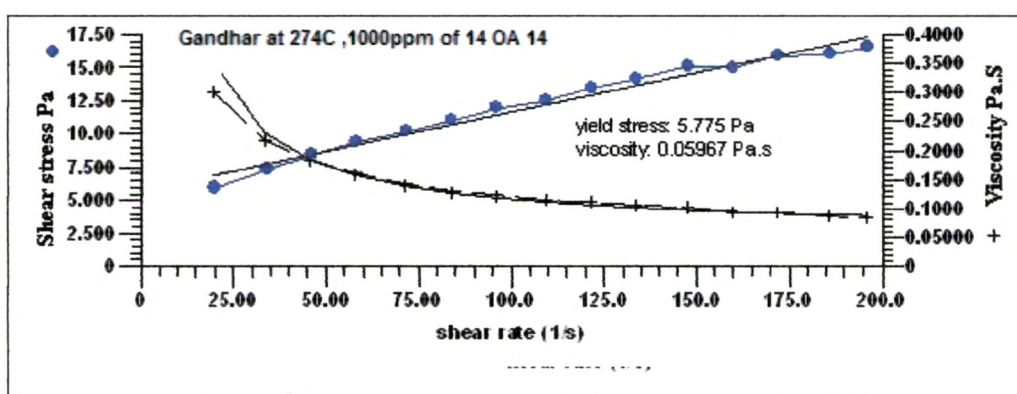


Fig 94 Gandhar with 1000ppm of 14 OA 14

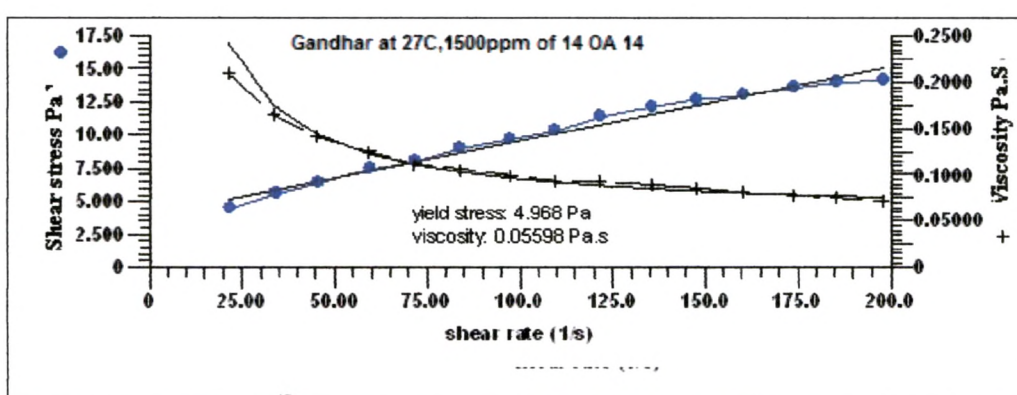


Fig 95 Gandhar with 1500ppm of 14 OA 14

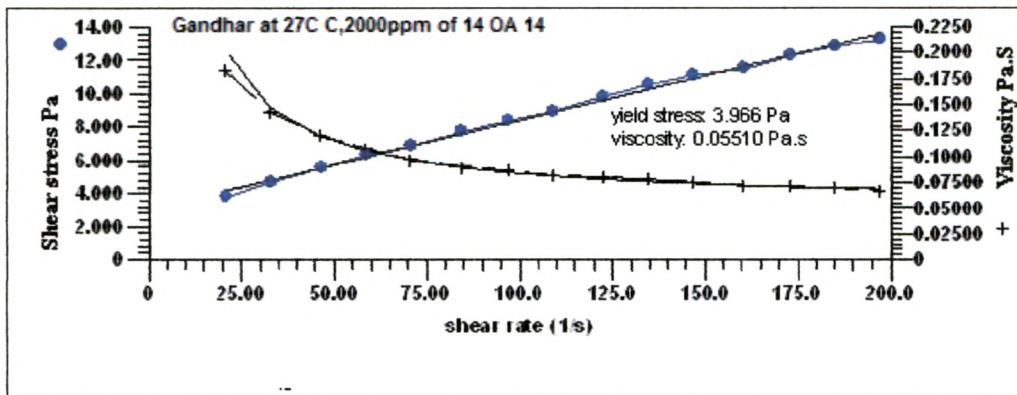


Fig 96 Gandhar with 2000ppm of 14 OA 14

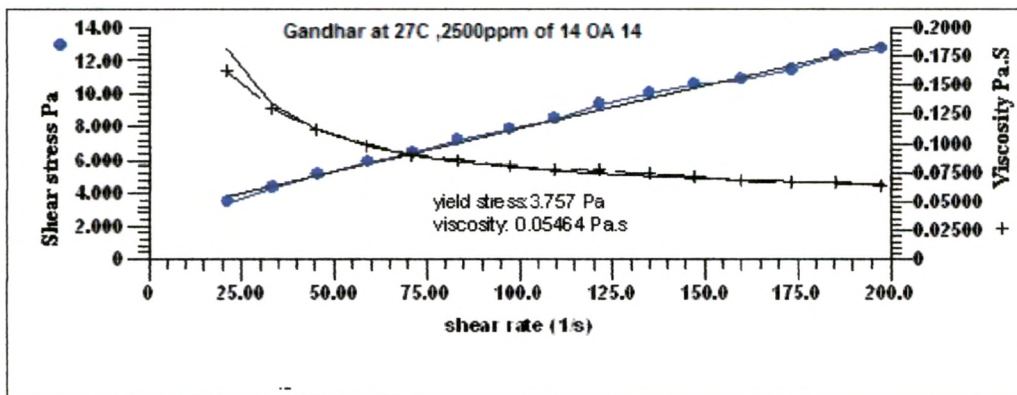


Fig 97 Gandhar with 2500ppm of 14 OA 14

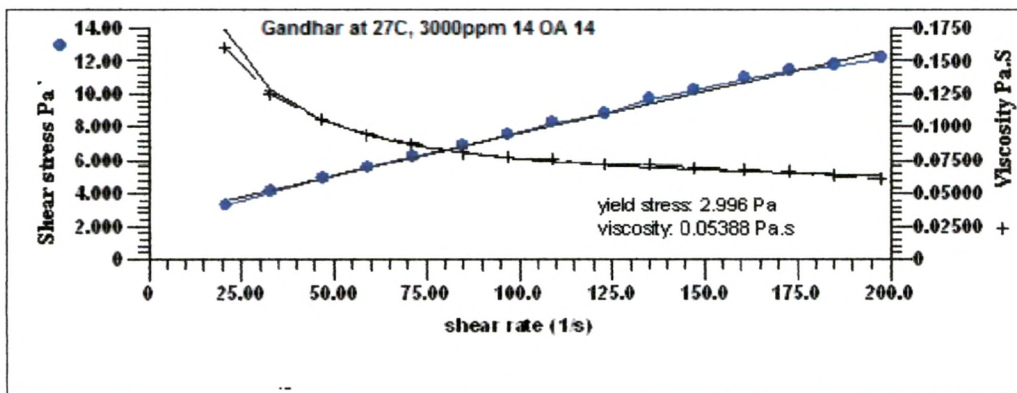


Fig 98 Gandhar with 3000ppm of 14 OA 14

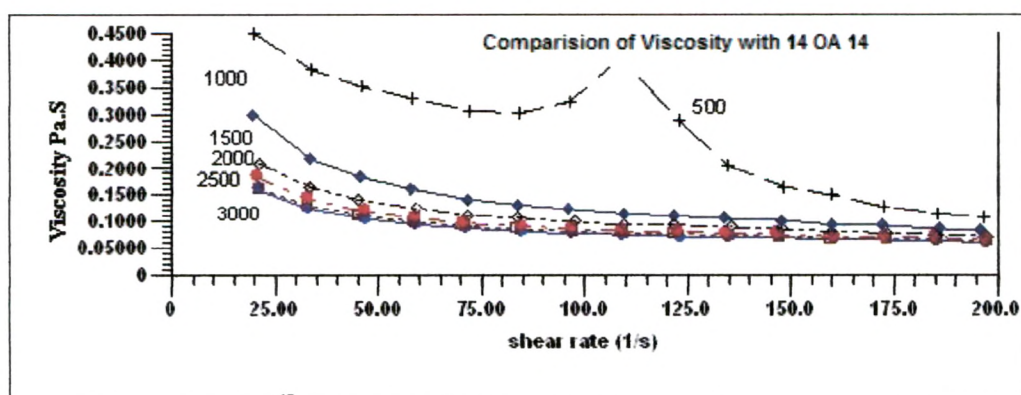


Fig 99 Comparison of Gandhar viscosity with doses of 14 OA 14

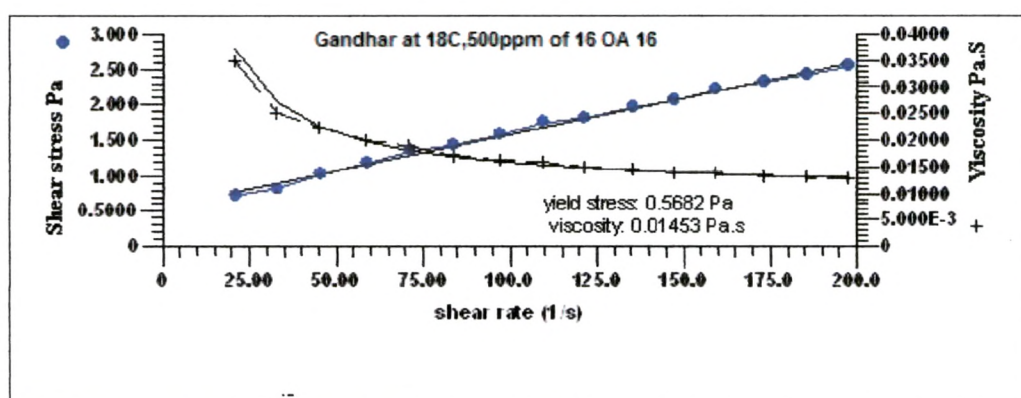


Fig 100 Gandhar with 500ppm of 16 OA 16

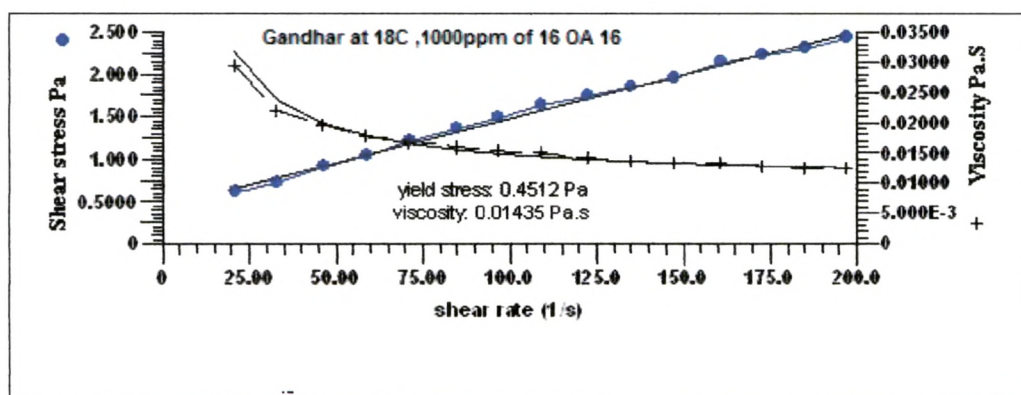


Fig 101 Gandhar with 1000ppm of 16 OA 16

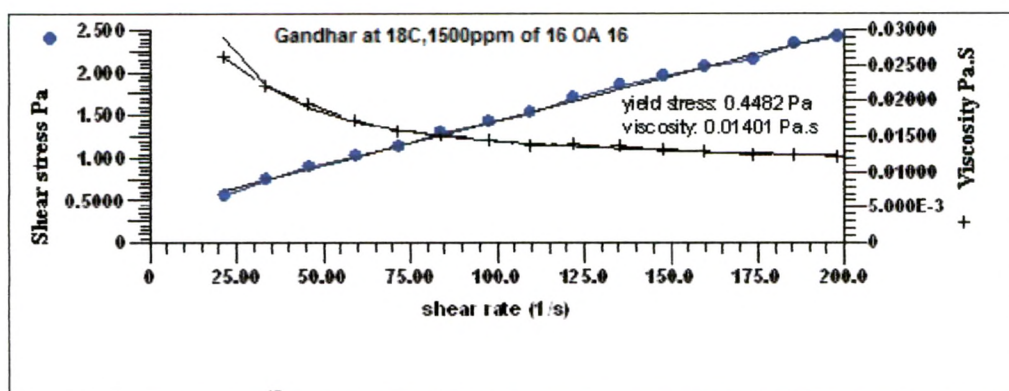


Fig 102 Gandhar with 1500ppm of 16 OA 16

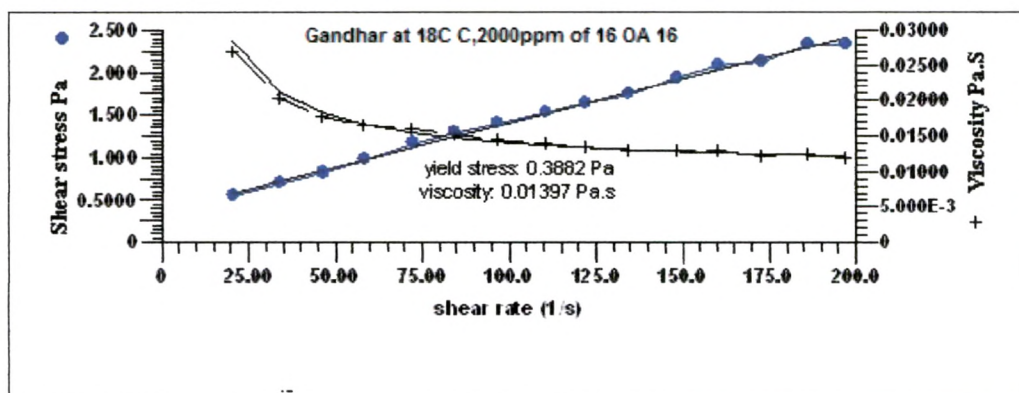


Fig 103 Gandhar with 2000ppm of 16 OA 16

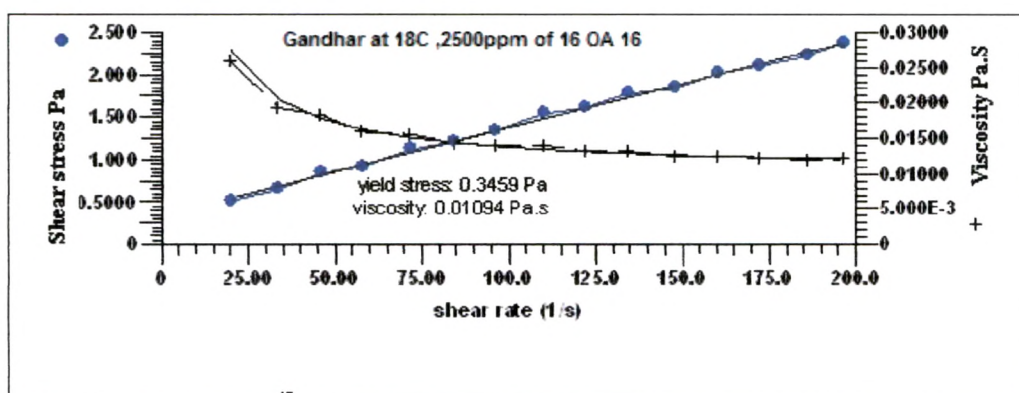


Fig 104 Gandhar with 2500ppm of 16 OA 16

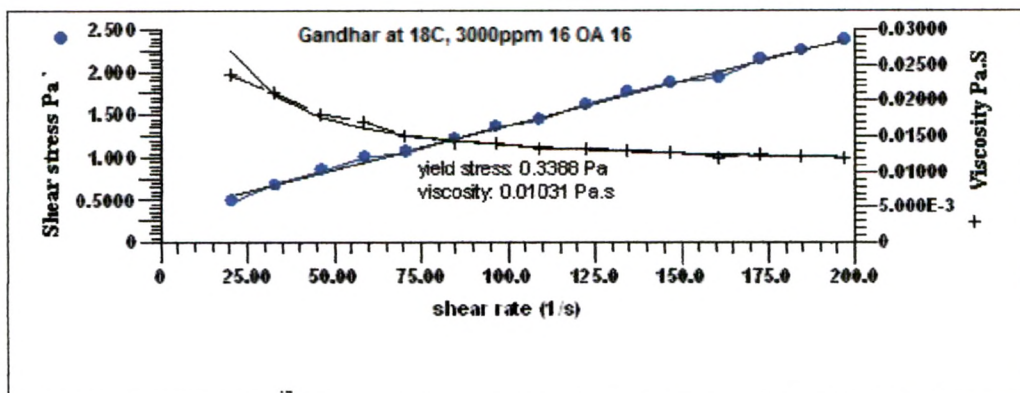


Fig 105 Gandhar with 3000ppm of 16 OA 16

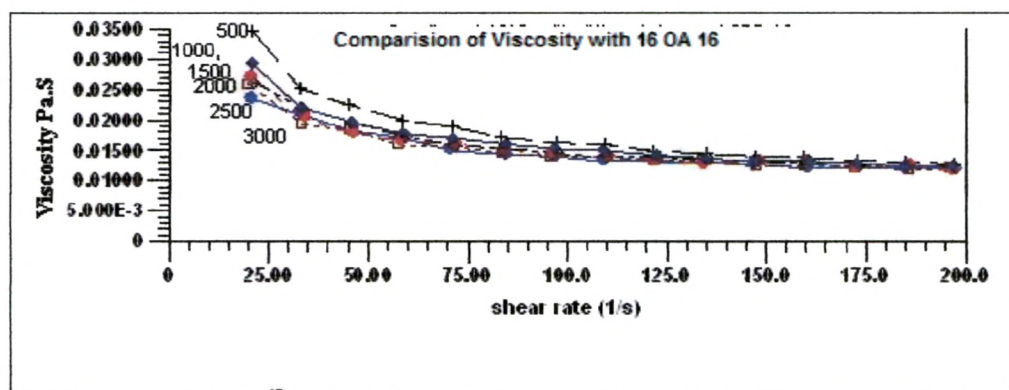


Fig 106 Comparison of Gandhar viscosity with doses of 16 OA 16

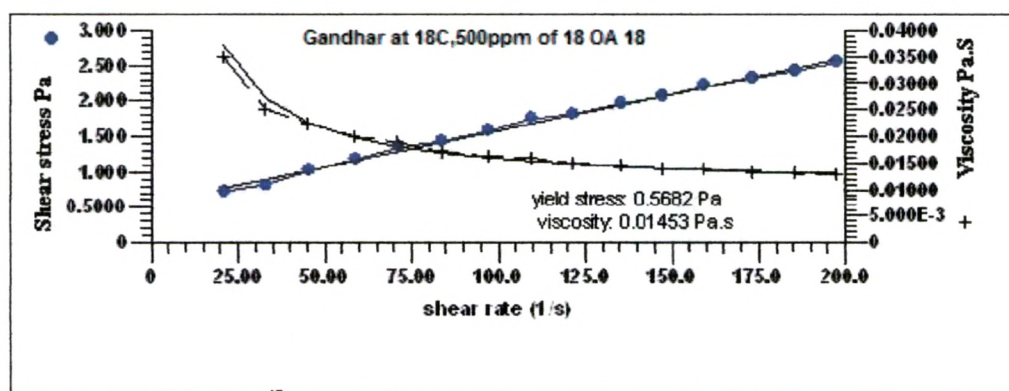


Fig 107 Gandhar with 500ppm of 18 OA 18

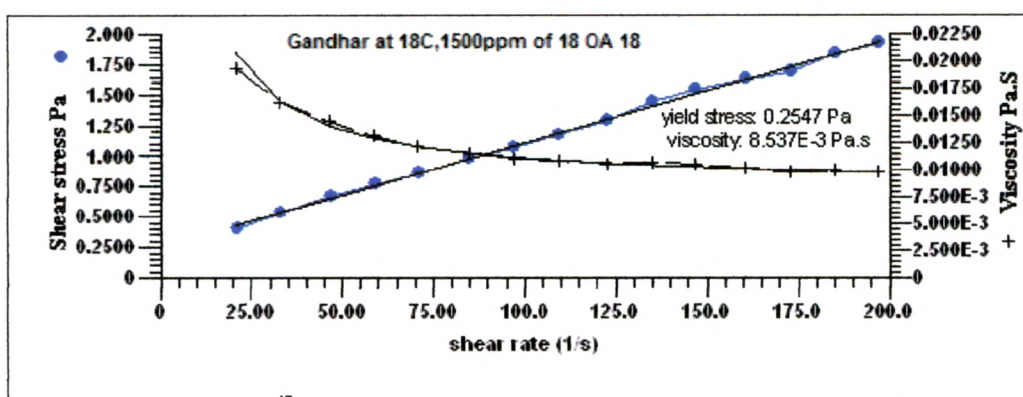


Fig 108 Gandhar with 1500ppm of 18 OA 18

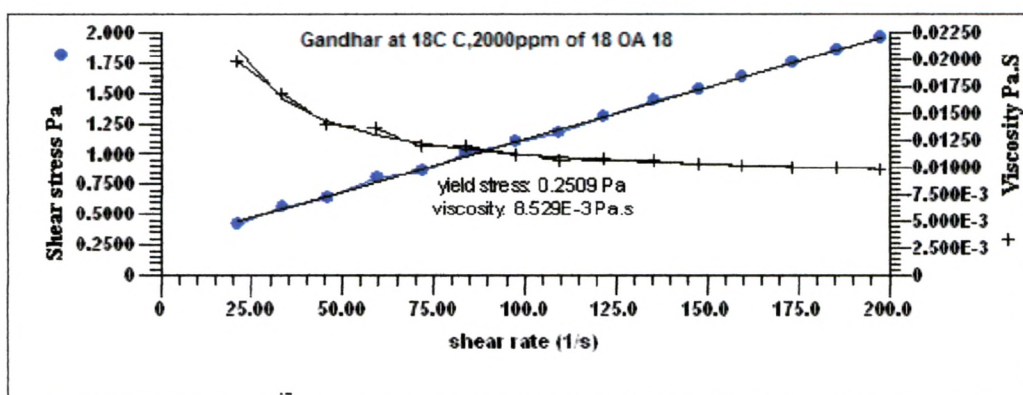


Fig 109 Gandhar with 2000ppm of 18 OA 18

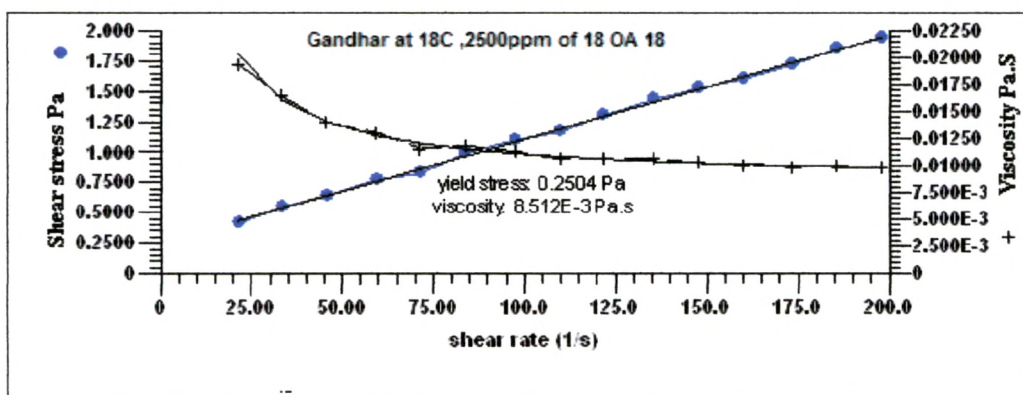


Fig 110 Gandhar with 2500ppm of 18 OA 18

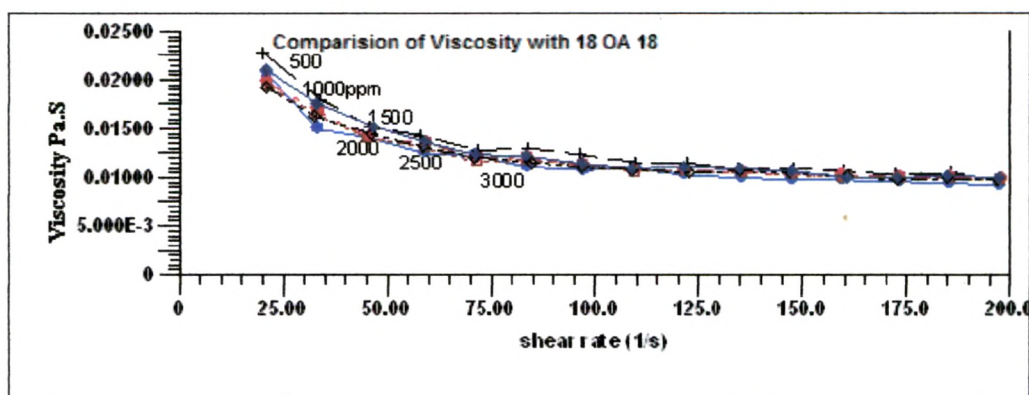


Fig 111 Comparision of Gandhar viscosity with doses of 18 OA 18

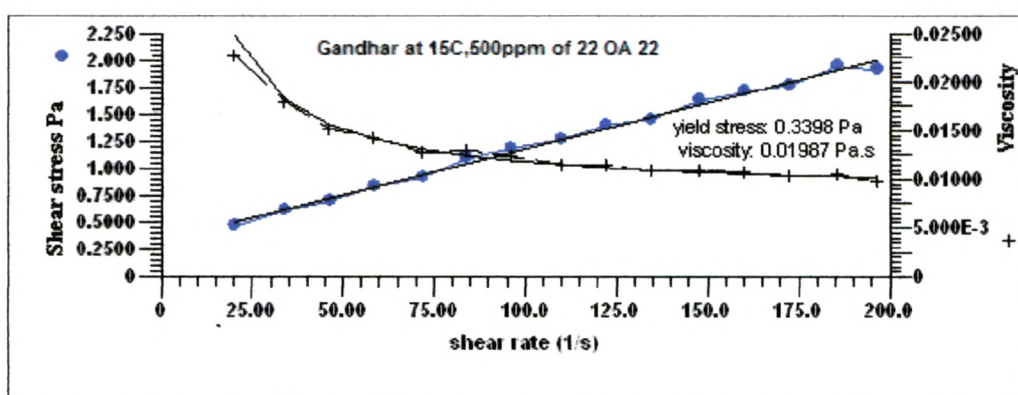


Fig 112 Gandhar with 500ppm of 22 OA 22

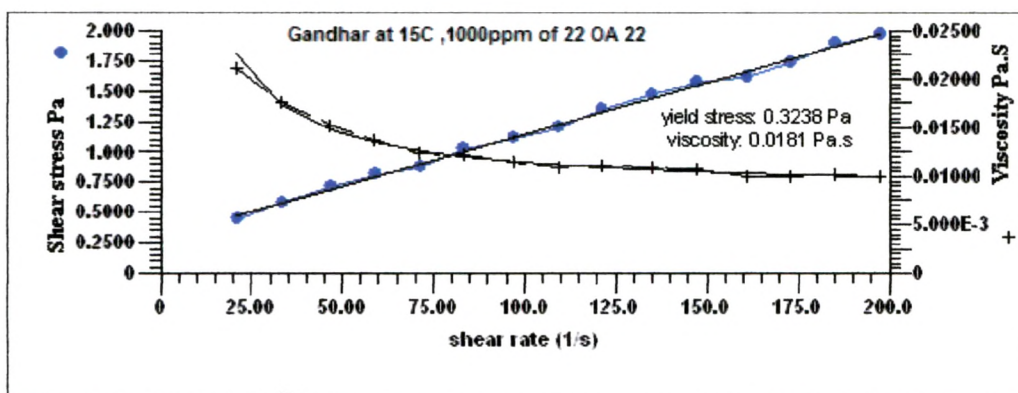


Fig 113 Gandhar with 1000ppm of 22 OA 22

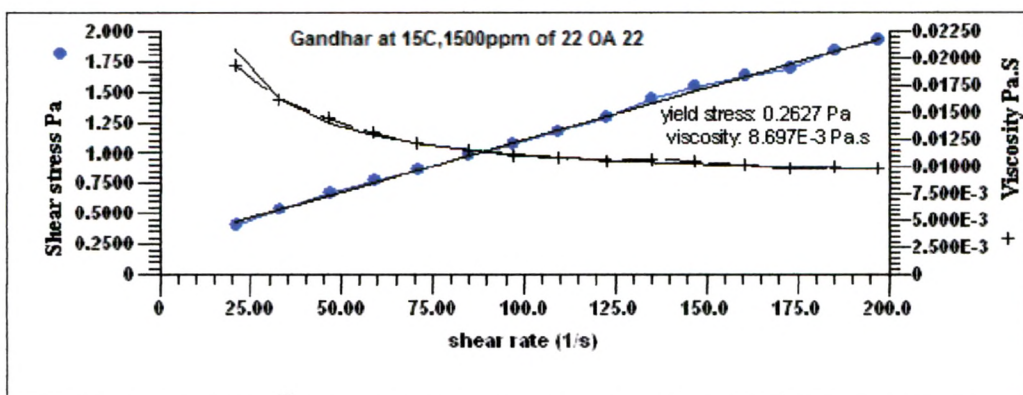


Fig 114 Gandhar with 1500ppm of 22 OA 22

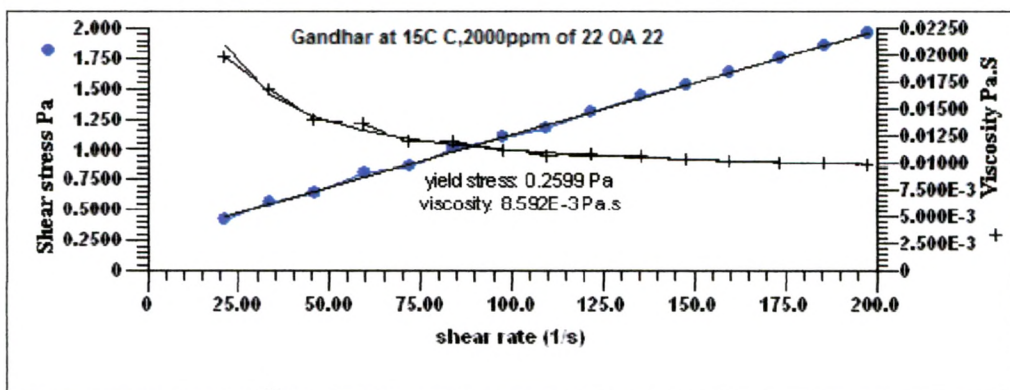


Fig 115 Gandhar with 2000ppm of 22 OA 22

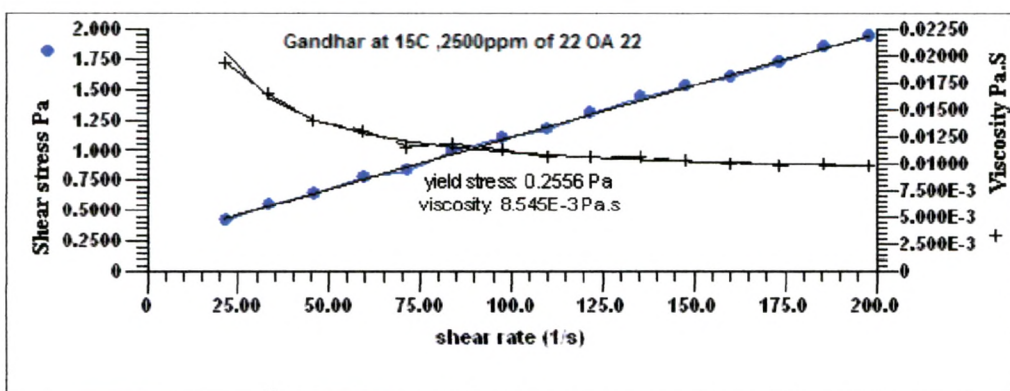


Fig 116 Gandhar with 2500ppm of 22 OA 22

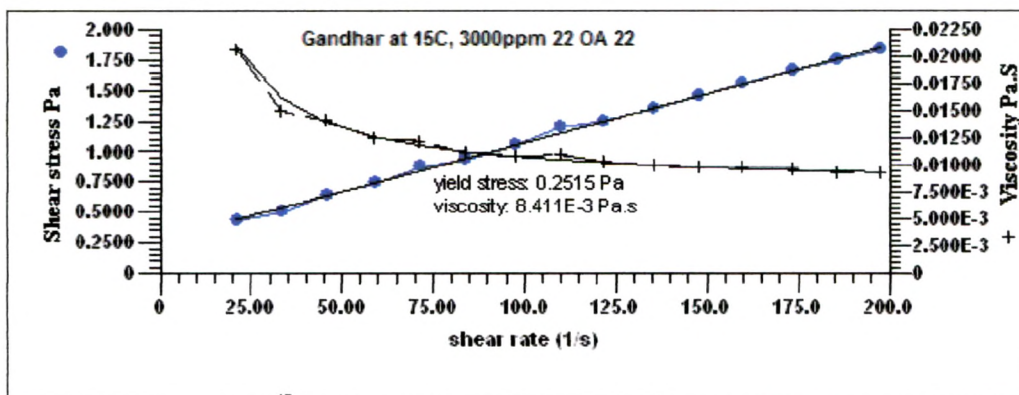


Fig 117 Gandhar with 3000ppm of 22 OA 22

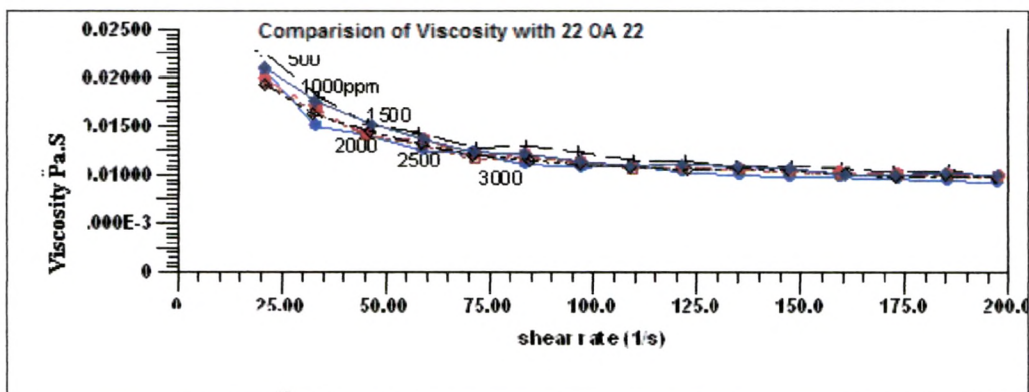


Fig 118 Comparision of Gandhar viscosity with doses of 22 OA 22

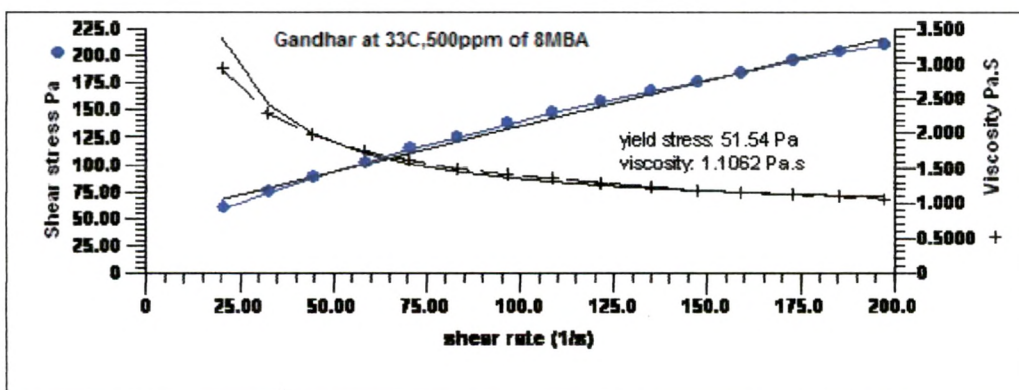


Fig 119 Gandhar with 500ppm of 8 MBA

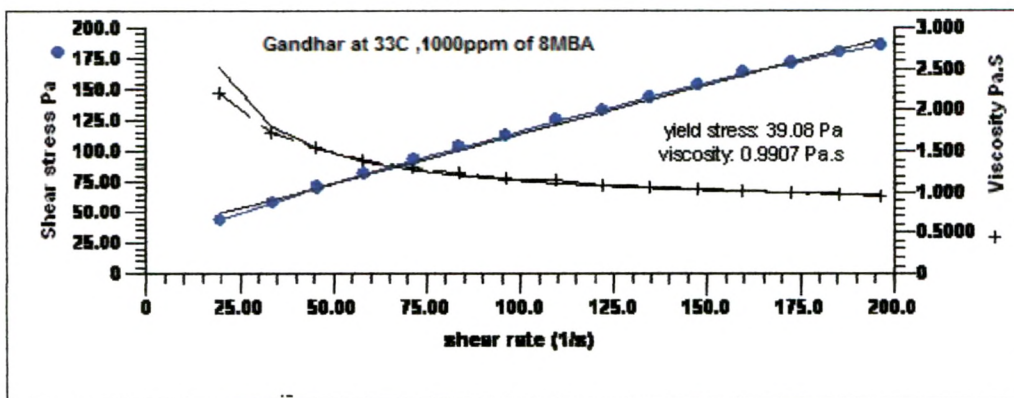


Fig 120 Gandhar with 1000ppm of 8 MBA

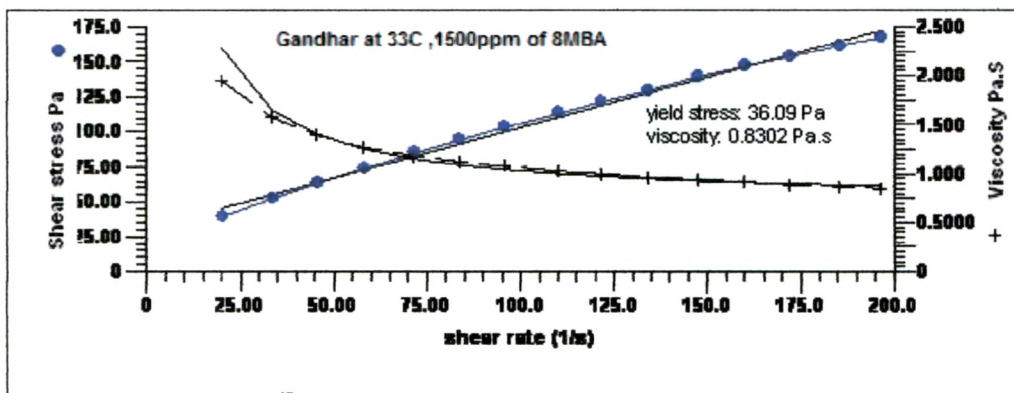


Fig 121 Gandhar with 1500ppm of 8 MBA

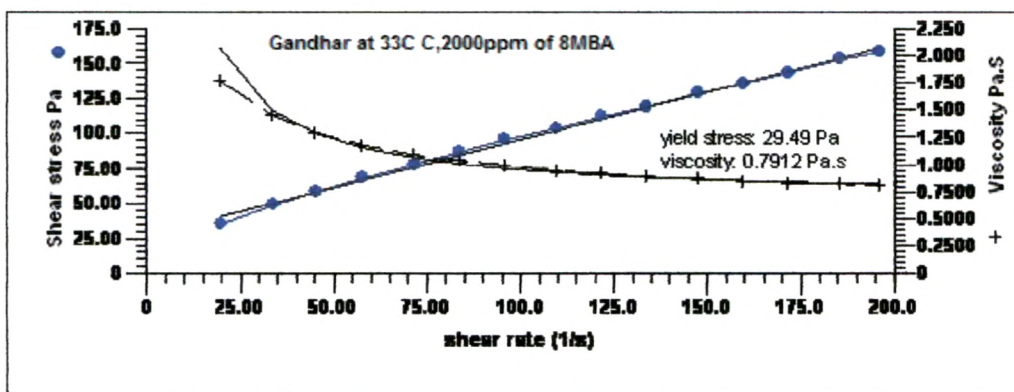


Fig 122 Gandhar with 2000ppm of 8 MBA

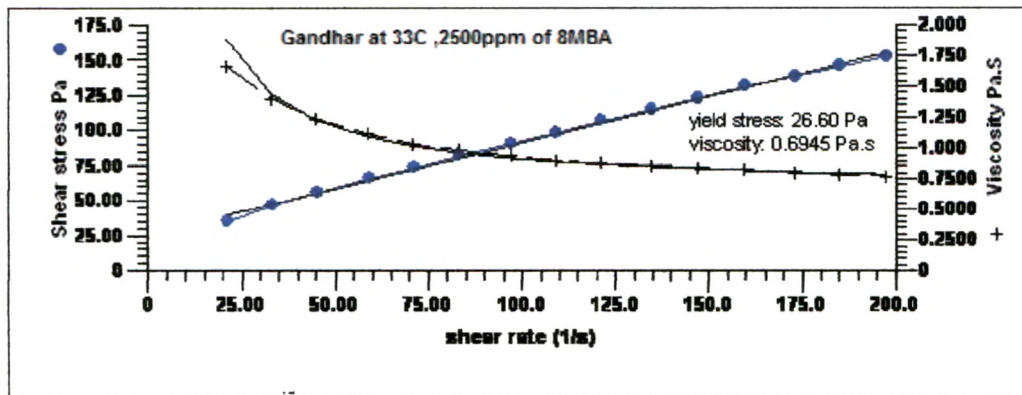


Fig 123 Gandhar with 2500ppm of 8 MBA

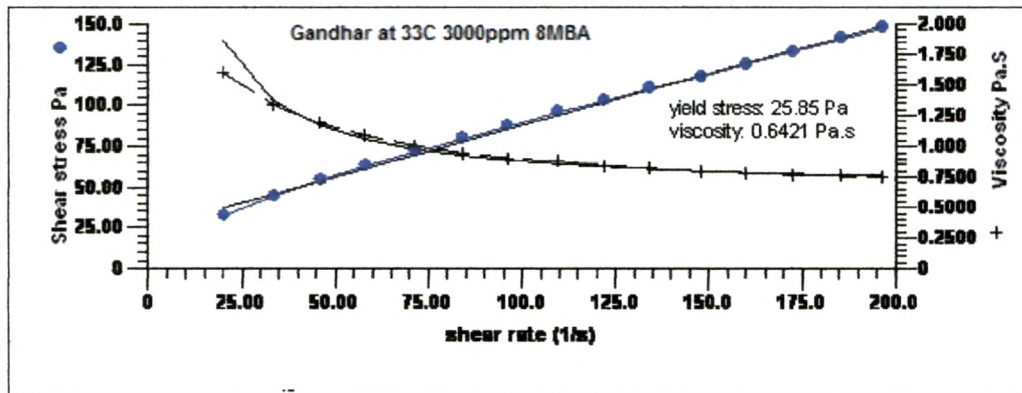


Fig 124 Gandhar with 3000ppm of 8 MBA

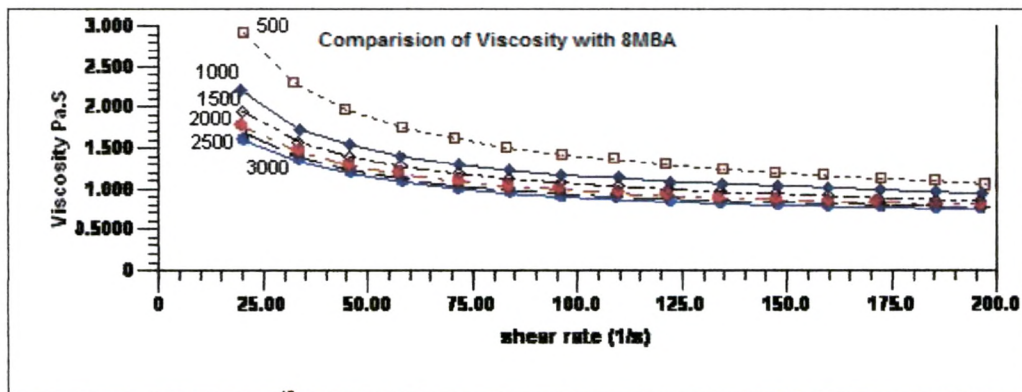


Fig 125 Comparision of Gandhar viscosity with doses of 8 MBA

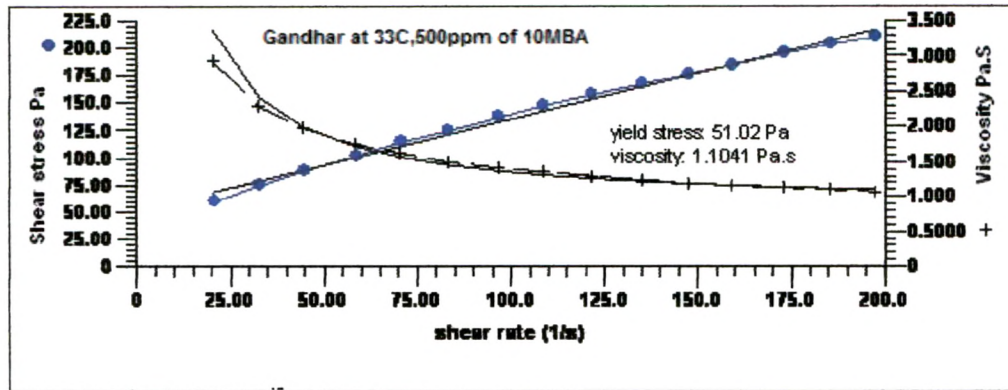


Fig 126 Gandhar with 500ppm of 10 MBA

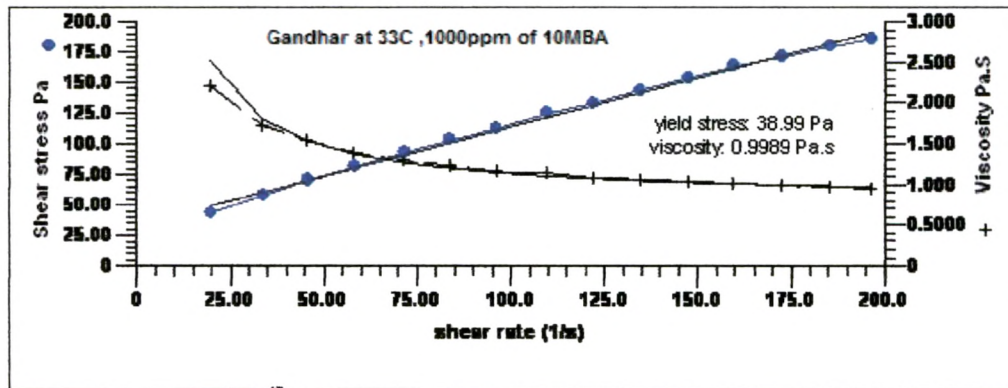


Fig 127 Gandhar with 1000ppm of 10 MBA

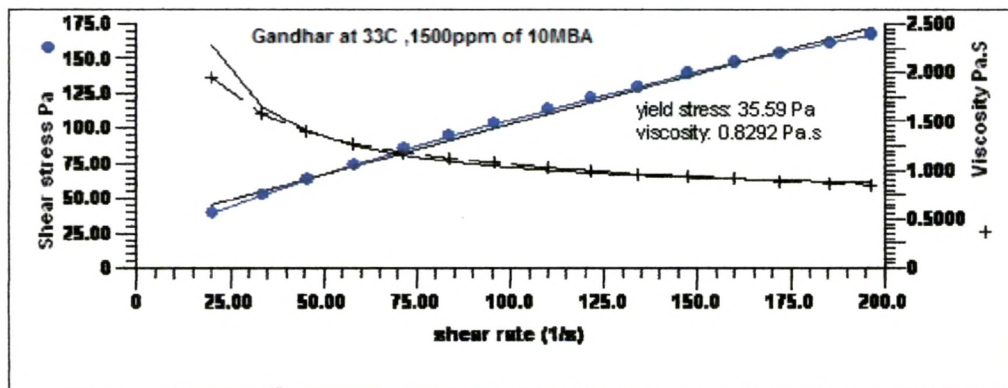


Fig 128 Gandhar with 1500ppm of 10 MBA

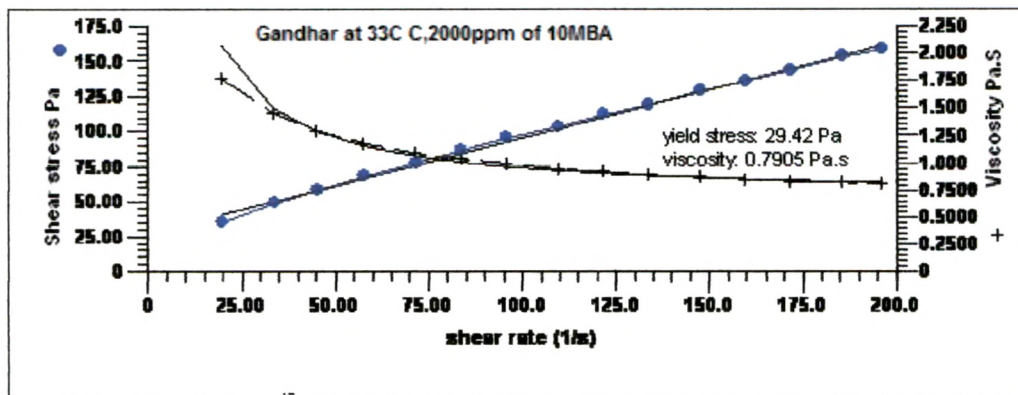


Fig 129 Gandhar with 2000ppm of 10 MBA

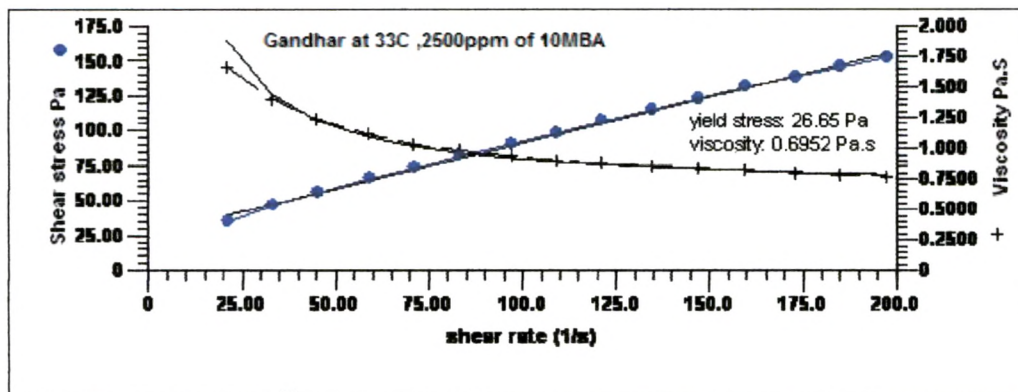


Fig 130 Gandhar with 2500ppm of 10 MBA

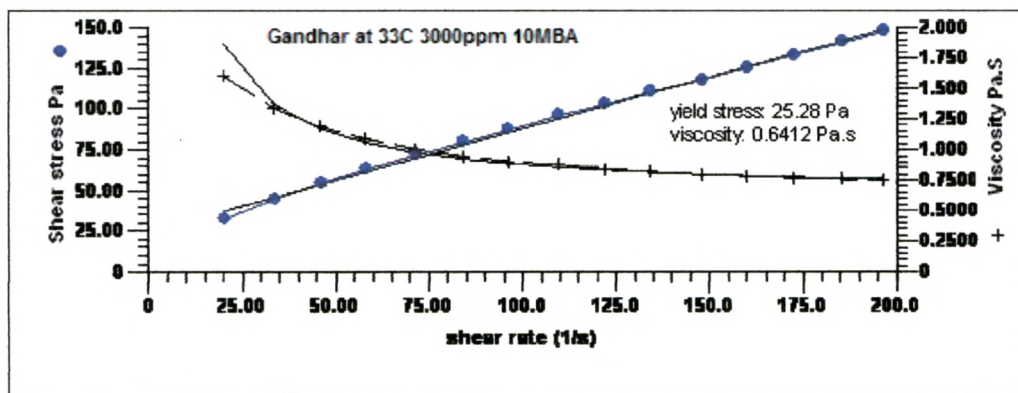


Fig 131 Gandhar with 3000ppm of 10 MBA

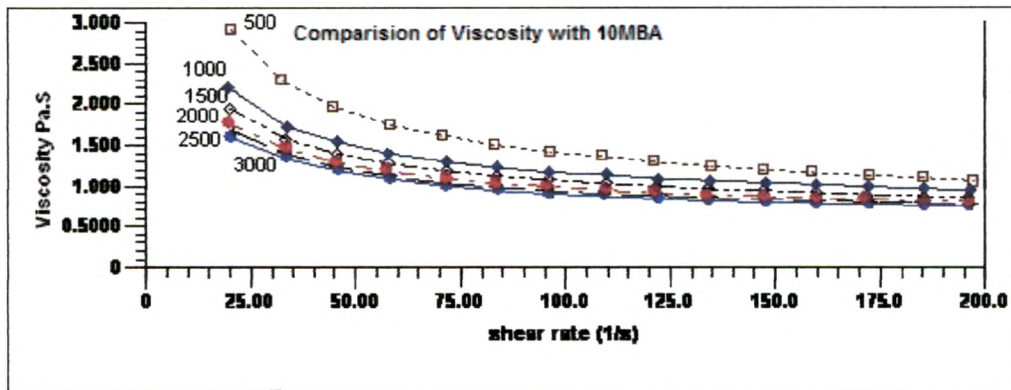


Fig 132 Comparison of Gandhar viscosity with doses of 10 MBA

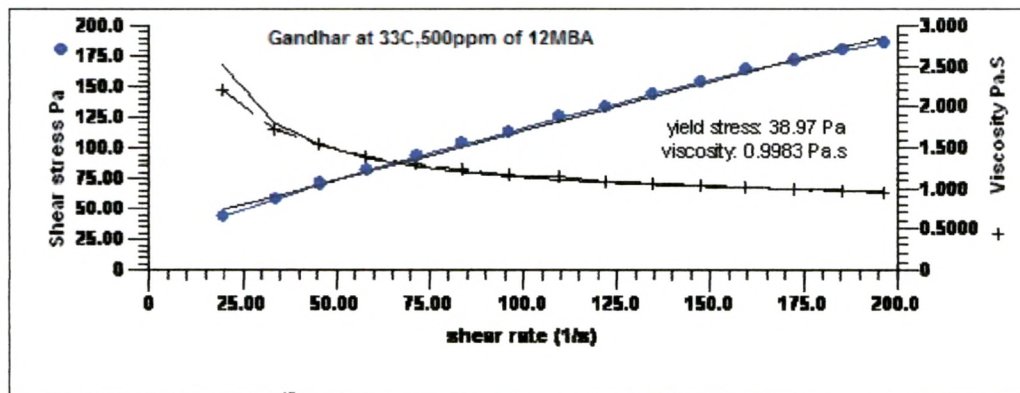


Fig 133 Gandhar with 500ppm of 12 MBA

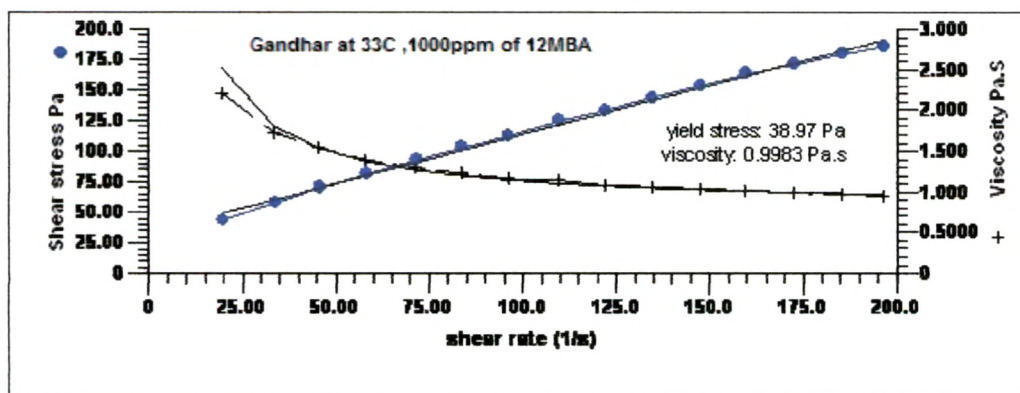


Fig 134 Gandhar with 1000ppm of 12 MBA

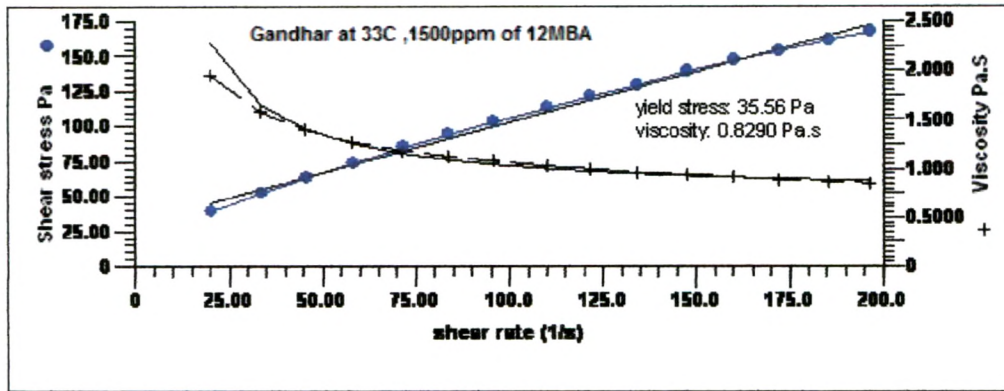


Fig 135 Gandhar with 1500ppm of 12 MBA

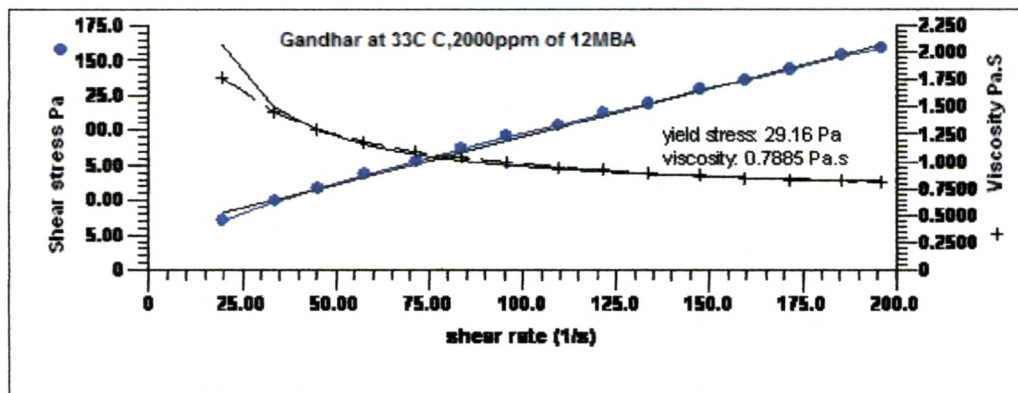


Fig 136 Gandhar with 2000ppm of 12 MBA

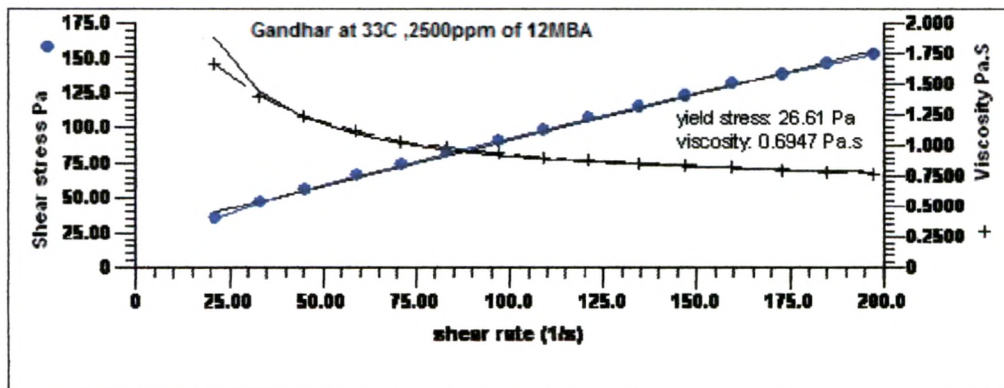


Fig 137 Gandhar with 2500ppm of 12 MBA

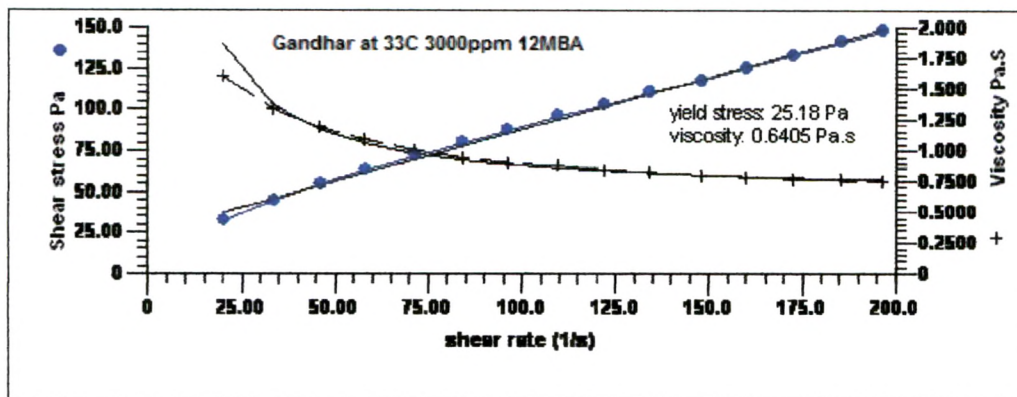


Fig 138 Gandhar with 3000ppm of 12 MBA

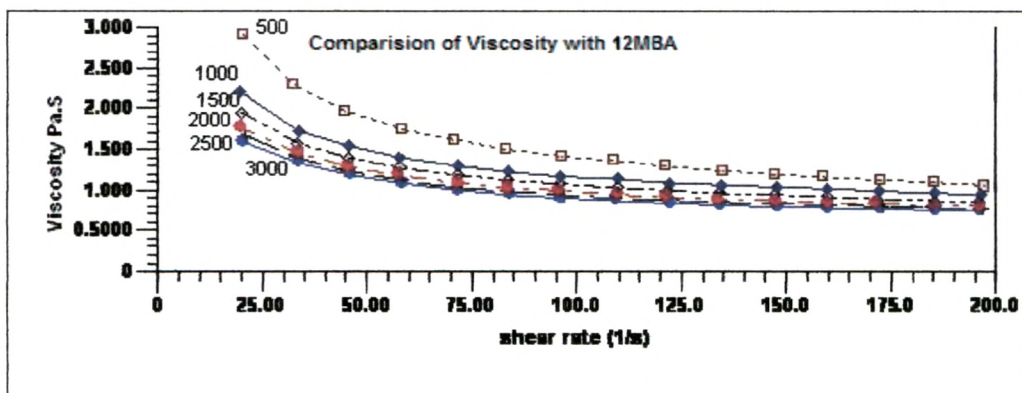


Fig 139 Comparison of Gandhar viscosity with doses of 12 MBA

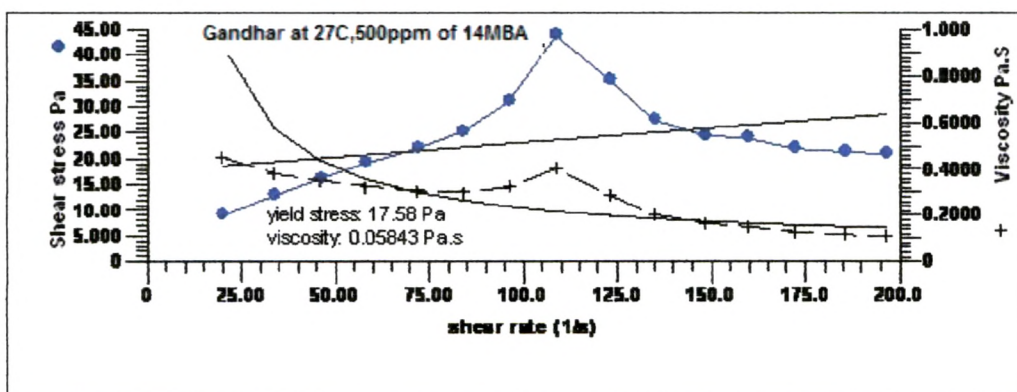


Fig 140 Gandhar with 500ppm of 14 MBA

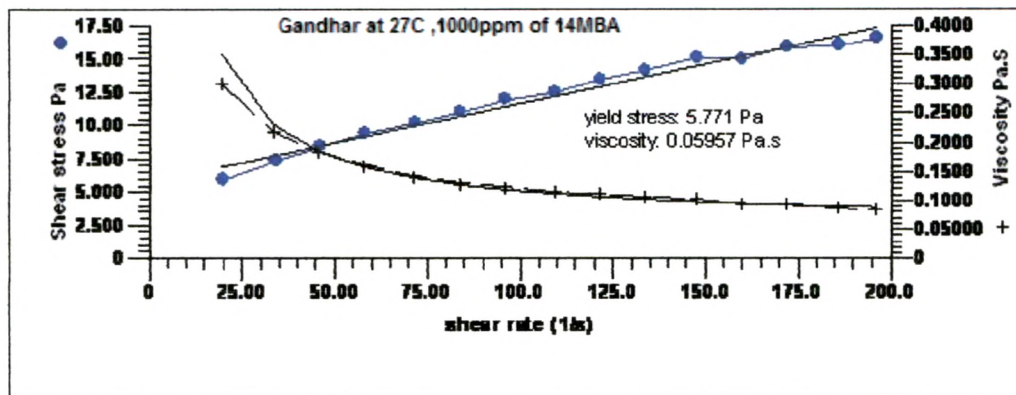


Fig 141 Gandhar with 1000ppm of 14 MBA

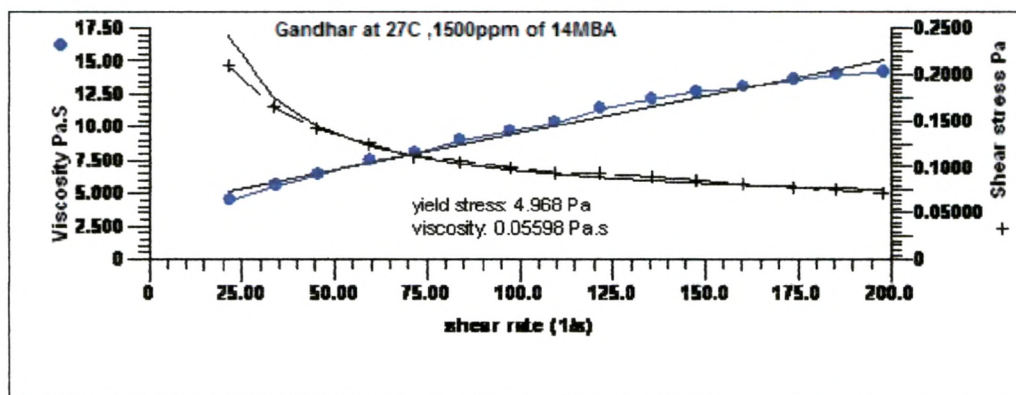


Fig 142 Gandhar with 500ppm of 14 MBA

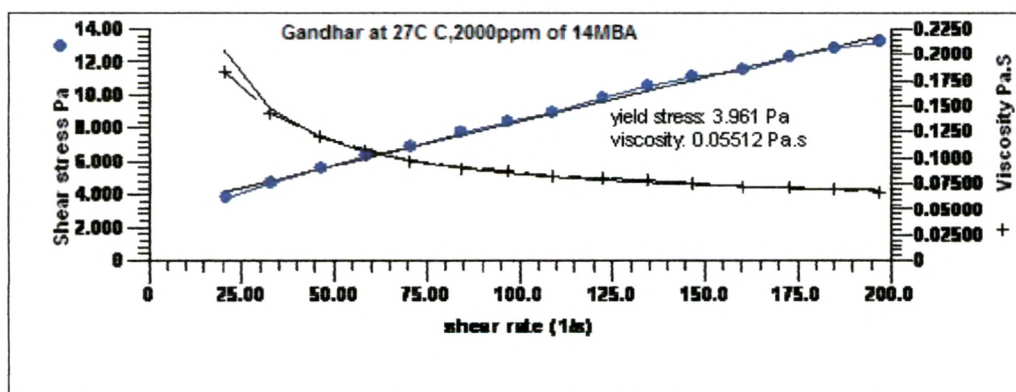


Fig 143 Gandhar with 2000ppm of 14 MBA

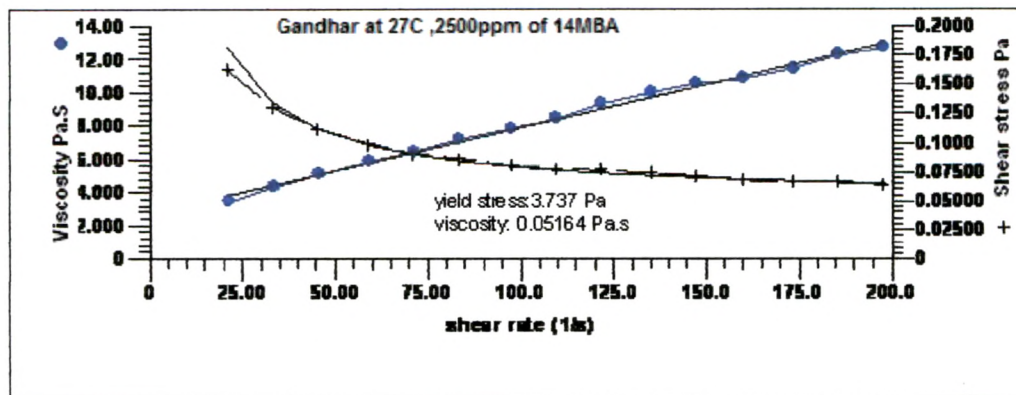


Fig 144 Gandhar with 2500ppm of 14 MBA

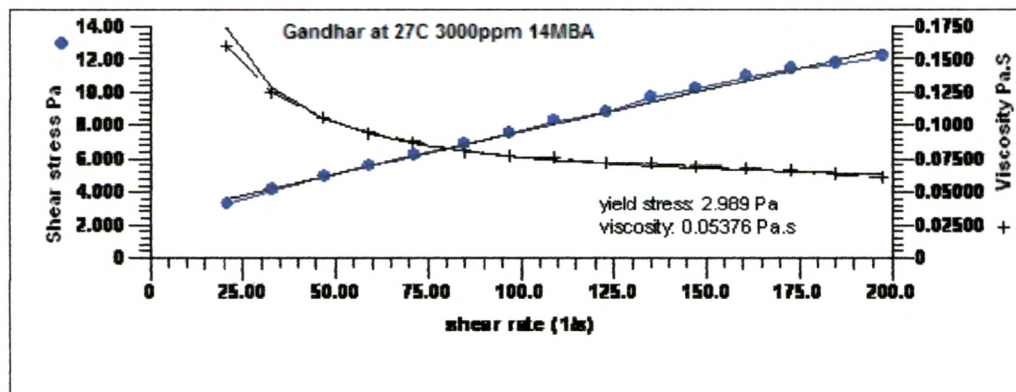


Fig 145 Gandhar with 3000ppm of 14 MBA

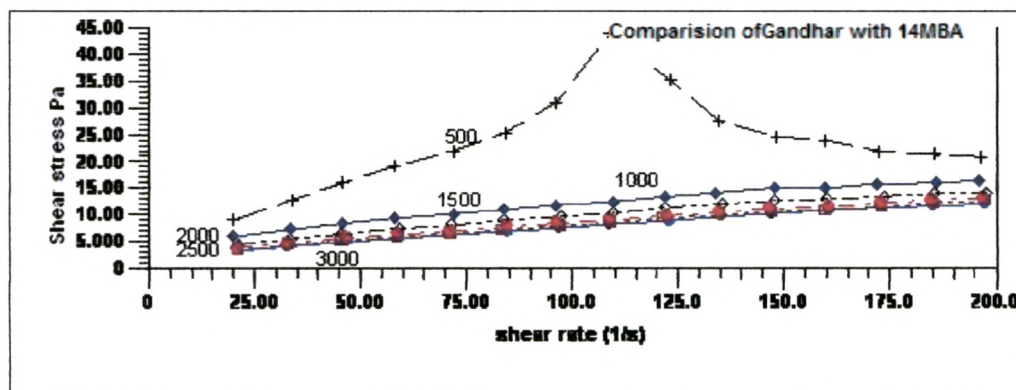


Fig 146 Comparison of Gandhar Behaviour with doses of 14 MBA

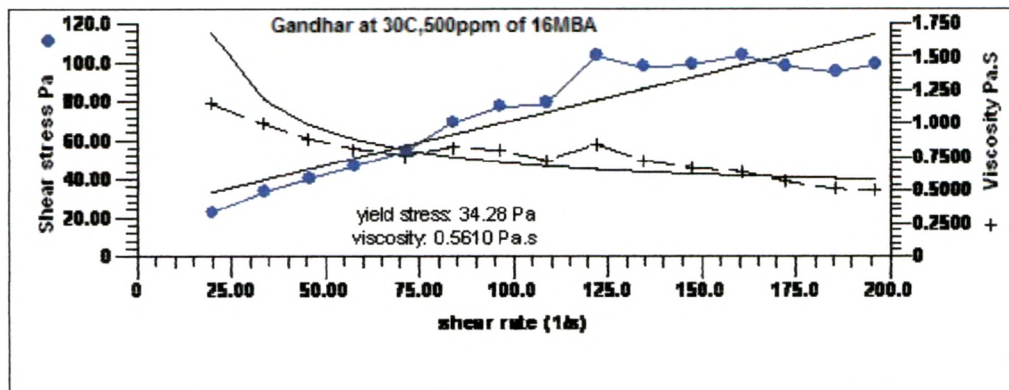


Fig 147 Gandhar with 500ppm of 16 MBA

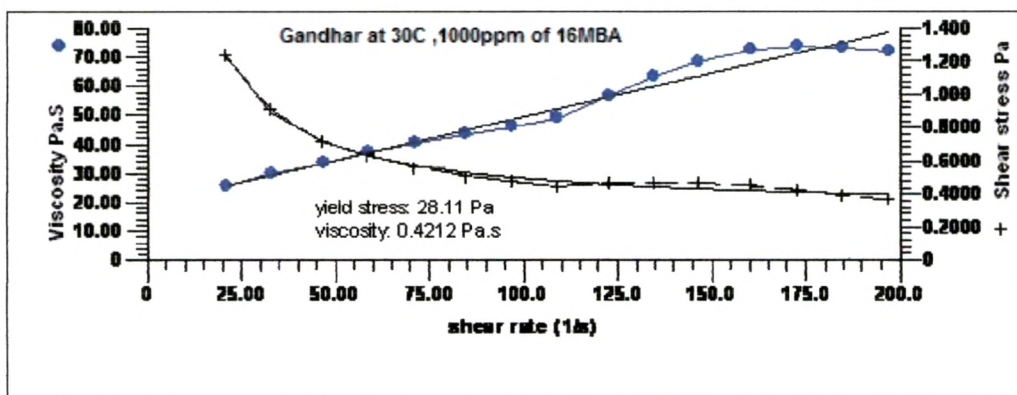


Fig 148 Gandhar with 1000ppm of 16 MBA

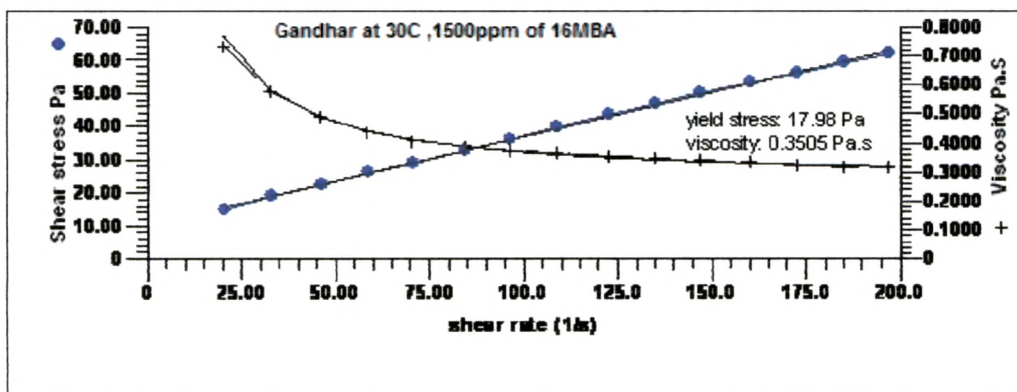


Fig 149 Gandhar with 1500ppm of 16 MBA

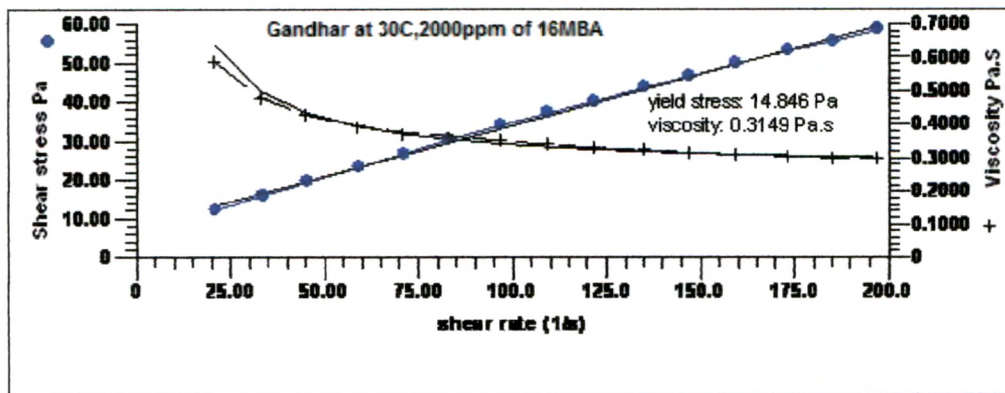


Fig 150 Gandhar with 2000ppm of 16 MBA

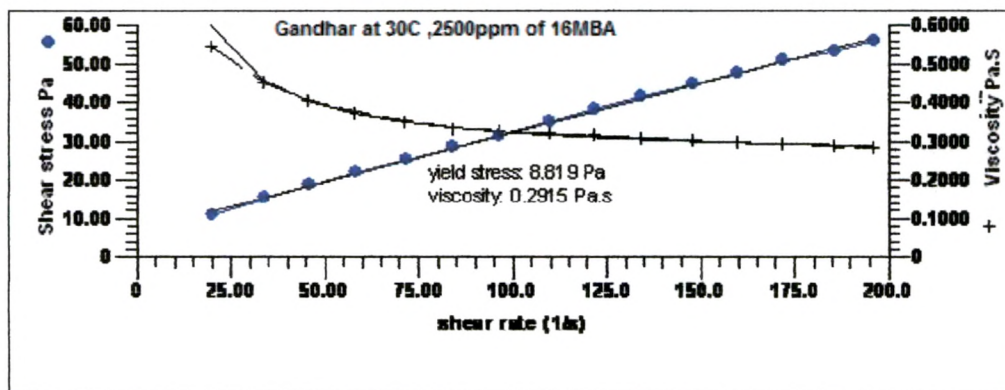


Fig 151 Gandhar with 2500ppm of 16 MBA

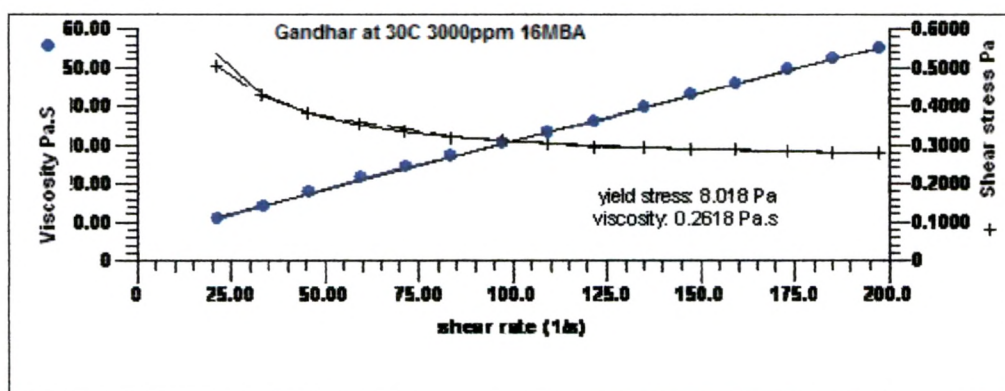


Fig 152 Gandhar with 3000ppm of 16 MBA

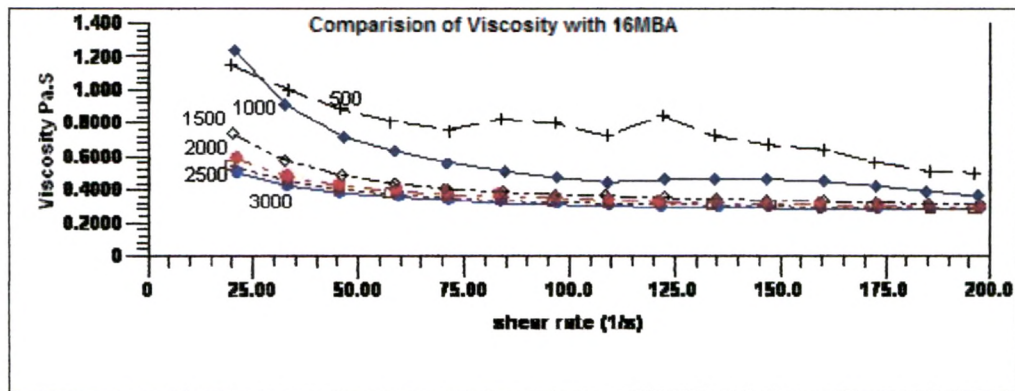


Fig 153 Viscosity comparison of Gandhar with doses of 16 MBA

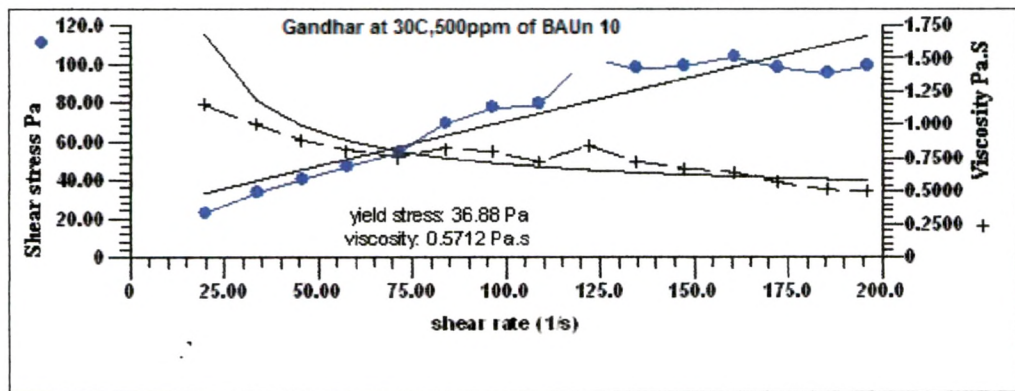


Fig 154 Gandhar with 500ppm of BAUn 10

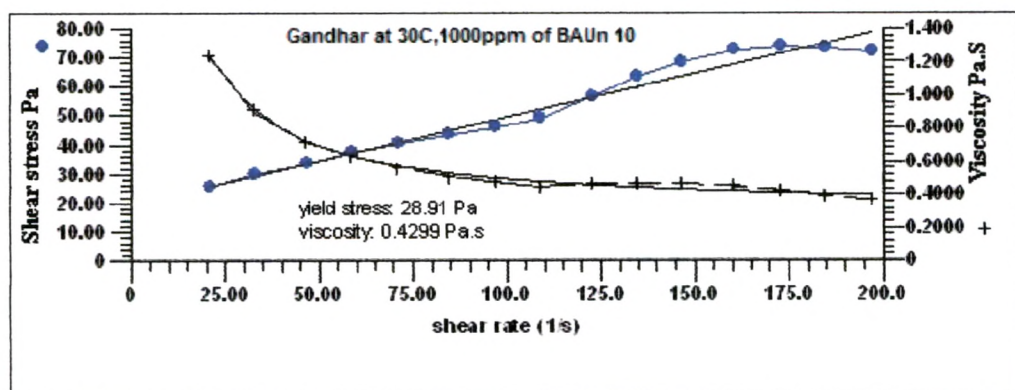


Fig 155 Gandhar with 1000ppm of BAUn 10

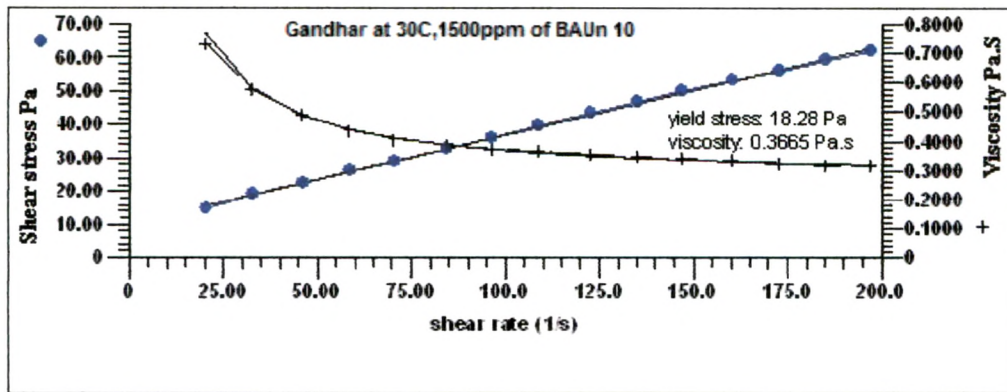


Fig 156 Gandhar with 1500ppm of BAUn 10

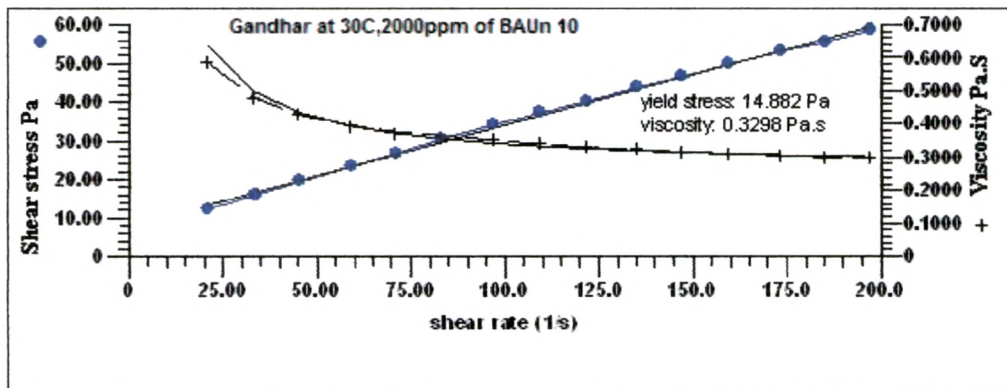


Fig 157 Gandhar with 2000ppm of BAUn 10

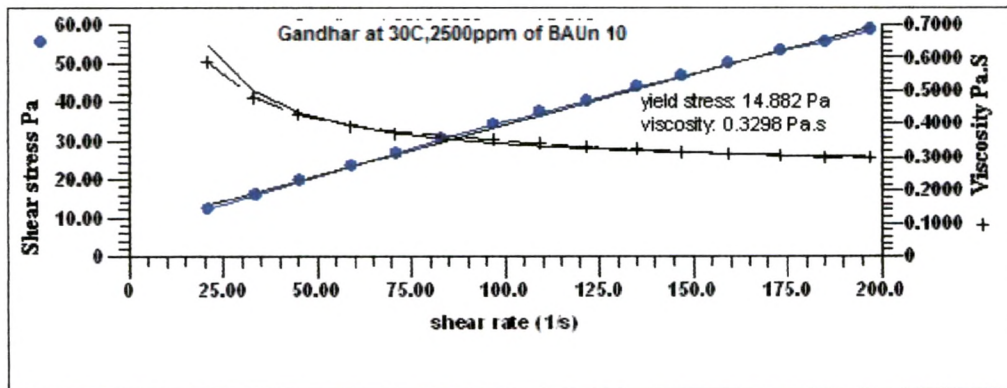


Fig 158 Gandhar with 2500ppm of BAUn 10

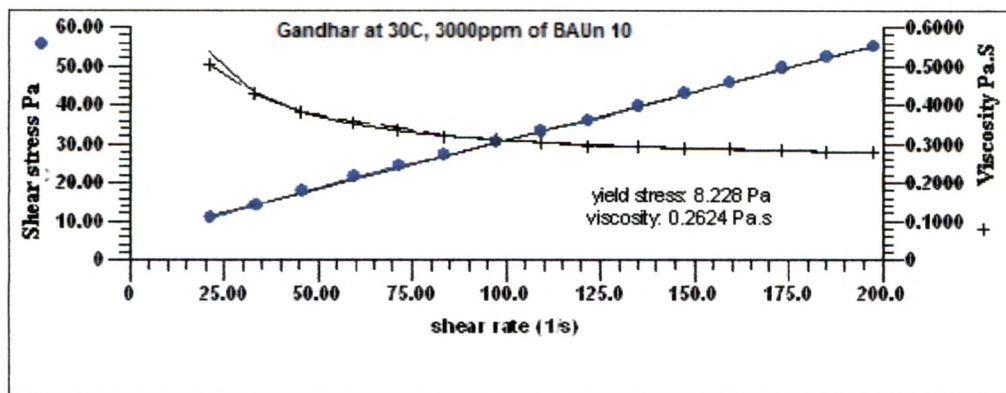


Fig 159 Gandhar with 3000ppm of BAUn 10

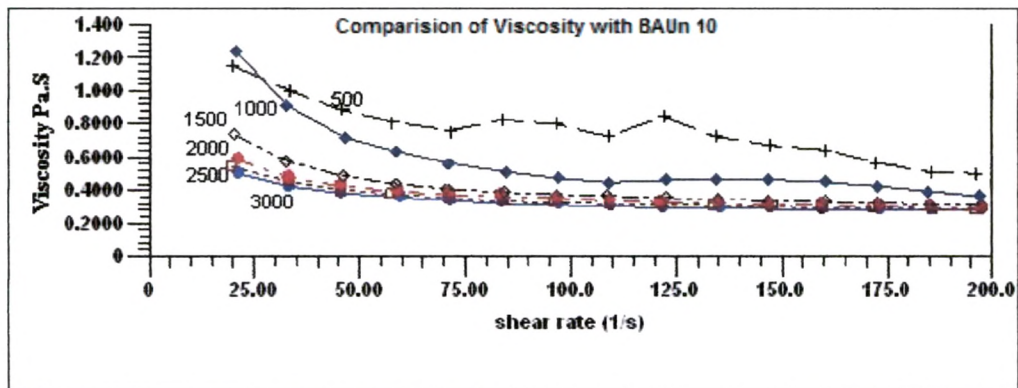


Fig 160 Viscosity comparison of Gandhar with doses of BAUn 10

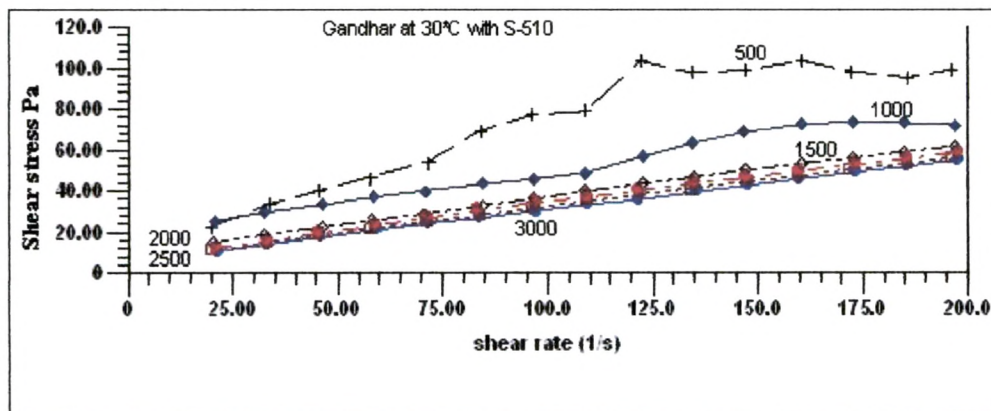


Fig 161 Comparison of Gandhar flow behaviour with doses of BAUn 10

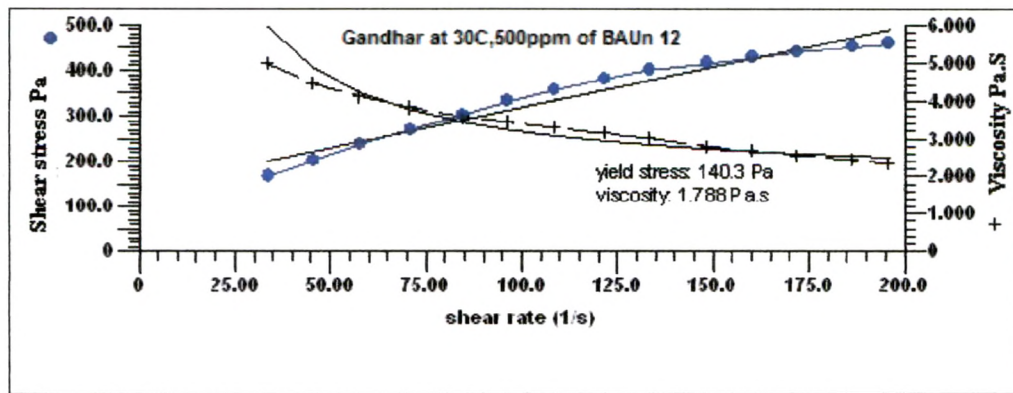


Fig 162 Gandhar with 500ppm of BAUn 12

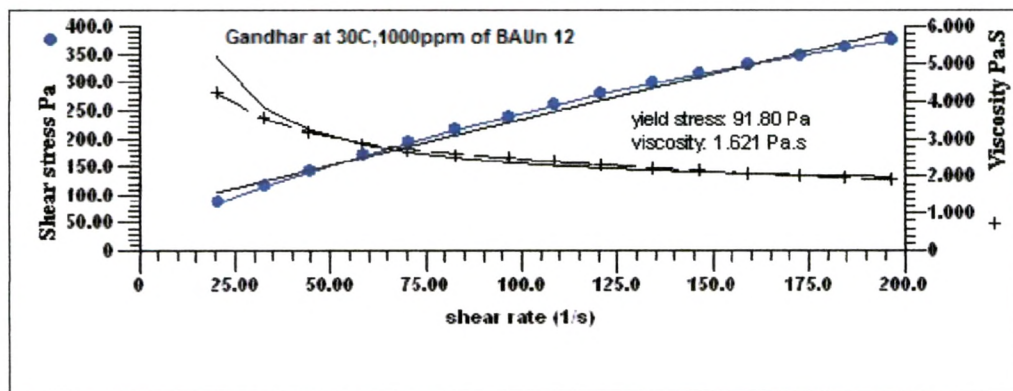


Fig 163 Gandhar with 1000ppm of BAUn 12

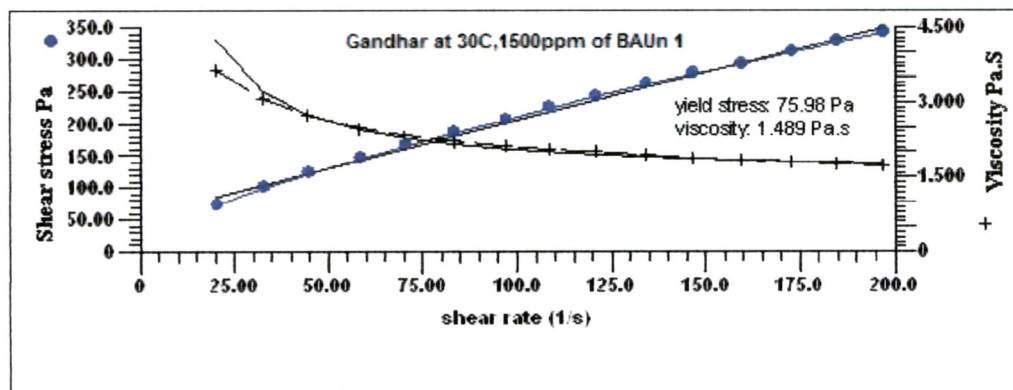


Fig 164 Gandhar with 3000ppm of BAUn 12

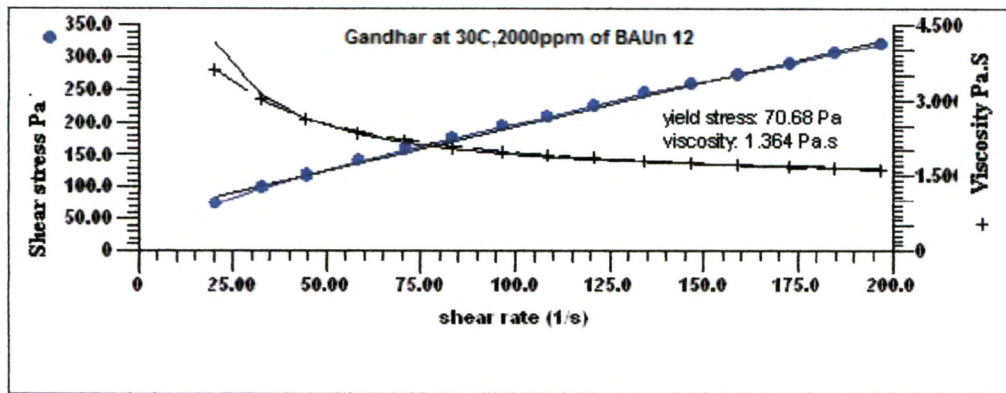


Fig 165 Gandhar with 2000ppm of BAUn 12

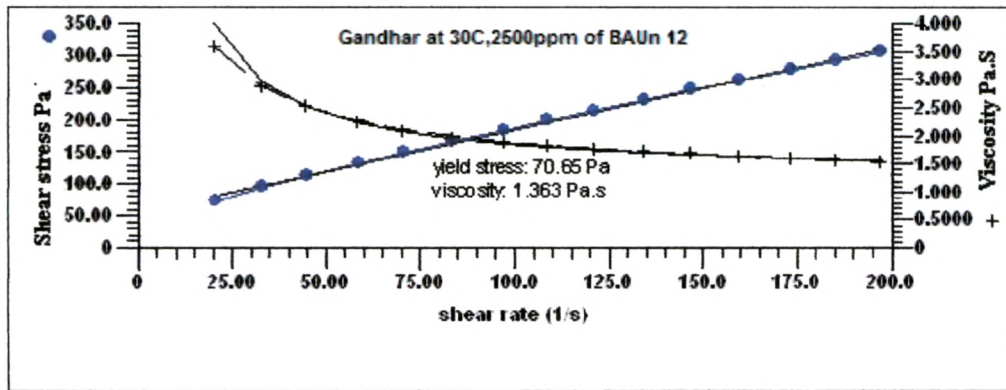


Fig 166 Gandhar with 2500ppm of BAUn 12

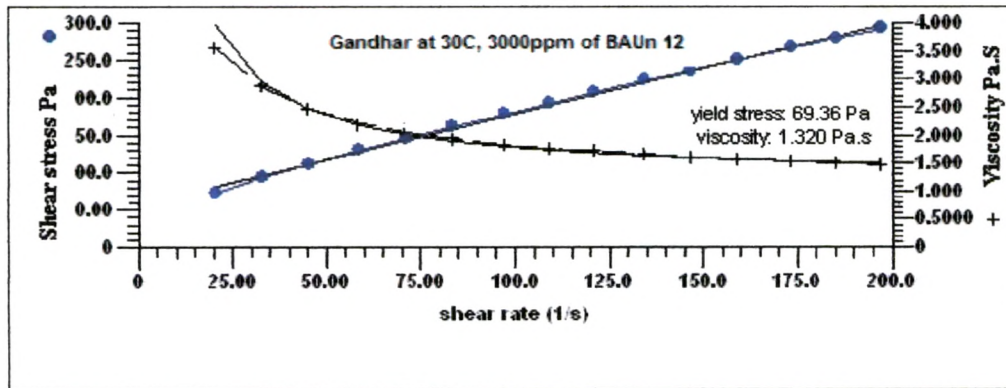


Fig 167 Gandhar with 3000ppm of BAUn 12

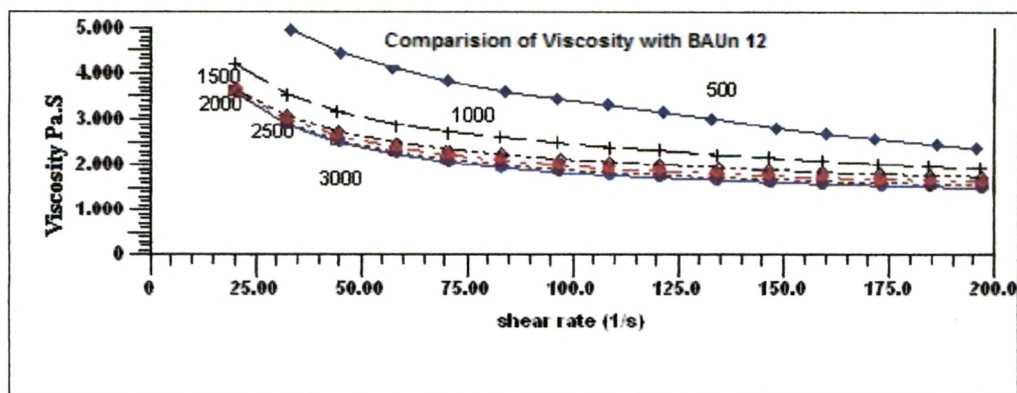


Fig 168 Comparison of viscosity of Gandhar with doses of BAUn 12

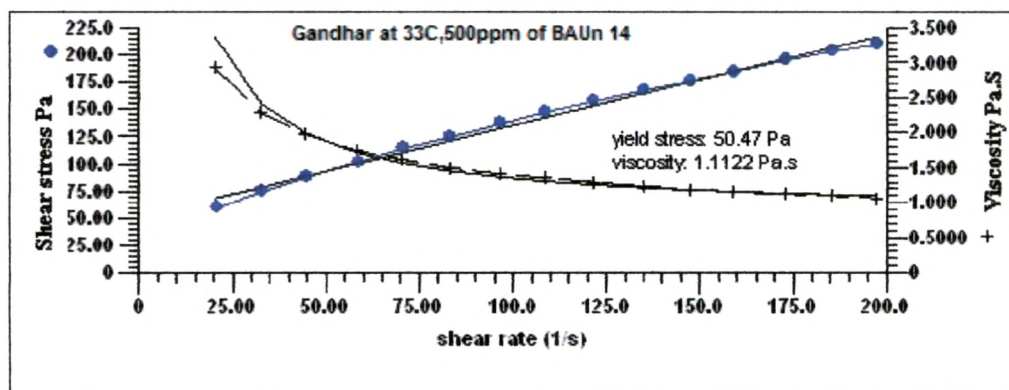


Fig 169 Gandhar with 500ppm of BAUn 14

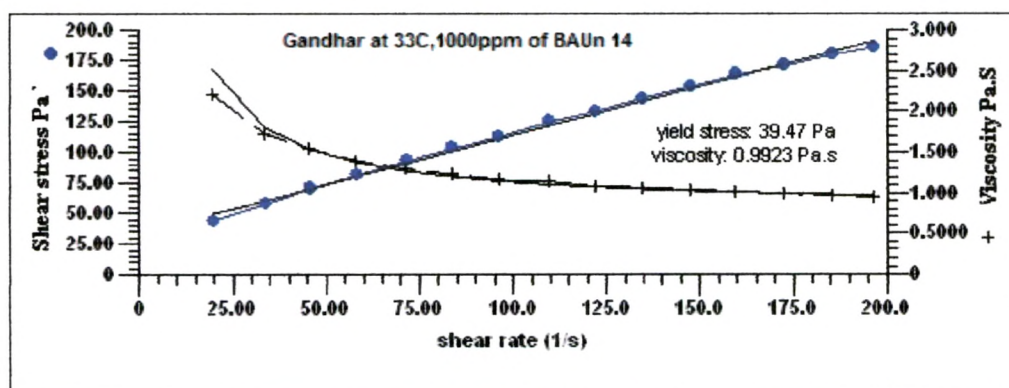


Fig 170 Gandhar with 1000ppm of BAUn 14

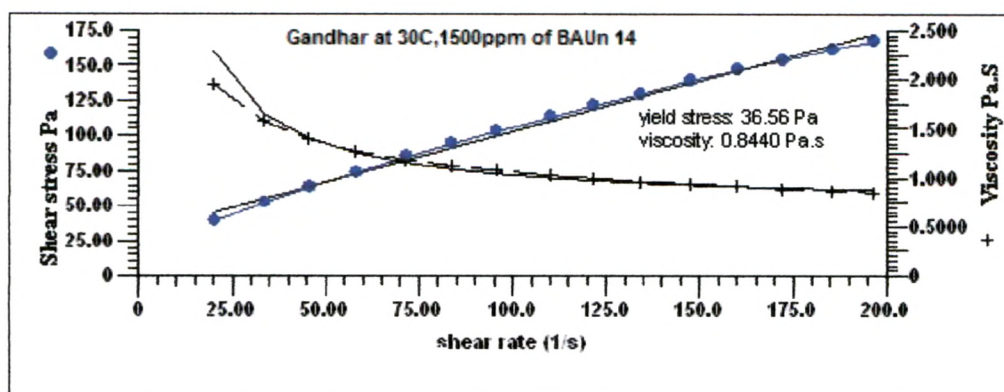


Fig 171 Gandhar with 1500ppm of BAUn 14

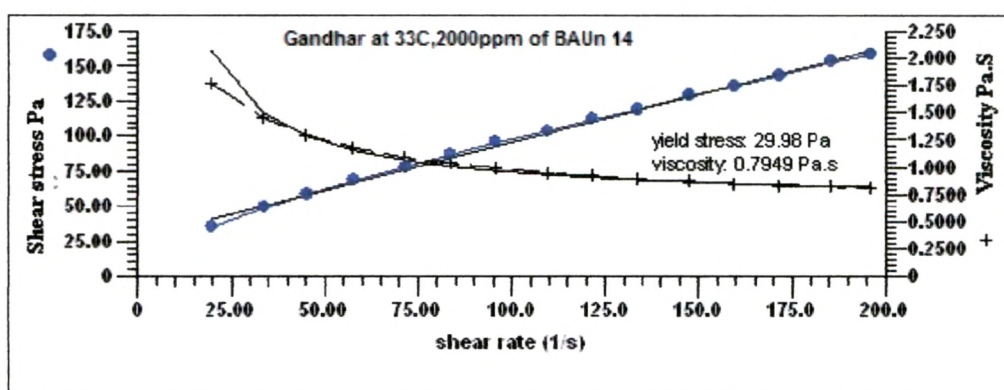


Fig 172 Gandhar with 2000ppm of BAUn 14

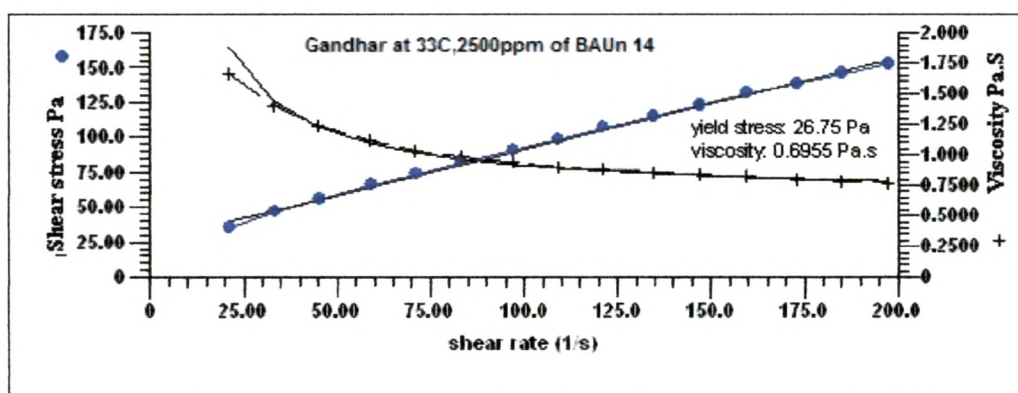


Fig 173 Gandhar with 2500ppm of BAUn 14

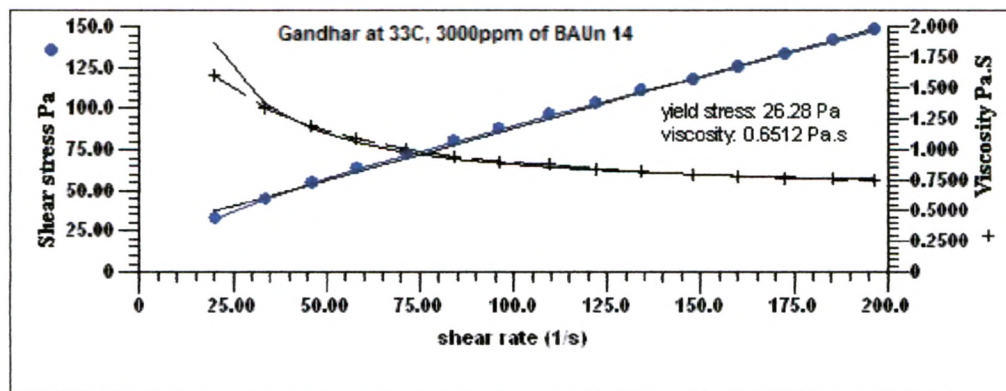


Fig 174 Gandhar with 3000ppm of BAUn 14

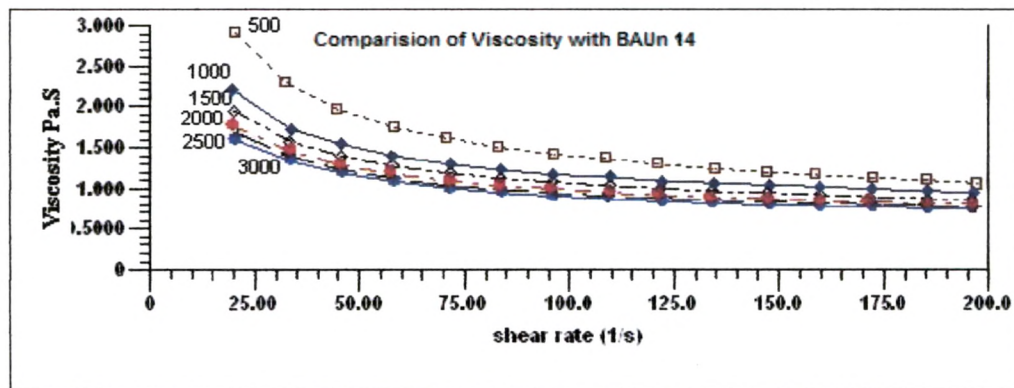


Fig 175 Gandhar viscosity with doses of BAUn 14

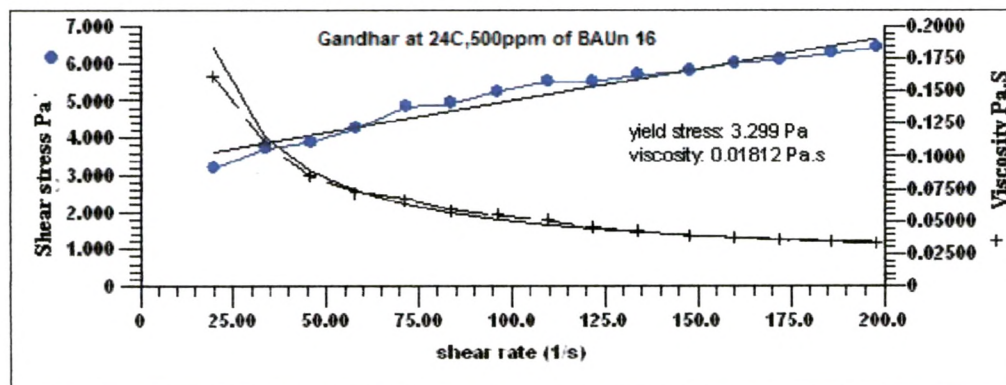


Fig 176 Gandhar with 500ppm of BAUn 16

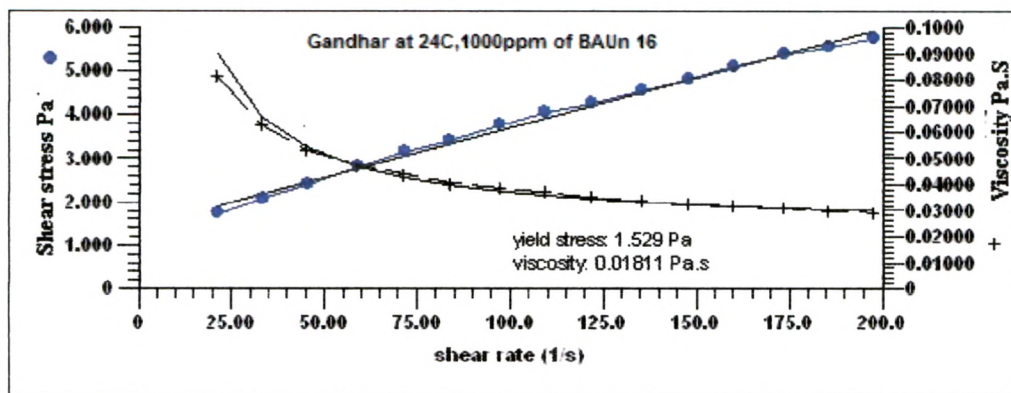


Fig 177 Gandhar with 1000ppm of BAUn 16

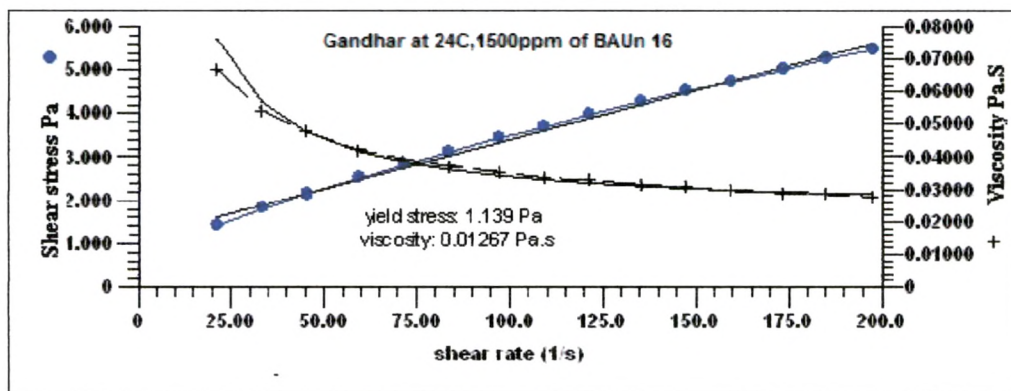


Fig 178 Gandhar with 1500ppm of BAUn 16

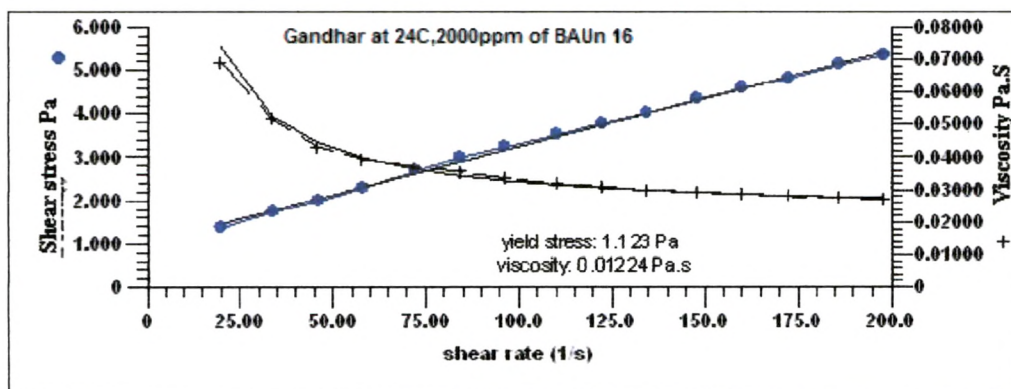


Fig 179 Gandhar with 2000ppm of BAUn 16

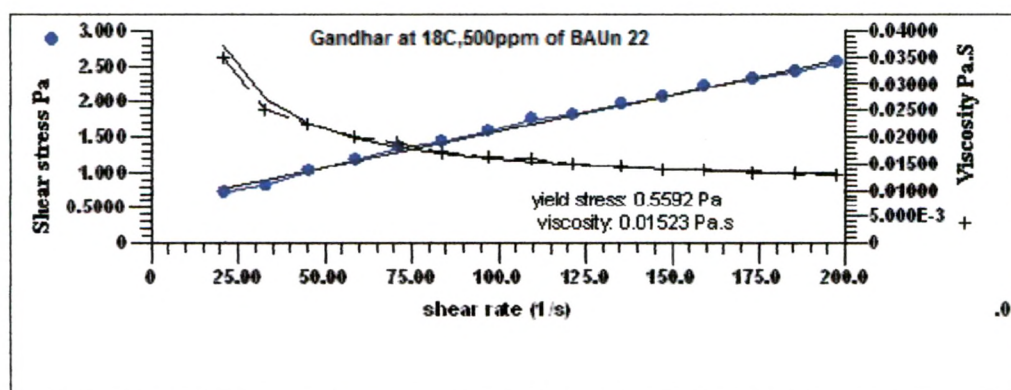


Fig 180 Gandhar with 500ppm of BAUn 22

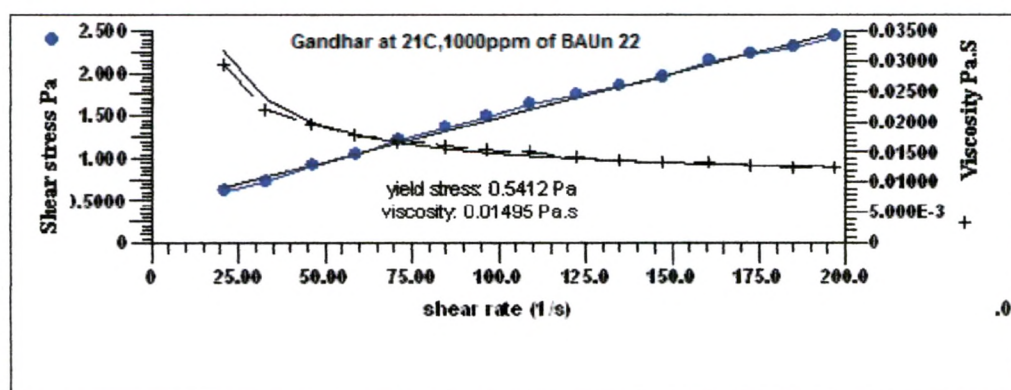


Fig 181 Gandhar with 1000ppm of BAUn 22

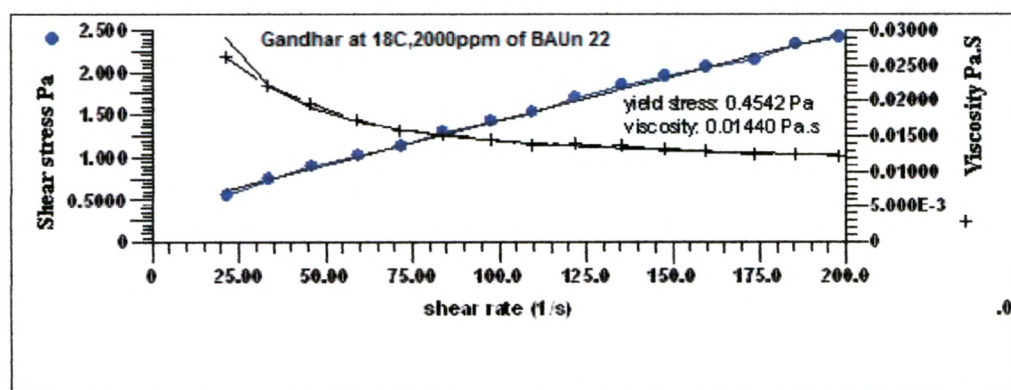


Fig 182 Gandhar with 2000ppm of BAUn 22

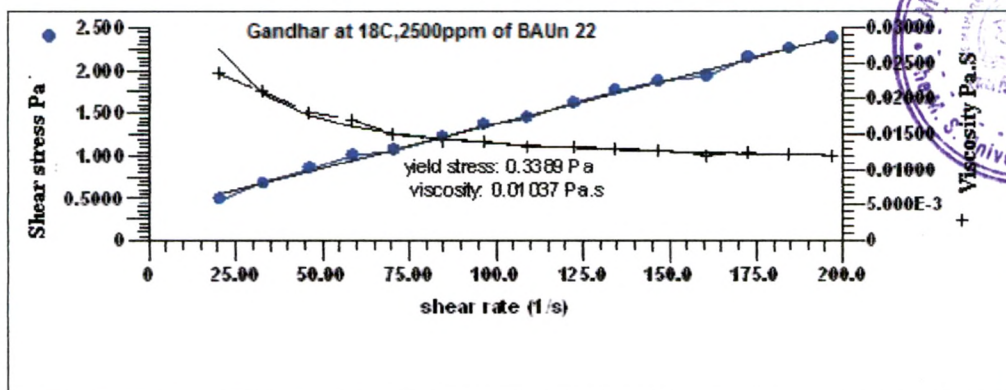


Fig 183 Gandhar with 2500ppm of BAUn 22

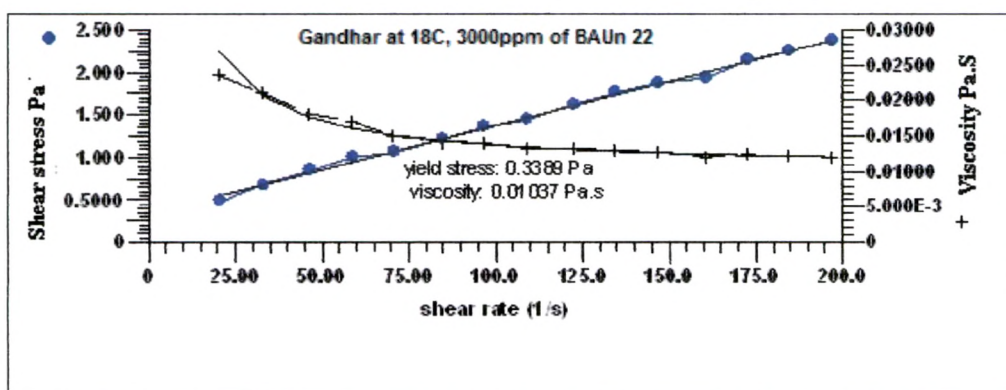


Fig 184 Gandhar with 3000ppm of BAUn 22

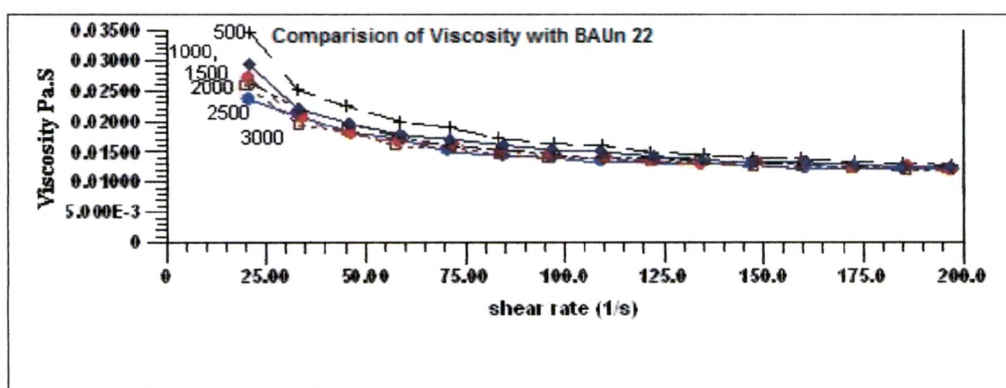


Fig 185 Comparison of Gandhar viscosity with doses of BAUn 22

4.1.5 Microscopic studies of Gandhar oil :



Figure 186 Photomicrograph of neat Gandhar crude oil at room tempeprature

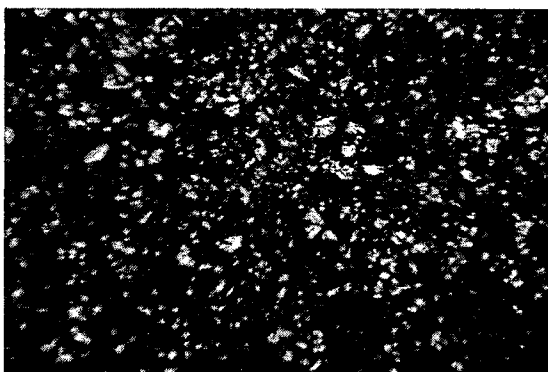


Fig: 187 Photomicrograph of 18 OA 18 additive treated Gandhar crude oil at room tempeprature

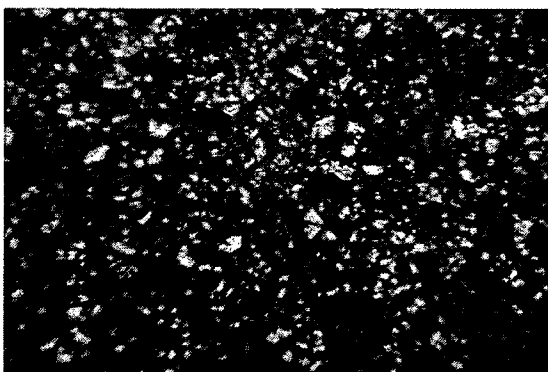


Fig 188 Photomicrograph of 22 OA 22additive treated Gandhar crude oil at room tempeprature

4.1.6 Cold Finger Test on Gandhar crude oil

Quantity required for running cold finger test is very high. So only the selected doses were tried. But this test is very useful for implementation in field conditions for any PPD.

Volume taken: 800ml

Temperature gradient: 55 - 30°C

PPD Name	Dose (mg/l)	Weight of deposit	% inhibition	M.P.of waxes °C	Wax(%) content
Blank	-	7.0		60	55
14 ABA	2000	3.0	57.14	58	49
18 ABA	2000	4.5	35.71	55	45
22 OA 22	2000	2.0	71.42	49	38
16 OA 16	2000	4.0	42.85	55	45
14 MBA	2000	4.0	42.85	54	44
18 MBA	2000	4.0	42.85	53	43
BAUn 18	2000	2.5	64.28	50	43
BAUn 22	2000	3	57.14	54	45

Table 38 Cold finger test data of Gandhar crude oil

4.1.7 Discussion:

Pour point

Physico-chemical properties of Gandhar crude shows it a medium density crude oil as reveals from Table 29 and is highly waxy in nature as having 28% wax in neat sample. Viscosity of the neat crude measured below and above pour point of the crude because the TA Rheometer is very sensitive to temperature and exact studies were possible. The viscosity is quite high at pour point i.e. at 33°C is 1959cps and yield stress is reported 129.8 as seen in the Fig:48. The values itself explains the susceptibility of crude for wax deposition below ambient temperatures. Pipe line deposit of gandhar was also studied for its chemical composition. It is quite hard physically and not easily soluble in any solvent. Solvency of the deposit is decreased by the presence of inorganic part. Results are summarized in the Table 32. Waxes

present in the deposit are more than 80%, oil is only 9%. Melting point of the deposit is 94°C is also quite high. So it is clear from the deposit study that with the 28% of waxes in neat oils the deposition occurs to a great extent from well head to the pipeline end adding to the transportation cost. Four series of the additives naming (n ABA, n OA n, n MBA and BAUn n) were prepared and tested on Gandhar crude from 500-3000 ppm. Higher dosages of additive are selected because of waxy nature of crude. Pour point results of the Gandhar crude with all the doses of PPD's are summarized in Table 37. It is observed that C₁₂ alkyl chain length of Oleate (12 OA 12) decreases the pour point to 24°C, OPP-16 to 18°C, 18 ABA to 24°C, 18 MBA to 21°C and BAUn 22 to 18 °C with all the doses (500,1000,1500,2000,2500 and 3000ppm). It is to be noted that there is no change in pour point with the increase in the dose of the additive. Further it is clear that one or two compounds from each series is effective to reduce the pour point with specific chain length. The most effective is 16 OA 16 and BAUn 22 which has lowered pour point to 18°C i.e Poly(n-alkyl oleate-co-maleic anhydride)dialkylates and Poly(benzyl undecylenate-co-maleic anhydride)dialkylates are useful as good PPD for gandhar oil. Alkyl chain has played an important role in decreasing the pour points. It is revealed from the studies that alkyl chain from C₁₆-C₂₂ are quite effective for this use. But it is quite interesting that there is not any role of the concentration of the additive. In all the four series of diesters prepared it has been observed that short pendant alkyl chain compounds failed to depress the pour point, but the compounds containing C₁₆, C₁₈, C₂₂ pendant alkyl chains have better depressing efficiency from 6°C to 15°C with any concentrations tried.

In Poly(n-alkyl acrylate-co-maleic anhydride)dibenzylate only C₁₈ worked, all rest of the compounds were inactive or little effect. So it is clear the additive was unable to co-crystallized properly with the wax crystal present in the crude. From the above results it is very clear that C₁₈ chains in Gandhar waxes are highly predominant.

In the compounds from diesters of Poly(alkylal methacrylate-co-maleic anhydride)dibenzylate i.e n MBA, the additive having C₁₈ chain (18 MBA) is highly effective and has decreased the pour point by 12°C.

The compounds from diesters of poly(alkyl oleate-co-maleic anhydride)dialkylate containing two long alkyl side chains of C₁₂ and C₁₆ (12 OA 12, 16 OA 16) has depressed the pour point of Gandhar crude more to 9°C and 15°C respectively. So it is

clear from the studies that only some specific number segment of the additive adsorbed properly and do not let crystallize waxes at ambient temperatures. Rest of the chains co-crystallizes with the waxes and added no effect in the pour point depression.

It is observed that the C_{12} chain in Poly(alkyl undecylenate co-maleic anhydride)dialkylates (BAUn 12) has increased the pour point of the oil which can be better explained by the addition of the copolymer to the side chain of waxes adding to the early coagulation. In this series (BAUn 18) C_{18} is rather effective and has decreased the pour point to 15°C .

Co-Crystallization: Buchler and Grave in 1927 showed that waxes, purified by successive recrystallizations, always formed plate crystals regardless of melting point and of the solvent or cooling rate. This work was the first evidence of a very important mechanism of wax crystal modification. The modifying agent, to be effective must crystallize from the solution at the same time as the n-alkanes comprising the wax. This phenomenon also explains that wax crystal modifier i.e chemical additive must match the solubility characteristics of the particular wax-oil medium combination. Since a range of n-alkanes is present, coming out of solution from highest to lowest carbon number, then a corresponding range of solubilities must exist in the additive mixture. Chemical additive have been selected of a wide range of molecular weights(hence solubilities) in an effort to make them more suitable for a wider range of crude oils (Mills 1986)⁹¹. The need to dissolve the modifier prior to crystallization suggests that modifier take part in the crystallization process rather than simply acting as a nucleating agent. The strong dependency of activity of an additive on its concentration in oil, the phenomenon of 'over-dosing' and sudden effect above a minimum concentration (Sifferman,1979)⁷⁶. Overdosing could be attributed to the participation of additive before the commencement of wax crystallization. Whether an additive co-crystallizes with the wax or adsorbed on to the surface and subsequently encased by the wax molecule could be considered to be a moot point. In explanation of specificity of additive, mechanism of co-crystallization would require matching the solubility and thermodynamics relationships of the additive and the wax, whereas adsorption mechanism would require the design of the specific molecular shapes. The efficiency of pour point depressant depends on its ability to keep the paraffin wax

components in solution. To explain the difference in response the type of additives, the paraffin distribution and wax content seems to be important as explained by the solubility theories. So it is important that the closer the structure of the additive to the waxes present in the crude better is the ability to reduce the pour point.

Rheological properties

The viscosity primarily originates from the interaction of hydrogen bonds and the mutual overlapping reaction of aromatic condensed ring planes of resins and asphaltene molecules in the crude oil⁹³. The interaction between resin and asphaltene molecule.

To reduce the viscosity of the crude oil, it is necessary to destroy the hydrogen bonds and inhibit the mutual overlapping of the condensed aromatic ring plane of resin and asphaltene molecules in the crude. When the PPD additive is incorporated in the crude oil, the strength of hydrogen bonds between PPD molecule and resin or asphaltene molecule is stronger than that among resin and asphaltene molecules. One PPD molecule can form hydrogen bonds with a few or a lot of asphaltene or resin molecules at a time. The resin and asphaltene molecule are linked to the PPD molecule through the hydrogen bonds, stretched in the space, so possibility of mutual overlapping of aromatic condensed ring planes of resin and asphaltene molecules is greatly inhibited. So the PPD molecules possessing polar groups in their structure, which can make stronger hydrogen bonds with polar groups of resins and asphaltene present in crude oil, the viscosity lowers down.

All the four series synthesized flow improvers are evaluated for low temperature performance for Gandhar crude oil with and without additive treatment. Firstly pour point was detected and then the sample was taken for rheological studies with all the doses i.e from 500ppm to 3000ppm. Studies on all the doses were possible because of the high sensitivity of TA Rheometer. It experiences even a single wax crystal present in the oil sample and records the viscosity to four decimal which is not possible with Fan VG meter. Moreover the sample required is 1-2 ml only, Results are more authentic and are useful for all applications in crude oil studies. The rheograms of the evaluated additives on the crude are given from Figures 46 to 185 and results of rheological studies are summarized in Table 34 to 37.

Figure 45 to 53 shows the rheograms for the neat Gandhar crude oil. Viscosity and yield stress data is summarized in Table 31. It is clear from the data that viscosity of gandhar neat crude is 1159 cps at pour point i.e at 33°C and is recorded 102cps at 40°C. When the temperature is subsequently decreased to 20°C it gives very high viscosity i.e 1803cps which reveals that as the temperature increases, the viscosity of the oil decreases and vice versa. Same is case with yield stress also. In the table 31 it is seen that that yield stress of gandhar neat crude at 20°C is 258 Pa and at it decreases to 8 Pa at 40°C. Crude behaves like Newtonian above the cloud point. So viscosity and yield stress follows the same trend in neat conditions. Figure 50 shows comparison of the rheological behavior of neat Gandhar oil at different temperatures. This rheogram is recorded between shear rate and shear stress. Fig 51 shows the comparison of viscosity of Gandhar crude at different temperatures, which is self explanatory. Fig 52 is the temperature ramp at constant shear rate i.e 10 sec⁻¹. It gives the information about the change in viscosity of the crude oil from high to low temperature. Pour point and cloud point can be recorded with highly precise investigation of this data. These results are also very useful in pipeline designing if studies are extended to different shear rates.

Table 34 shows the viscosity and yields stress results with different doses (500-3000 ppm) of the prepared(8 ABA - 18 ABA) C₆ to C₁₈ alkyl chain length additives of Diester of Poly(n-alkyl acrylate-co-maleic anhydride)dibenzylate. (14 ABA),i.e Poly(tetradecyl acrylate-co-maleic anhydride)dibenzylate C₁₄ chain length additive has decreased viscosity from 1159 to 56.43cps and yield stress from 129 to 17.49 Pa at 500ppm and 258 to 50cps and yield stress to 2.5 Pa at 3000ppm. (18ABA) C₁₈ side chain length additive has also been found quite effective for gandhar crude oil. It also decreases the viscosity to 21 cps and yield stress to 0.8 Pa revealing that these alkyl chain lengths derivatives are able to dissolve the crude oil waxes and can keep them in solution form decreasing their molecular sizes.

Table 35 shows the rheological results of Gandhar crude oil with the different doses(500-3000ppm of OPP additives i.e Poly(n-alkyl oleate-co-maleic anhydride)dialkylates. Pour points of gandhar crude with these additives has been explained in the above discussion. It is very clear from the table 35 that additves which has decreased pour point also has subsequently improved the flow behavior of

the crude oil. Means that they have decreased viscosity and yield stress of the oil at ambient temperatures. It is clear from the table 35 that as the alkyl chain length increases from C₁₀ to C₂₂(10 OA 10, 22 OA 22) the viscosity and yield stress are decreased in a way improving flow behavior towards even Newtonian side. (10 OA 10) C₁₀ chain length has given viscosity 1110cps at 500ppm and decreased to 642 cps with 3000ppm though the pour point remained the same in all the doses. Same is the case with yield stress, it is 49 Pa at 500 ppm and becomes as low as 26 Pa at 3000 ppm following the viscosity trend. It reveals that the additive on increasing concentrations though there is no change in pour point but very much helpful in decreasing wax deposition property of the crude and improving flow behavior of the crude. C₁₂ chain additive(12 OA 12) has decreased viscosity to 18 cps at 500ppm and lowered to 13 cps at 3000ppm. It gives yield stress 3 to 0.8 Pa from 500 ppm to 3000 ppm showing that crude has become highly flowable at higher concentrations. Same is the trend followed by (18 OA 18, 22 OA 22) C₁₈ and C₂₂ chain of this class polymer i.e viscosity has been lowered to 8.4cps and yield stress to 0.25 cps making the crude nearly Newtonian.

Table 36 shows the rheology results of Alkyl chain length from(8 MBA – 18 MBA) C₈-C₁₈ of Diester of Poly(n-alkyl methacrylate-co-maleic anhydride)dibenzylate.8 MBA-6 to 12 MBA) additives has very little effect on viscosity and yield stress. Results are almost similar to neat crude oil.14 MBA-14 and 18 MBA additives has decreased viscosity to good extent ie viscosity to 19cps and yield stress to 0.9 Pa. Figure 53 to 185 shows the experimental results of Rheological studies of Gandhar crude with all the doses of synthesized polymers. Figures are self explanatory. Experimental results can easily be extended towards field applications. Rheological results are quite encouraging for the use in problematic areas in the Gandhar oilfield of South Gujarat.

Table 37 shows the viscosity and yields stress study results with different doses (500-3000ppm) of the prepared (BAUn 10 – BAUn 22) C₁₀ to C₂₂ alkyl chain length additives of Diester of Poly(n-alkyl undecylenate-co-maleic anhydride)dialkylate. (BAUn 10), C₁₀ chain length additive has decreased viscosity from 1159 to 571cps and yield stress from 129 to 36 Pa at 500ppm and 258 to 262cps and yield stress to 8 Pa at 3000ppm. (BAUn 12)C₁₂ is the only additive which has increased the viscosity to 1788 and shear stress to 140 Pa which has been explained in pour point discussion.

(BAUn 18 and BAUn 22), C₁₈ and C₂₂ chain length additives in this series are also highly effective. Viscosity and yield stress with BAUn 18 additive is 15cps and 0.55 Pa with 500 ppm concentration. There is slight decrease in viscosity and yield stress on 3000 ppm

n-Alkanes as liquids have the effect of reducing both viscosity and the viscosity-temperature dependence of the oil. Therefore as the n-alkanes leaves the liquid to join the wax crystal, the viscosity of the remaining fluid must increase. This would occur most notably in the boundary layer adjacent to the crystal surface which would be depleted of n-alkanes to greater extent than bulk fluid. This would bias the crystallization process towards mass transfer limited mechanisms. One study (Reddy & McMillan, 1981)⁴⁴ has noted that those polymeric additives could be influencing the liquid viscosity. Although the polymer could conceivably be altering the apparent viscosity. No measurement have appeared in the literature showing an effect of the polymer on shear viscosity of the oil in the liquid state.

Cold Finger Test:

All synthesized Chemical additives evaluated for pour point and rheology for the doses of 500 ppm to 3000 ppm. But in case of cold finger tests only those additives which have given very good results in the above studies are evaluated. In the cold finger test the quantity of crude oil required for each experiment is very high i.e minimum 1000 ml and the minimum time required is 4-5 hrs. For this reason only selected doses of effective polymers has been evaluated. Neat crude oil of Gandhar has given wax deposit of 7 grams showing a very high wax deposition tendency in pipeline and well head. When the gandhar crude was treated with 2000ppm (medium) dose of 22 OA 22 and 16 OA 16 additives in separate bottles and experiment were run the deposition has decreased to 2gm and 4gm respectively. Results are summarized in Table 38. In the same contest 2000 ppm of 14 ABA and 18 ABA is tried and it has been observed that depositional tendency has decreased to almost 50% as the weight of the deposit has decreased from 7 gm to 4 gm. Further 14 MBA and 18 MBA has also given the same results. But in case of BAUn 18 and BAUn 22 deposit weight has been decreased to almost 2.5 gm. So it is clear from the Table 38 that the synthesized Diester of Poly(n-alkyl undecylenate-co-maleic anhydride)dialkylate are also useful as wax dispersants in the Gandhar oil field.

Microscopic Studies

The synthesized flow improvers are evaluated for change in size and shape of wax crystal in the Gandhar crude oil by using cross polarizing microscope. The results are produced in Figures 186 to 188, from which it is concluded that the flow improvers produces smaller wax crystals from larger wax crystals. The 18 OA 18 and 22 OA 22 inhibits the wax crystal growth and produces the smaller crystals from larger wax crystals. Microscopic Studies gives strength to the all practical data. It very clearly seen in the studies that the original waxes crystal has larger size and has susceptible for the deposition below ambient temperatures but with additive the size of the wax crystals in the crude oil decrease to a great extent which inhibits the crystal growth adding to the low pour points and increasing flow behavior of the crude oil.

CHAPTER-IV-II

TESTING OF SYNTHESIZED POLYMER ADDITIVES ON KOSAMBA FIELD CRUDE OIL

4.2.1 Physico-chemical Properties of Kosamba crude oil

Kosamba crude oil is medium to high density oil. The sample taken is composite sample from kosamba field. Kosamba crude has high water cut which increases the field problems. Commercially Kosamba crude is as good as Gandhar crude seen from distillation characteristics of the oil. Kosamba crude It is also very highly waxy in nature as it has nearly 30% of wax and pour point is 36°C which is a problem in summer season also but when temperature goes down to 20°C it become very difficult to handle. The physical properties of Kosamba crude oil are given in Table 39 .

Table 40 shows the distillation behavior of the Kosamba crude oil from zero to 300°C temperature. The initial boiling point (IBP) of the crude oil is 57°C which is quite low.

Sr. No.	Properties	Unit	Result
1	Density	g/cc	0.8772
2	Specific gravity	g/cc	0.8776
3	API gravity	Degree	30.7
4	Pour point	°C	36
5	Wax content	% wt	30.55
6	Saturates	% wt	80.78
7	Aromatics	--	12.99
8	N,S,O	--	6.23
9	Asphaltene	% wt	0.98
10	Cloud Point	°C	57
11	IBP	°C	57.00

Table 39 Geo-Chemical Characterization of Kosamba crude oil

Distillation:

Volume taken = 100 ml

Initial Boiling Point (IBP) = 57°C

Sr. No.	Temperature (°C)	Volume of oil (ml)
1	57-75	02
2	75-100	06
3	100-125	11
4	125-150	19
5	150-175	25
6	175-200	31
7	200-225	39
8	225-250	45
9	250-275	53
10	275-300	62

Table 40. Distillation characteristics of Kosamba crude oil

Temperature °C	Viscosity cps	Yield stress Pa
20	995.5	132.8
25	957.4	130.2
30	907.8	69.95
35	616	47.46
36 (pour point)	560.8	38.66
40	444.8	47.13
50	392	14.33

Table 41. Viscosity at different temperatures of Neat Kosamba oil

4.2.2 Kosamba field Wax Deposit Analysis:

S.No	Parameter	Unit	Results
1	Water Content	% Vol	5
2	Wax Content	% Wt	84.5
3	Asphaltene Content	% Wt	0.10
4	Oil Content	% Wt	6.4
5	Inorganics	% Wt	4.9
6	Resin content	% Wt	1.89
7	M.P of waxes	°C	91
8	M.P of Deposit	°C	96

Table 42. Analysis of Deposit Sample of Kosamba

4.2.3 Pour Point Analysis of Kosamba oil:

Sr. No.	Additive code	Pour point of Kosamba oil (°C)	Pour point of additive treated crude oil (ppm)						Extent of depression in pour point (°C)
		Doses	500	1000	1500	2000	2500	3000	500 -3000
1	8 ABA	36	39	39	39	39	39	39	-3
2	10 ABA	36	27	27	27	27	27	27	9
3	12 ABA	36	24	24	24	24	24	24	12
4	14 ABA	36	27	27	27	27	27	27	9
5	16 ABA	36	21	21	21	21	21	21	15
6	18 ABA	36	15	15	15	15	15	15	21
7	8 OA 8	36	15	15	15	15	15	15	21
8	10 OA 10	36	39	39	39	39	39	39	-3
9	12 OA 12	36	33	33	33	33	33	33	3
10	14 OA 14	36	27	27	27	27	27	27	9

11	16 OA 16	36	21	21	21	21	21	21	15
12	18 OA 18	36	27	27	27	27	27	27	9
13	22 OA 22	36	30	30	30	30	30	30	6
14	6 MBA	36	36	36	36	36	36	36	-
15	8 MBA	36	33	33	33	33	33	33	3
16	10 MBA	36	33	33	33	33	33	33	3
17	12 MBA	36	30	30	30	30	30	30	6
18	14 MBA	36	24	24	24	24	24	24	12
19	16 MBA	36	21	21	21	21	21	21	15
20	18 MBA	36	18	18	18	18	18	18	18
21	BAUn 8	36	36	36	36	36	36	36	-
22	BAUn 10	36	42	42	42	42	42	42	-6
23	BAUn 12	36	39	39	39	39	39	39	-3
24	BAUn 14	36	39	39	39	39	39	39	-3
25	BAUn 16	36	39	39	39	39	39	39	-3
26	BAUn 18	36	30	30	30	30	30	30	6

Table 43. Pour points of polymeric additive treated Kosamba crude oil

4.2.4 Rheological Studies results of Kosamba oil:

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress (Pa)
1	8 ABA	500	33	799.9	21.57
2	8 ABA	1000	33	699.2	20.88
3	8 ABA	1500	33	691.1	20.21
4	8 ABA	2000	33	689.1	19.94
5	8 ABA	2500	33	677.6	17.95

6	8 ABA	3000	33	598.7	17.56
7	10 ABA	500	33	799.2	21.54
8	10 ABA	1000	33	698.9	20.12
9	10 ABA	1500	33	688.5	19.83
10	10 ABA	2000	33	685.7	18.88
11	10 ABA	2500	33	677.4	17.29
12	10 ABA	3000	33	598.2	17.52
13	12 ABA	500	30	598.6	18.85
14	12 ABA	1000	30	484.9	18.68
15	12 ABA	1500	30	484.9	17.76
16	12 ABA	2000	30	458.5	17.08
17	12 ABA	2500	30	405.9	16.93
18	12 ABA	3000	30	396.3	14.50
19	14 ABA	500	24	99.94	3.99
20	14 ABA	1000	24	89.63	3.97
21	14 ABA	1500	24	79.42	3.61
22	14 ABA	2000	24	78.14	3.54
23	14 ABA	2500	24	69.84	3.13
24	14 ABA	3000	24	69.84	3.13
25	16 ABA	500	21	69.02	2.84
26	16 ABA	1000	21	69.37	2.14
27	16 ABA	1500	21	68.95	2.04
28	16 ABA	2000	21	66.34	1.94
29	16 ABA	2500	21	63.58	1.76
30	16 ABA	3000	21	59.31	1.68
31	18 ABA	500	18	59.07	1.47
32	18 ABA	1000	18	58.72	1.33
33	18 ABA	1500	18	54.61	1.28
34	18 ABA	2000	18	48.79	1.11
35	18 ABA	2500	18	43.20	1.08
36	18 ABA	3000	18	39.93	0.98

Table 44 Viscosity data of kosamba oil treated with n ABA additive

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress (Pa)
1	8 OA 8	500	15	51.45	1.23
2	8 OA 8	1000	15	48.59	1.22
3	8 OA 8	1500	15	45.20	1.20
4	8 OA 8	2000	15	45.20	1.20
5	8 OA 8	2500	15	41.80	1.11
6	8 OA 8	3000	15	39.4	0.98
7	10 OA 10	500	39	3198	239.4
8	10 OA 10	1000	39	1545	190.55
9	10 OA 10	1500	39	879.9	59.75
10	10 OA 10	2000	39	541.9	37.51
11	10 OA 10	2500	39	513.5	35.78
12	10 OA 10	3000	39	474.5	31.54
13	12 OA 12	500	33	799.6	21.55
14	12 OA 12	1000	33	691.5	20.02
15	12 OA 12	1500	33	681.9	20.00
16	12 OA 12	2000	33	685.5	19.69
17	12 OA 12	2500	33	673.6	17.80
18	12 OA 12	3000	33	596.6	17.64
19	14 OA 14	500	27	309.4	15.58
20	12 OA 12	1000	27	198.7	14.66
21	12 OA 12	1500	27	169.4	8.98
22	12 OA 12	2000	27	149.8	7.79
23	12 OA 12	2500	27	141.2	6.76
24	12 OA 12	3000	27	130.8	5.179
25	16 OA 16	500	21	68.84	2.75
26	16 OA 16	1000	21	67.37	1.84
27	16 OA 16	1500	21	67.34	1.67
28	16 OA 16	2000	21	66.44	1.66
29	16 OA 16	2500	21	59.64	1.59
30	16 OA 16	3000	21	57.81	1.56

31	18 OA 18	500	27	304.1	14.76
32	18 OA 18	1000	27	196.4	14.48
33	18 OA 18	1500	27	168.1	8.94
34	18 OA 18	2000	27	145.5	7.78
35	18 OA 18	2500	27	141.0	6.75
36	18 OA 18	3000	27	130.5	5.16
37	22 OA 22	500	30	596.2	18.91
38	22 OA 22	1000	30	486.2	18.59
39	22 OA 22	1500	30	478.5	17.70
40	22 OA 22	2000	30	453.2	17.06
41	22 OA 22	2500	30	400.7	16.55
42	22 OA 22	3000	30	399.4	14.57

Table 45 Viscosity data of kosamba oil treated with n OA n Additive

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress (Pa)
1	8 MBA	500	33	799.2	21.57
2	8 MBA	1000	33	699.2	20.88
3	8 MBA	1500	33	691.1	20.21
4	8 MBA	2000	33	689.1	19.94
5	8 MBA	2500	33	677.6	17.95
6	8 MBA	3000	33	598.7	17.58
7	10 MBA	500	33	799.2	21.54
8	10 MBA	1000	33	698.9	20.65
9	10 MBA	1500	33	690.04	20.12
10	10 MBA	2000	33	688.5	19.83
11	10 MBA	2500	33	677.4	17.79
12	10 MBA	3000	33	598.2	17.52
13	12 MBA	500	30	598.6	18.85
14	12 MBA	1000	30	485.5	18.69
15	12 MBA	1500	30	484.9	17.76

16	12 MBA	2000	30	458.5	17.08
17	12 MBA	2500	30	405.9	16.93
18	12 MBA	3000	30	396.3	14.50
19	14 MBA	500	24	107.9	4.51
20	14 MBA	1000	24	99.94	3.99
21	14 MBA	1500	24	88.03	3.77
22	14 MBA	2000	24	79.42	3.61
23	14 MBA	2500	24	78.14	3.54
24	14 MBA	3000	24	69.84	3.13
25	16 MBA	500	21	69.02	2.848
26	16 MBA	1000	21	69.37	2.149
27	16 MBA	1500	21	68.95	2.042
28	16 MBA	2000	21	66.34	1.942
29	16 MBA	2500	21	63.58	1.768
30	16 MBA	3000	21	59.31	1.689
31	18 MBA	500	18	59.07	1.477
32	18 MBA	1000	18	58.72	1.333
33	18 MBA	1500	18	54.61	1.286
34	18 MBA	2000	18	48.79	1.113
35	18 MBA	2500	18	43.2	1.088
36	18 MBA	3000	18	39.53	0.985

Table 46 Viscosity data of kosamba oil treated with n MBA

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress (Pa)
1	BAUn 10	500	30	599.2	18.89
2	BAUn 10	1000	30	483.2	18.72
3	BAUn 10	1500	30	481.9	17.75
4	BAUn 10	2000	30	457.2	17.57
5	BAUn 10	2500	30	455.2	17.16
6	BAUn 10	3000	30	396.2	14.54

7	BAUn 12	500	30	1938	140.99
8	BAUn 12	1000	30	1898	78.38
9	BAUn 12	1500	30	1667	132.6
10	BAUn 12	2000	30	1656	112.6
11	BAUn 12	2500	30	1449	98.75
12	BAUn 12	3000	30	1418	94.15
13	BAUn 14	500	39	3086	241.90
14	BAUn 14	1000	39	1559	191.98
15	BAUn 14	1500	39	866.9	61.95
16	BAUn 14	2000	39	546.7	39.94
17	BAUn 14	2500	39	575.8	36.89
18	BAUn 14	3000	39	474.5	32.75
19	BAUn 16	500	39	3097	240.40
20	BAUn 16	1000	39	1537	191.39
21	BAUn 16	1500	39	864.9	61.92
22	BAUn 16	2000	39	546.8	39.98
23	BAUn 16	2500	39	515.4	36.84
24	BAUn 16	3000	39	473.7	32.59
25	BAUn 18	500	39	3067	239.8
26	BAUn 18	1000	39	1532	190.32
27	BAUn 18	1500	39	864.1	61.90
28	BAUn 18	2000	39	546.6	39.96
29	BAUn 18	2500	39	515.1	36.8
30	BAUn 18	3000	39	473.1	32.52
31	BAUn 22	500	30	599.20	18.89
32	BAUn 22	1000	30	483.20	18.72
33	BAUn 22	1500	30	481.9	17.52
34	BAUn 22	2000	30	457.2	17.57
35	BAUn 22	2500	30	455.2	17.16
36	BAUn 22	3000	30	396.2	14.54

Table 47 Viscosity data of kosamba oil treated with BAUn n Additive

4.2.5 Rheological studies on Rheometer:

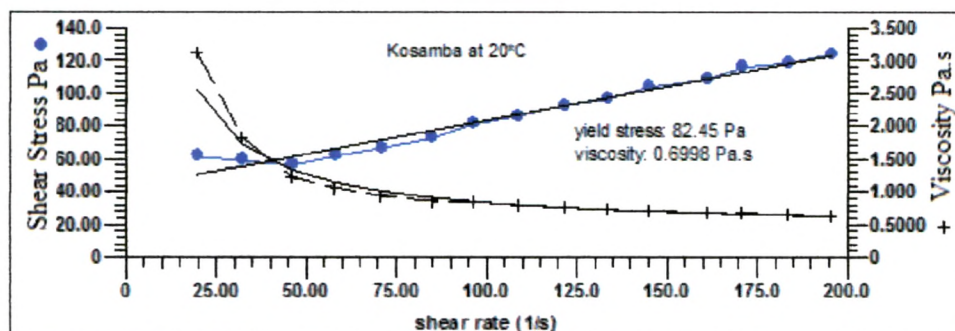


Fig 189 Kosamba Rheogram neat at 20°C

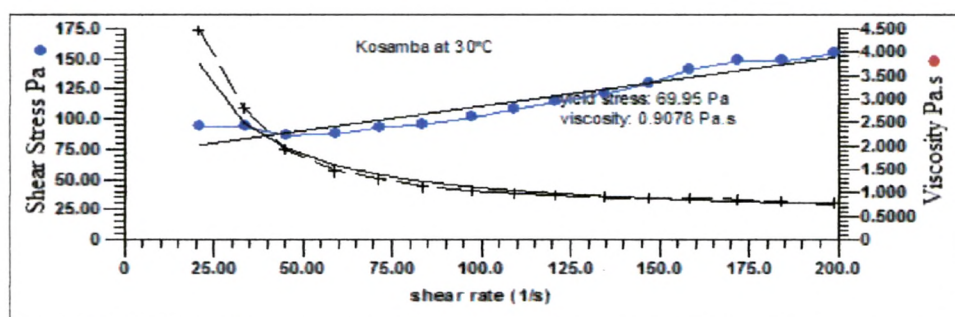


Fig 190 Kosamba Rheogram neat at 30°C

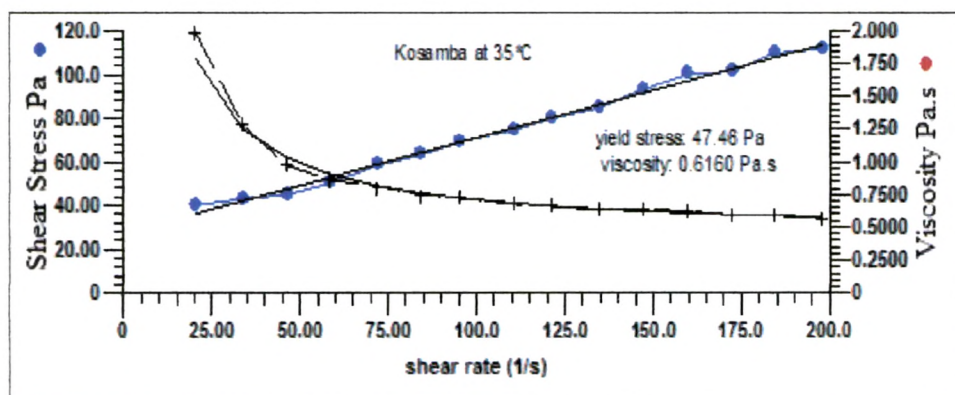


Fig 191 Kosamba Rheogram neat at 35°C

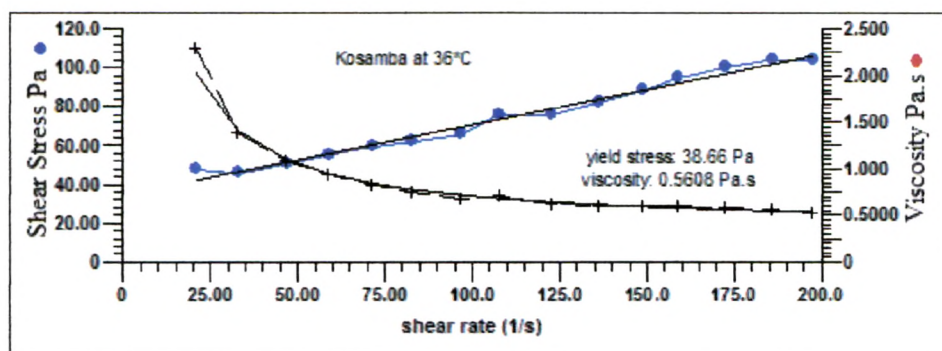


Fig 192 Kosamba Rheogram neat at 40°C

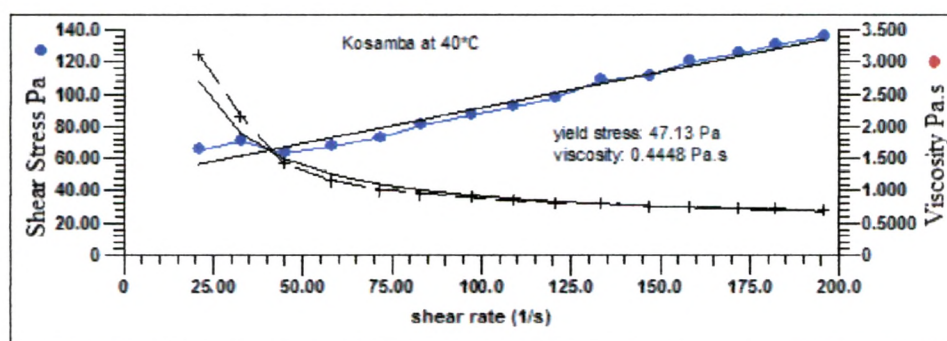


Fig 193 Kosamba Rheogram neat at 40°C

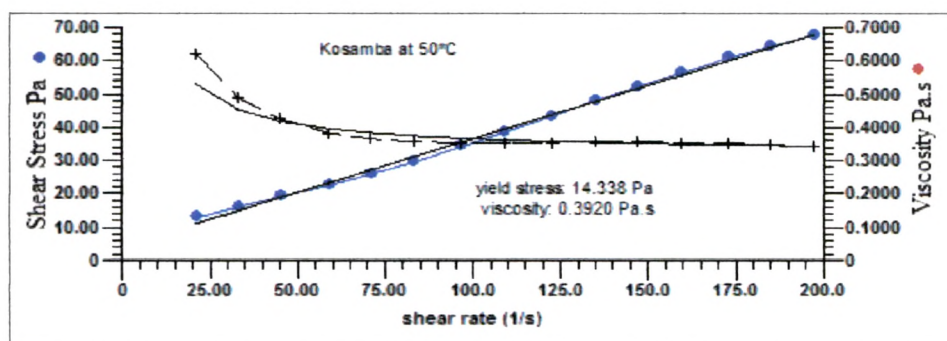


Fig 194 Kosamba Rheogram neat at 50°C

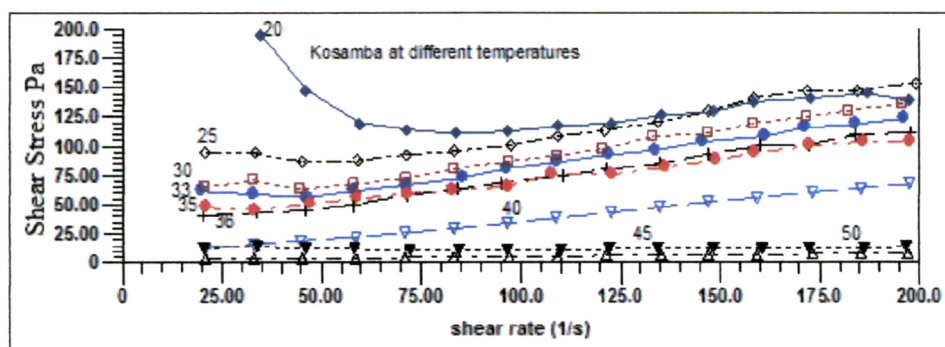


Fig 195 Kosamba Flow behavior comparison at different temperatures

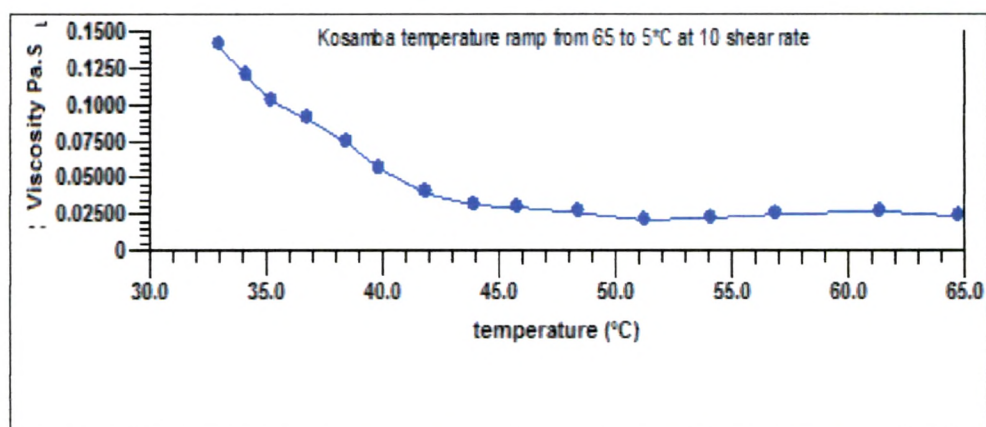


Fig 196 Kosamba T-ramp

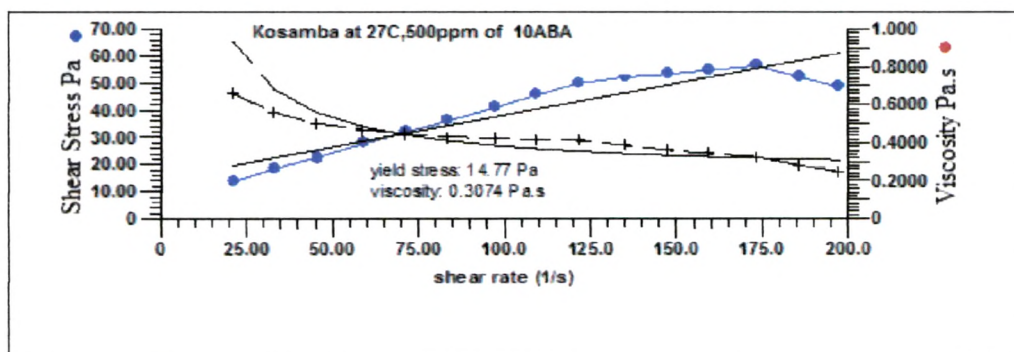


Fig 197 Kosamba with 500ppm of 10 ABA

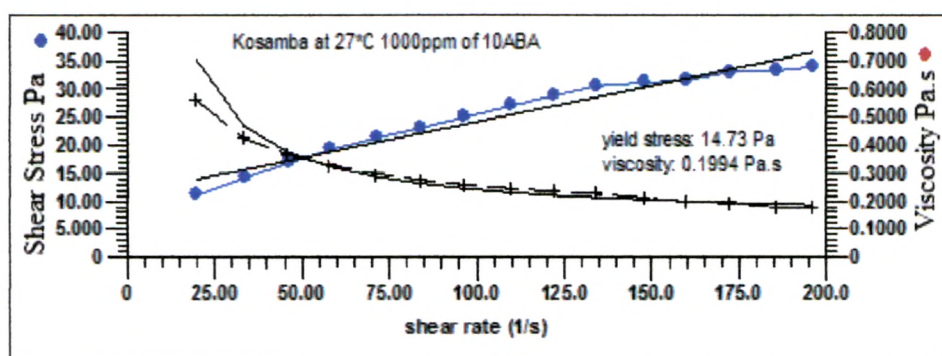


Fig 198 Kosamba with 1000ppm of 10 ABA

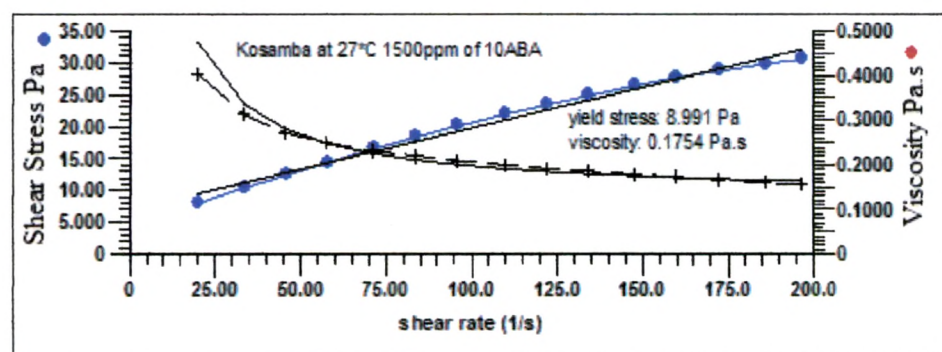


Fig 199 Kosamba with 1500ppm of 10 ABA

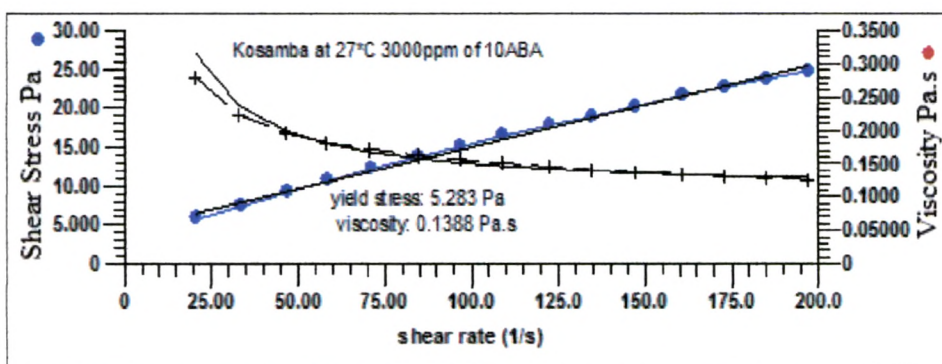


Fig 200 Kosamba with 3000ppm of 10 ABA

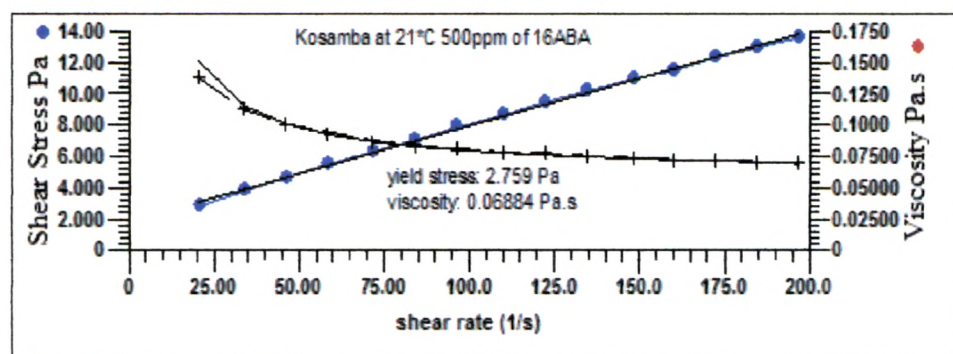


Fig 201 Kosamba with 500ppm of 16 ABA

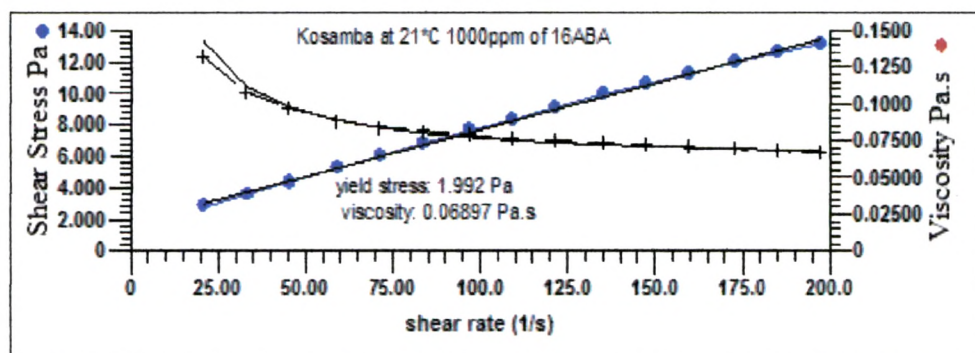


Fig 202 Kosamba with 1000ppm of 16 ABA

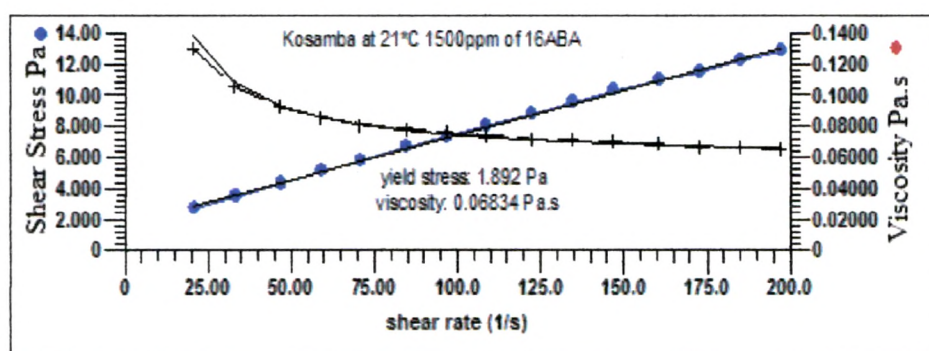


Fig 203 Kosamba with 1500ppm of 16 ABA

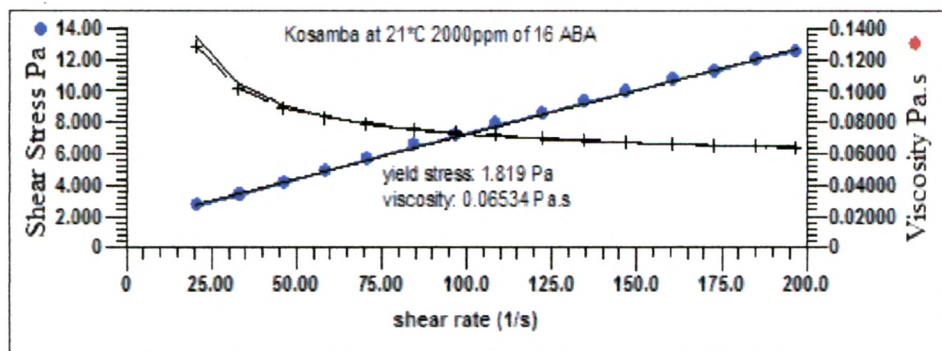


Fig 204 Kosamba with 2000ppm of 16 ABA

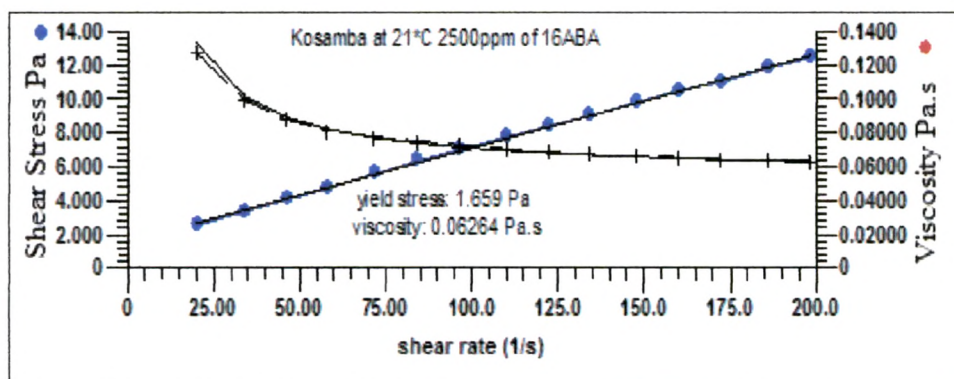


Fig 205 Kosamba with 2500 ppm of 16 ABA

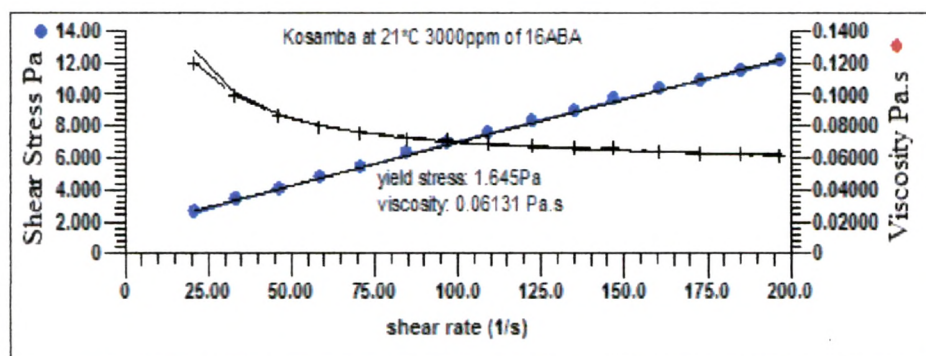


Fig 206 Kosamba with 3000ppm of 16 ABA

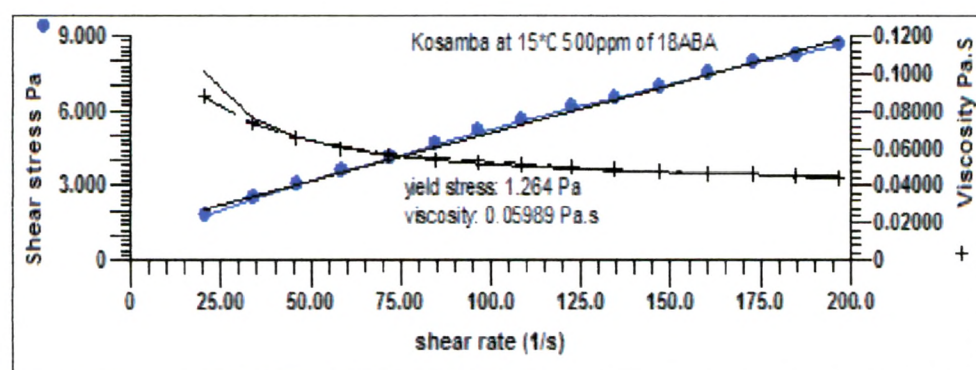


Fig 207 Kosamba with 500ppm of 18MBA

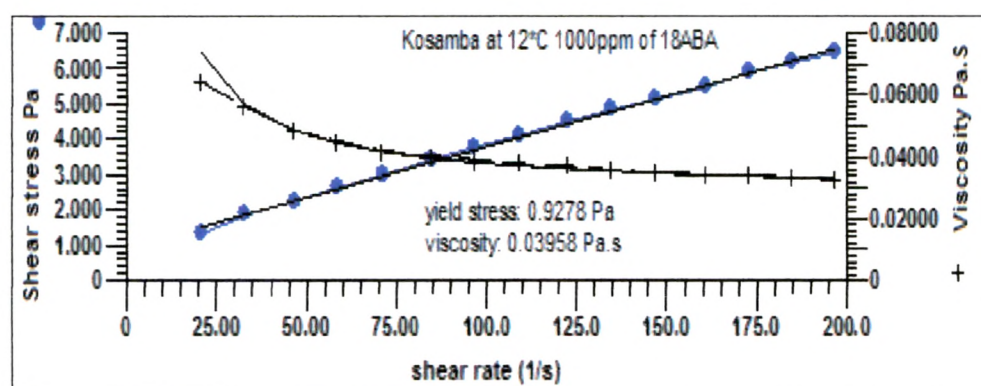


Fig 208 Kosamba with 1000ppm of 18MBA

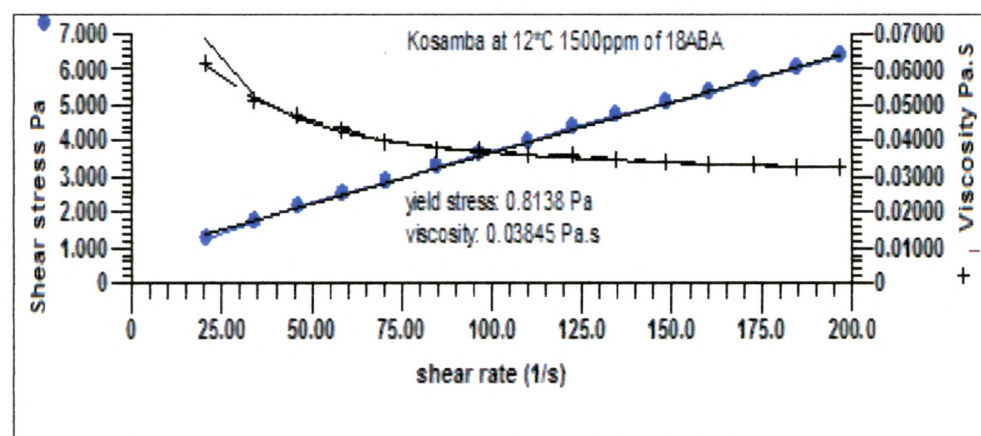


Fig 209 Kosamba with 1500ppm of 18MBA

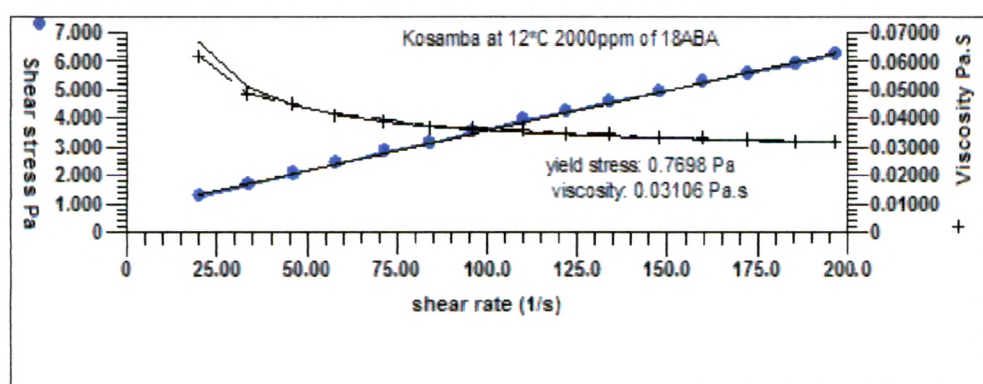


Fig 210 Kosamba with 2000ppm of 18MBA

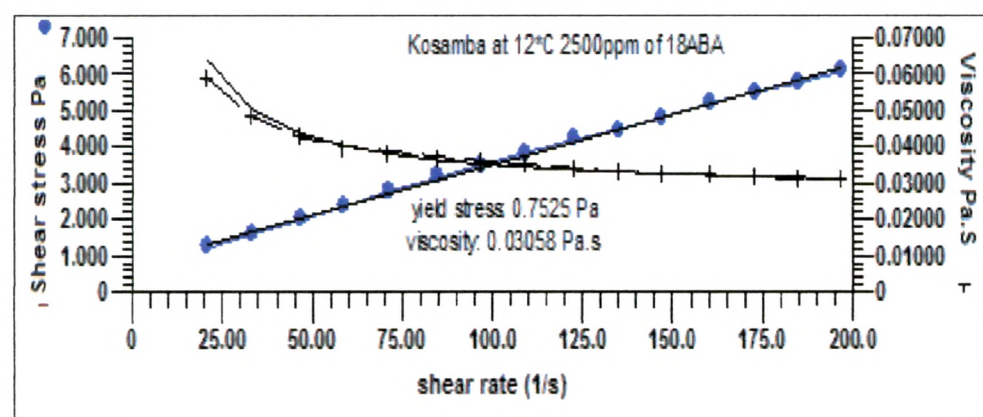


Fig 211 Kosamba with 2500ppm of 18MBA

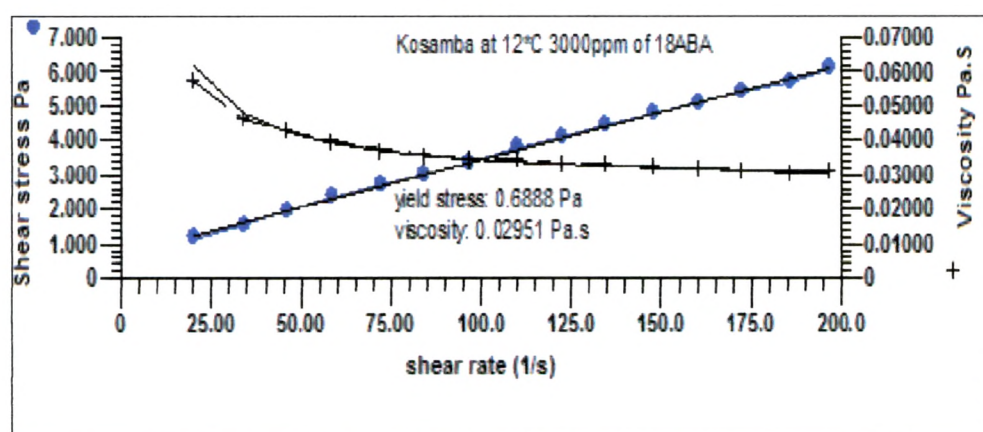


Fig 212 Kosamba with 3000 ppm of 18MBA

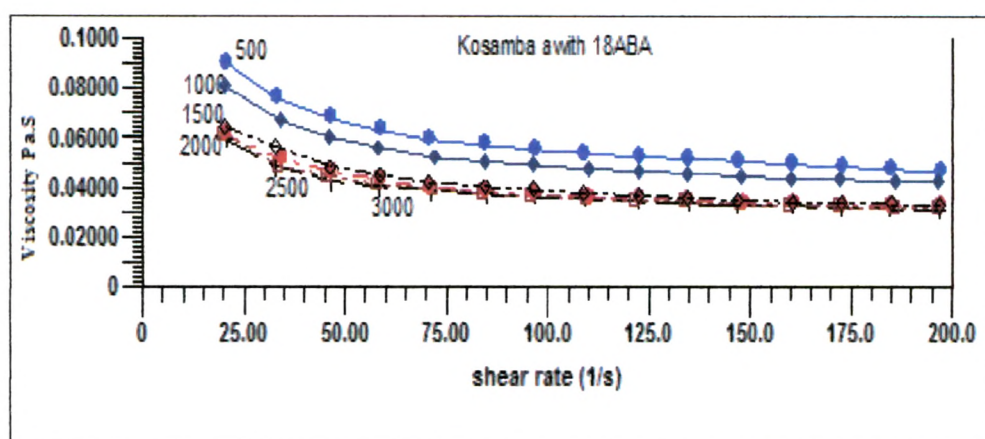


Fig 213 Kosamba Comaprision of viscositywith doses of 18MBA

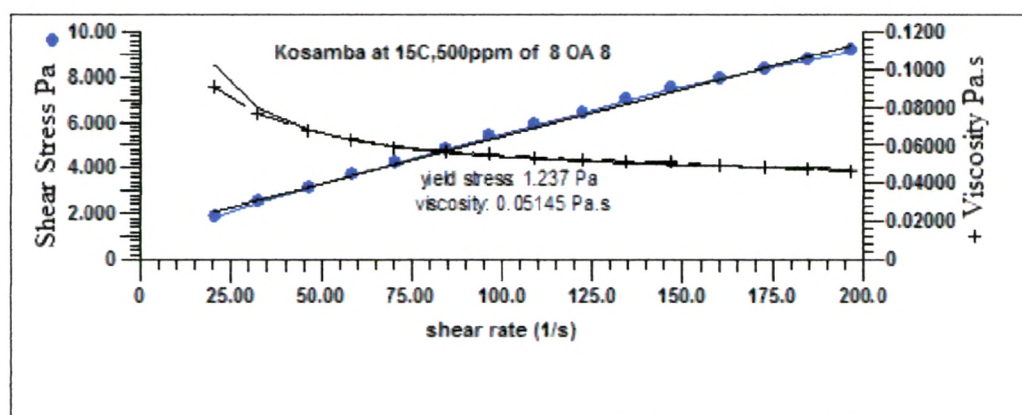


Fig 214 Kosamba with 500ppm of 8 OA 8

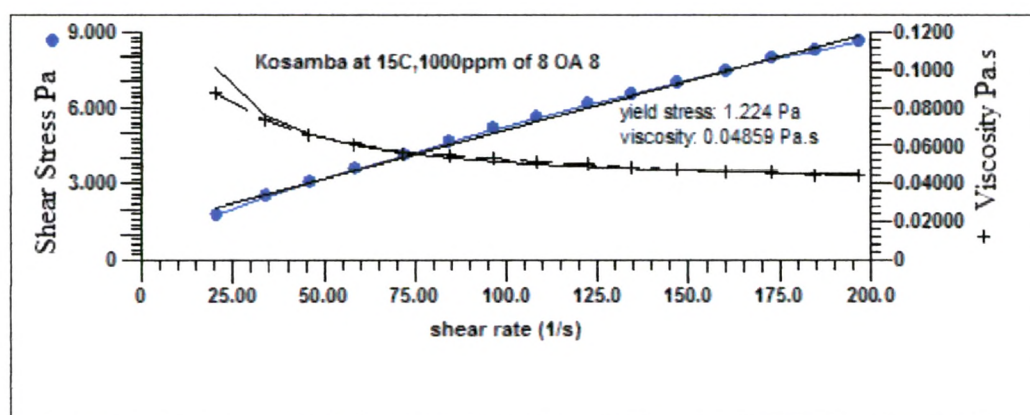


Fig 215 Kosamba with 1000ppm of 8 OA 8

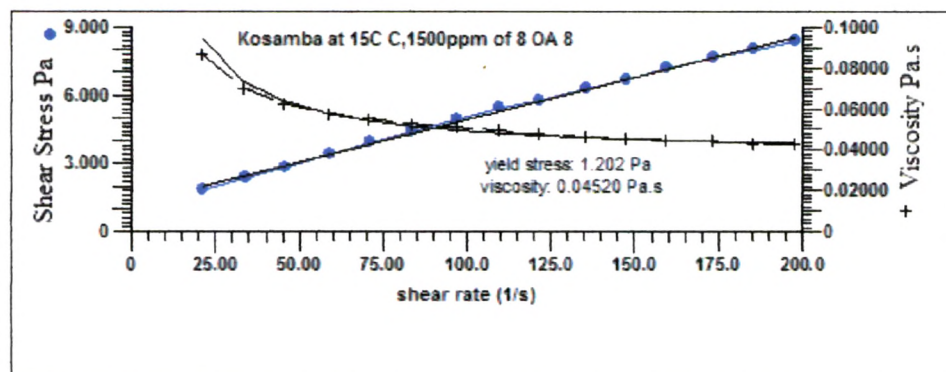


Fig 216 Kosamba with 1500ppm of 8 OA 8

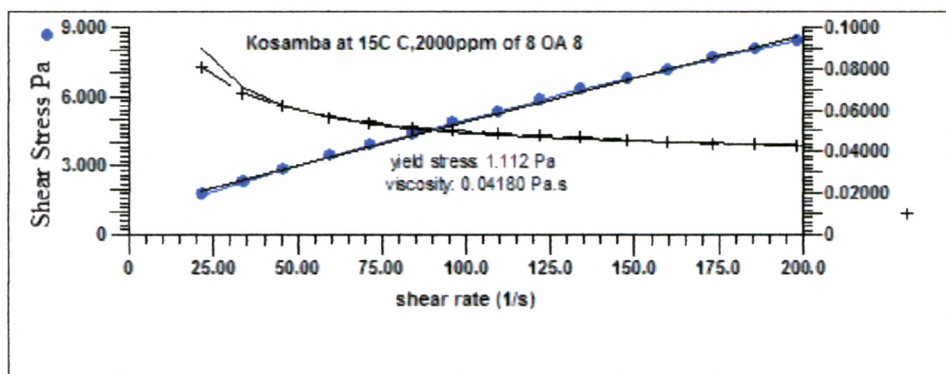


Fig 217 Kosamba with 2000ppm of 8 OA 8

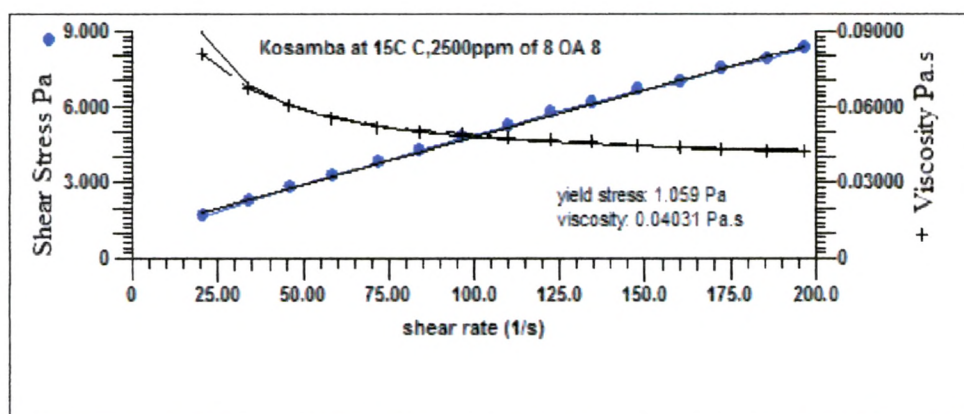


Fig 218 Kosamba with 2500ppm of 8 OA 8

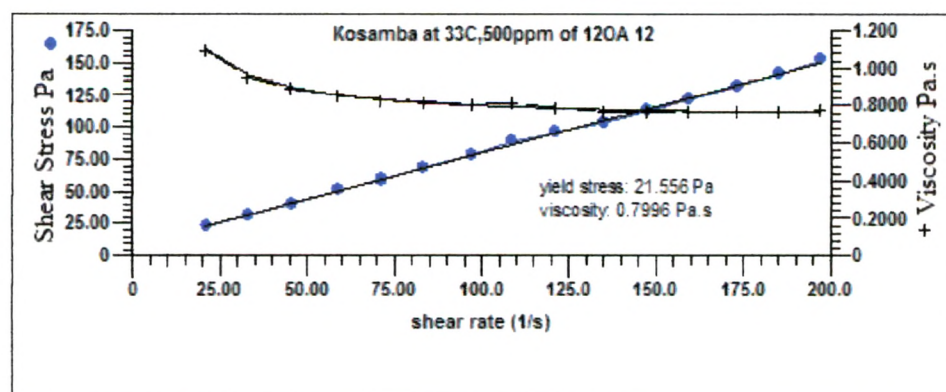


Fig 219 Kosamba with 500ppm of 12 OA 12

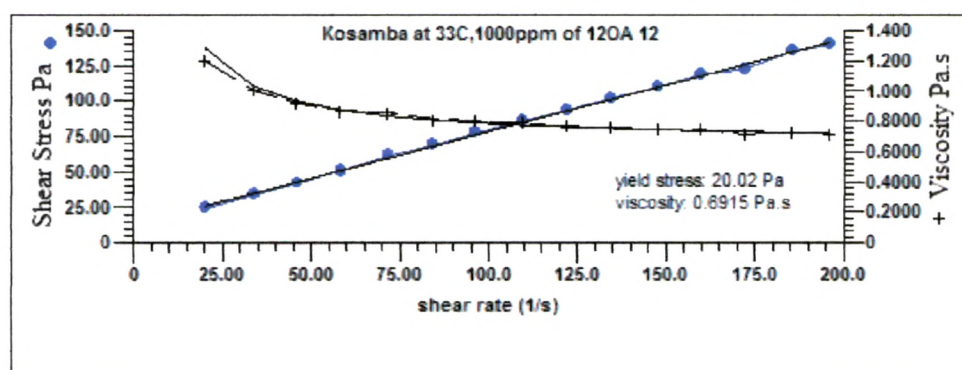


Fig 220 Kosamba with 1000ppm of 12 OA 12

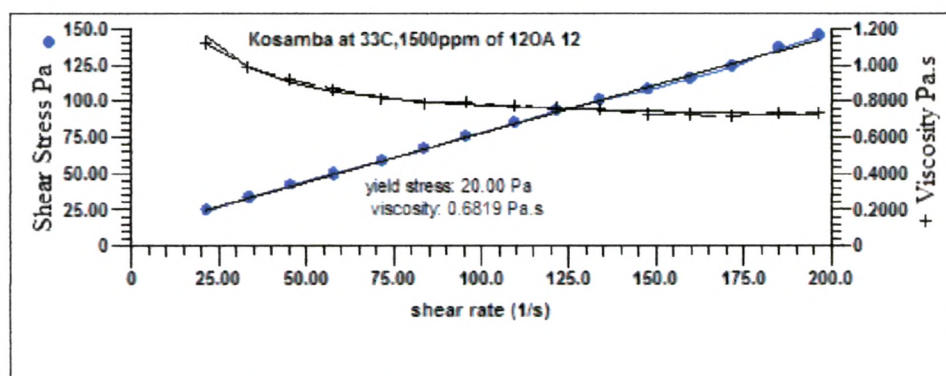


Fig 221 Kosamba with 1500ppm of 12 OA 12

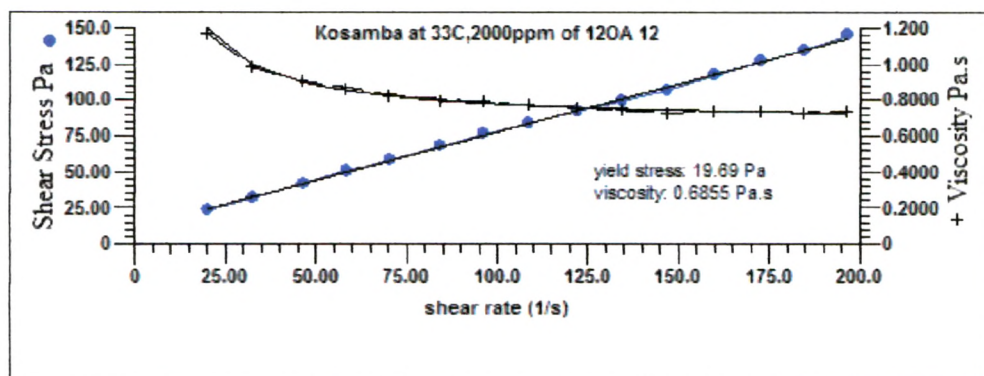


Fig 222 Kosamba with 2000ppm of 12 OA 12

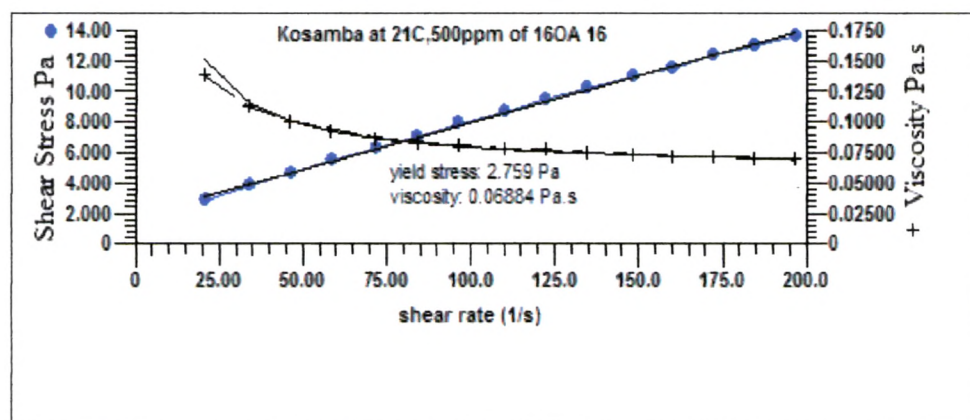


Fig 223 Kosamba with 500ppm of 16 OA 16

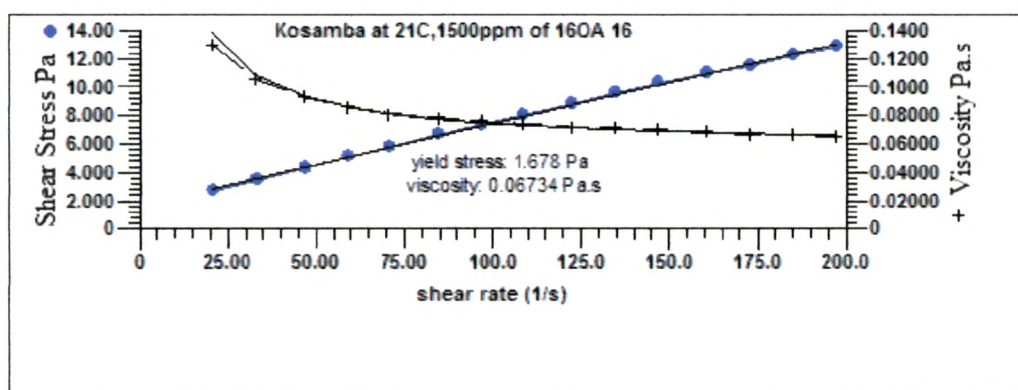


Fig 224 Kosamba with 1500ppm of 16 OA 16

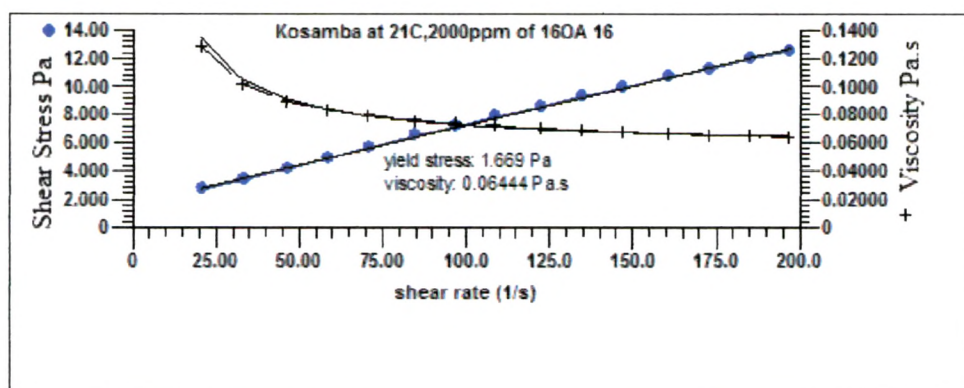


Fig 225 Kosamba with 2000ppm of 16 OA 16

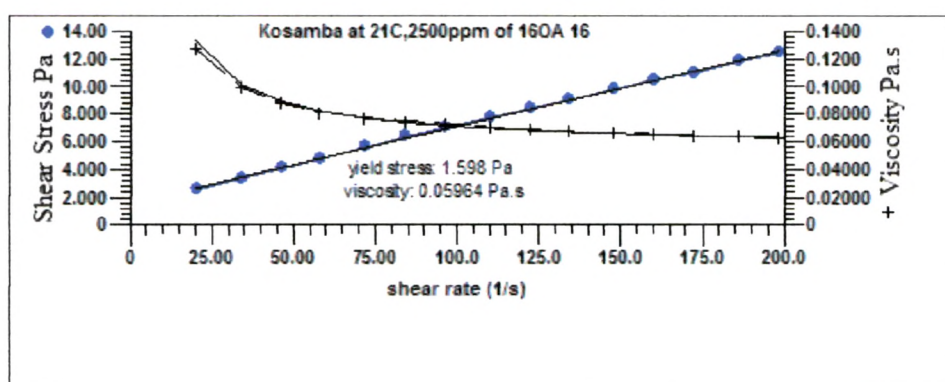


Fig 226 Kosamba with 2500ppm of 16 OA 16

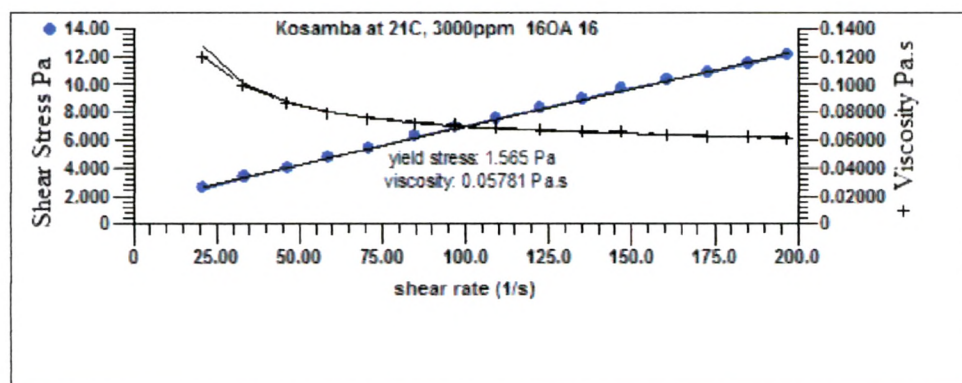


Fig 227 Kosamba with 3000ppm of 16 OA 16

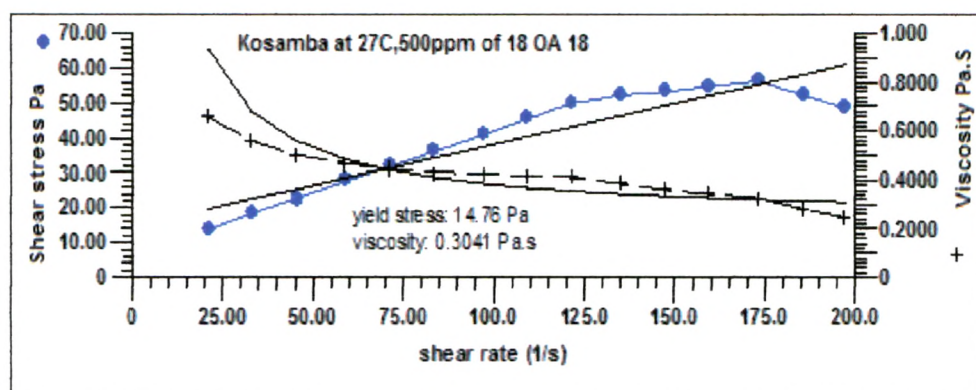


Fig 228 Kosamba with 500ppm of 18 OA 18

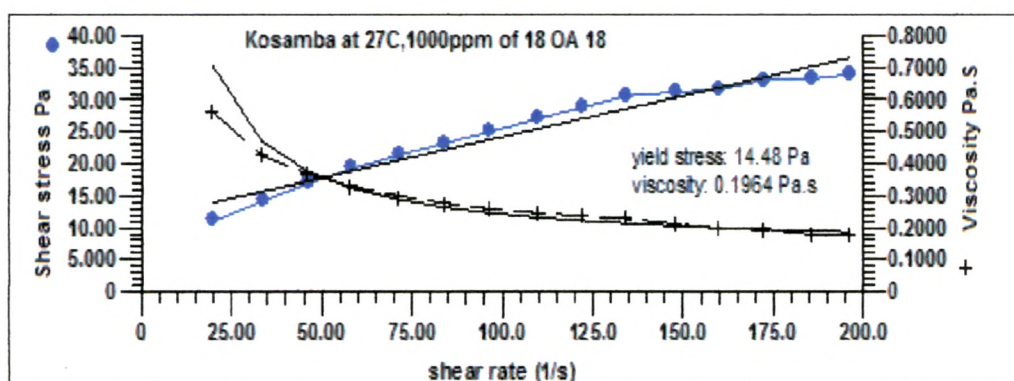


Fig 229 Kosamba with 1000ppm of 18 OA 18

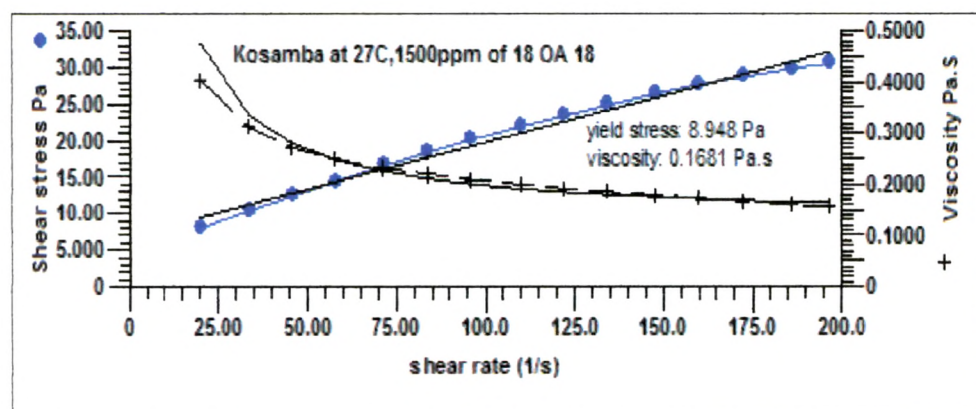


Fig 230 Kosamba with 1000ppm of 18 OA 18

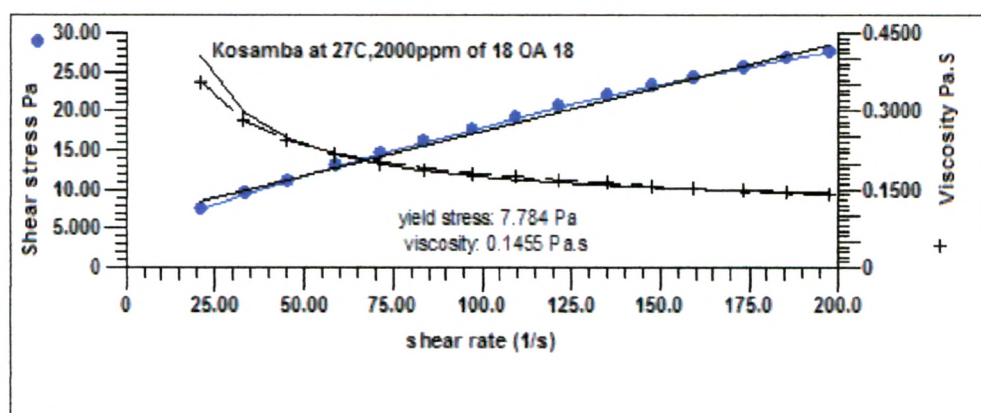


Fig 231 Kosamba with 2000ppm of 18 OA 18

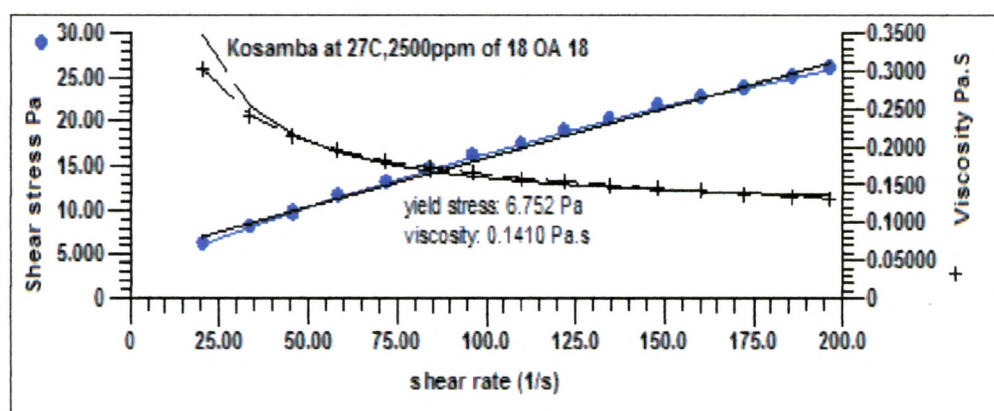


Fig 232 Kosamba with 2500ppm of 18 OA 18

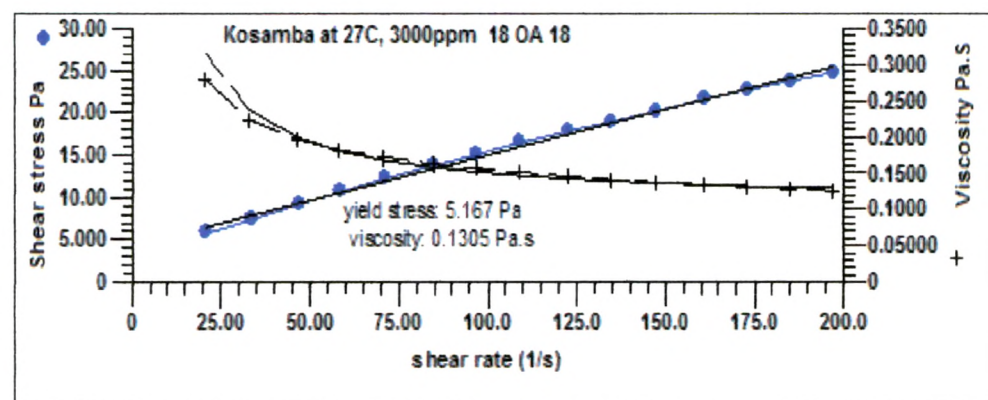


Fig 233 Kosamba with 3000ppm of 18 OA 18

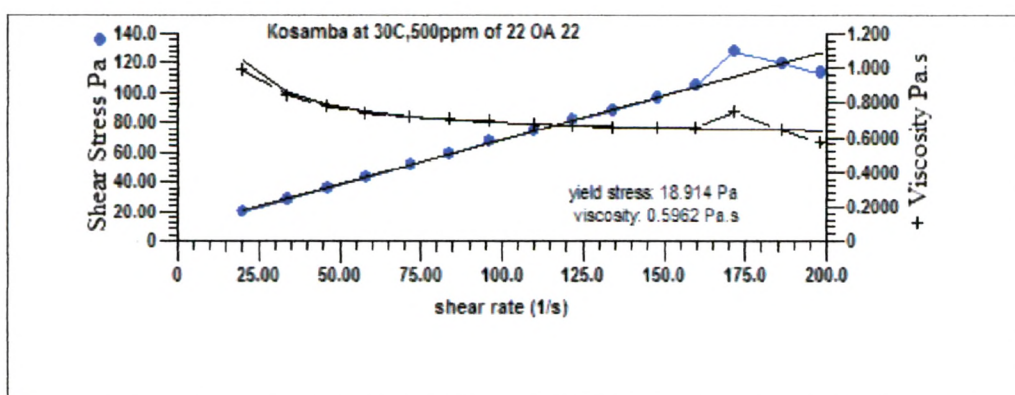


Fig 234 Kosamba with 500ppm of 22 OA 22

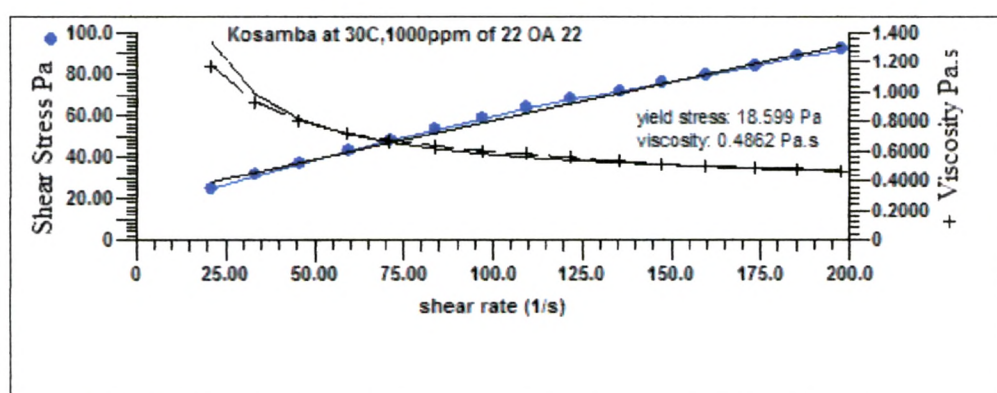


Fig 235 Kosamba with 1000ppm of 22 OA 22

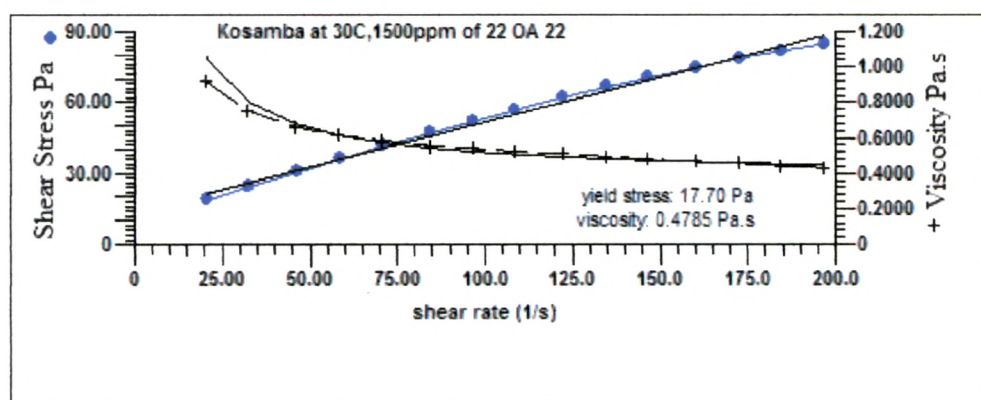


Fig 236 Kosamba with 1500ppm of 22 OA 22

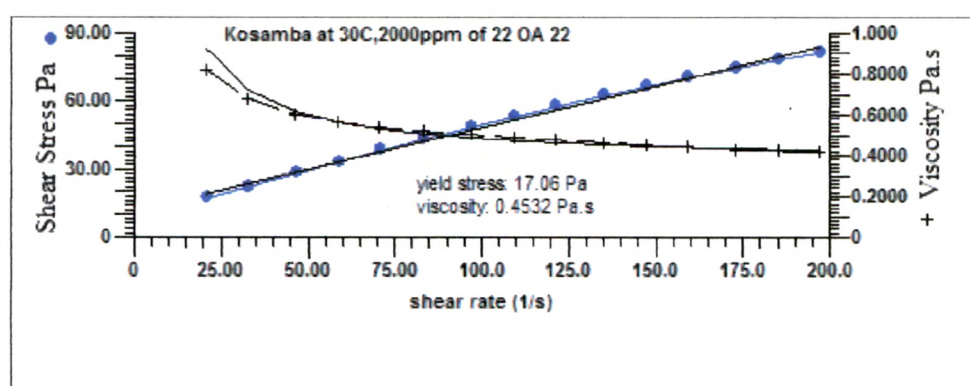


Fig 237 Kosamba with 2000ppm of 22 OA 22

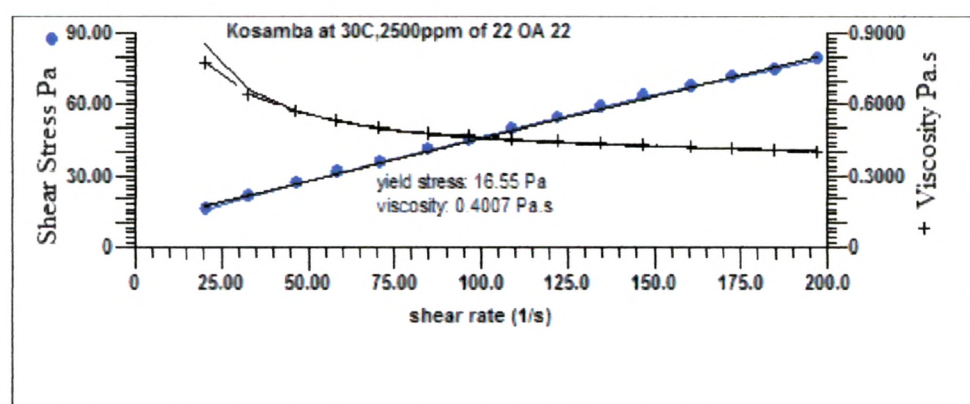


Fig 238 Kosamba with 2500ppm of 22 OA 22

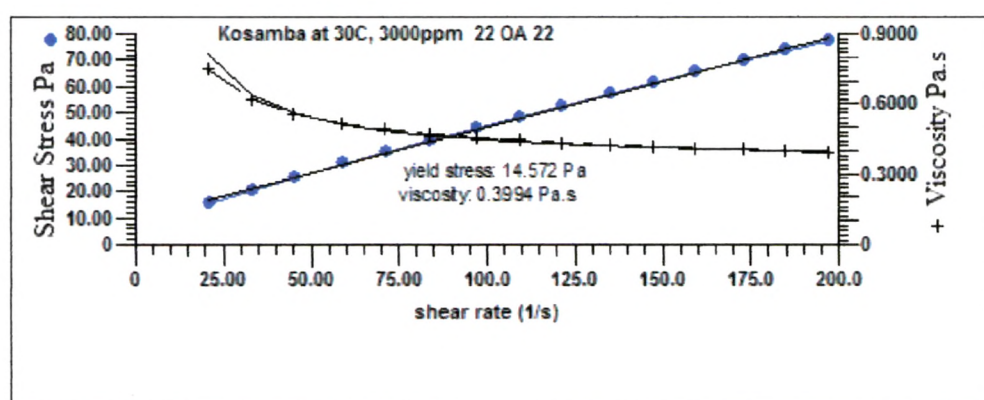


Fig 239 Kosamba with 3000ppm of 22 OA 22

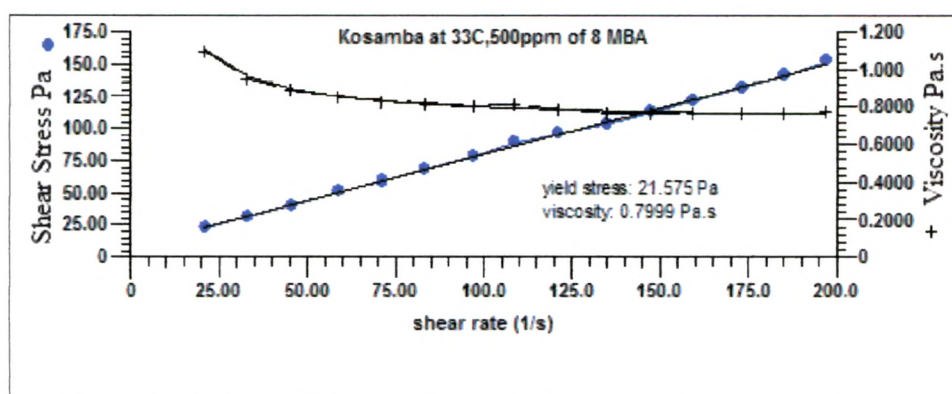


Fig 240 Kosamba with 500ppm of 8MBA

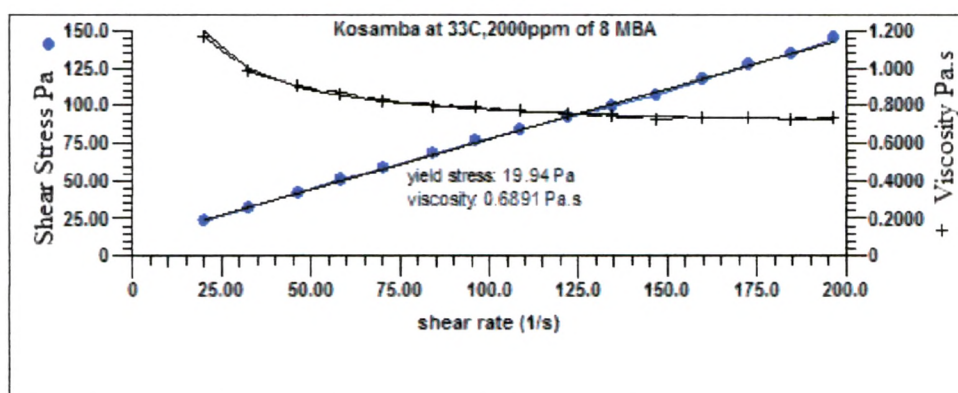


Fig 241 Kosamba with 2000 of 8MBA

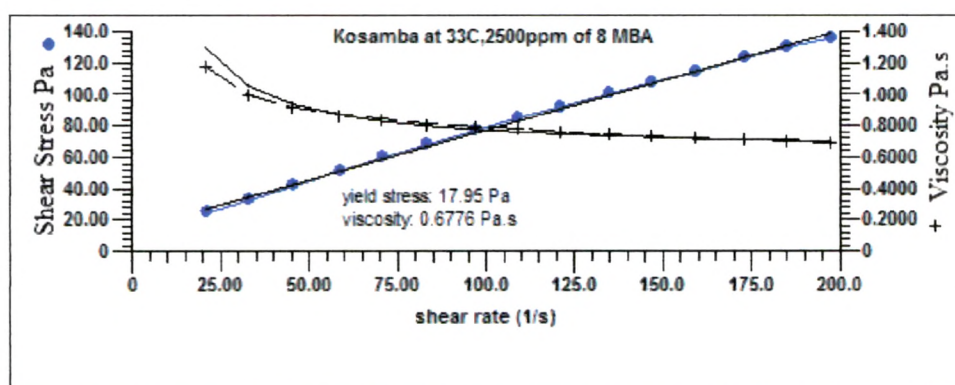


Fig 242 Kosamba with 2500 of 8MBA

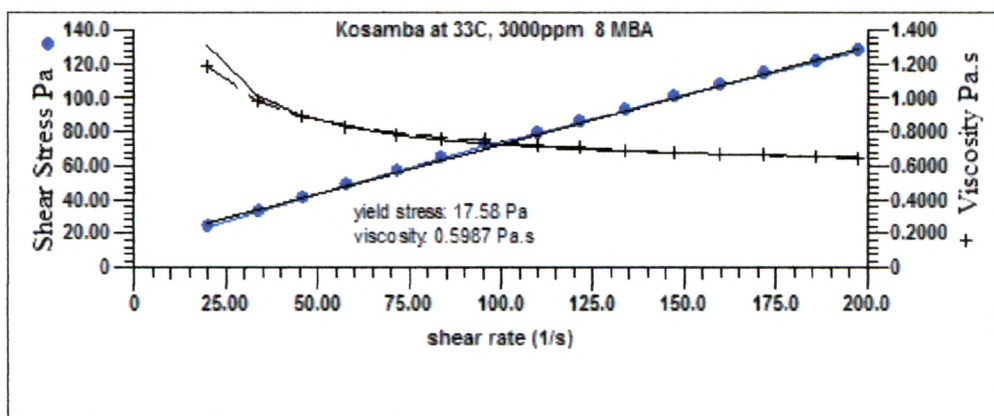


Fig 243 Kosamba with3000 of 8MBA

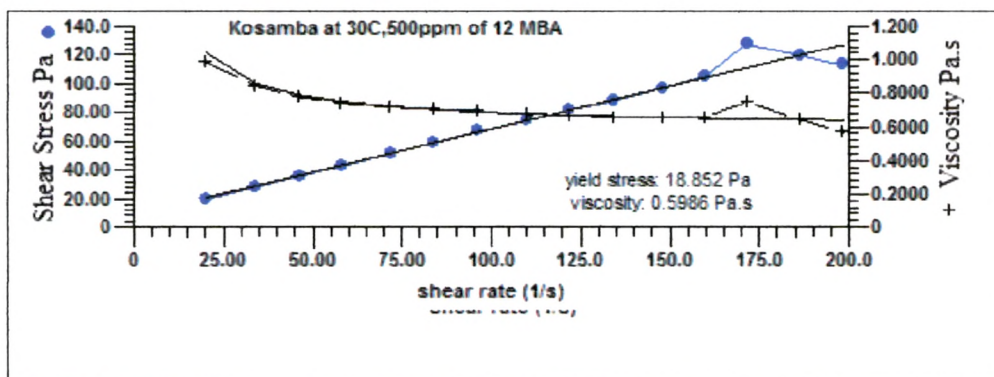


Fig 244 Kosamba with500 of 12MBA

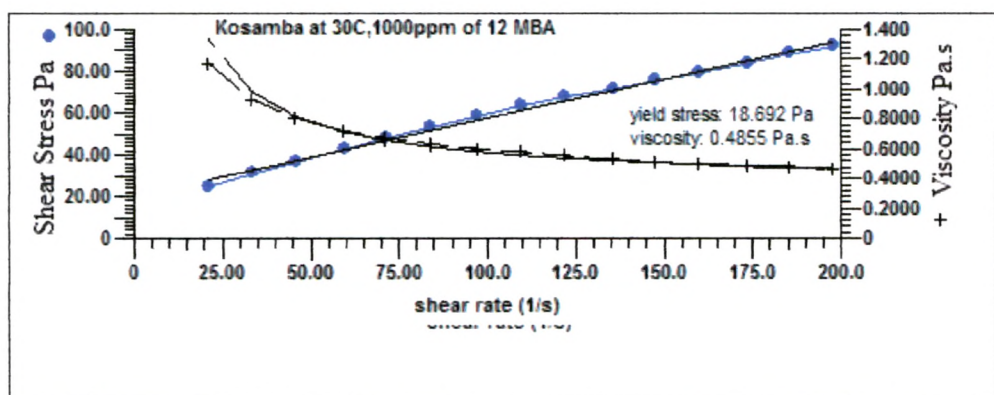


Fig 245 Kosamba with1000 of 12MBA

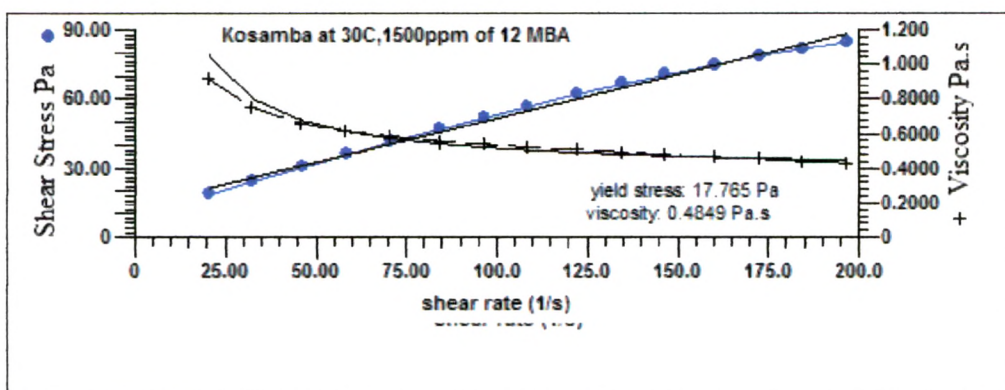


Fig 246 Kosamba with1500 of 12MBA

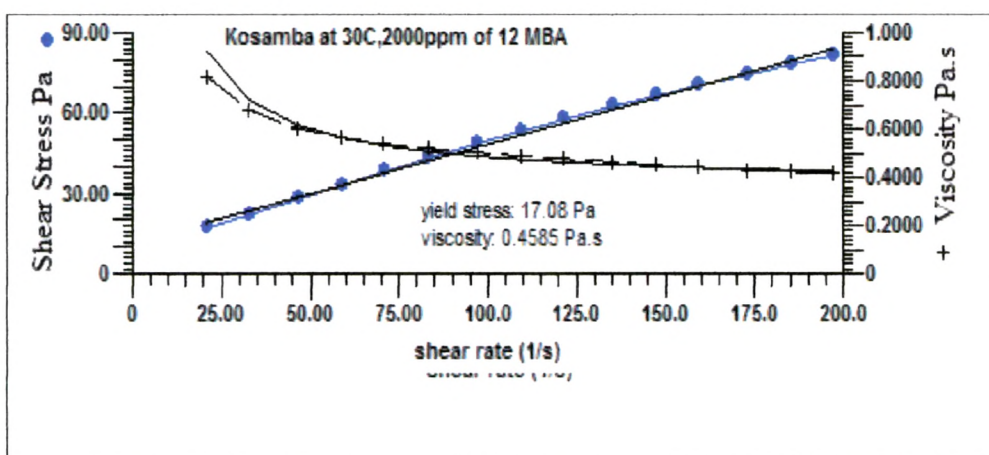


Fig 247 Kosamba with2000 of 12MBA

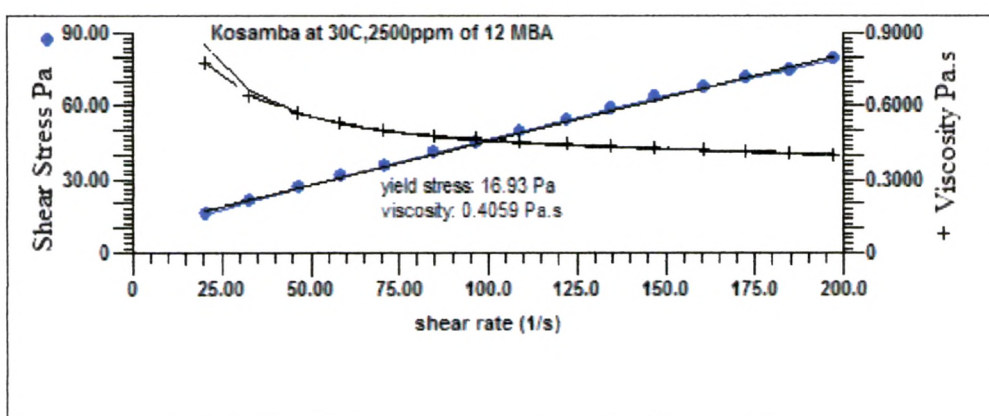


Fig 248 Kosamba with2500 of 12MBA

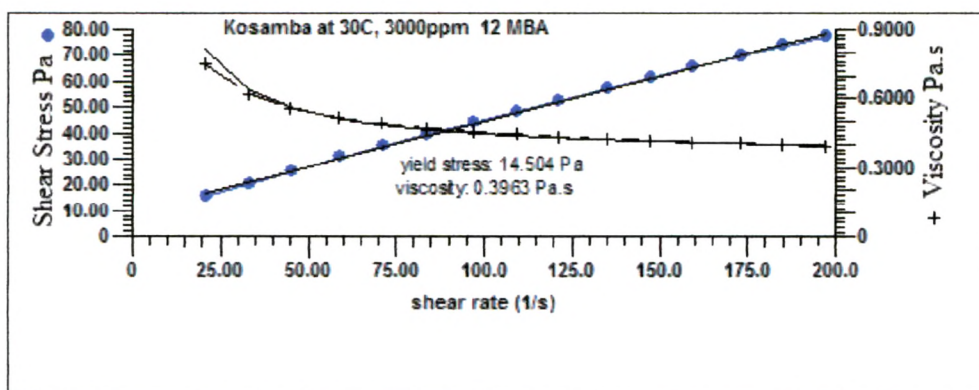


Fig 249 Kosamba with 3000 of 12MBA

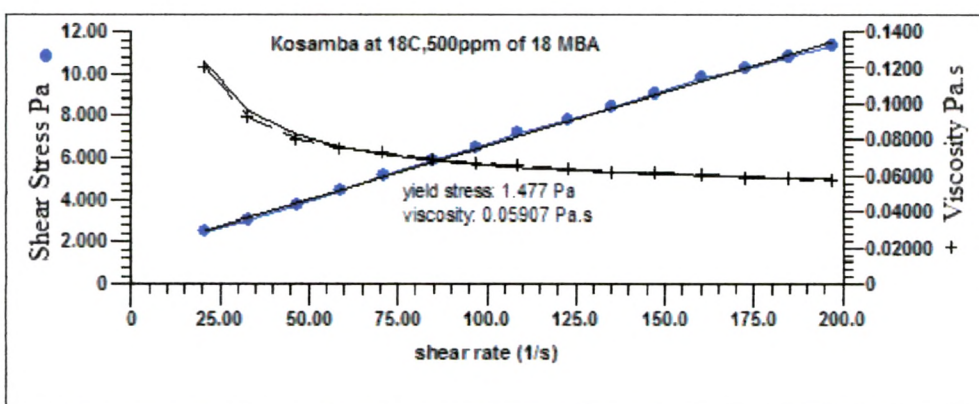


Fig 250 Kosamba with 500 of 18MBA

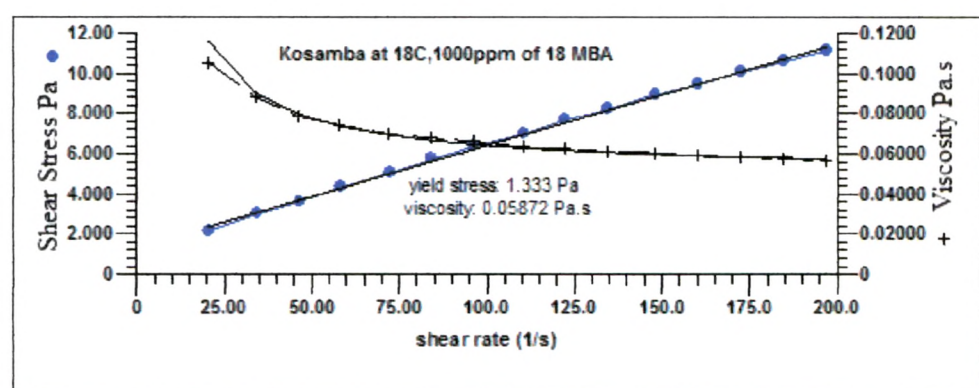


Fig 251 Kosamba with 1000 of 18MBA

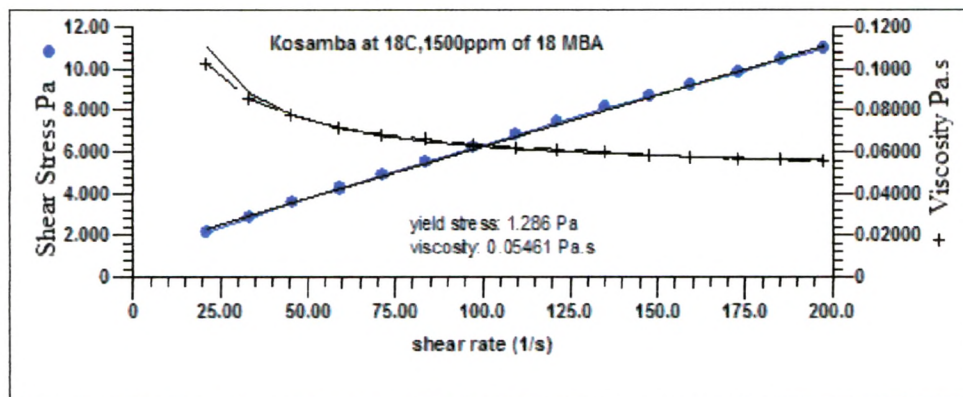


Fig 252 Kosamba with 1500 of 18MBA

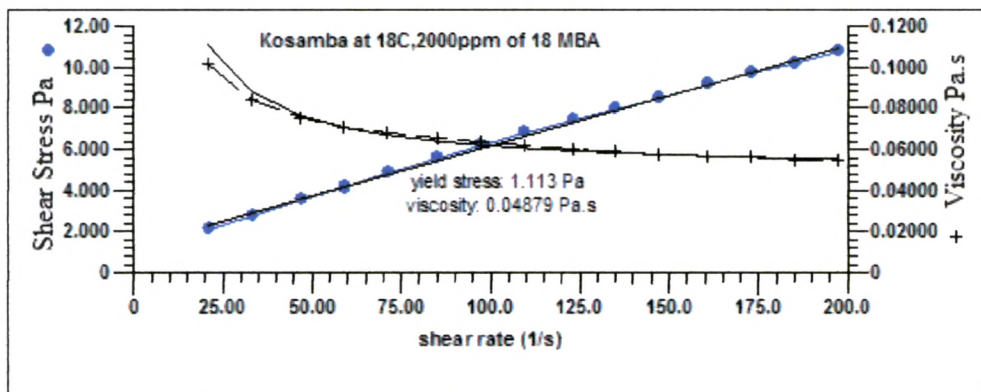


Fig 253Kosamba with 2000 of 18MBA

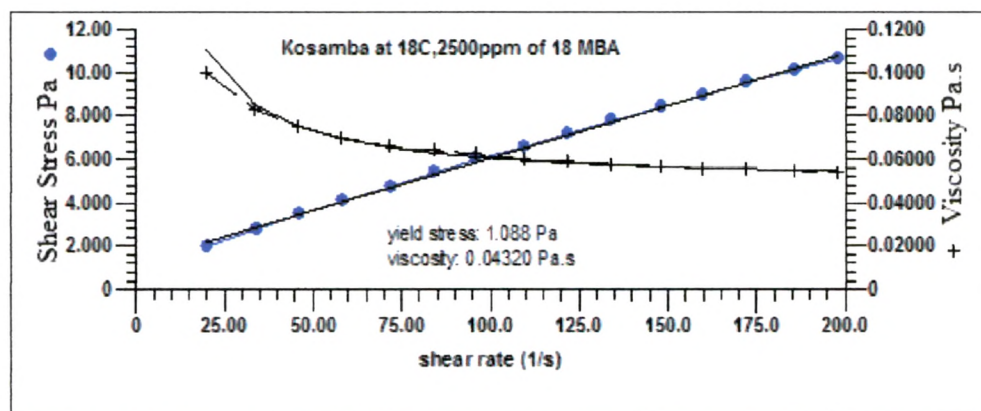


Fig 254 Kosamba with 2500 of 18MBA

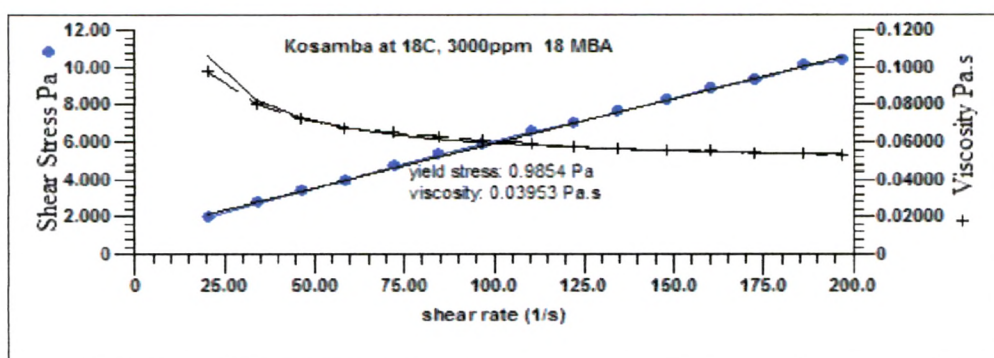


Fig 255 Kosamba with 3000 of 18MBA

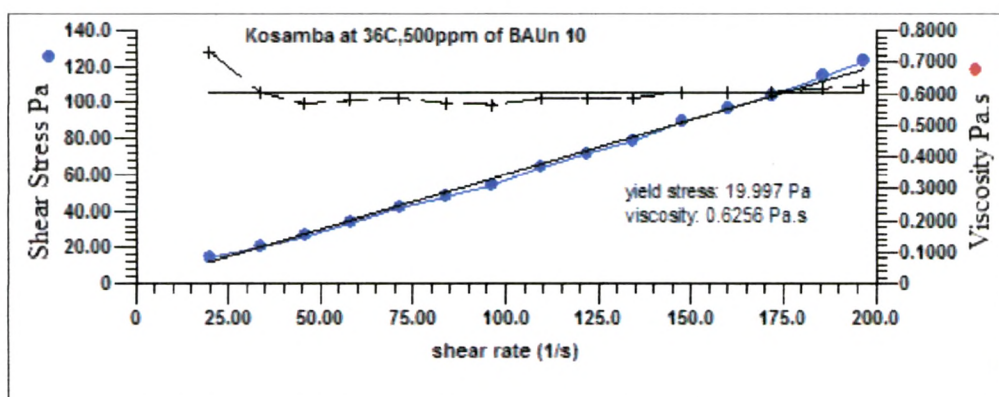


Fig 256 Kosamba with 500 of BAUn10

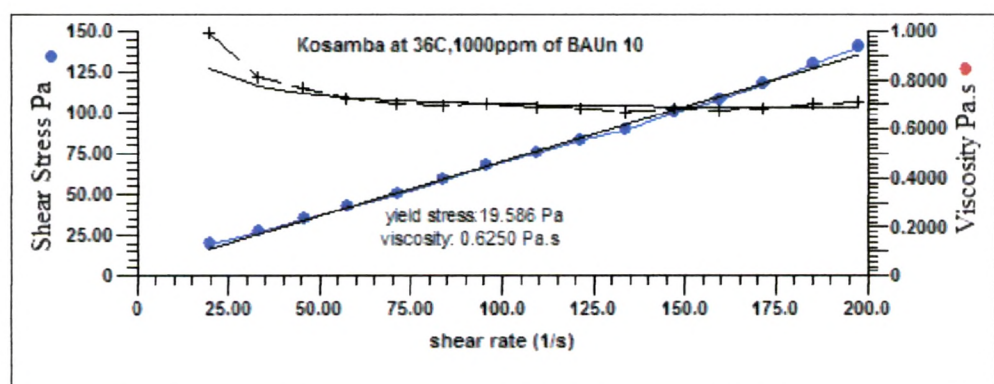


Fig 257 Kosamba with 1000 of BAUn10

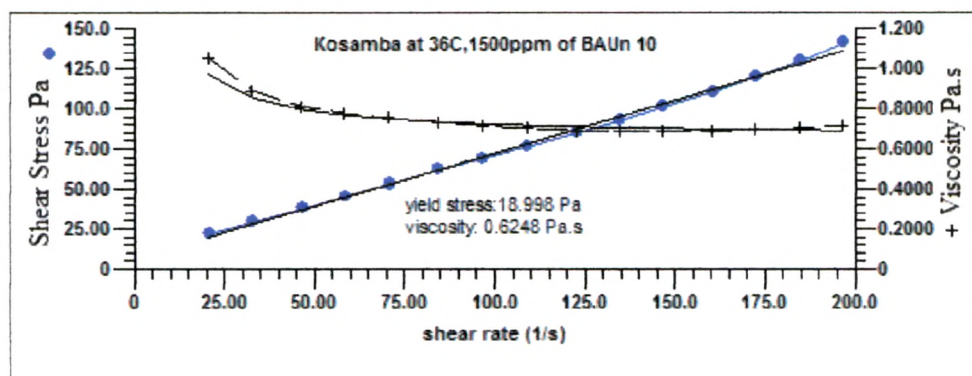


Fig 258 Kosamba with 1500 of BAUn10

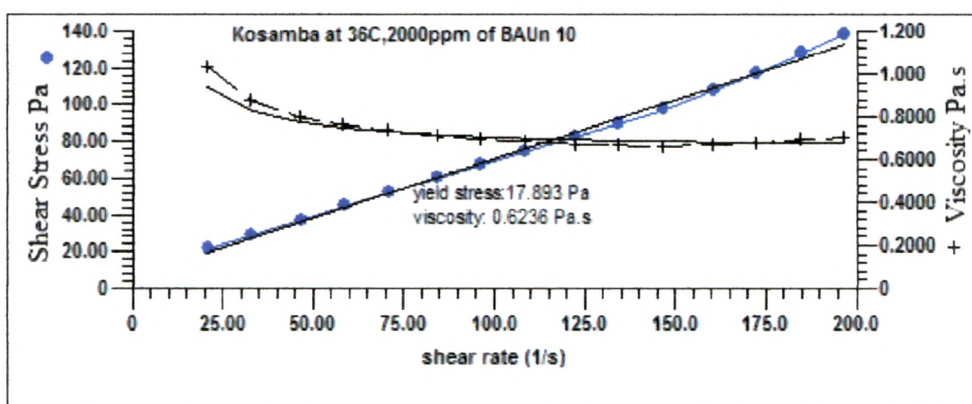


Fig 259 Kosamba with 2000 of BAUn10

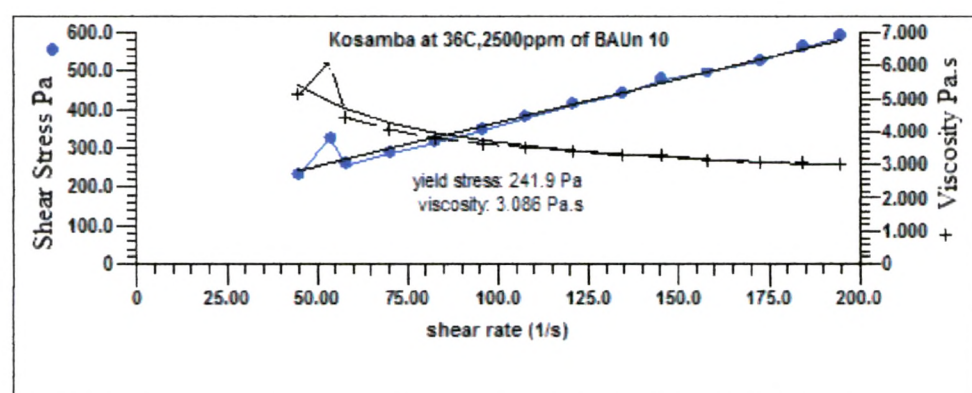


Fig 260 Kosamba with 2500 of BAUn1

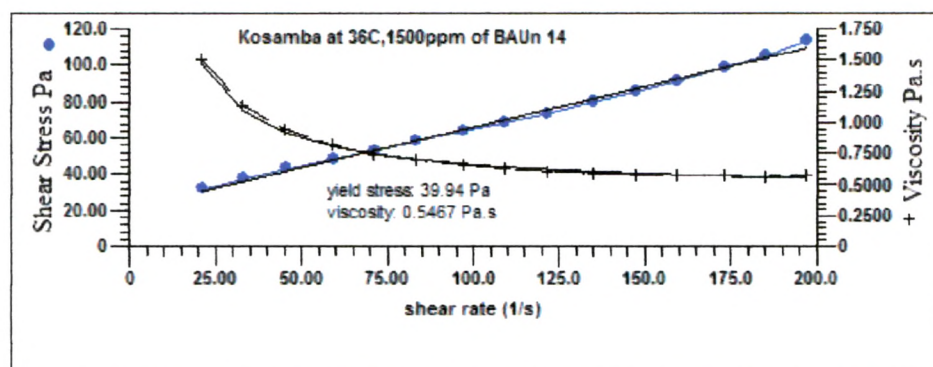


Fig 261 Kosamba with 1500 of BAUn14

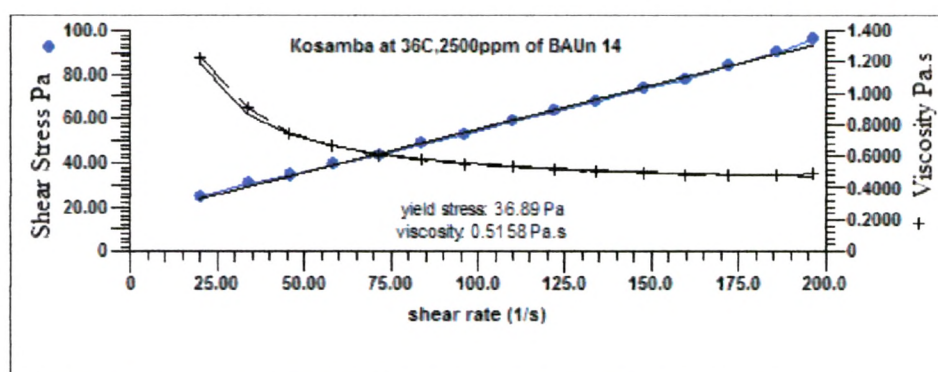


Fig 262 Kosamba with 2500 of BAUn14

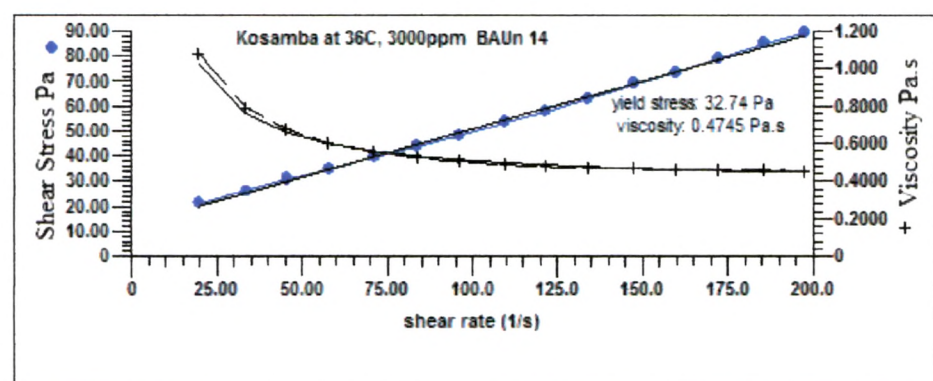


Fig 263 Kosamba with 3000 of BAUn14

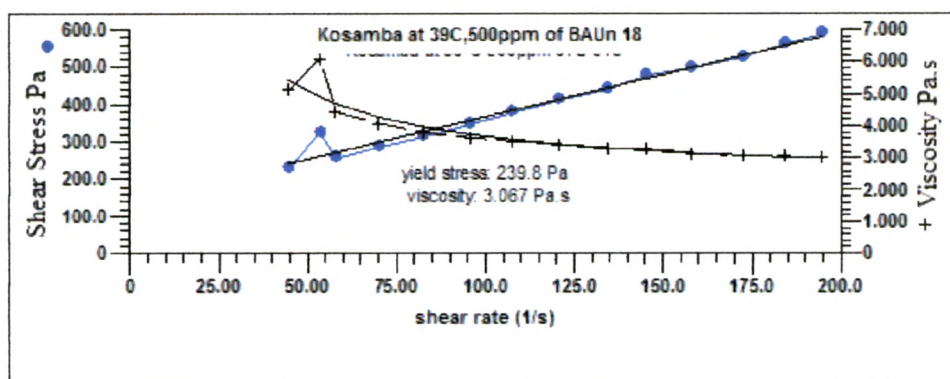


Fig 264 Kosamba with 500 of BAUn18

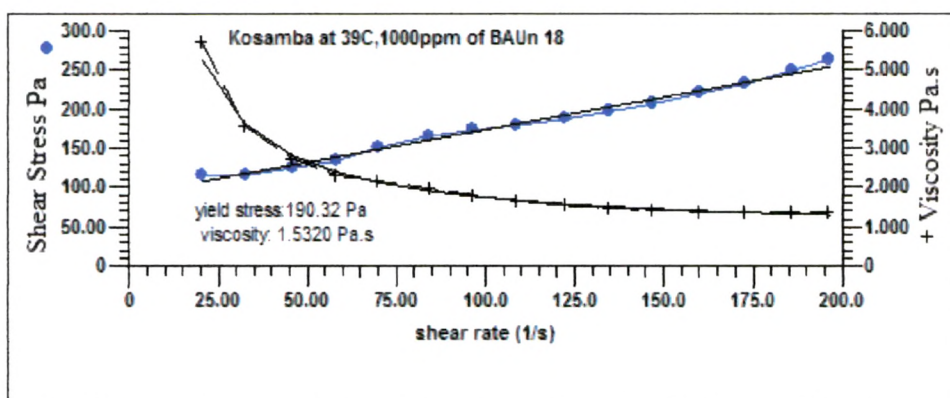


Fig 265 Kosamba with 1000 of BAUn18

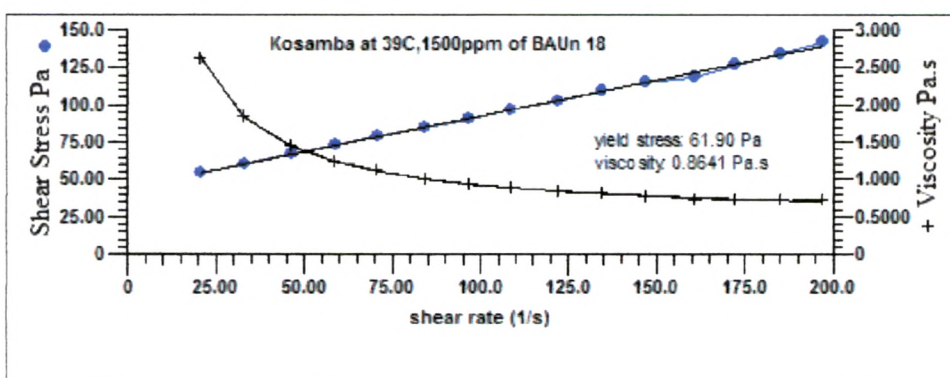


Fig 266Kosamba with 1500 of BAUn18

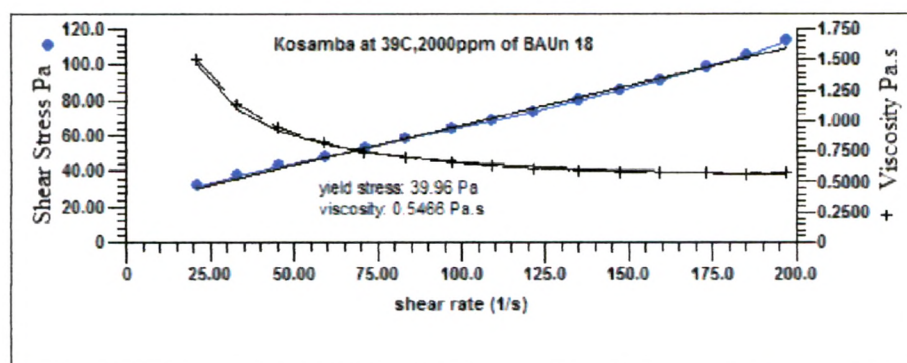


Fig 267 Kosamba with 2000 of BAUn18

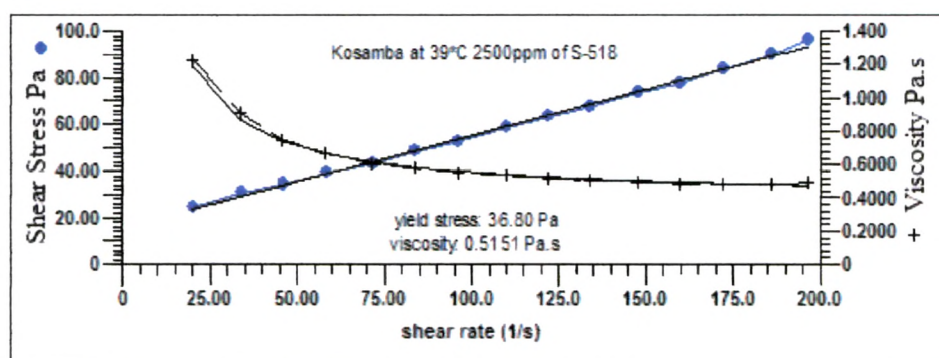


Fig 268 Kosamba with 2500 of BAUn18

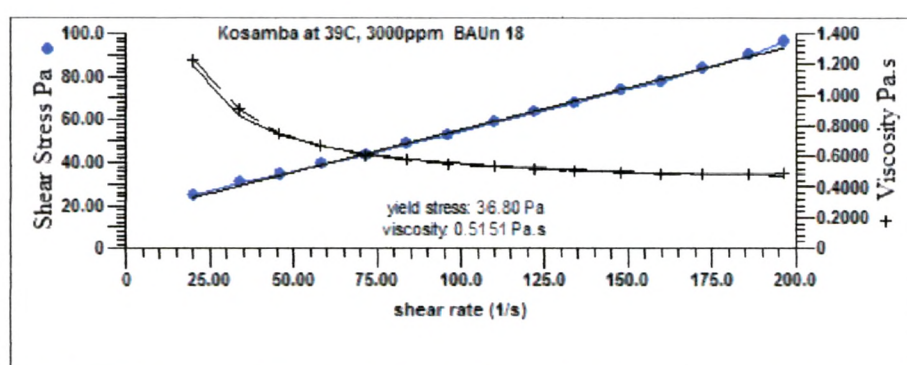


Fig 269 Kosamba with 3000 of BAUn18

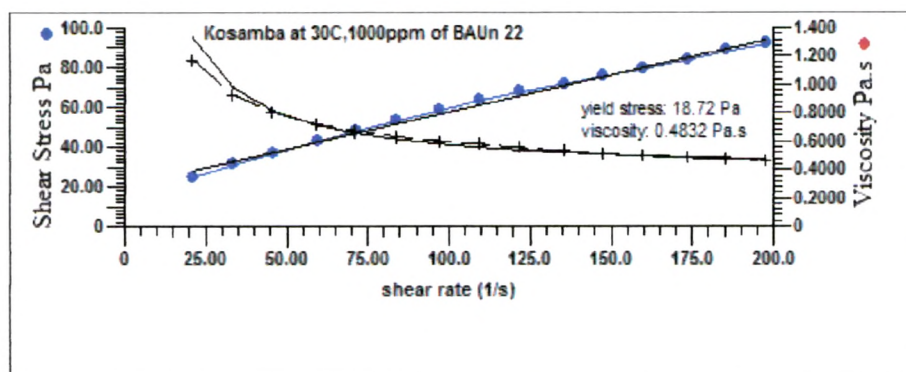


Fig 270 Kosamba with 500 of BAUn22

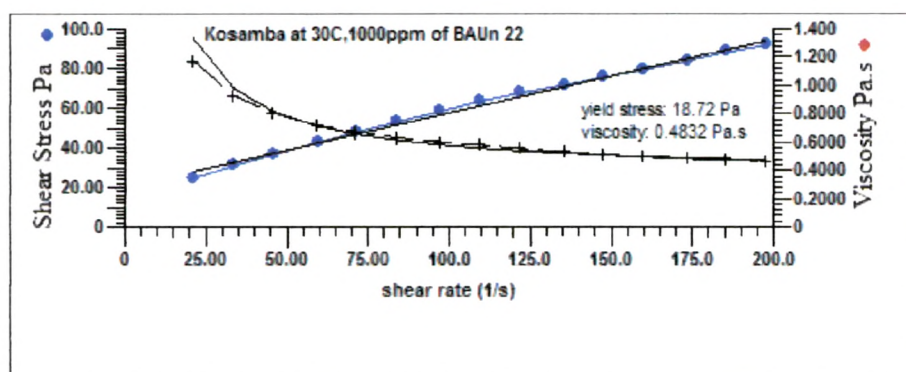


Fig 271 Kosamba with 1000 of BAUn22

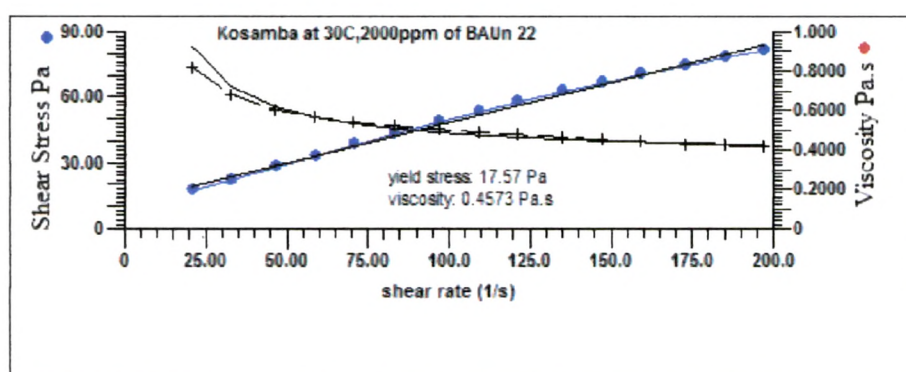


Fig 272 Kosamba with 2000 of BAUn22

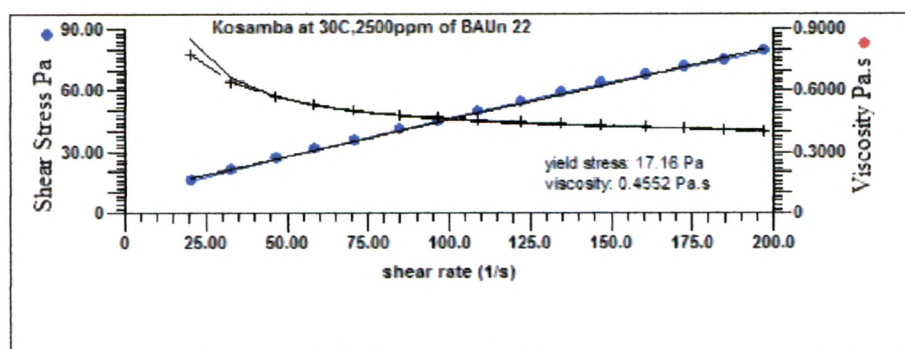


Fig 273 Kosamba with 2500 of BAUn22

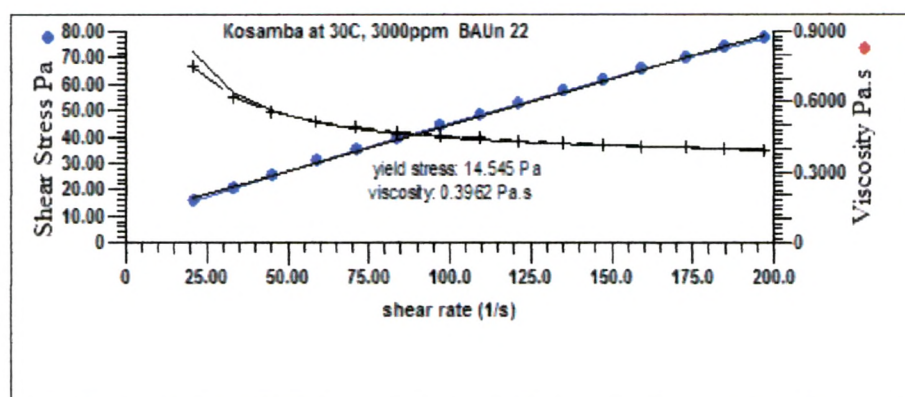


Fig 274 Kosamba with 3000 of BAUn22

4.2.6 Cold Finger Test on Kosamba crude oil:

Quantity of crude required for running cold finger test is very high. So only selected the doses were tried. But this test is very useful for implementation in field conditions for any PPD.

Volume taken: 800ml

Temperature gradient: 65 - 35°C

Sr.No	PPD Name	Dose (mg/l)	Weight deposit	of % inhibition	M.P.of waxes °C	Wax(%) content
1	Blank	-	6.50		56	60
2	18 ABA	2000	2.0	66.66	40	42
3	16ABA	2000	4.0	38.46	45	49

5	8 OA 8	2000	3.5	46.15	40	47
6	18 MBA	2000	4.0	38.46	46	51
7	16MBA	2000	4.0	38.46	48	55
8	BAUn18	2000	7.2	- 15.20	50	60
9	BAUn22	2000	6.5	-	50	60

Table 48 Cold Finger data for Kosamba crude oil

4.3.7 Discussion:

Pour point

Physico-chemical properties of Kosamba crude shows it a medium density crude oil and is highly waxy in nature as having 30% wax in neat sample. Viscosity of the neat crude measured below and above pour point of the crude. The viscosity is quite high at pour point i.e at 36°C is 560 cps and yield stress is reported 38 Pa as seen in the Fig:192. Crude oil is very highly susceptible to wax deposition and it is observed from the experimental experience that this crude gives a very sharp pour point. If the temperature decrease rate is even slow it shows typical behavior that at one temperature it is flowing and just one degree below it is solid which explains its high tendency towards deposition. Pipe line deposit of Kosamba was also studied for its chemical composition. Results are summarized in the Table 42. Waxes present in the deposit are more than 84%, oil is only 6%. Melting point of the deposit is 96°C is also quite high. So it is clear from the deposit study that because of the 30% of waxes in neat oils the deposition occurs to a great extent from well head to the pipeline end.

Four series of the additives naming nABA, n OA n MBA and BAUn n were prepared and tested on Kosamba crude oil from 500-3000 ppm. Pour point results of the Kosamba crude with all the doses of PPD's are summarized in Table 43 It is observed that 8 OA 8 and 16 OA16 has lowered the pour point from 36 to 15°C and 21°C. This shows high effectiveness of these two additives of Oleate series. 18 OA 18 has also decreased the pour point to a good extent ie to 27°C. 10 OA 10 has increased the pour point to 39°C, Rest of the additives of this seires remained dormant to the pour point.

It is quite interesting to note that as in OA series 8 carbon side chain length additive (8 OA 8) has depressed the pour point to 15 °C, in ABA series 8 ABA has worked reversely as it has increased the pour point to 39 °C. It shows that pendent chain length is not only the important factor in chemical additives as pour point depressant but the type of chemical corresponding to the type(physio-chemical characteristics) of crude is also of great importance for getting the better results. 10 ABA and 14 ABA has decreased the pour point to 27°C. 12 ABA has given the pour point 24°C, 16 ABA has decreased it to 21°C and 18 ABA to 15°C from 36°C. These results fully explains that as the type of additive matching to the waxes present in Kosamba oil decreases the pour point and as the chain length increases the effectiveness also increases showing the increasing trend in carbon number present in the kosamba crude oil waxes. It is observed that in these type of crude the concentration of chemical additive is not of much importance in decreasing the pour point. In case of n MBA series it is noticed that 8 MBA, 10 MBA and 12 MBA are not much effective. But 14 MBA, 16 MBA and 18 MBA has decreased the pour point of Kosamba oil to 24, 21 and 18 °C. So the results of Methacrylates are also encouraging. In the series BAUn 10 to BAUn 22 mainly the reverse effect is seen as these additives has increased the pour point to 39 and 42 °C showing their ineffectiveness in Kosamba crude. These chains co-crystallize with the waxes and added reverse effect in the pour point depression.

Rheological properties

All the four series synthesized flow improvers are evaluated for low temperature performance for Kosamba crude oil with and without additive treatment. Firstly pour point was detected and then the sample was subjected to rheological studies with all the doses i.e from 500 ppm to 3000 ppm. Studies on all the doses were possible because of the high sensitivity of TA Rheometer. The rheograms of the evaluated additives on the crude are given in the Figures 189 to 274 and results of rheological studies are summarized in Table 44 to 47.

Figure 189 to 196 shows the rheograms for the neat Kosamba crude oil. Viscosity and yield stress results of neat Kosamba oil are summarized in Table 41. It is clear from the results that viscosity of Kosamba neat crude is 560 cps at pour point i.e at 36°C and is recorded 392 cps at 50°C. When the temperature is subsequently decreased to 20°C it gives very high viscosity i.e 995cps which reveals that as the temperature increases, the viscosity of the oil decreases and vice versa. Same is case with yield

stress also. In the table 41 it is seen that that yield stress of Kosamba neat crude at 20°C is 132 Pa and at it decreases to 14 Pa at 50°C. So viscosity and yield stress follows the same trend in neat conditions. Figure 195 shows comparison of the rheological behavior of neat Kosamba oil at different temperatures. This rheogram is recorded between shear rate and shear stress. Fig 196 is the temperature ramp at constant shear rate i.e 10 sec⁻¹. It gives the information about the change in viscosity of the crude oil from high to low temperature. Pour point and cloud point can be recorded with highly precise investigation of this rheogram.

Table 44 explains the rheological results of additives of the series n ABA i.e Diester of Poly(n-alkyl acrylate-co-maleic anhydride)dibenzylate. In this series 6ABA , 10 ABA and 12 ABA are not much effective in decreasing the viscosity at 500ppm doses but with the increase of concentrations these additives have somewhat improved the flow behavior. 14 ABA, 16ABA and 18 ABA has depressed the viscosity to 69 at 500ppm and 39cps at 3000ppm.They have reduced yield stress to as low as 1.4 Pa. So it is clear from the table 44 that higher alkyl chains of this series are more effective in increasing the flow behavior of Kosamba crude oil.

Table 45 shows the rheological results of Kosamba crude oil with the different doses(500-3000ppm of n OA n additives i.e Diester of Poly(n-alkyl oleate-co-maleic anhydride)dialkylate. Pour point with these additives with all the doses has been explained already. It is very clear from the table 45 that those carbon chains which has decreased pour point also has subsequently improved the flow behavior of the crude oils, they have decreased viscosity and yield stress of the oil at ambient temperatures. It is clear from the table 45 that 6 OA 6, 10 OA 10 and 12 OA 12 has no effect on viscosity. 8 OA 8 and 16 OA 16 has decreased viscosity to as low as 51 and 68 cps with 500ppm dose. Yield stress is also decreased to 1.2 and 2.7 Pa. 14 OA 14 and 18 OA 18 are less effective but has decreased the viscosity to 309 and 168cps and yield stress to 15 and 8 Pa. So in Oleate series 8 and 16 additives are found to effective in decreasing the viscosity of Kosamba crude.

Table 46 summarize rheological results of the series (nMBA)Diester of Poly(n-alkyl methacrylate-co-maleic anhydride)dibenzylate. In this series also lower number chain additive ie from 6 MBA to 14 MBA has hardly any effect on viscosity and flow behavior of Kosamba. So higher concentrations are found to more useful for field

applications. It is also noticeable in rheological studies of Kosamba oil that only specific additives are effective and in many cases only higher chain length additives are found effective. It is also revealed that waxes present in the Kosamba oil are nearly matching to the chain length of 16 to 18 side chain length additives.

Table 47 shows the rheological study results of (BAUn 10)Diester of Poly(n-alkyl undecylenate-co-maleic anhydride)dialkylate series. These additives have given reverse results that is increased the viscosity of Kosamaba oil. It is seen from the table 47 that with the increasing pendent chains the viscosity and yield stress has been increased. Flow behavior has been decreased to very high extent. Flow is almost stopped. BAUn 10 to BAUn 22 the viscosity has increased from 599 to 3067 cps. Yield stress is also increased to 239 showing reverse affect of the additive. So it is very much clear from the por point and rheological results that undecylenate additives are not useful for Kosamba oil.

It is finally concluded that ABA series is very much useful for Kosamba field trials.

Cold Finger Test:

All synthesized Chemical additives evaluated for pour point and rheology for the doses of 500ppm to 3000ppm. But in case of cold finger tests only those additives which have given very good results in the above studies are evaluated. Neat crude oil of Kosamba has given wax deposit of 6.5 grams showing a very high wax deposition tendencyof kosamba crude. When the Kosamba crude was treated with 2000ppm) dose of 8 OA 8 and 14 OA 14 additives the deposition has decreased to 4gm and 3.5gm respectively. Results are summarized in Table 48. 2000 ppm of 18 ABA and 16 ABA has decreased to 2gm and 4 gm. Further MdeBA-18 has reduced to 4 gm respectively. In case of BAUn 10 deposit weight has been found to 6.5 gm. So it is clear from the Table 48 that cold finger test results data exactly followed the pour point and viscosity results.

CHAPTER-IV-III

TESTING OF SYNTHESIZED POLYMER ADDITIVES ON NADA FIELD CRUDE OIL

4.3.1 Physico-chemical Properties of Nada crude oil

Nada crude oil is light to medium density oil. The sample taken is composite sample from Nada field. Sample from Nada is very exclusive, as it is situated very distant from Gandhar also, RGL, Baroda has helped in getting the sample. Nada has also high water cut which increases the problems in handling the crude. Commercially Nada crude is Very good as seen from distillation characteristics of the oil. Nada crude is also very highly waxy in nature as it has nearly 31% of wax and pour point is 33°C which is not a bigger problem in summer season also but when temperature goes down to 20°C it become very difficult to handle. The physical properties of Nada crude oil are given in Table 49

Table 50 shows the distillation behavior of the Nada crude oil from zero to 300°C temperature. The initial boiling point (IBP) of the crude oil is 52°C which is quite low.

Sr. No.	Properties	Unit	Result
1	Density	g/cc	0.8341
2	Specific gravity	g/cc	0.8345
3	API ¹ gravity	Degree	39.9
4	Pour point	°C	33
5	Wax content	% wt	31.26
6	Saturates	% wt	84.97
7	Aromatics	--	10.22
8	N,S,O	--	4.81
9	Asphaltene	% wt	0.54
10	Cloud Point	°C	54
11	IBP ²	°C	52

Table 49 Geo-Chemical Characterization of Nada crude oil

Distillation:

Volume taken = 100 ml

Initial Boiling Point (IBP) = 52°C

Sr. No.	Temperature (°C)	Volume of oil (ml)
1	52-75	04
2	75-100	08
3	100-125	13
4	125-150	21
5	150-175	27
6	175-200	33
7	200-225	42
8	225-250	49
9	250-275	57
10	275-300	68

Table 50 Distillation characteristics of Nada crude oil

Temperature °C	Viscosity cps	Yield stress Pa
20	955.7	82.45
25	753.2	63.99
30	231.3	22.73
33 (pour point)	282.9	21.97
35	207.8	21.19
36	207.6	20.99
40	122.9	14.96
50	33.0	2.91

Table 51 Viscosity at different temperatures of Neat Nada Crude

4.3.2 Nada field Deposit Study:

Sr.No	Parameter	Unit	Results
1	Water Content	% Vol	3
2	Wax Content	% Wt	86.7
3	Asphaltene Content	% Wt	0.13
4	Oil Content	% Wt	5.6
5	Inorganics	% Wt	3.9
6	Resin content	% Wt	1.88
7	M.P of waxes	°C	94
8	M.P of Deposit	°C	95

Table 52. Analysis of Deposit Sample from Nada field

4.3.3 Pour Point Studies:

Sr. No.	Additive code	Pour point of Nada crude oil (°C)	Pour point of additive treated crude oil (ppm)						Extent of depression in pour point (°C)
		Doses-	500	1000	1500	2000	2500	3000	500
1	8 ABA	33	33	33	33	33	33	33	-
2	10 ABA	33	30	30	30	30	30	30	3
3	12 ABA	33	30	30	30	30	30	30	3
4	14 ABA	33	27	27	27	27	27	27	6
5	16 ABA	33	21	21	21	21	21	21	12
6	18 ABA	33	30	30	30	30	30	30	3
7	8 OA 8	33	30	30	30	30	30	30	3

8	10 OA 10	33	36	36	36	36	36	36	-3
9	12 OA 12	33	30	30	30	30	30	30	3
10	14 OA 14	33	27	27	27	27	27	27	6
11	16 OA 16	33	33	33	33	33	33	33	-
12	18 OA 18	33	30	30	30	30	30	30	3
13	22 OA 22	33	27	27	27	27	27	27	6
14	6 MBA	33	33	33	33	33	33	33	-
15	8 MBA	33	33	33	33	33	33	33	-
16	10 MBA	33	30	30	30	30	30	30	3
17	12 MBA	33	24	24	24	24	24	24	9
18	14 MBA	33	27	27	27	27	27	27	6
19	16 MBA	33	21	21	21	21	21	21	12
20	18 MBA	33	30	30	30	30	30	30	3
21	BAUn 8	33	33	33	33	33	33	33	-
22	BAUn 10	33	33	33	33	33	33	33	-
23	BAUn 12	33	30	30	30	30	30	30	3
24	BAUn 14	33	27	27	27	27	27	27	6
25	BAUn 16	33	30	30	30	30	30	30	3
26	BAUn 18	33	30	30	30	30	30	30	3

Table 53. Pour points of polymeric additive treated Nada crude oil

4.4.4 Rheological Studies results on Nada oil :

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress(Pa)
1	8 ABA	500	33	127.5	10.77
2	8 ABA	1000	33	124.7	6.64
3	8 ABA	1500	33	122.4	5.87
4	8 ABA	2000	33	58.64	4.29
5	8 ABA	2500	33	49.95	3.65
6	8 ABA	3000	33	35.88	2.39
7	10 ABA	500	27	21.98	1.15
8	10 ABA	1000	27	21.89	1.14
9	10 ABA	1500	27	20.80	1.38
10	10 ABA	2000	27	20.79	1.37
11	10 ABA	2500	27	20.78	1.37
12	10 ABA	3000	27	20.65	1.23
13	12 ABA	500	30	21.92	1.15
14	12 ABA	1000	30	21.85	1.14
15	12 ABA	1500	30	20.81	1.38
16	12 ABA	2000	30	20.72	1.37
17	12 ABA	2500	30	20.68	1.36
18	12 ABA	3000	30	20.59	1.22
19	14 ABA	500	27	13.19	0.55
20	14 ABA	1000	27	12.95	0.51
21	14 ABA	1500	27	15.23	0.48
22	14 ABA	2000	27	14.54	0.48
23	14 ABA	2500	27	13.56	0.48
24	14 ABA	3000	27	13.36	0.48
25	16 ABA	500	21	8.37	0.41
26	16 ABA	1000	21	8.36	0.34
27	16 ABA	1500	21	8.35	0.34
28	16 ABA	2000	21	8.26	0.30
29	16 ABA	2500	21	8.26	0.29
30	16 ABA	3000	21	8.26	0.27

31	18 ABA	500	30	21.91	1.14
32	18 ABA	1000	30	21.90	1.14
33	18 ABA	1500	30	20.74	1.37
34	18 ABA	2000	30	20.71	1.37
35	18 ABA	2500	30	20.62	1.36
36	18 ABA	3000	30	20.49	1.22

Table 54 Viscosity data of Nada oil treated with n ABA

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress(Pa)
1	8 OA 8	500	30	21.23	1.14
2	8 OA 8	1000	30	21.21	1.14
3	8 OA 8	1500	30	20.54	1.31
4	8 OA 8	2000	30	20.58	1.38
5	8 OA 8	2500	30	20.26	1.37
6	8 OA 8	3000	30	20.21	1.29
7	10 OA 10	500	36	577.7	25.62
8	10 OA 10	1000	36	498.9	21.11
9	10 OA 10	1500	36	434.6	18.66
10	10 OA 10	2000	36	399.1	15.13
11	10 OA 10	2500	36	374.5	14.62
12	10 OA 10	3000	36	293.9	9.00
13	12 OA 12	500	30	31.4	1.976
14	12 OA 12	1000	30	31.79	1.57
15	12 OA 12	1500	30	29.46	1.49
16	12 OA 12	2000	30	28.88	1.35
17	12 OA 12	2500	30	31.89	1.32
18	12 OA 12	3000	30	27.92	1.32
19	14 OA 14	500	27	29.72	1.36
20	12 OA 12	1000	27	19.13	0.99
21	12 OA 12	1500	27	15.92	0.72

22	12 OA 12	2000	27	14.92	0.67
23	12 OA 12	2500	27	14.65	0.66
24	12 OA 12	3000	27	14.55	0.59
25	16 OA 16	500	33	43.87	2.99
26	16 OA 16	1000	33	33.51	2.69
27	16 OA 16	1500	33	32.85	2.45
28	16 OA 16	2000	33	31.97	2.46
29	16 OA 16	2500	33	26.75	2.43
30	16 OA 16	3000	33	26.45	2.32
31	18 OA 18	500	30	31.32	1.53
32	18 OA 18	1000	30	29.44	1.48
33	18 OA 18	1500	30	28.52	1.32
34	18 OA 18	2000	30	28.66	1.32
35	18 OA 18	2500	30	26.45	1.31
36	18 OA 18	3000	30	26.45	1.31
37	22 OA 22	500	27	29.72	1.36
38	22 OA 22	1000	30	19.23	0.99
39	22 OA 22	1500	30	15.92	0.72
40	22 OA 22	2000	30	14.94	0.67
41	22 OA 22	2500	30	14.65	0.66
42	22 OA 22	3000	30	14.55	0.59

Table 55 Viscosity data of Nada oil treated with n OA n

Sr. No	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress(Pa)
1	8 MBA	500	33	127.8	10.79
2	8 MBA	1000	33	124.1	6.60
3	8 MBA	1500	33	122.6	5.87
4	8 MBA	2000	33	58.41	4.22
5	8 MBA	2500	33	48.94	3.39
6	8 MBA	3000	33	35.67	2.28

7	10 MBA	500	30	22.87	1.15
8	10 MBA	1000	30	22.18	1.15
9	10 MBA	1500	30	20.98	1.39
10	10 MBA	2000	30	20.88	1.38
11	10 MBA	2500	30	20.35	1.37
12	10 MBA	3000	30	20.33	1.29
13	12 MBA	500	24	14.86	0.58
14	12 MBA	1000	24	14.67	0.54
15	12 MBA	1500	24	14.90	0.53
16	12 MBA	2000	24	13.59	0.49
17	12 MBA	2500	24	13.43	0.43
18	12 MBA	3000	24	10.44	0.42
19	14 MBA	500	30	21.94	1.14
20	14 MBA	1000	30	21.94	1.14
21	14 MBA	1500	30	20.94	1.39
22	14 MBA	2000	30	20.84	1.38
23	14 MBA	2500	30	20.36	1.38
24	14 MBA	3000	30	20.51	1.29
25	16 MBA	500	30	22.81	1.15
26	16 MBA	1000	30	21.98	1.14
27	16 MBA	1500	30	20.88	1.39
28	16 MBA	2000	30	20.81	1.38
29	16 MBA	2500	30	20.28	1.37
30	16 MBA	3000	30	20.31	1.29
31	18 MBA	500	30	22.80	1.15
32	18 MBA	1000	30	21.95	1.14
33	18 MBA	1500	30	20.85	1.39
34	18 MBA	2000	30	20.78	1.38
35	18 MBA	2500	30	20.25	1.37
36	18 MBA	3000	30	20.25	1.29

Table 56 Viscosity data of Nada oil treated with n MBA

Sr.	Additive code	Additive Conc (ppm)	Temperature (°C)	Viscosity(Cps)	Yield stress(Pa)
1	BAUn 10	500	33	289.9	21.99
2	BAUn 10	1000	33	285.7	21.50
3	BAUn 10	1500	33	284.4	20.88
4	BAUn 10	2000	33	282.2	19.75
5	BAUn 10	2500	33	281.2	19.56
6	BAUn 10	3000	33	281.2	19.55
7	BAUn 12	500	33	43.88	2.99
8	BAUn 12	1000	33	33.51	2.69
9	BAUn 12	1500	33	32.94	2.49
10	BAUn 12	2000	33	32.09	2.45
11	BAUn 12	2500	33	26.99	2.43
12	BAUn 12	3000	33	26.65	2.32
13	BAUn 14	500	30	22.98	1.15
14	BAUn 14	1000	30	23.28	1.14
15	BAUn 14	1500	30	20.89	1.38
16	BAUn 14	2000	30	20.84	1.38
17	BAUn 14	2500	30	20.83	1.38
19	BAUn 16	500	27	13.18	0.55
20	BAUn 16	1000	27	12.91	0.50
21	BAUn 16	1500	27	12.23	0.48
22	BAUn 16	2000	27	12.54	0.49
23	BAUn 16	2500	27	12.34	0.48
24	BAUn 16	3000	27	12.32	0.48
25	BAUn 18	500	30	23.75	1.15
26	BAUn 18	1000	30	23.38	1.14
27	BAUn 18	1500	30	20.84	1.38
28	BAUn 18	2000	30	20.81	1.38
29	BAUn 18	2500	30	20.69	1.37
30	BAUn 18	3000	30	20.59	1.28
31	BAUn 22	500	30	23.78	1.15
32	BAUn 22	1000	30	23.35	1.15
33	BAUn 22	1500	30	20.95	1.39
34	BAUn 22	2000	30	14.97	0.67
35	BAUn 22	2500	30	14.62	0.66
36	BAUn 22	3000	30	14.59	0.59

Table 57 Viscosity data of Nada oil treated with BAUn 22 Additives

4.4.5 Rheological Studies on Nada oil on TA AR500 Rheometer:

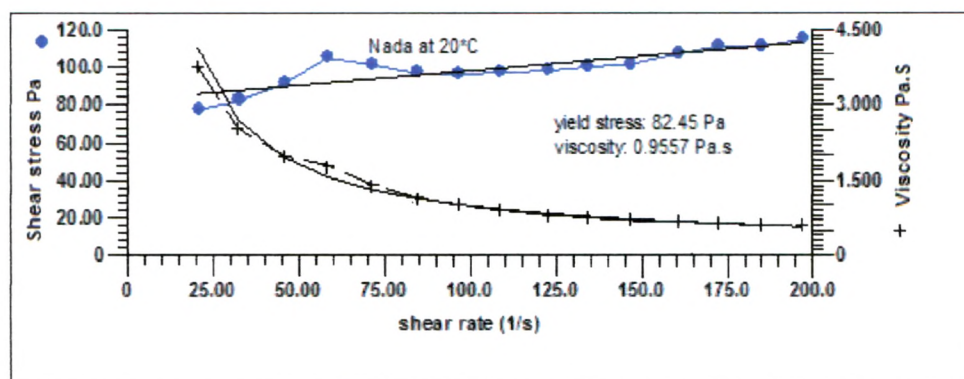


Fig 275 Nada neat at 20°C

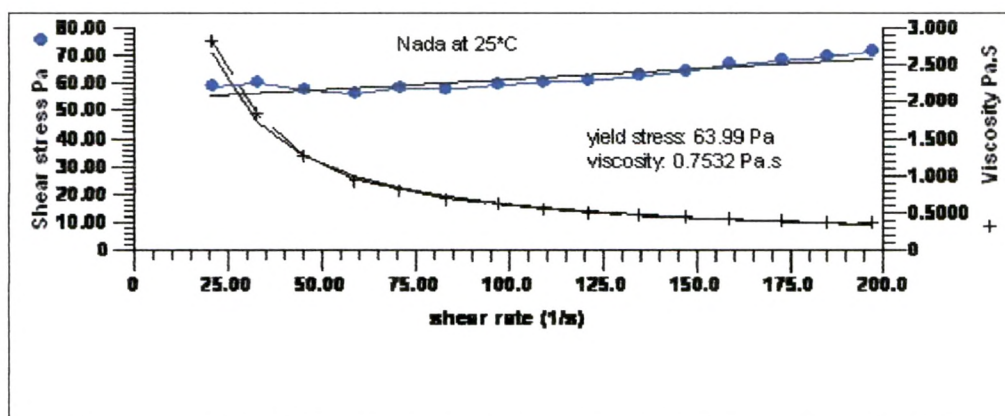


Fig 276 Nada neat at 25°C

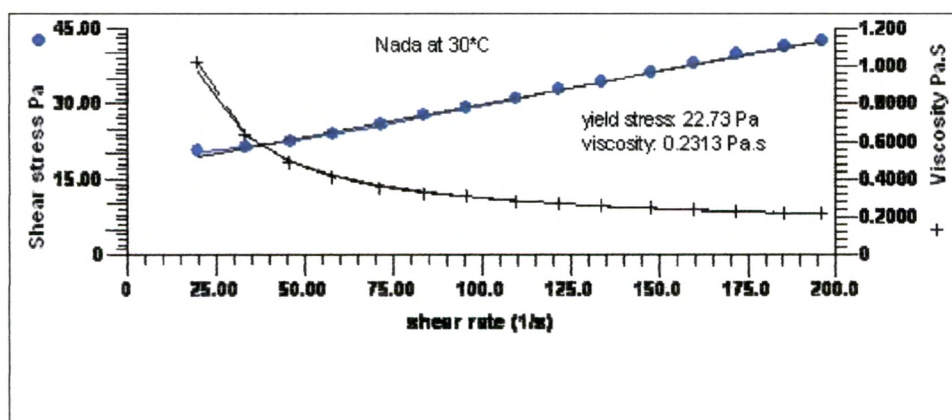


Fig 277 Nada neat at 30°C

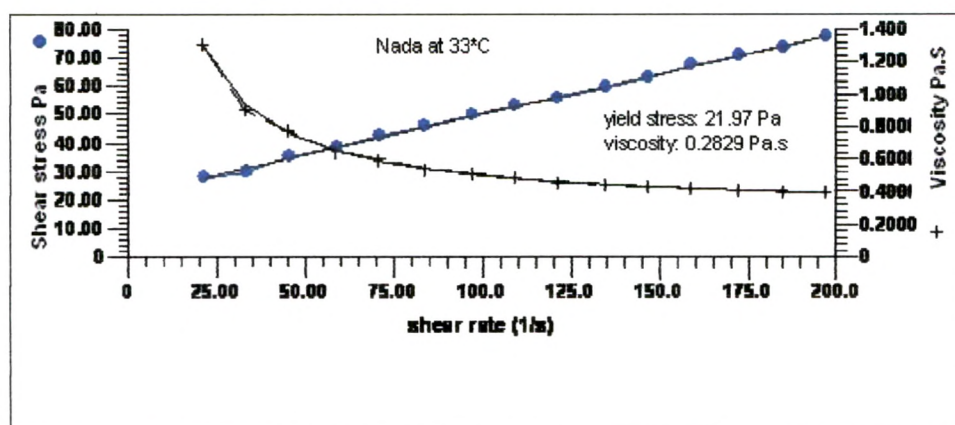


Fig 278 Nada neat at 33°C

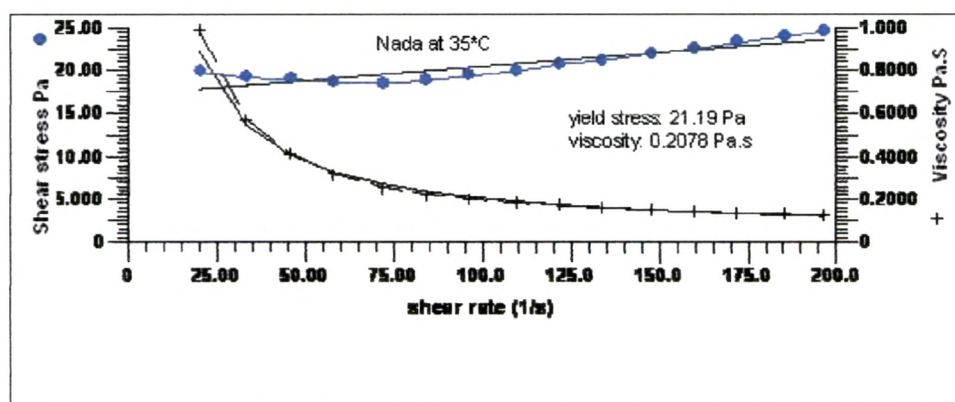


Fig 279 Nada neat at 35°C

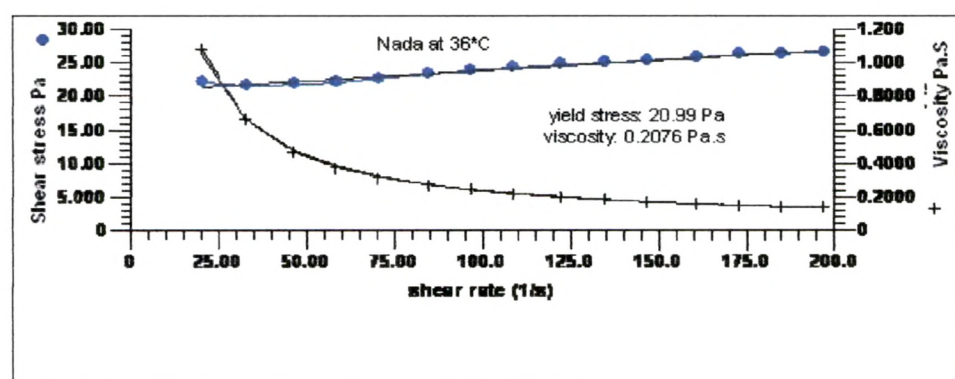


Fig 280 Nada neat at 36°C

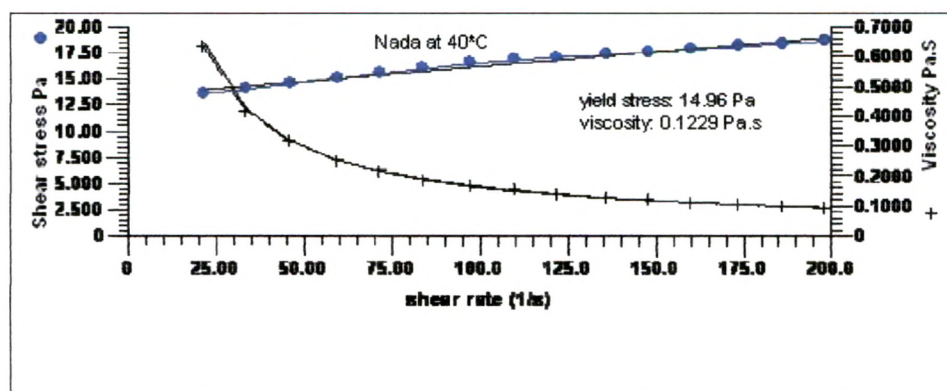


Fig 281 Nada neat at 40°C

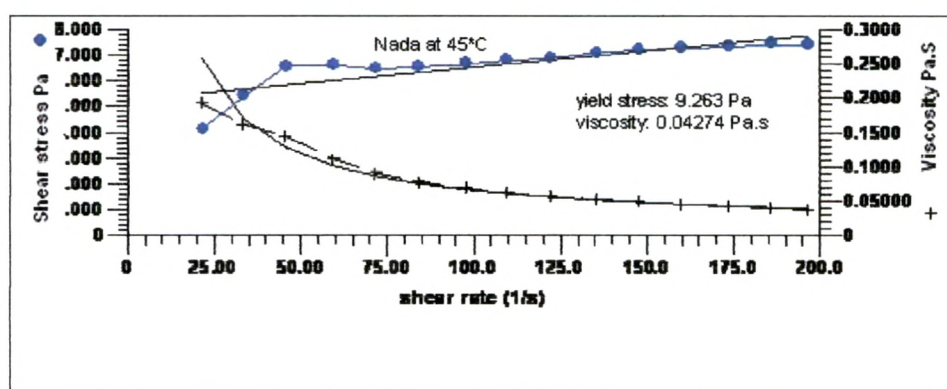


Fig 282 Nada neat at 45°C

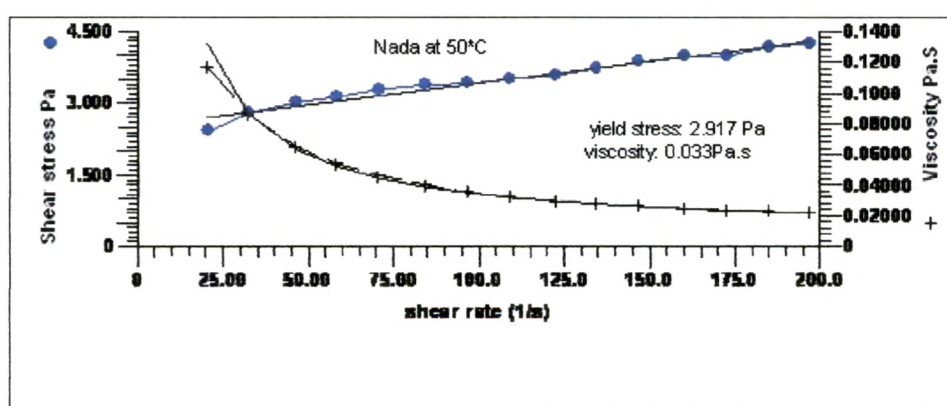


Fig 283 Nada neat at 50°C

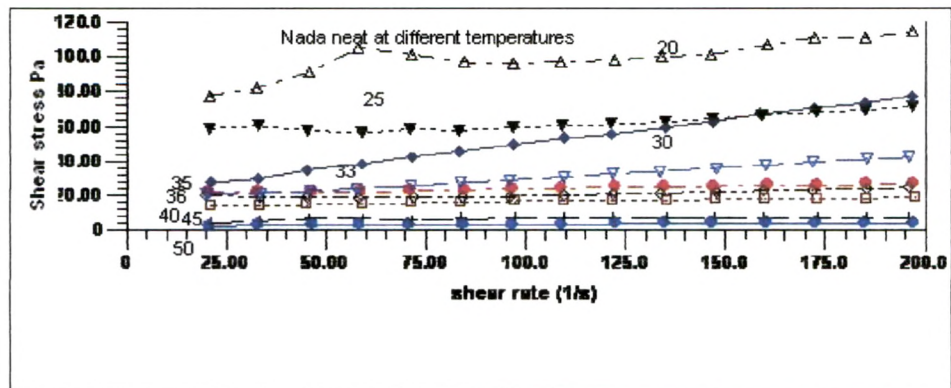


Fig 284 Comparison of Nada flow behavior at different temperatures

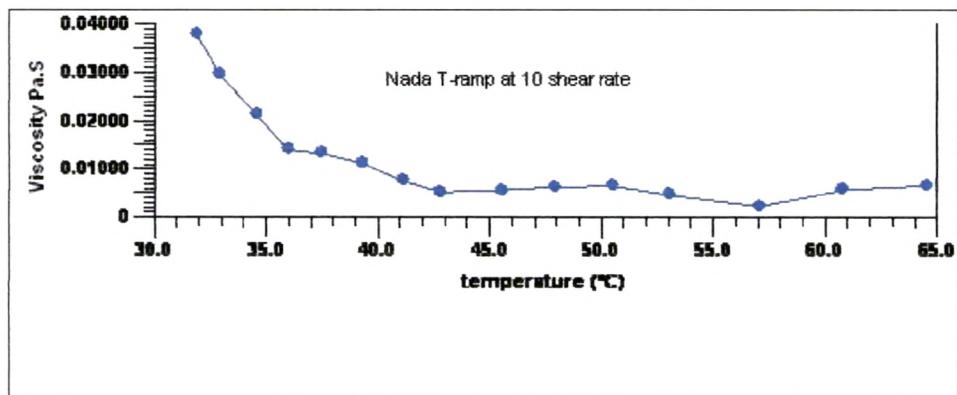


Fig 285 T-ramp of Nada neat oil

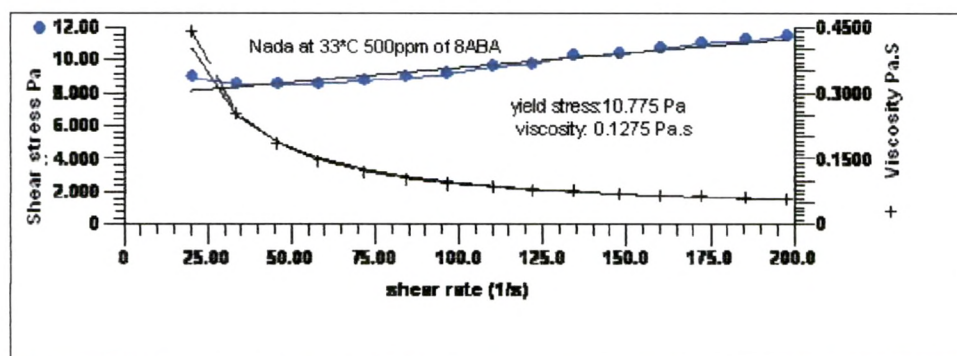


Fig 286 Nada with 500 ppm of 8 ABA

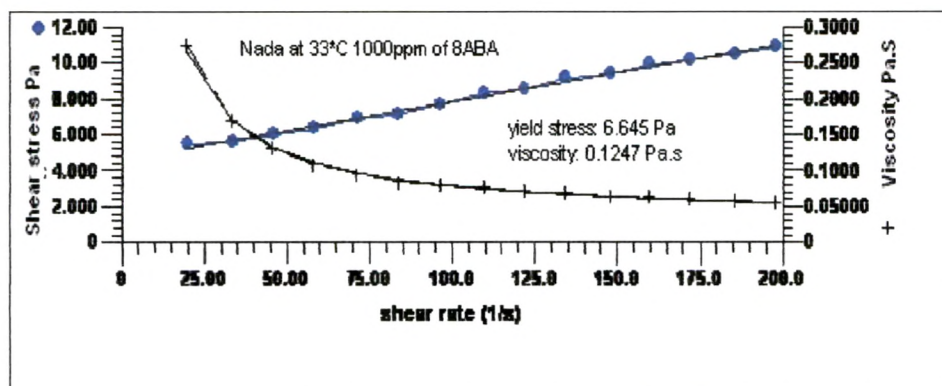


Fig 287 Nada with 1000 ppm of 8 ABA

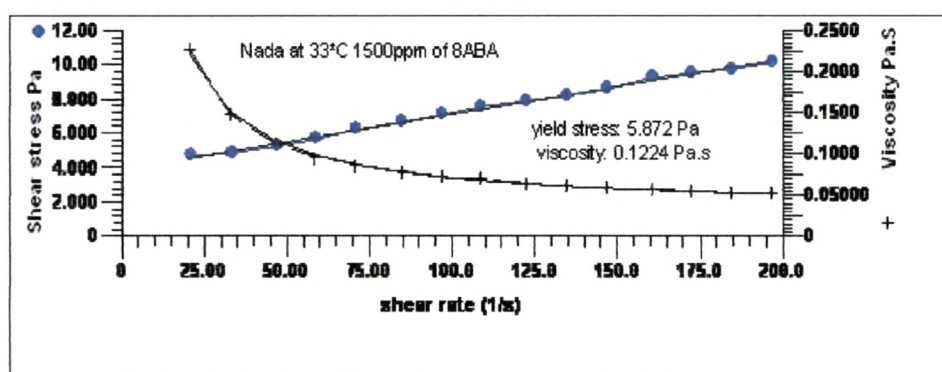


Fig 288 Nada with 1500 ppm of 8 ABA

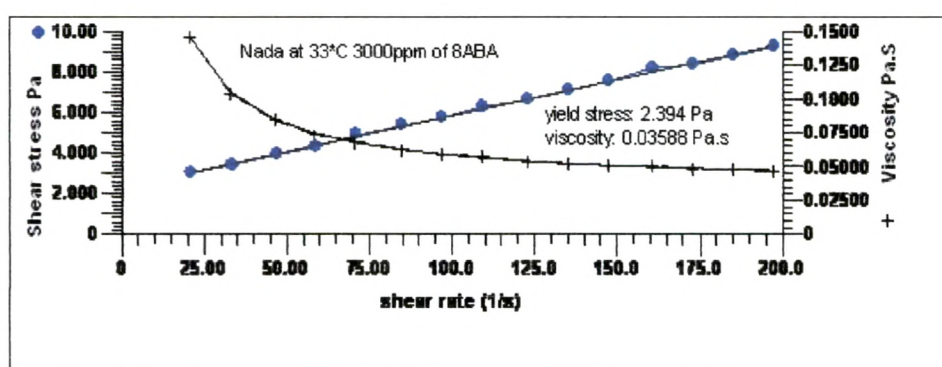


Fig 289 Nada with 3000 ppm of 8 ABA

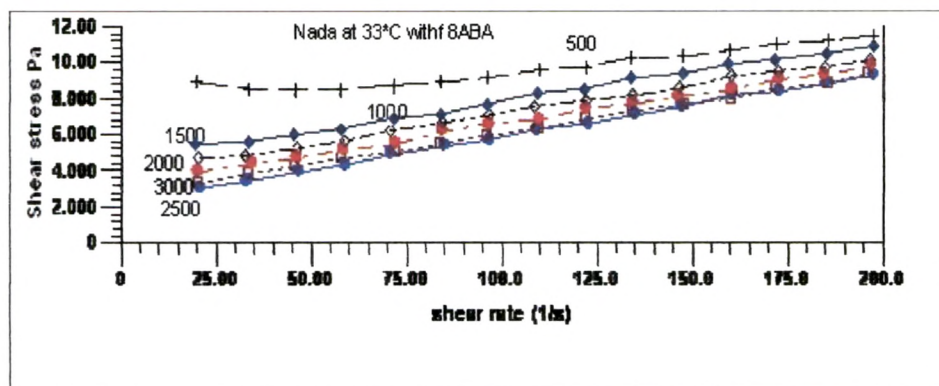


Fig 290 Comparison of Nada with doses of 8 ABA

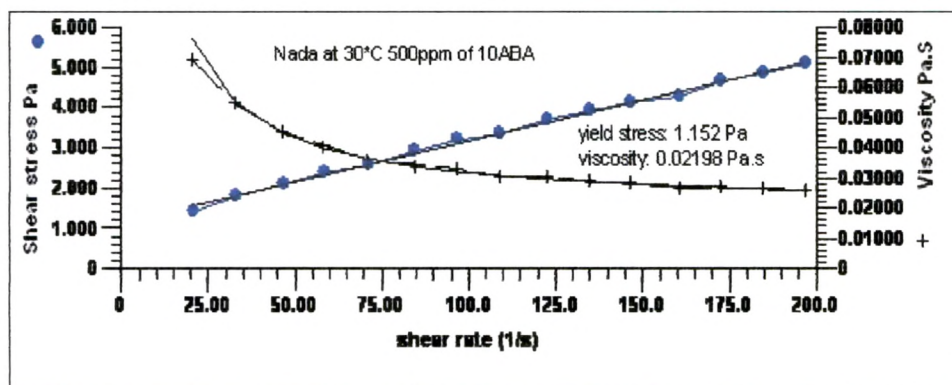


Fig 291 Nada with 500 ppm of 10 ABA

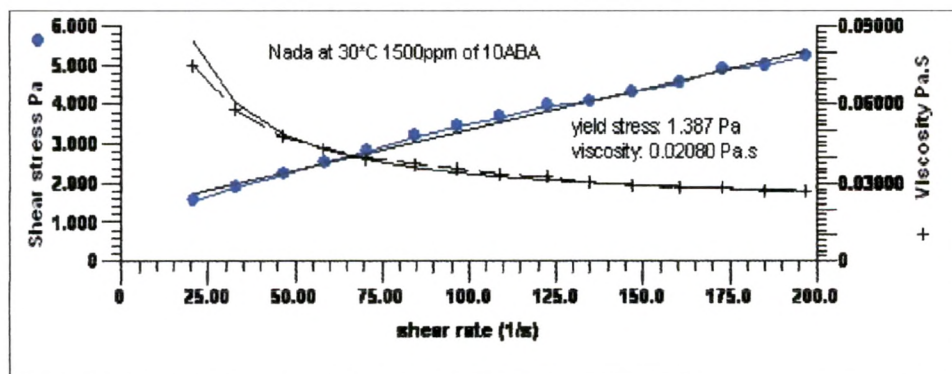


Fig 292 Nada with 1000 ppm of 10 ABA

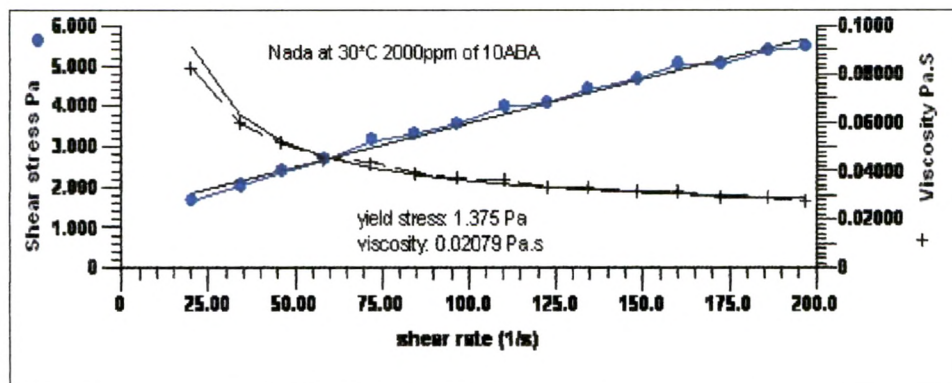


Fig 293 Nada with 1500 ppm of 10 ABA

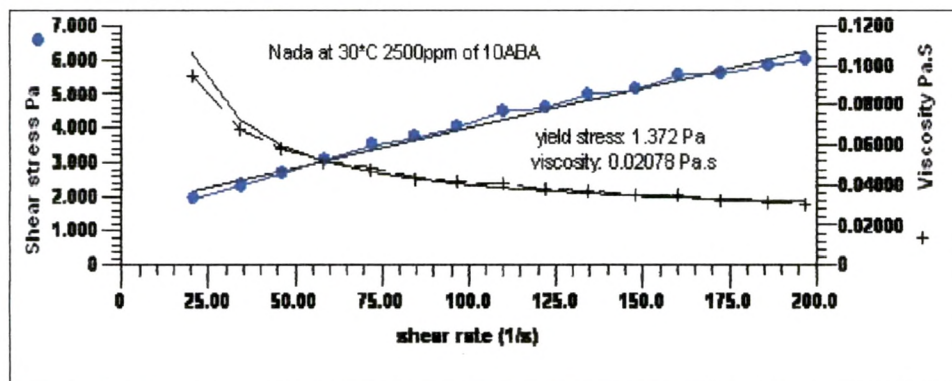


Fig 294 Nada with 2000 ppm of 10 ABA

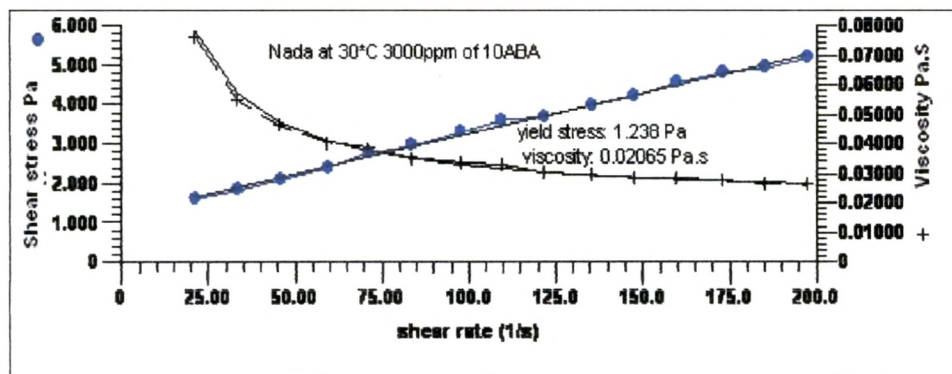


Fig 295 Nada with 2500 ppm of 10 ABA

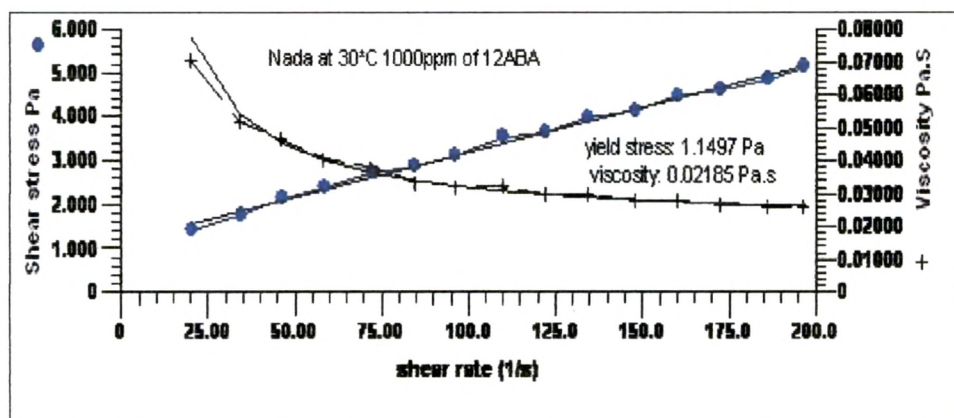


Fig 296 Nada with 1000 ppm of 12 ABA

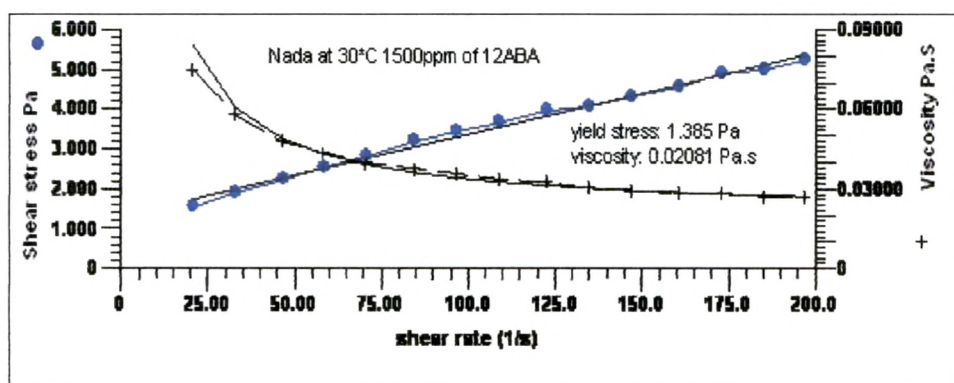


Fig 297 Nada with 1500 ppm of 12 ABA

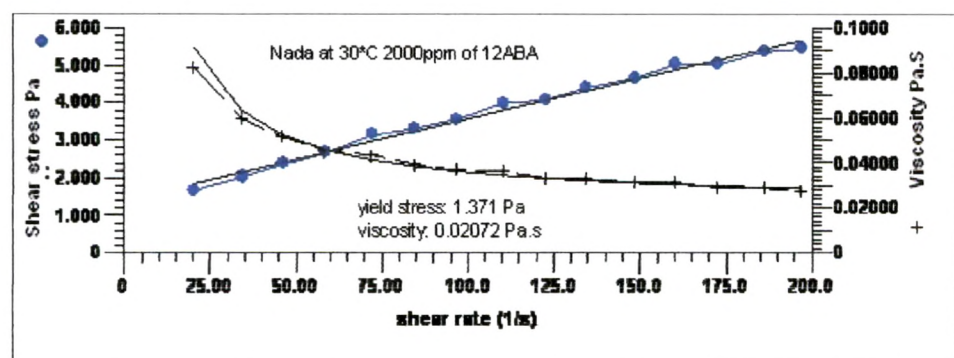


Fig 298 Nada with 2000 ppm of 12 ABA

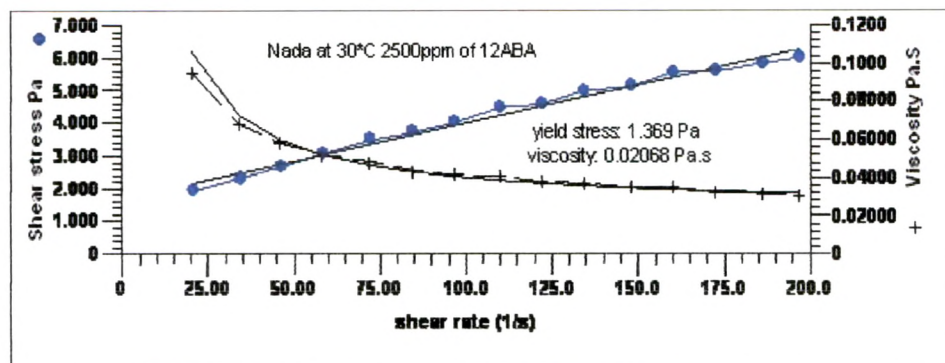


Fig 299 Nada with 2500 ppm of 12 ABA

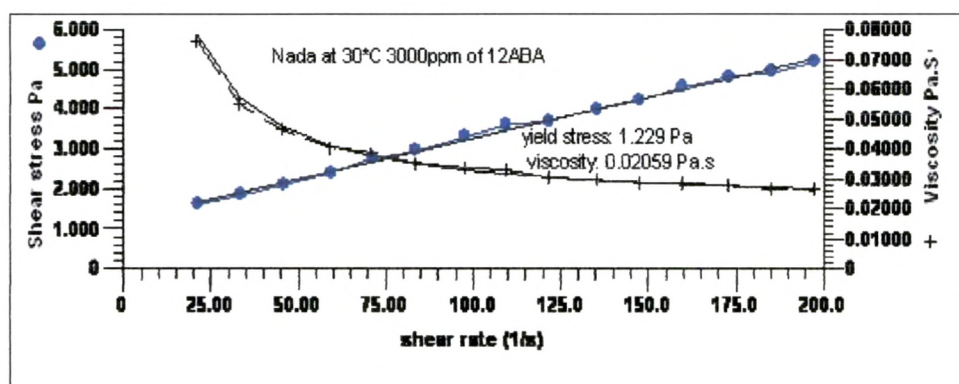


Fig 300 Nada with 3000 ppm of 12 ABA

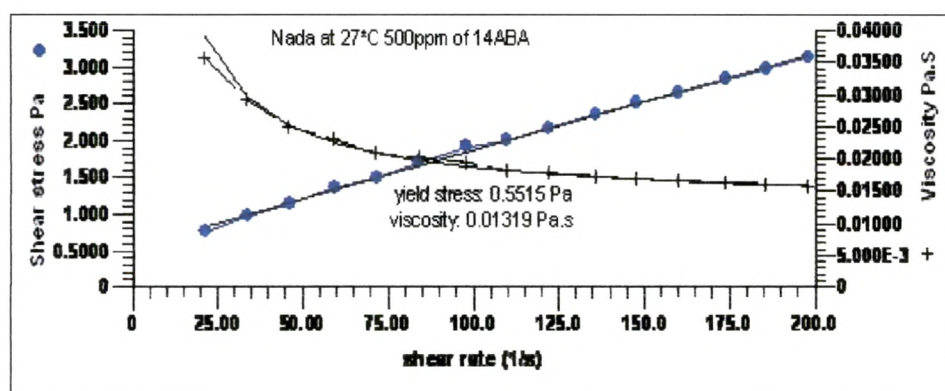


Fig 301 Nada with 500 ppm of 14ABA

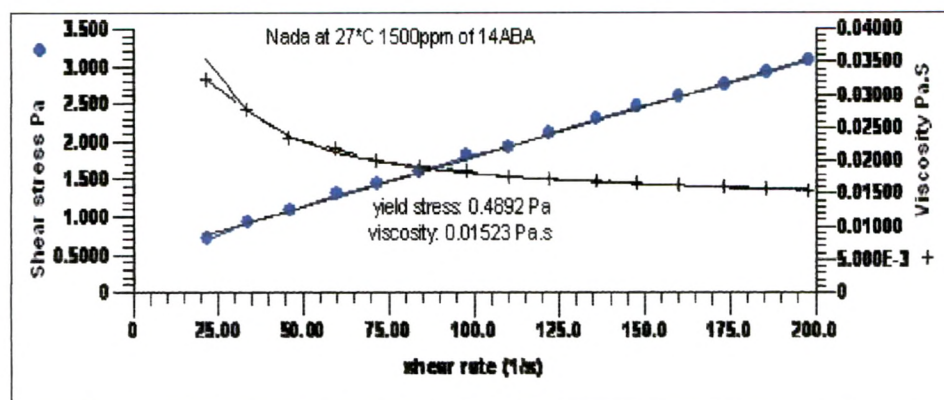


Fig 302 Nada with 1500 ppm of 14ABA

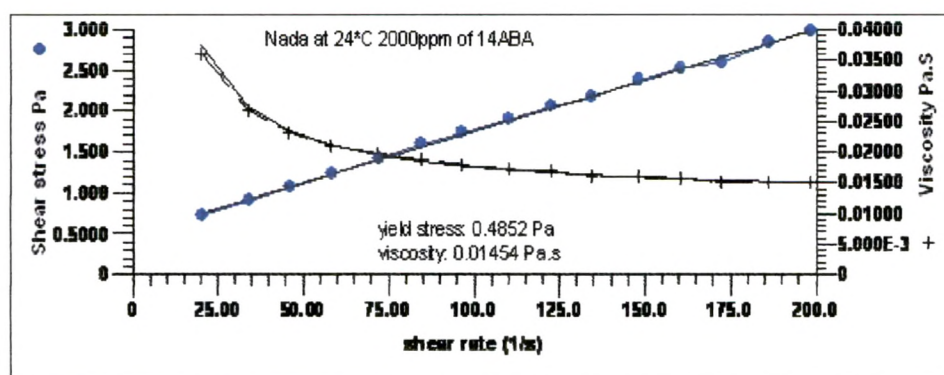


Fig 303 Nada with 2000 ppm of 14ABA

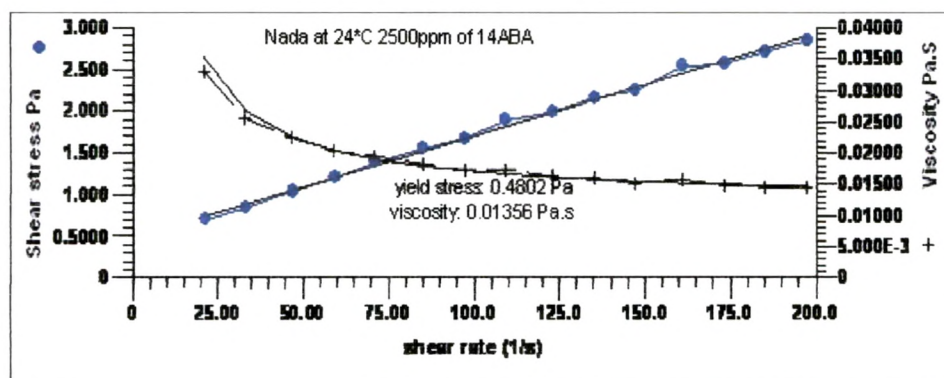


Fig 304 Nada with 2500 ppm of 14ABA

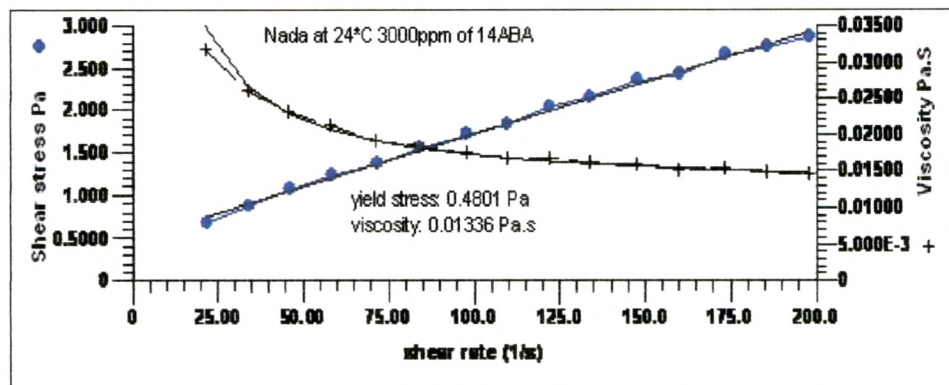


Fig 305 Nada with 3000 ppm of 14ABA

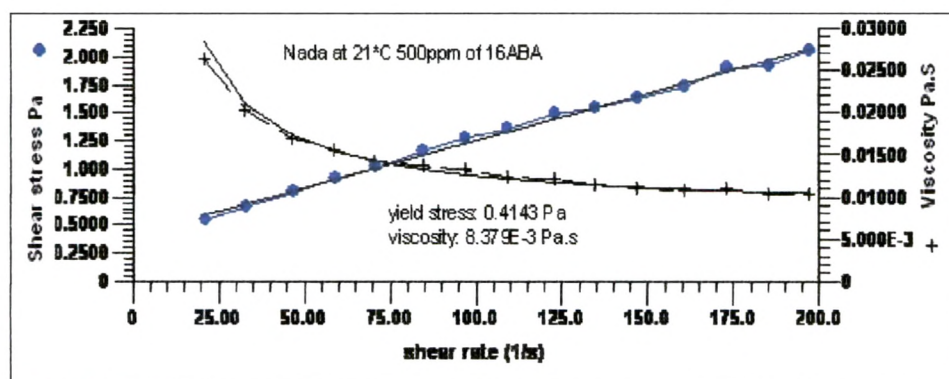


Fig 306 Nada with 500 ppm of 16 ABA

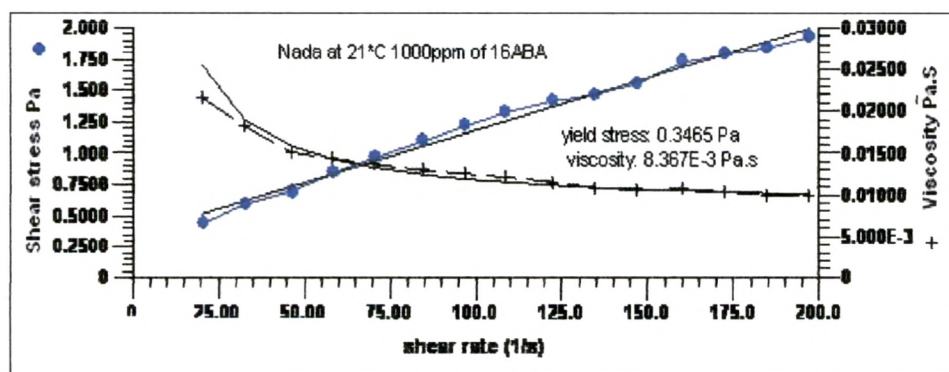


Fig 307 Nada with 1000 ppm of 16 ABA

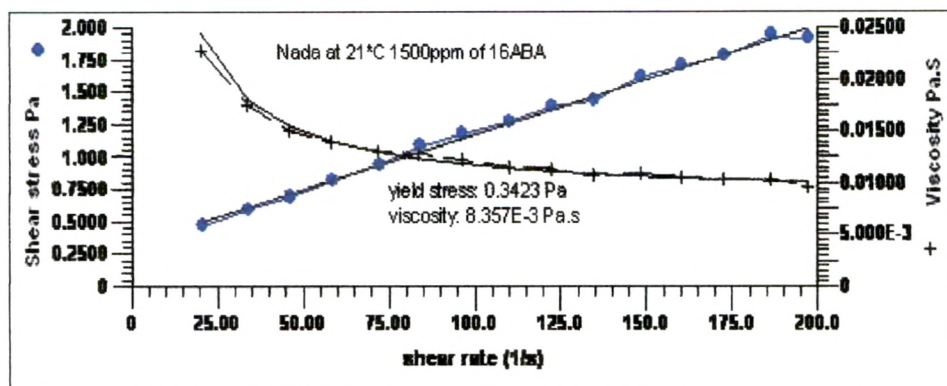


Fig 308 Nada with 1500 ppm of 16 ABA

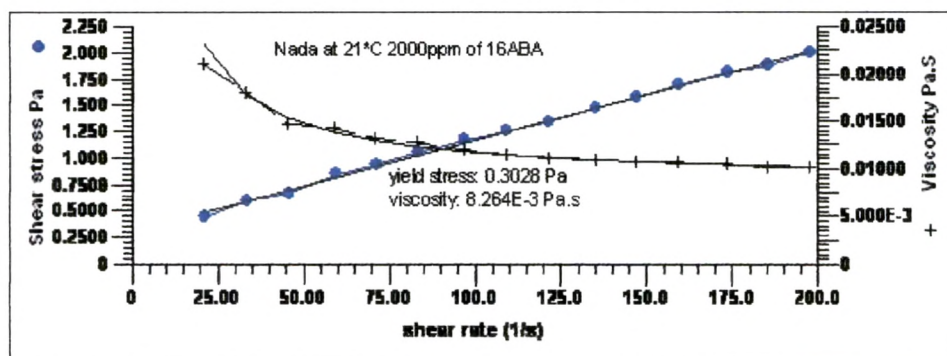


Fig 309 Nada with 2000 ppm of 16 ABA

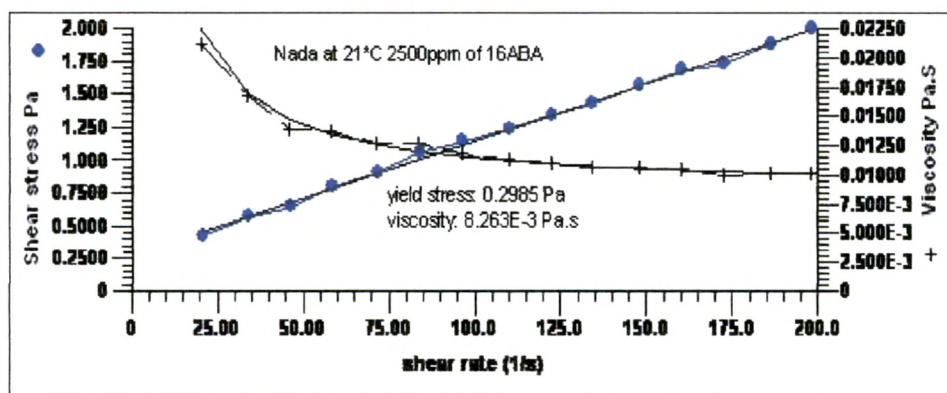


Fig 310 Nada with 2500 ppm of 16 ABA

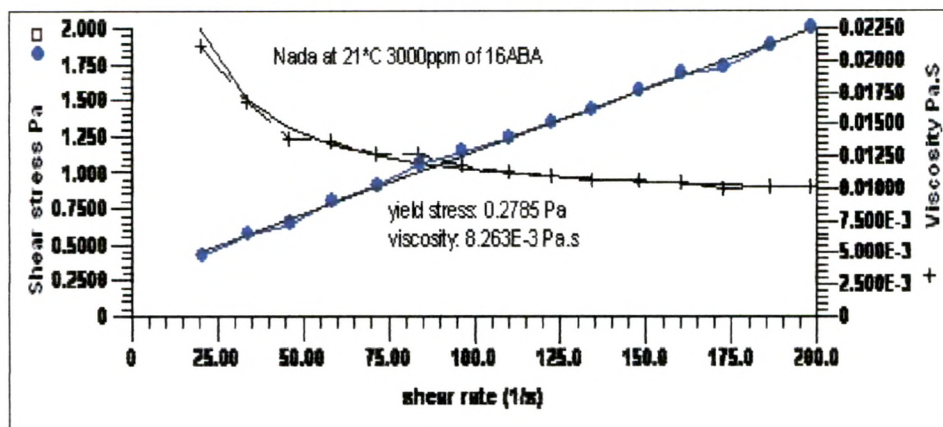


Fig 311 Nada with 3000 ppm of 16 ABA

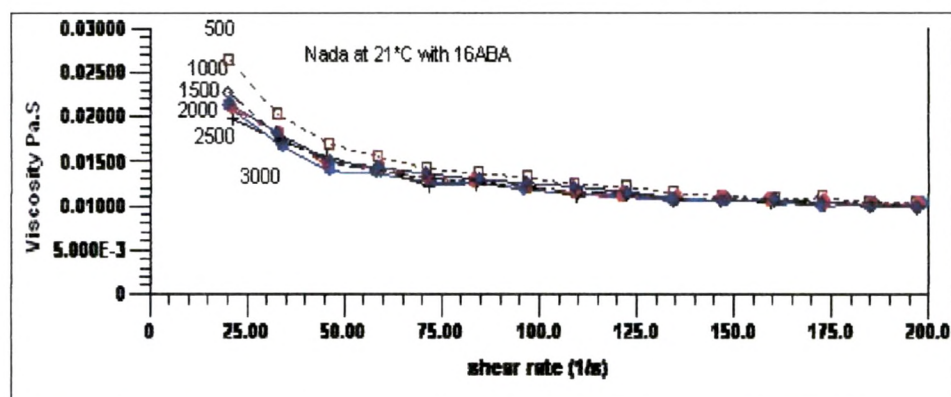


Fig 312 Comparison of Nada with doses of 16 ABA

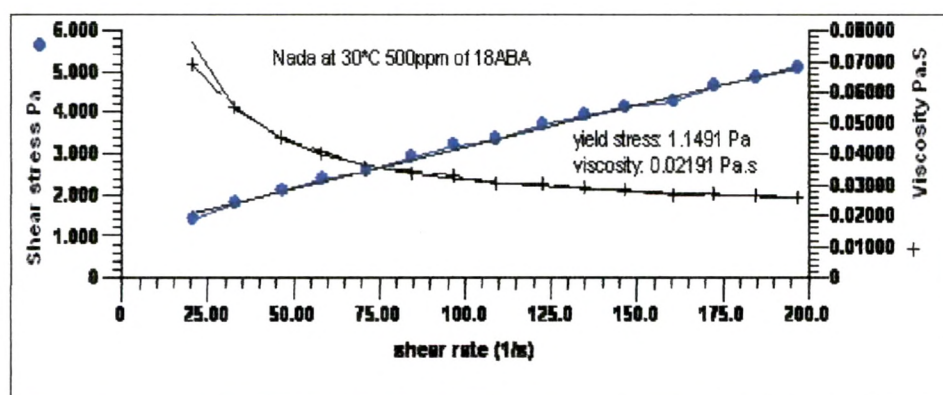


Fig 313 Nada with 500 ppm of 18 ABA

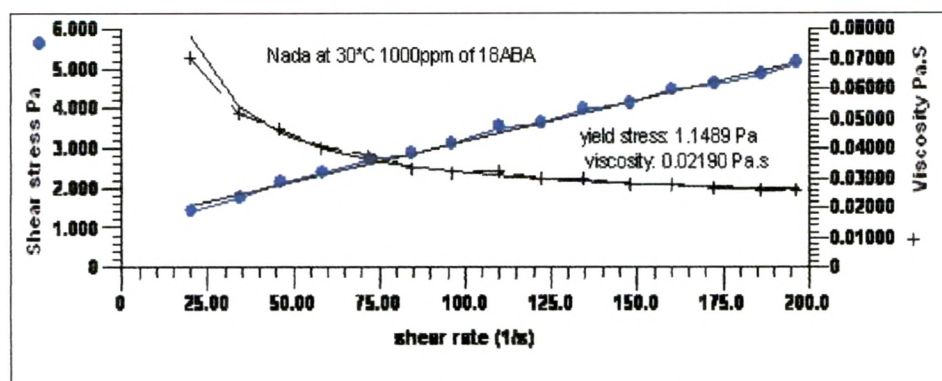


Fig 314 Nada with 1000 ppm of 18 ABA

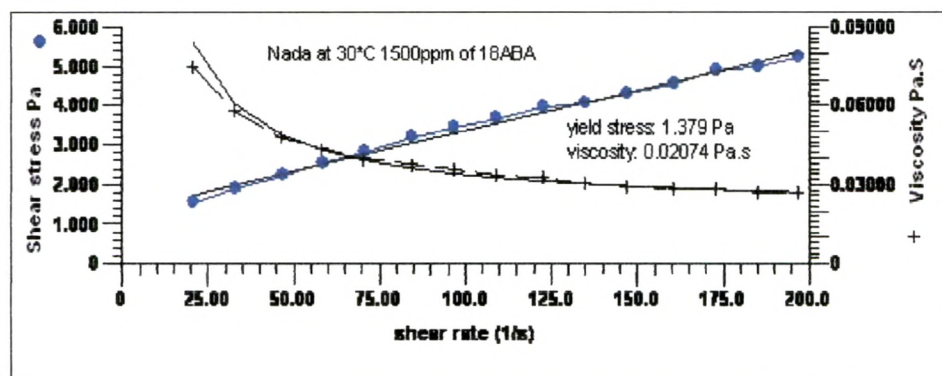


Fig 315 Nada with 1500 ppm of 18 ABA

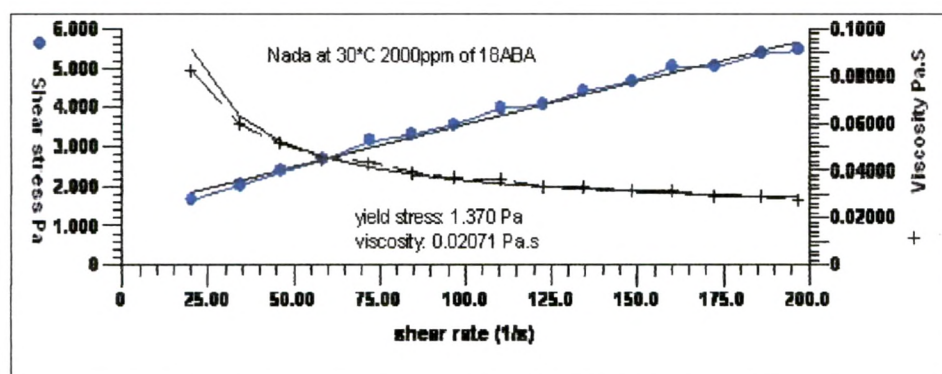


Fig 316 Nada with 2000 ppm of 18 ABA

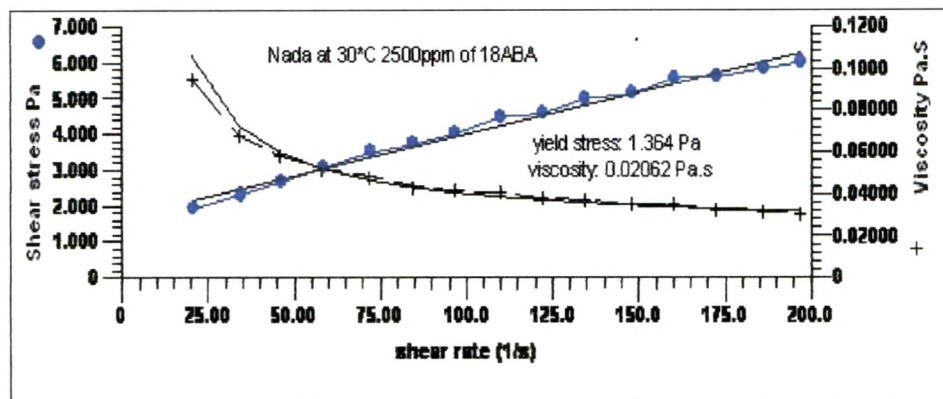


Fig 317 Nada with 2500 ppm of 18 ABA

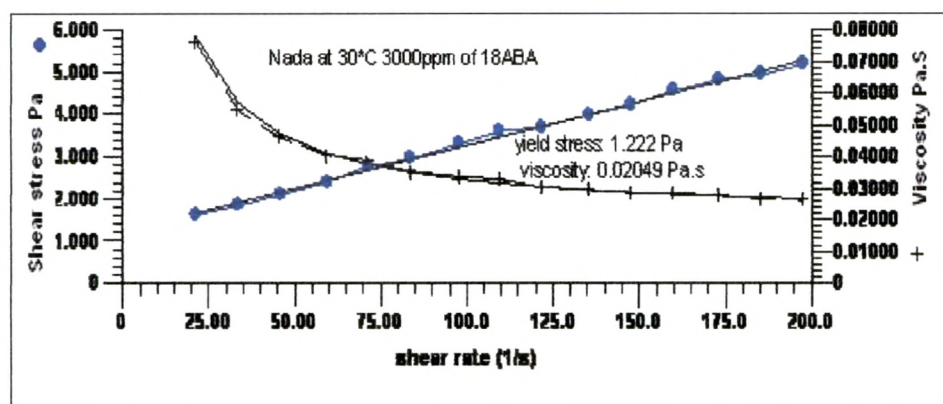


Fig 318 Nada with 3000 ppm of 18 ABA

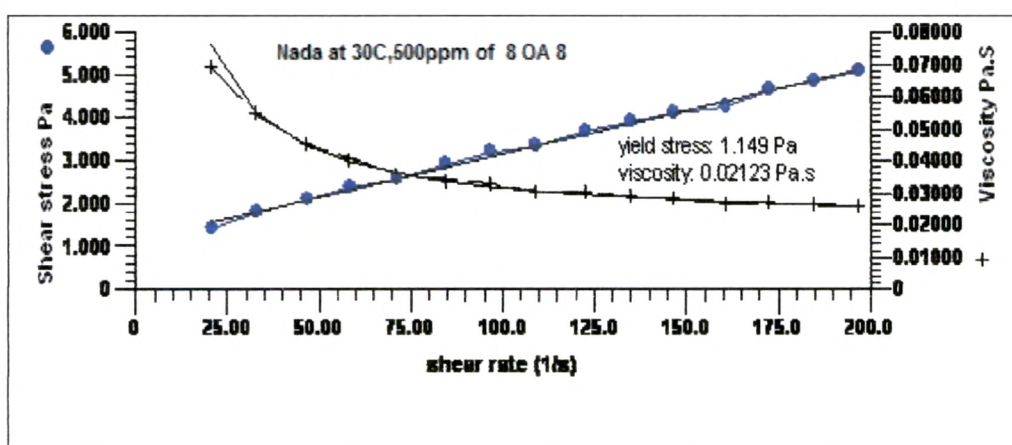


Fig 319 Nada with 500 ppm of 8 OA 8

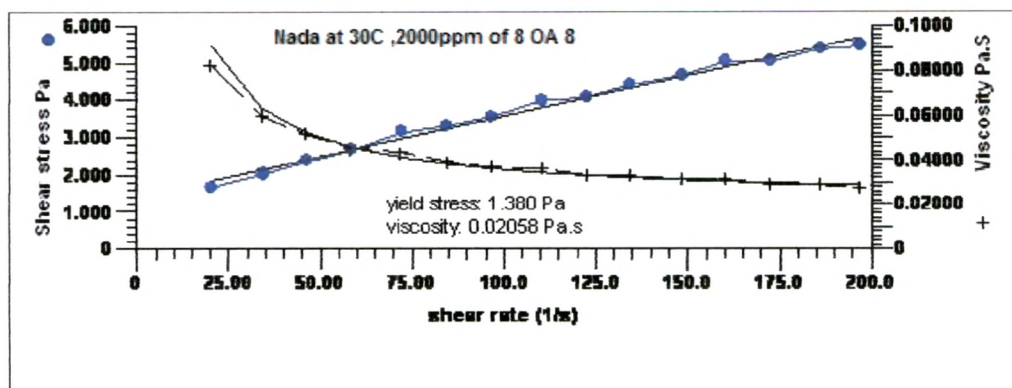


Fig 320 Nada with 2000 ppm of 8 OA 8

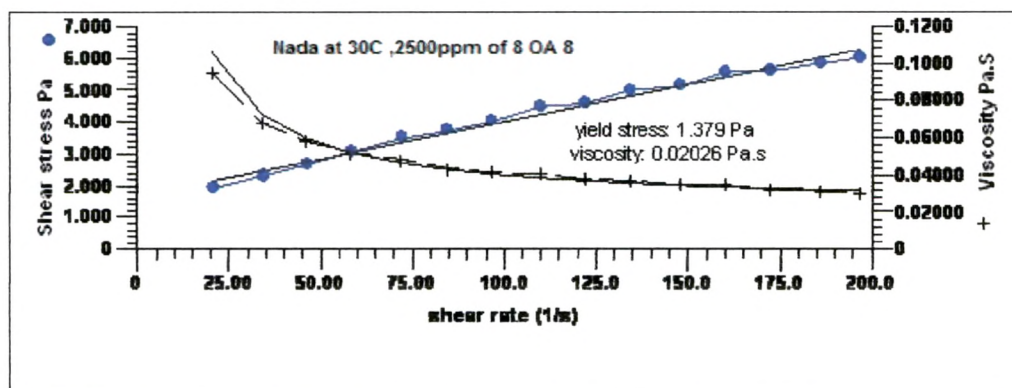


Fig 321 Nada with 2500 ppm of 8 OA 8

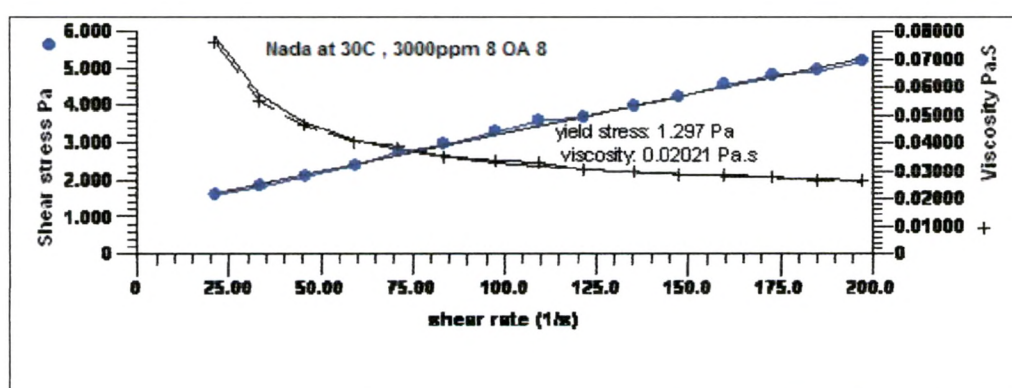


Fig 322 Nada with 3000 ppm of 8 OA 8

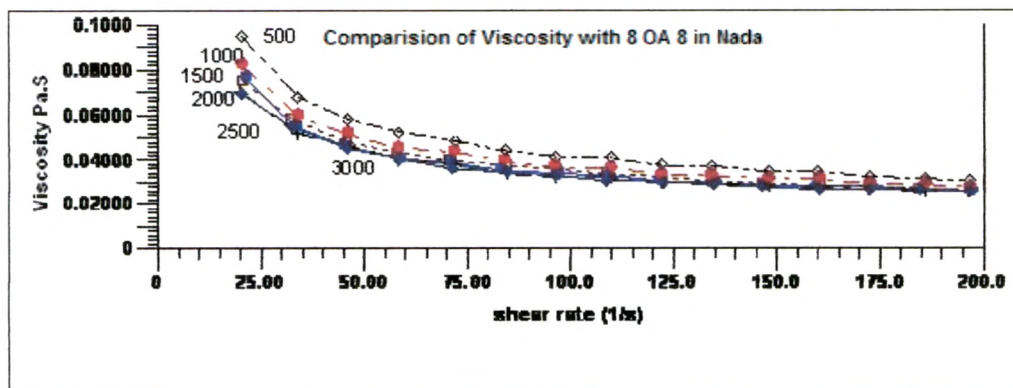


Fig 323 Comaparision of Nada viscosity with 8 OA 8

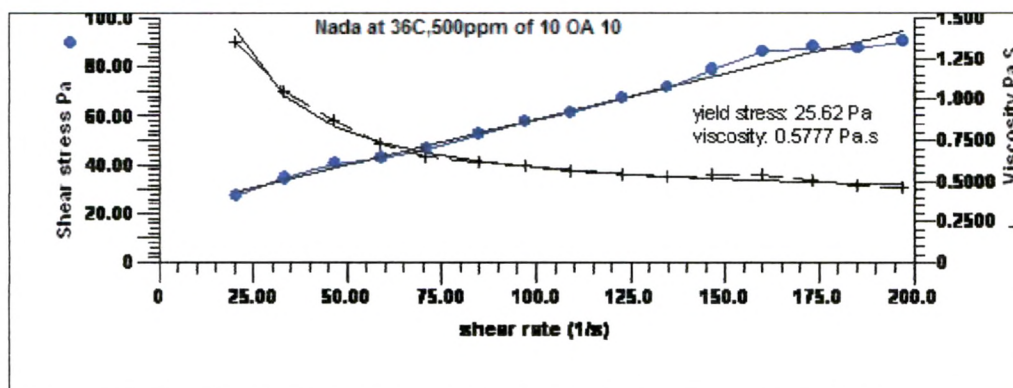


Fig 324 Nada with 500 ppm of 10 OA 10

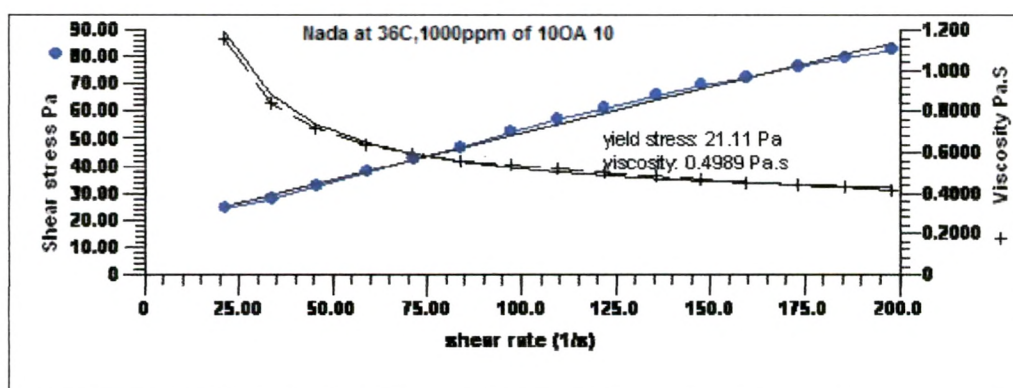


Fig 325 Nada with 1000 ppm of 10 OA 10

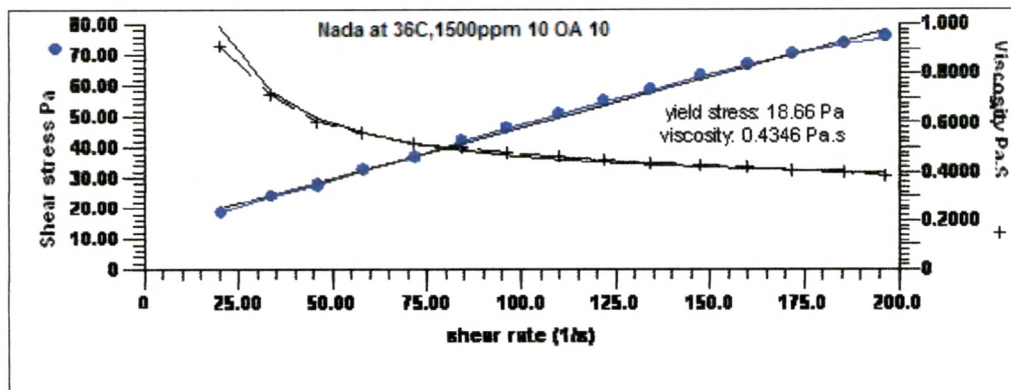


Fig 326 Nada with 1500 ppm of 10 OA 10

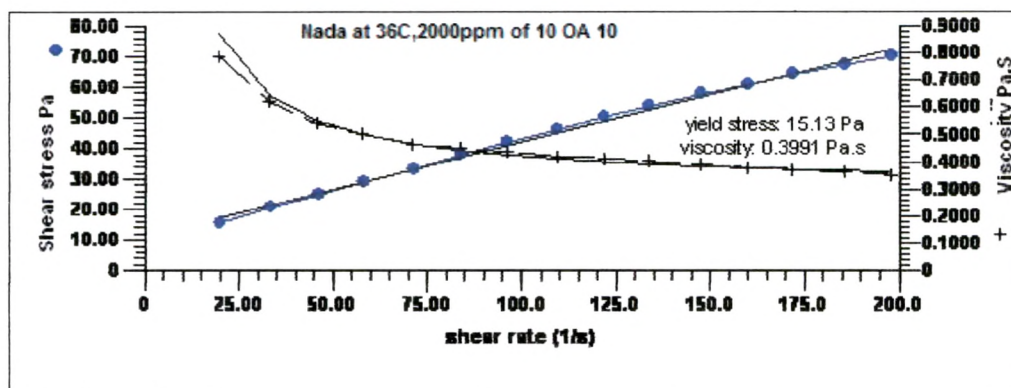


Fig 327 Nada with 2000 ppm of 10 OA 10

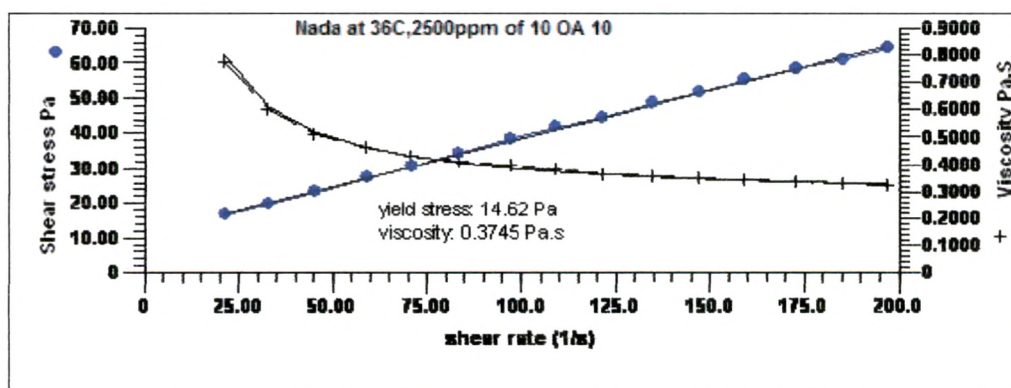


Fig 328 Nada with 2000 ppm of 10 OA 10

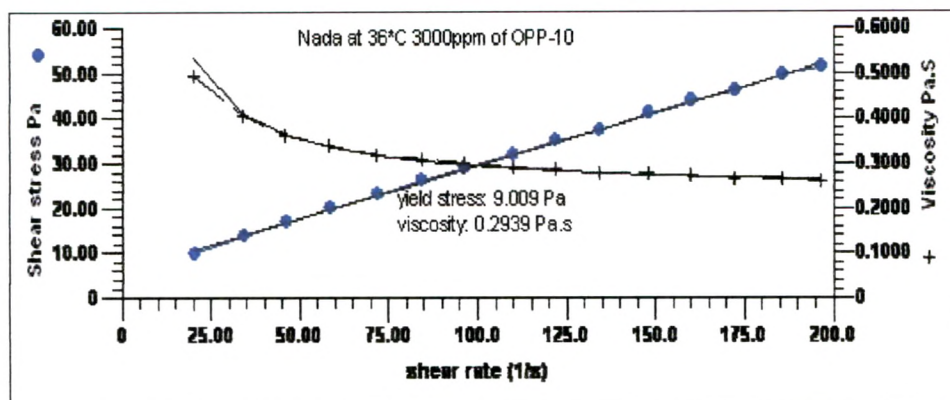


Fig 329 Nada with 3000 ppm of 10 OA 10

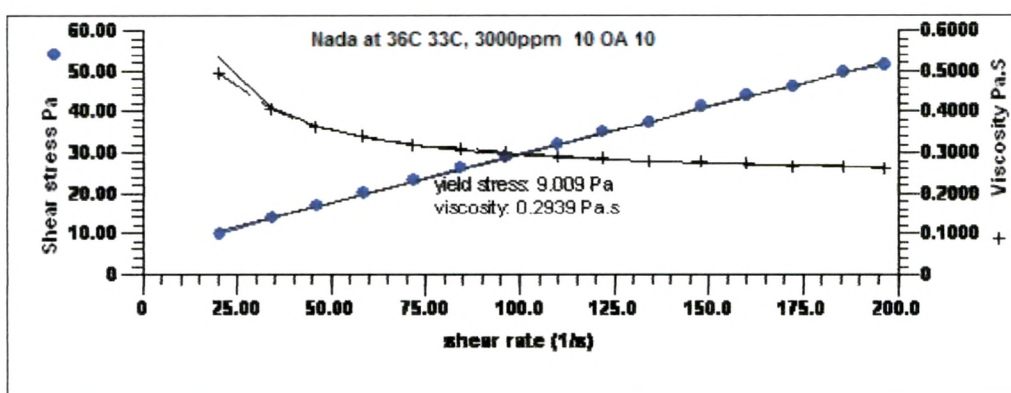


Fig 330 Nada with 3000 ppm of 10 OA 10

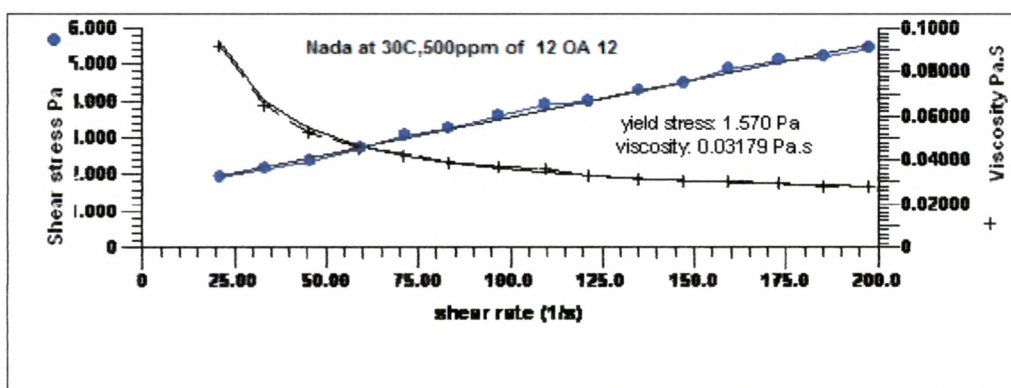


Fig 331 Nada with 500 ppm of 12 OA 12

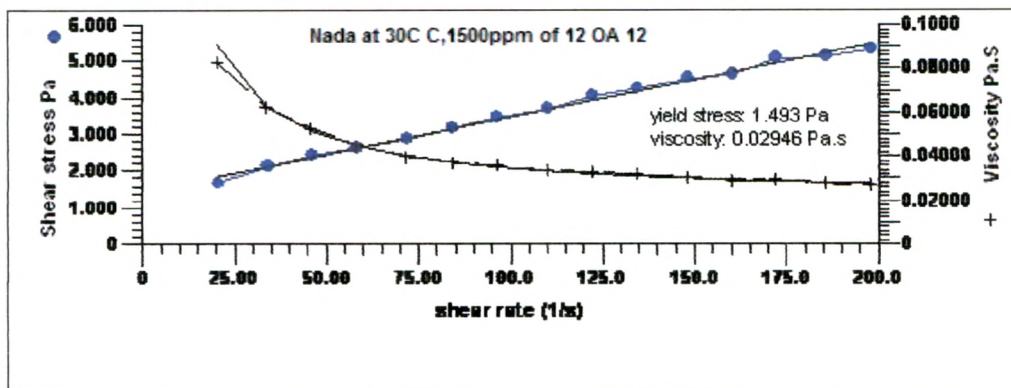


Fig 332 Nada with 1000 ppm of 12 OA 12

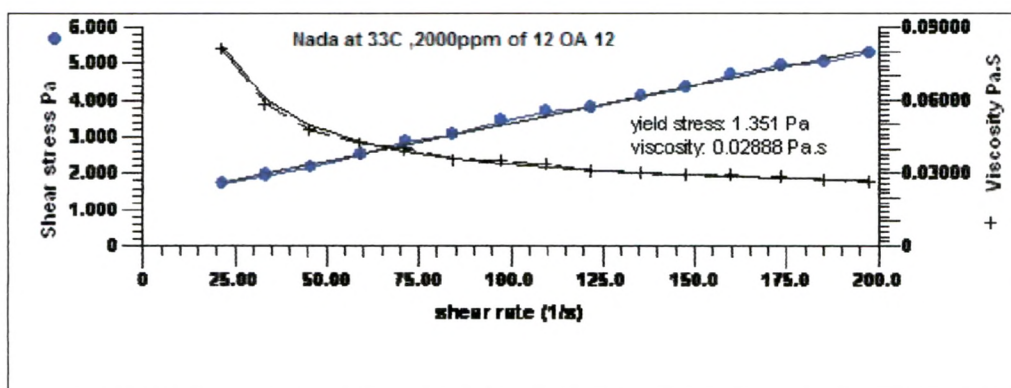


Fig 333 Nada with 2000 ppm of 12 OA 12

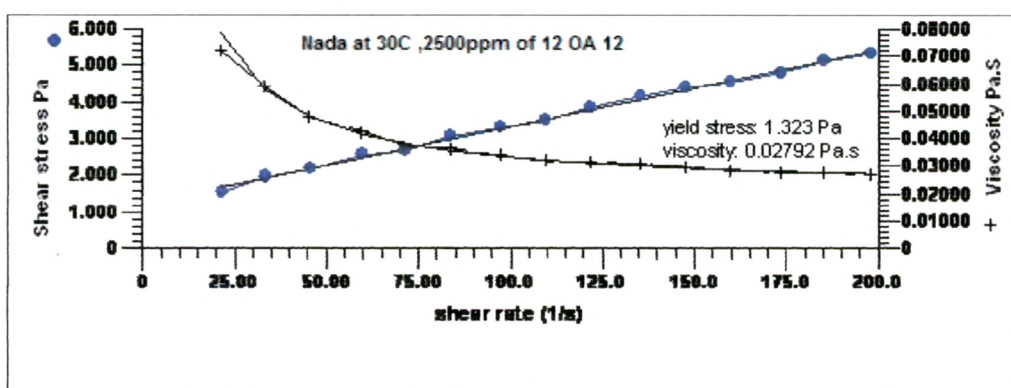


Fig 334 Nada with 2500 ppm of 12 OA 12

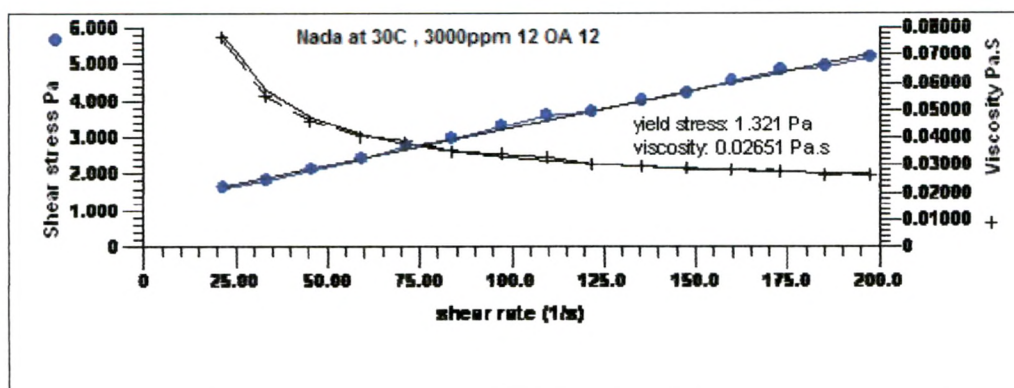


Fig 335 Nada with 3000 ppm of 12 OA 12

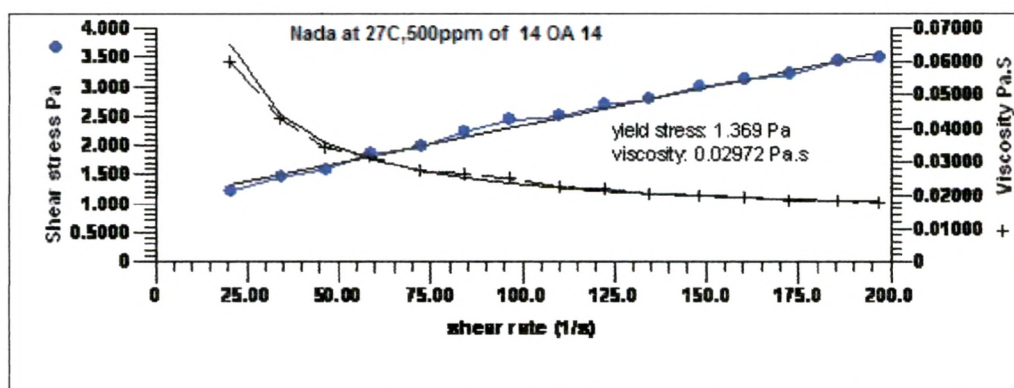


Fig 336 Nada with 500 ppm of 14 OA 14

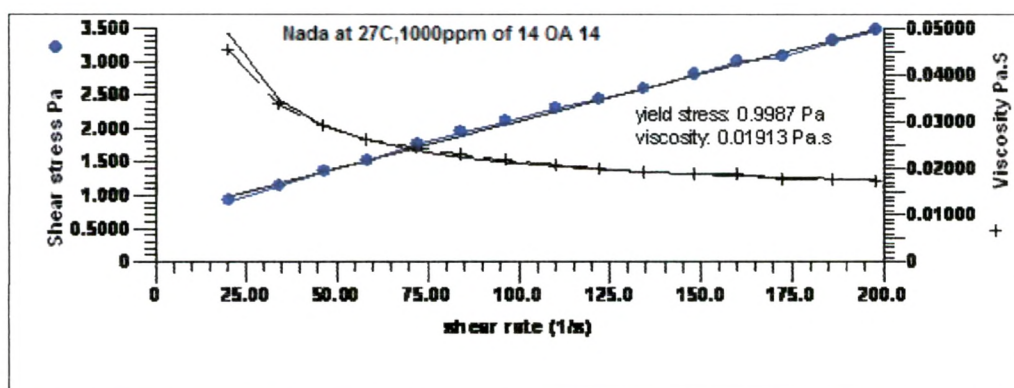


Fig 337 Nada with 500 ppm of 14 OA 14

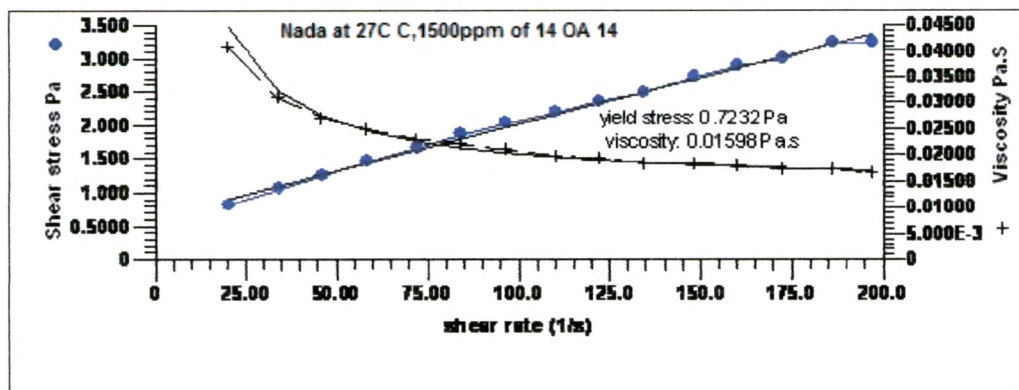


Fig 338 Nada with 1500 ppm of 14 OA 14

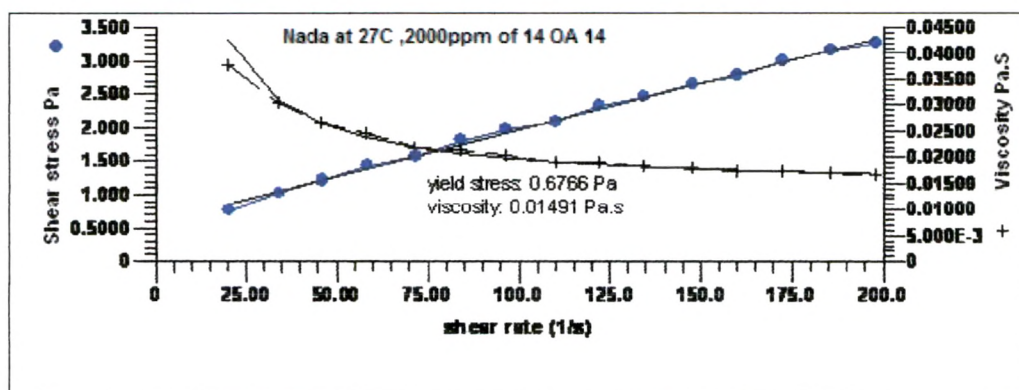


Fig 339 Nada with 2000 ppm of 14 OA 14

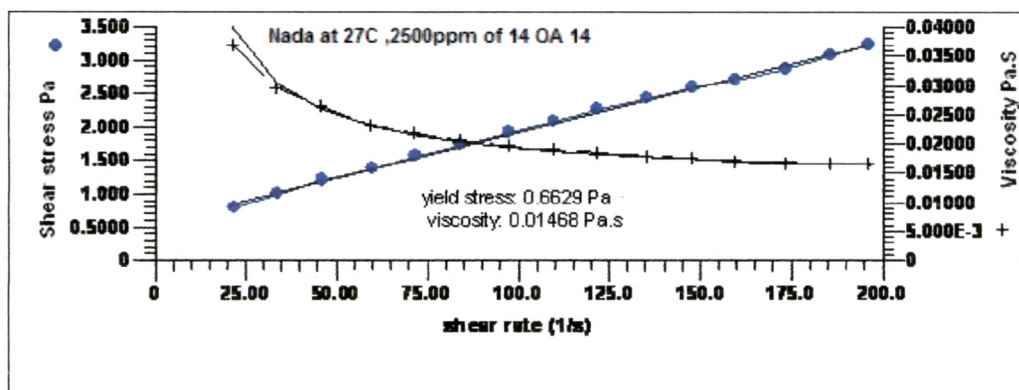


Fig 340 Nada with 2500 ppm of 14 OA 14

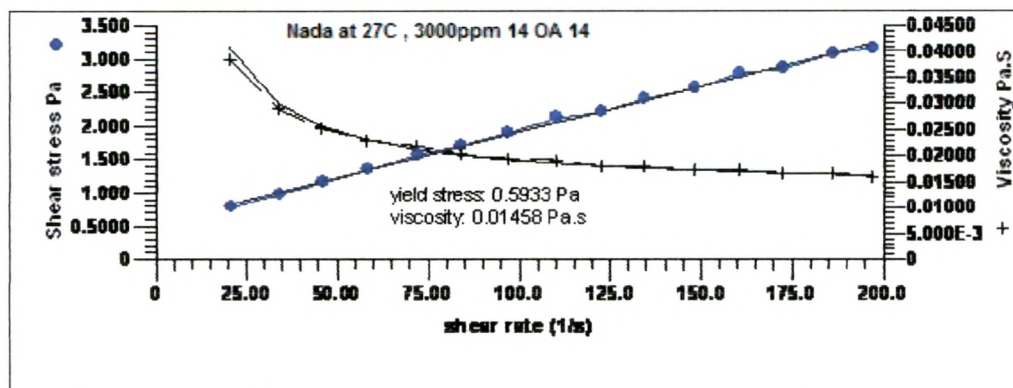


Fig 341 Nada with 3000 ppm of 14 OA 14

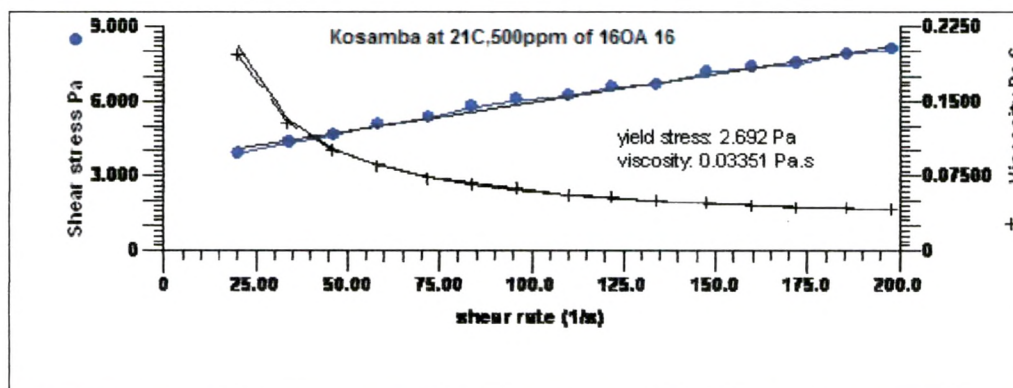


Fig 342 Nada with 500 ppm of 16 OA 16

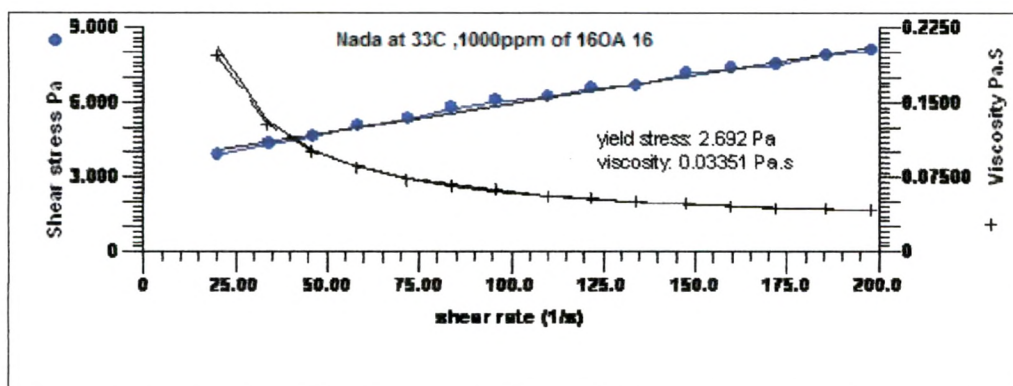


Fig 343 Nada with 1000 ppm of 16 OA 16

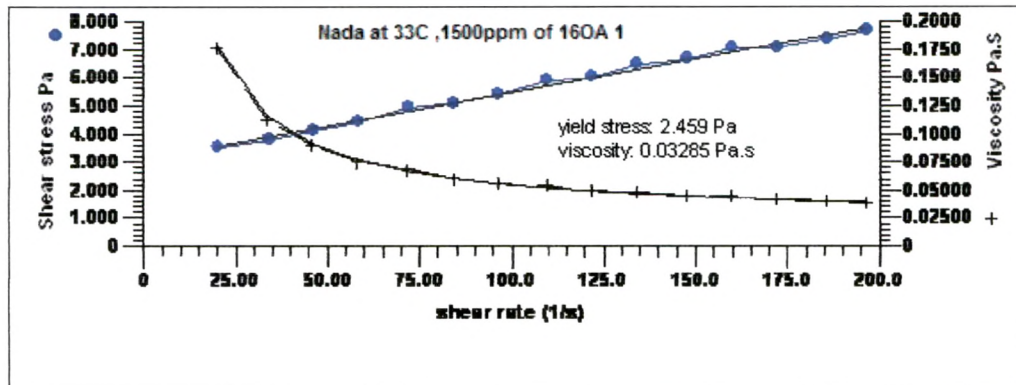


Fig 344 Nada with 1500 ppm of 16 OA 16

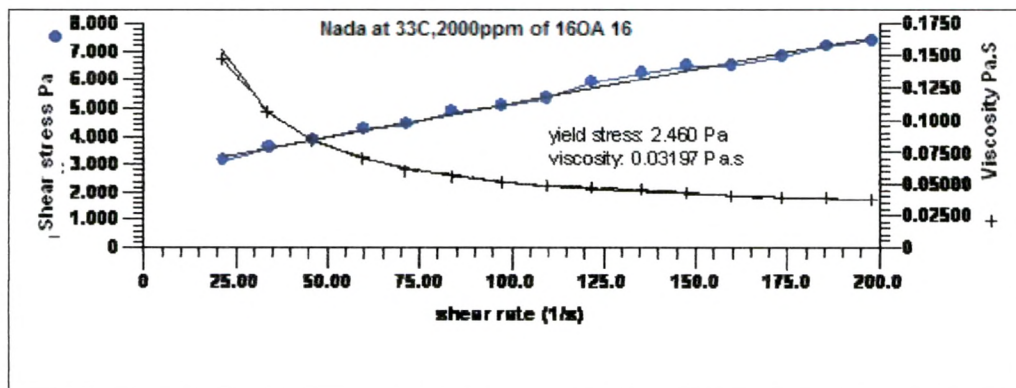


Fig 345 Nada with 2000 ppm of 16 OA 16

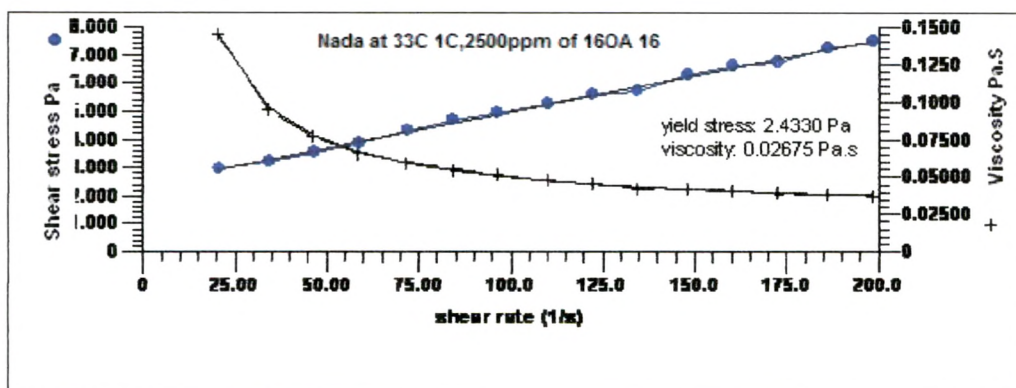


Fig 346 Nada with 2500 ppm of 16 OA 16

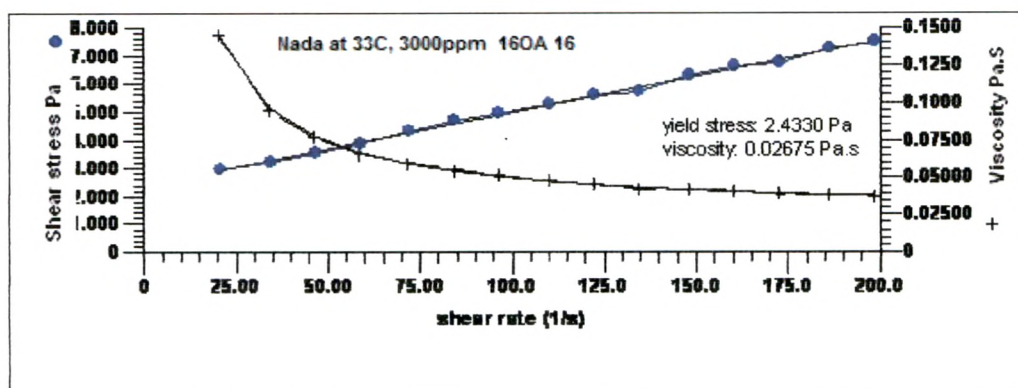


Fig 347 Nada with 3000 ppm of 16 OA 16

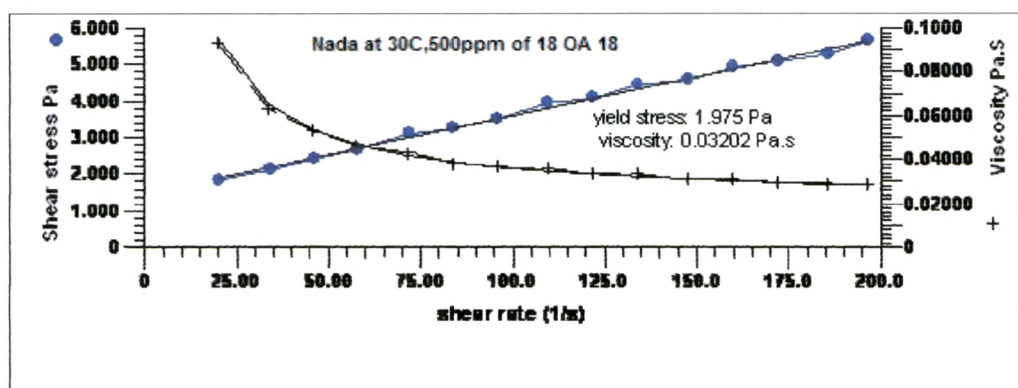


Fig 348 Nada with 500 ppm of 18 OA 18

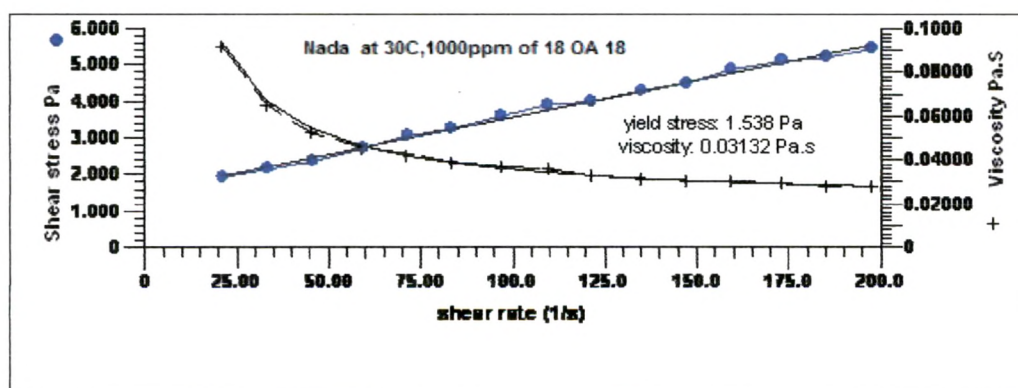


Fig 349 Nada with 1000 ppm of 18 OA 18

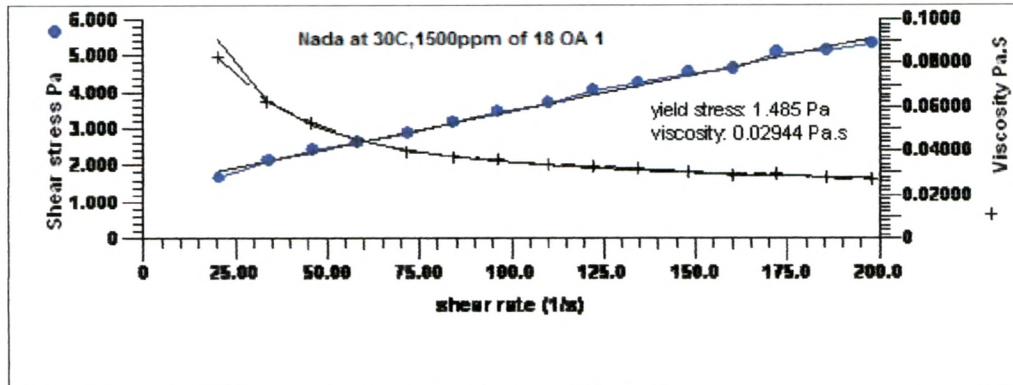


Fig 350 Nada with 1500 ppm of 18 OA 18

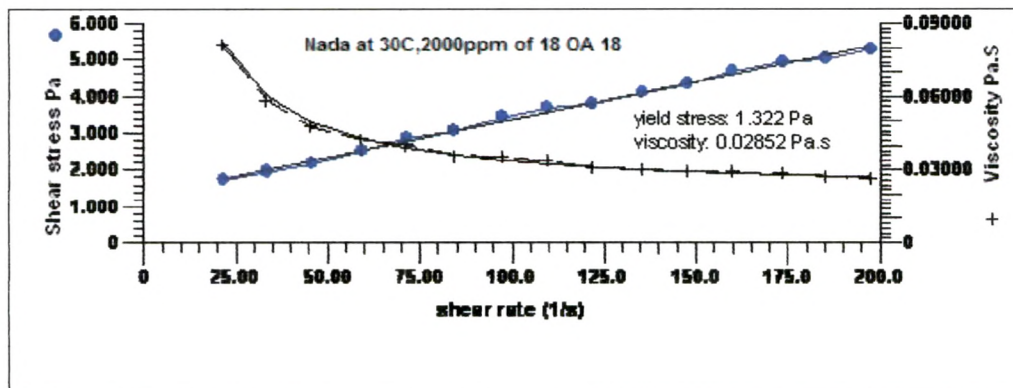


Fig 351 Nada with 2000 ppm of 18 OA 18

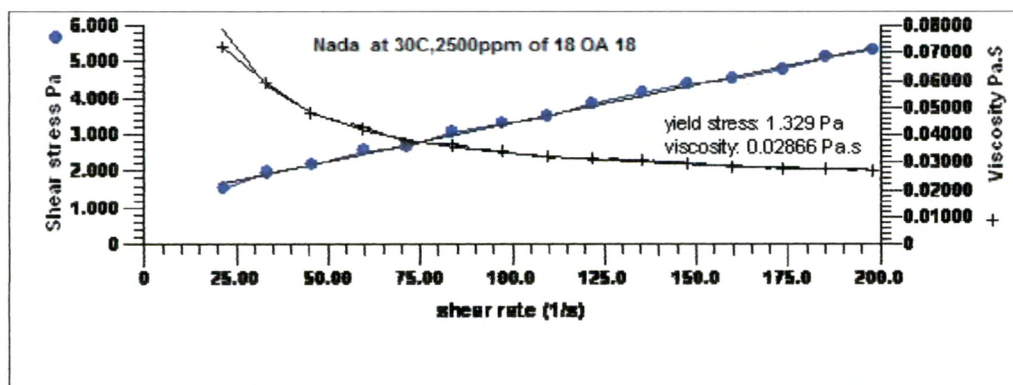


Fig 352 Nada with 2500 ppm of 18 OA 18

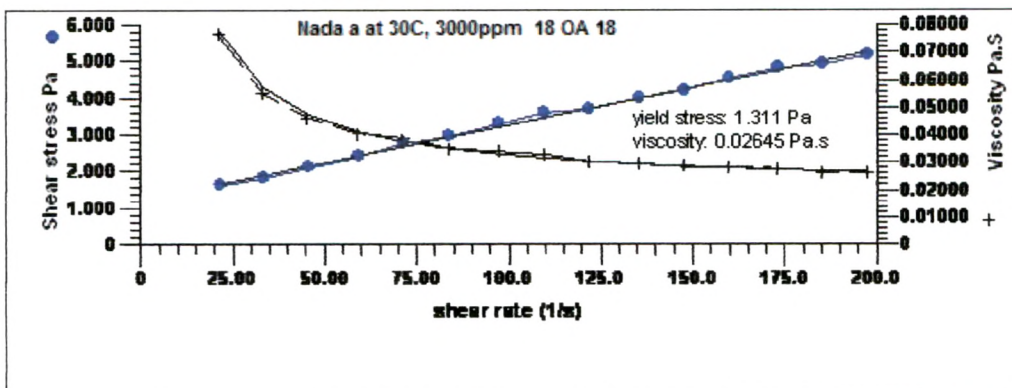


Fig 353 Nada with 3000 ppm of 18 OA 18

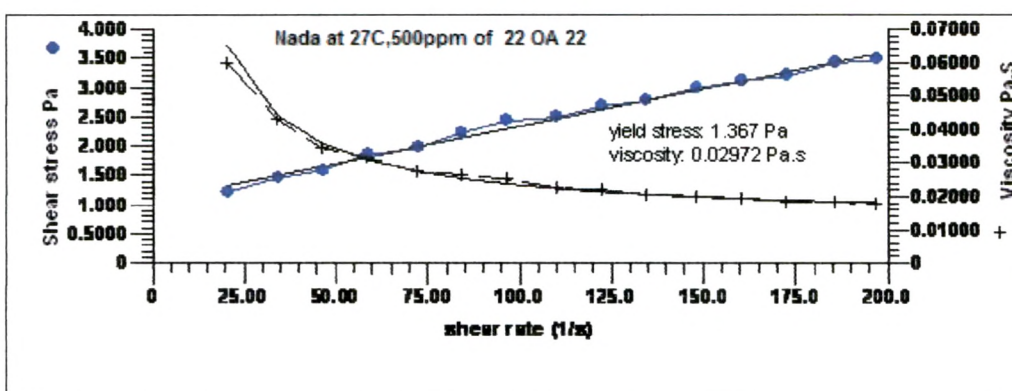


Fig 354 Nada with 500 ppm of 22 OA 22

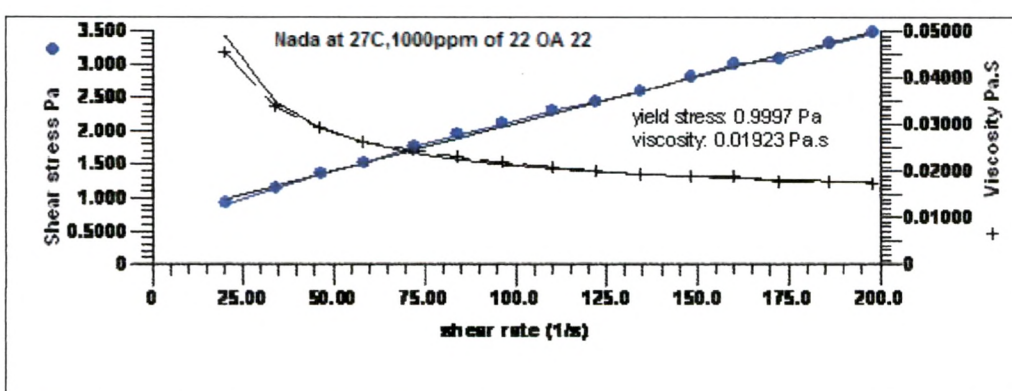


Fig 355 Nada with 1000 ppm of 22 OA 22

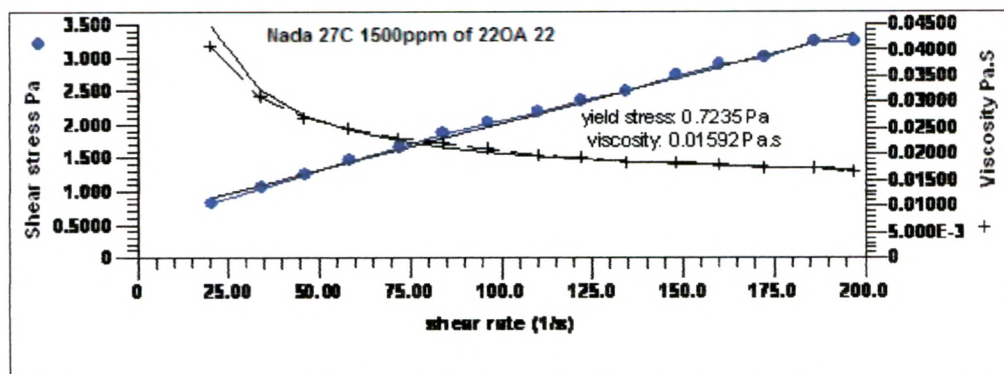


Fig 356 Nada with 1500 ppm of 22 OA 22

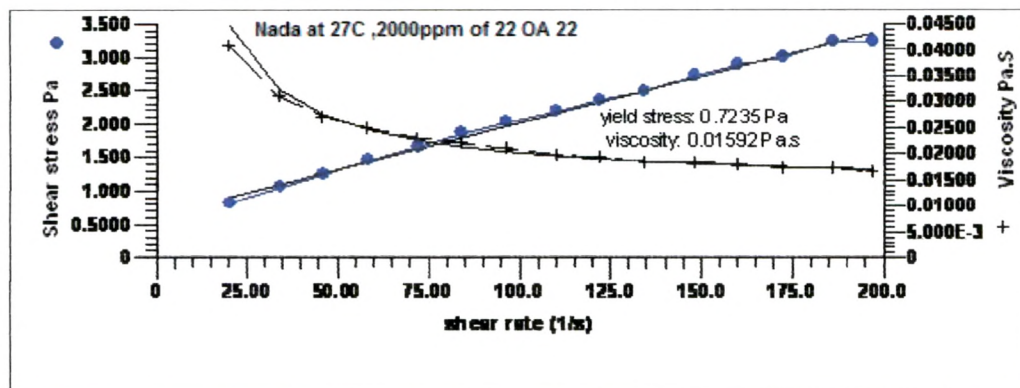


Fig 357 Nada with 2000 ppm of 22 OA 22

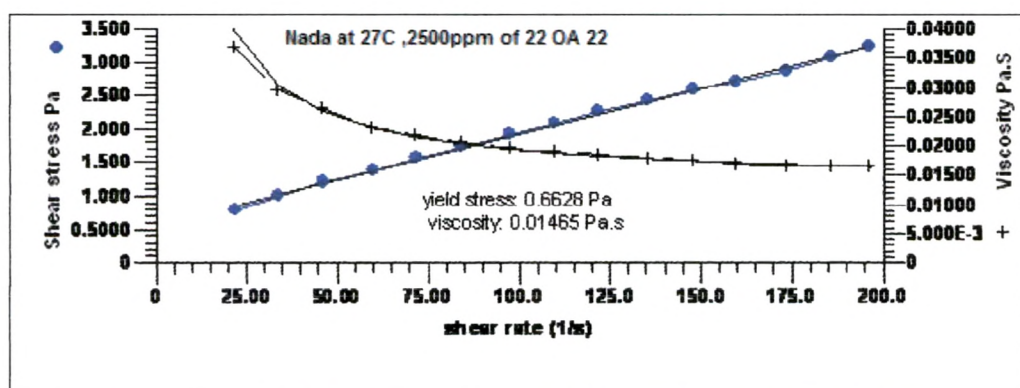


Fig 358 Nada with 2500 ppm of 22 OA 22

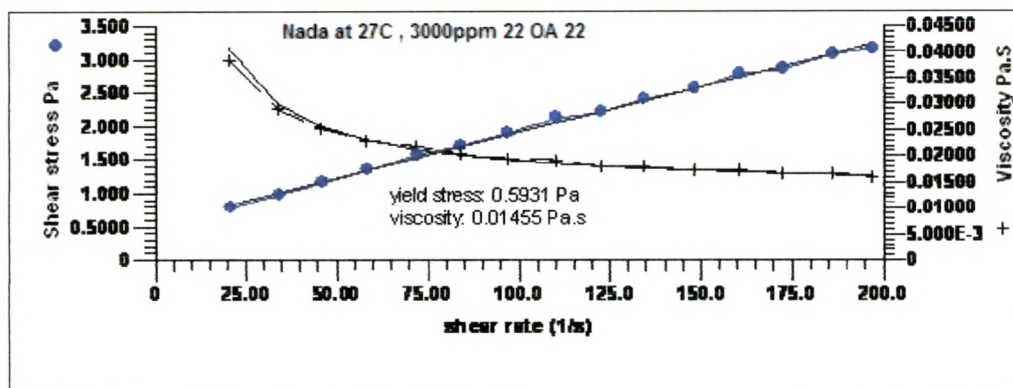


Fig 359 Nada with 3000 ppm of 22 OA 22

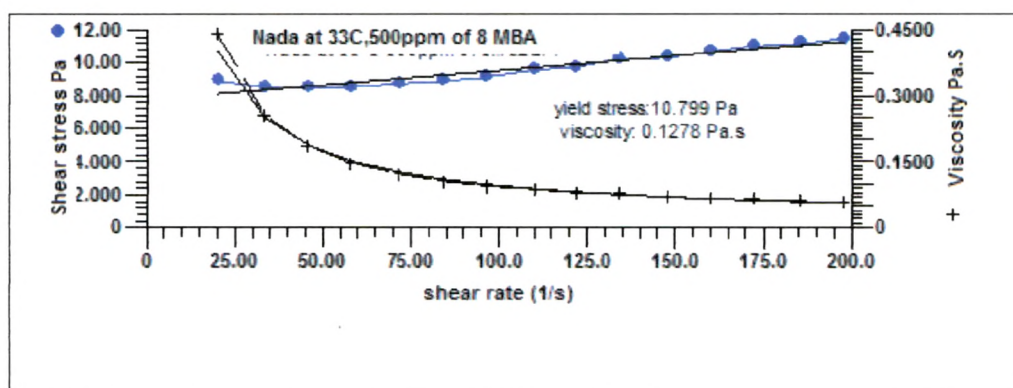


Fig 360 Nada with 500 ppm of 8 MBA

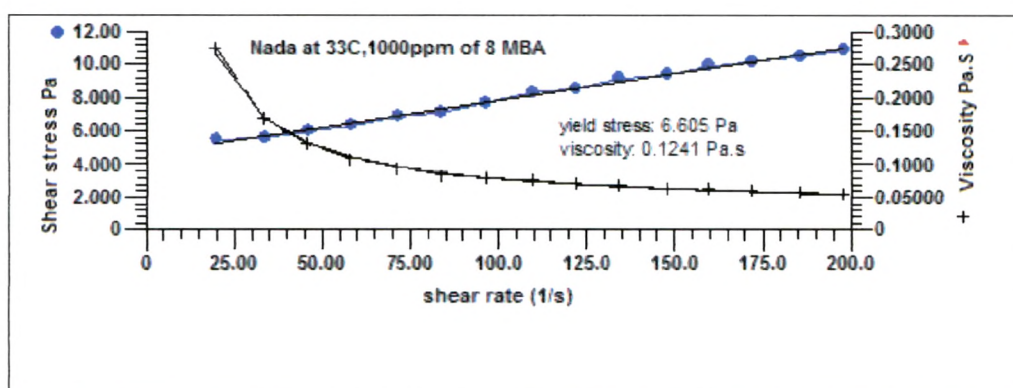


Fig 361 Nada with 10 ppm of 8 MBA

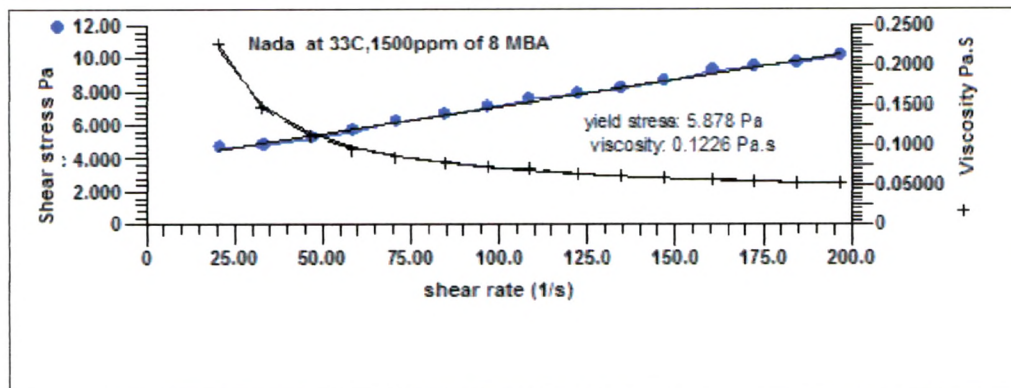


Fig 362 Nada with 1500 ppm of 8 MBA

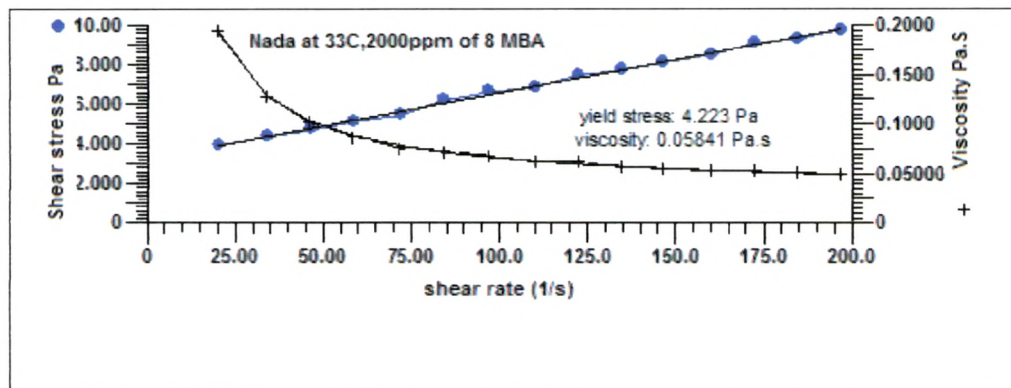


Fig 363 Nada with 2000 ppm of 8 MBA

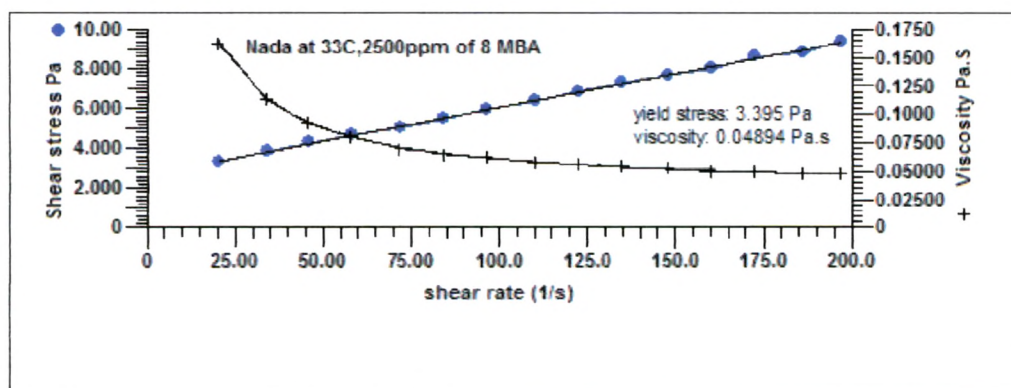


Fig 364 Nada with 2500 ppm of 8 MBA

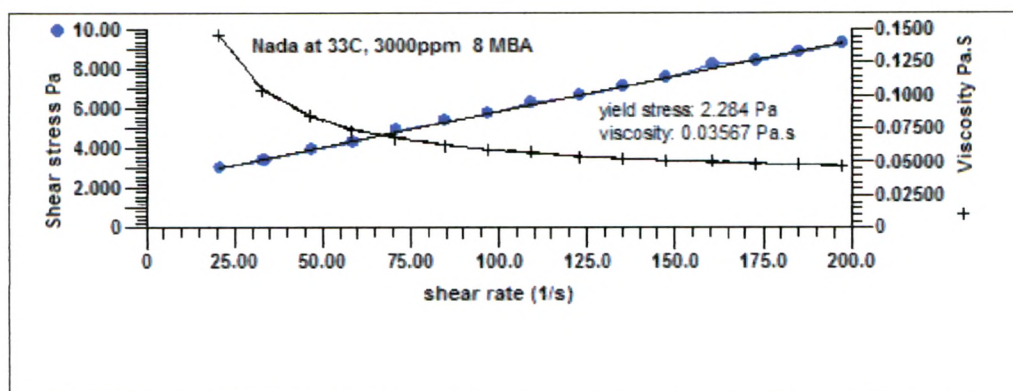


Fig 365 Nada with 3000 ppm of 8 MBA

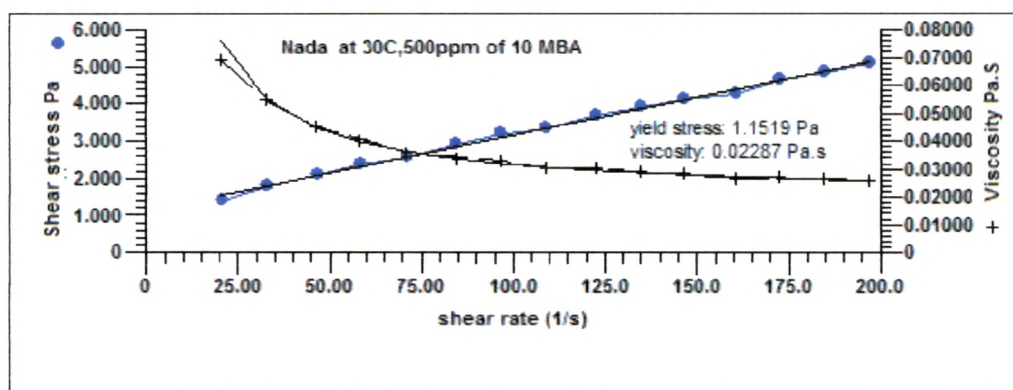


Fig 366 Nada with 500 ppm of 10 MBA

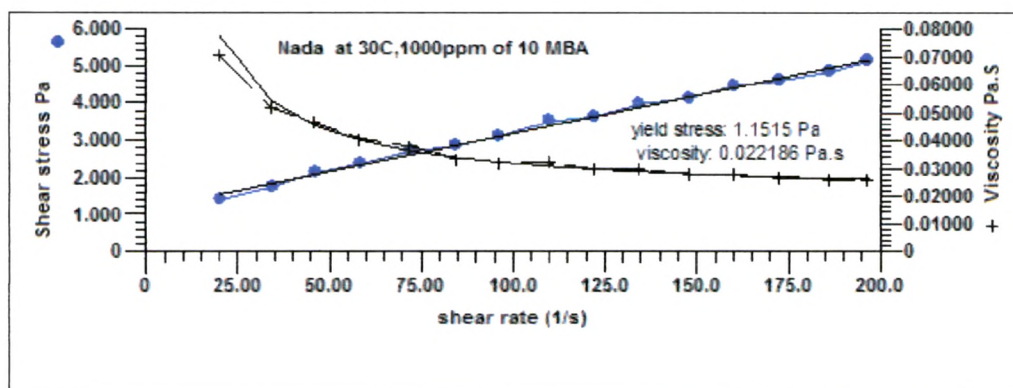


Fig 367 Nada with 1000 ppm of 10 MBA

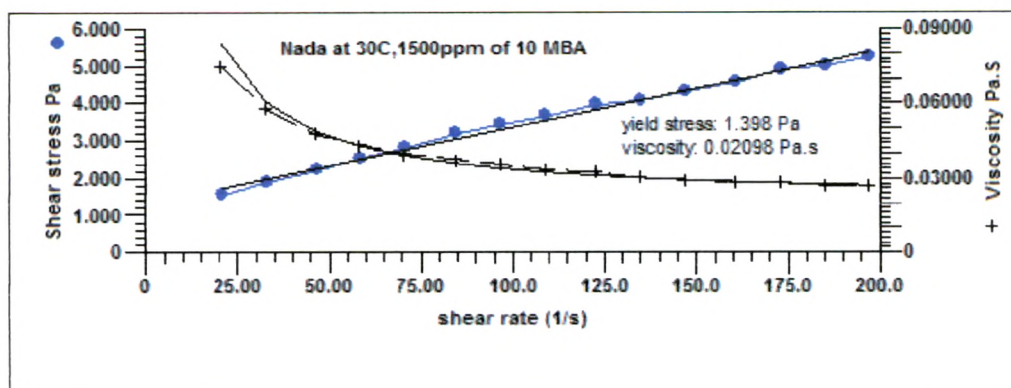


Fig 368 Nada with 1500 ppm of 10 MBA

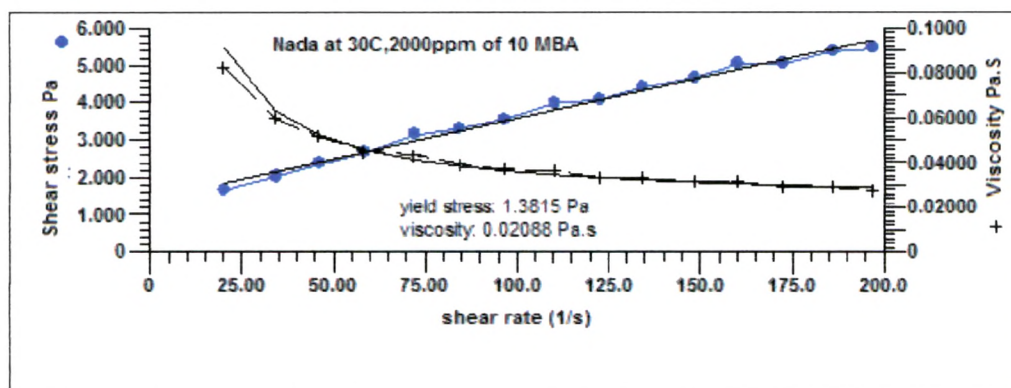


Fig 369 Nada with 2000 ppm of 10 MBA

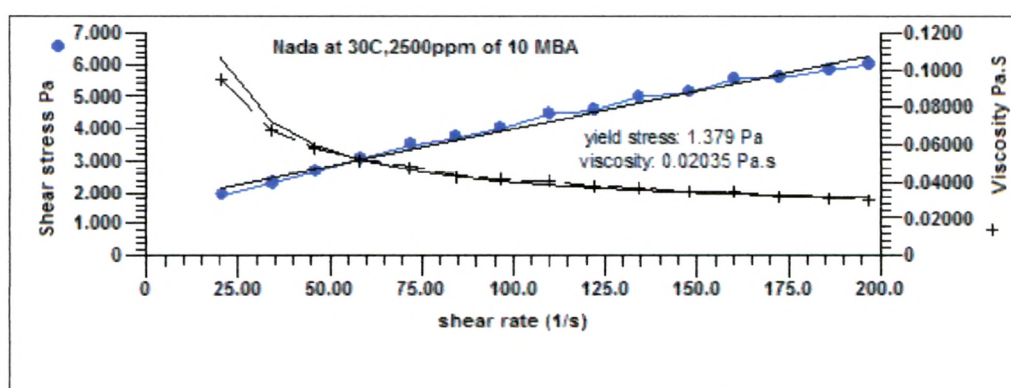


Fig 370 Nada with 2500 ppm of 10 MBA

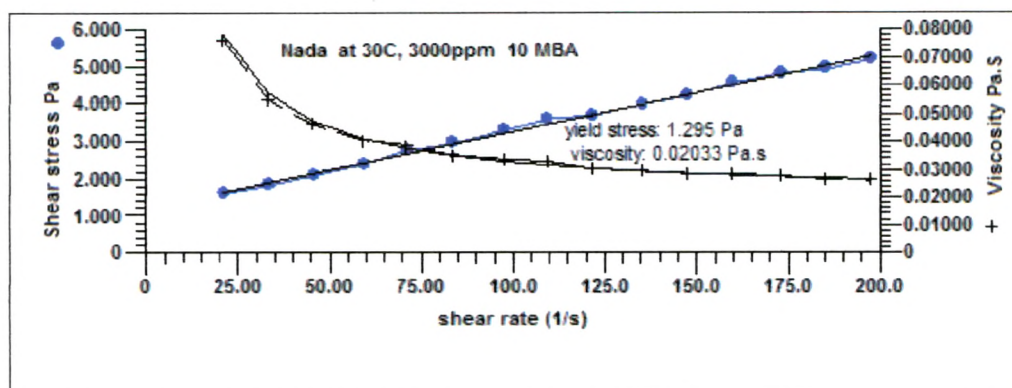


Fig 371 Nada with 3000 ppm of 10 MBA

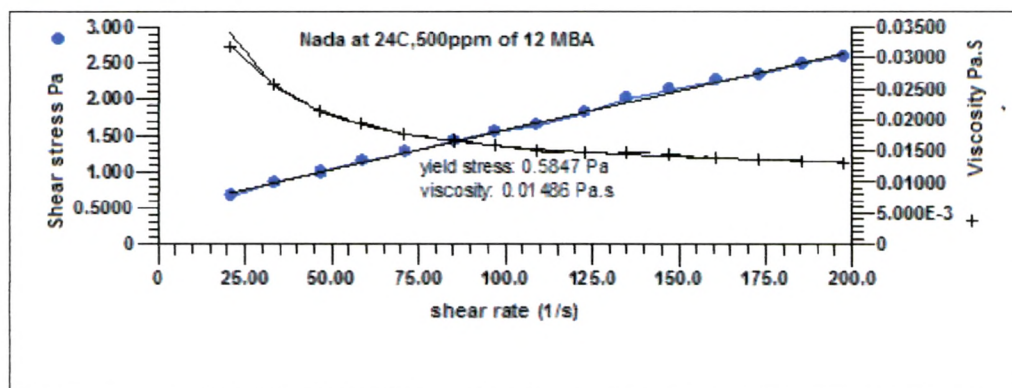


Fig 372 Nada with 500 ppm of 12 MBA

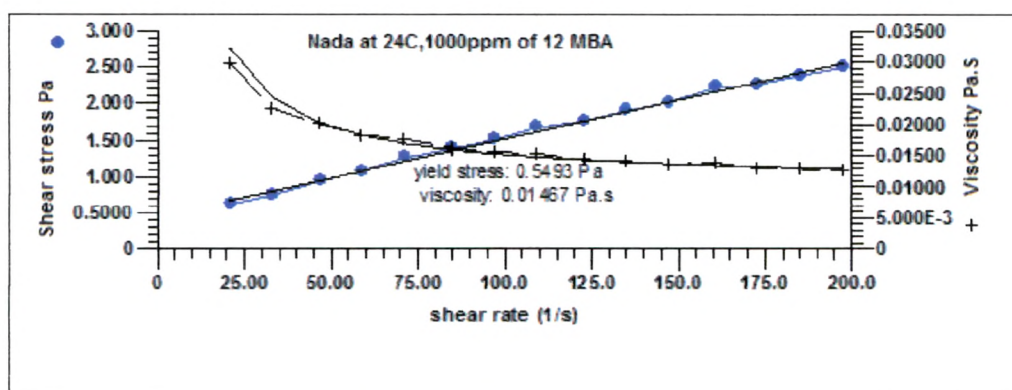


Fig 373 Nada with 1000 ppm of 12 MBA

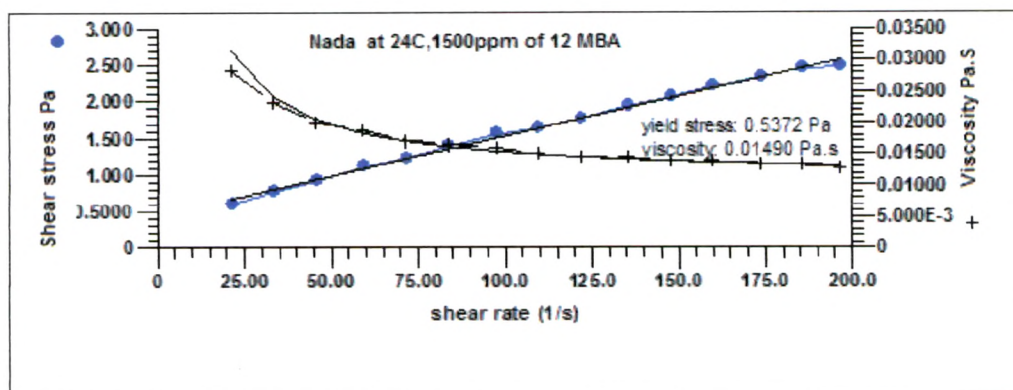


Fig 374 Nada with 1500 ppm of 12 MBA

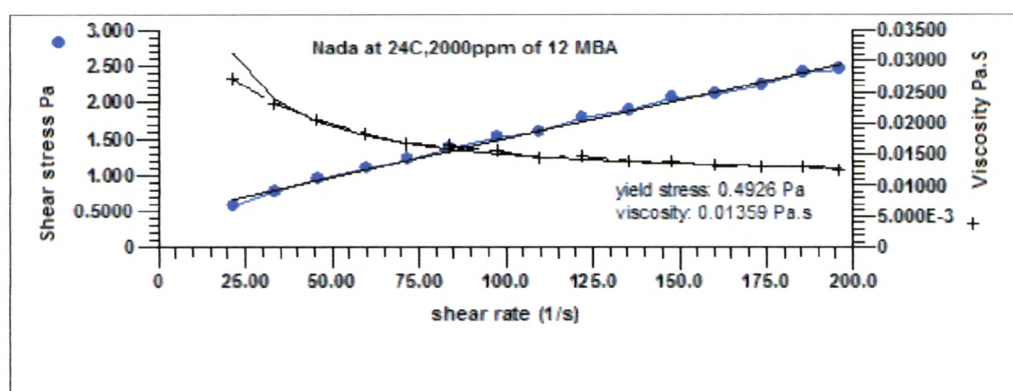


Fig 375 Nada with 2000 ppm of 12 MBA

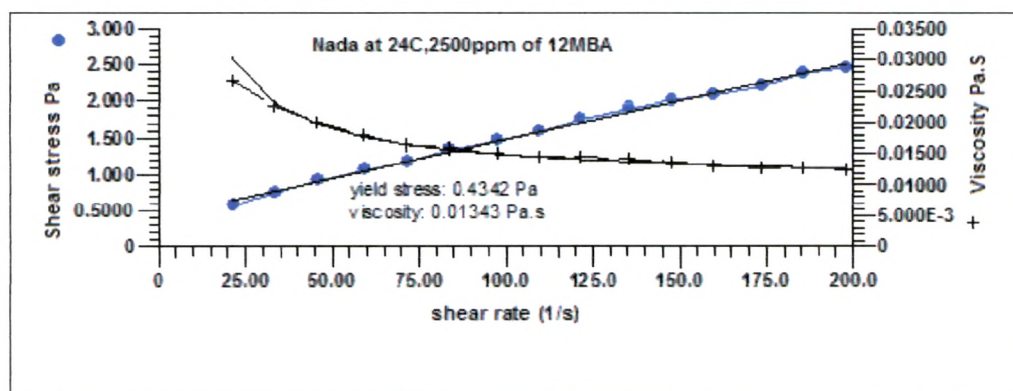


Fig 376 Nada with 2500 ppm of 12 MBA

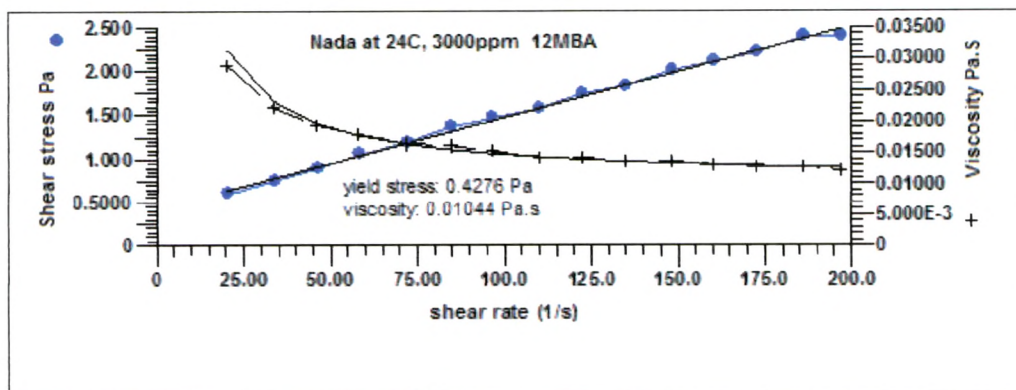


Fig 377 Nada with 3000 ppm of 12 MBA

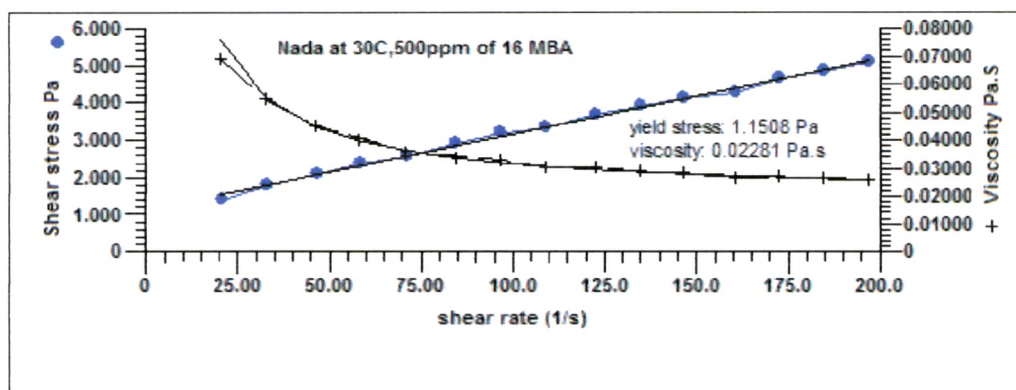


Fig 378 Nada with 500 ppm of 16 MBA

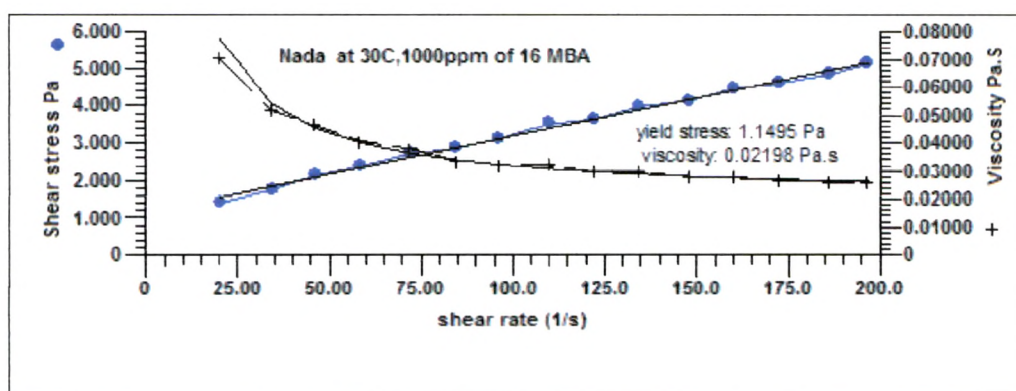


Fig 379 Nada with 1000 ppm of 16 MBA

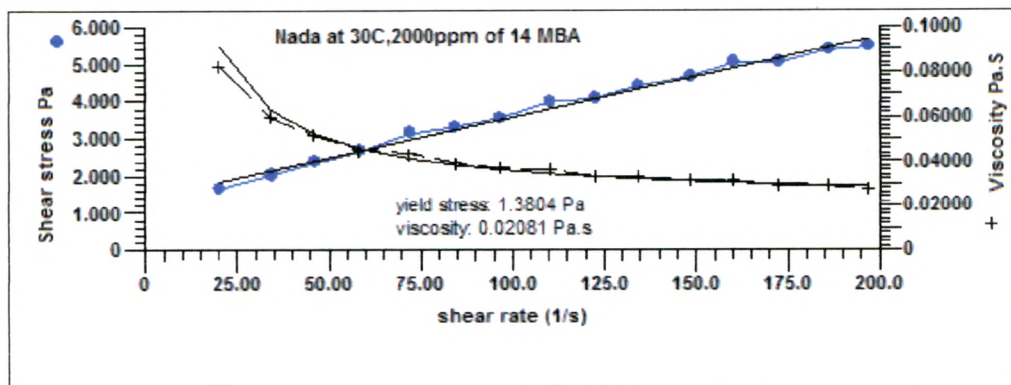


Fig 380 Nada with 2000 ppm of 16 MBA

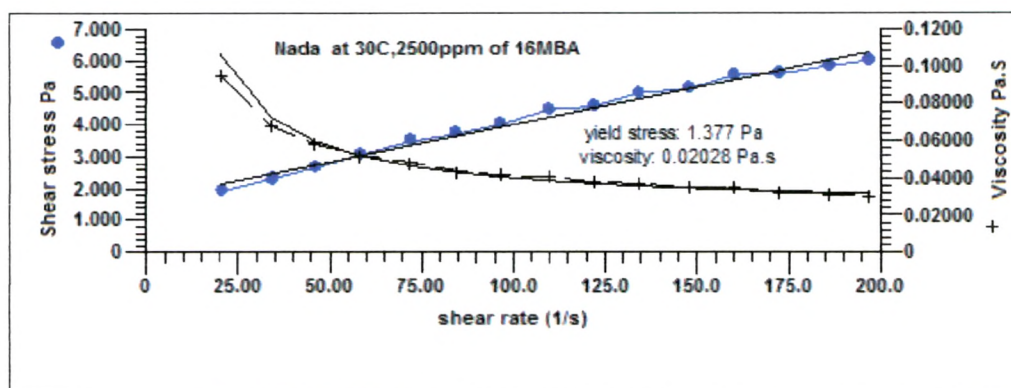


Fig 381 Nada with 2500 ppm of 16 MBA

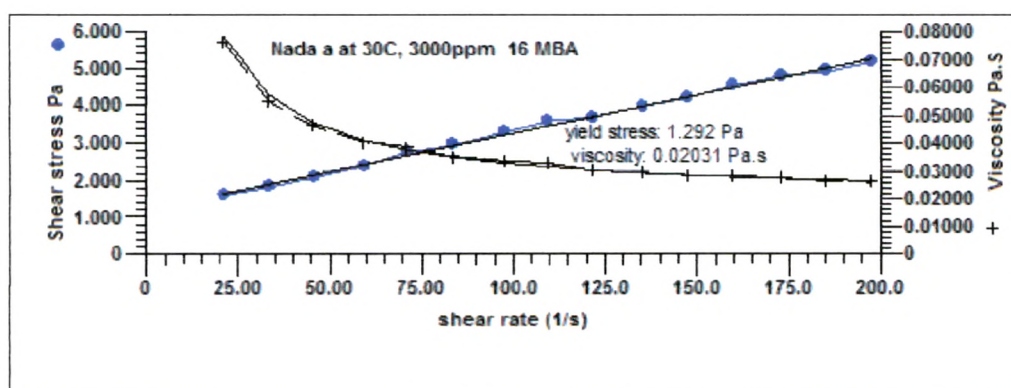


Fig 382 Nada with 3000 ppm of 16 MBA

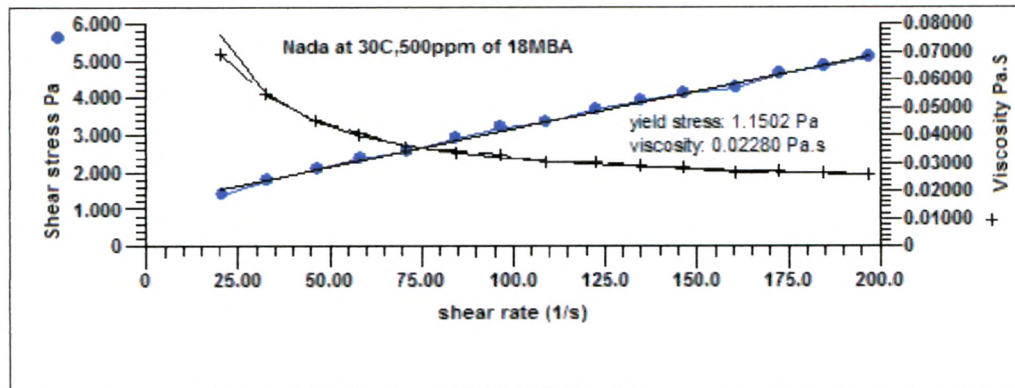


Fig 383 Nada with 500 ppm of 18MBA

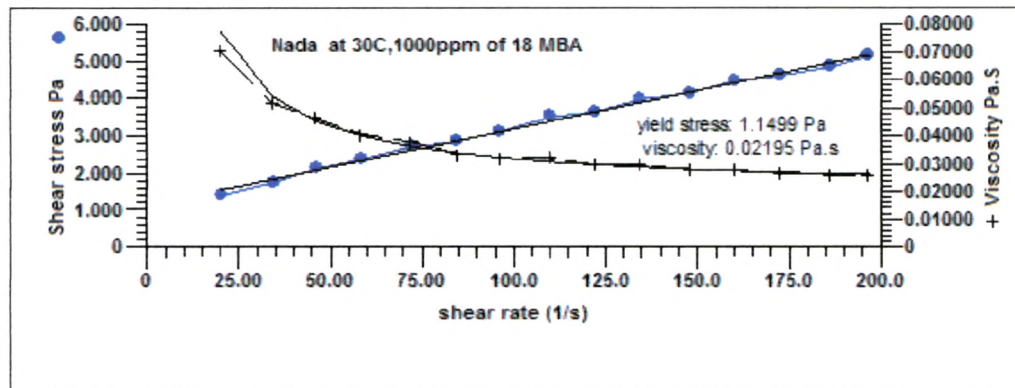


Fig 384 Nada with 1000 ppm of 18MBA

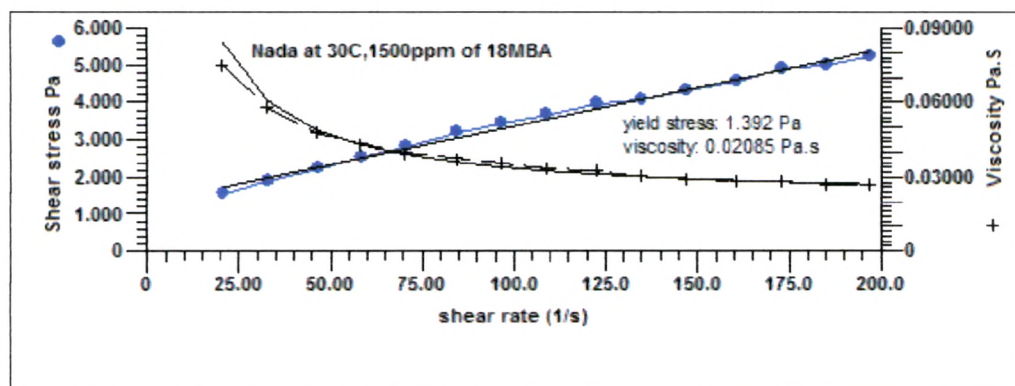


Fig 385 Nada with 1500 ppm of 18MBA

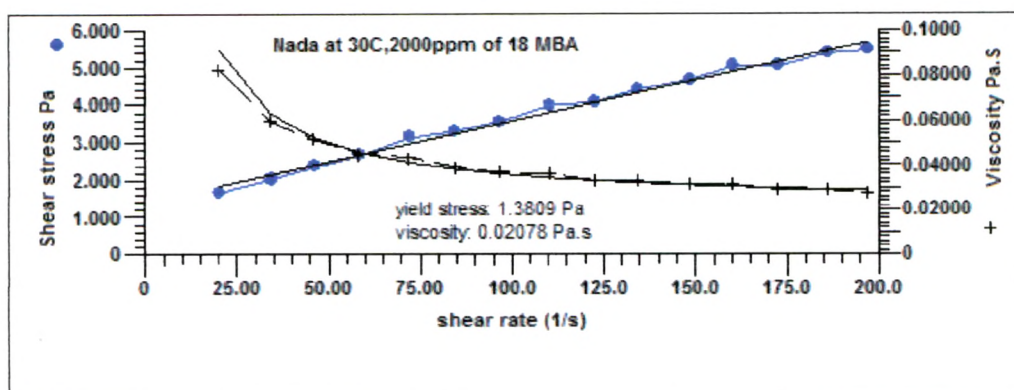


Fig 386 Nada with 2000 ppm of 18MBA

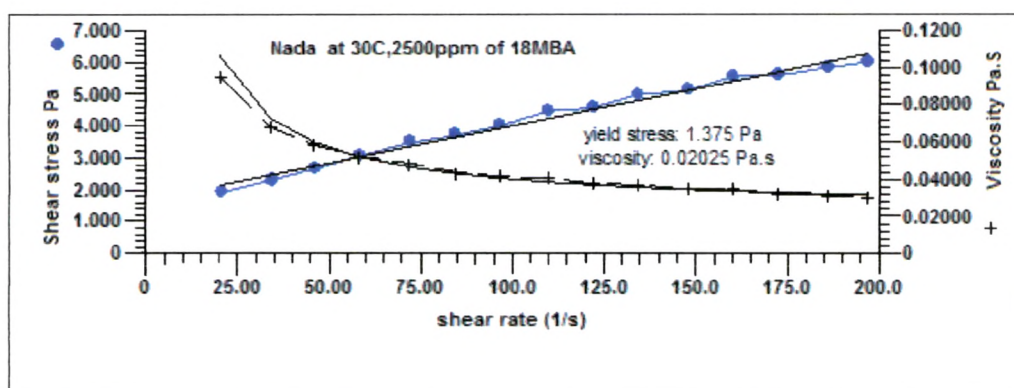


Fig 387 Nada with 2500 ppm of 18MBA

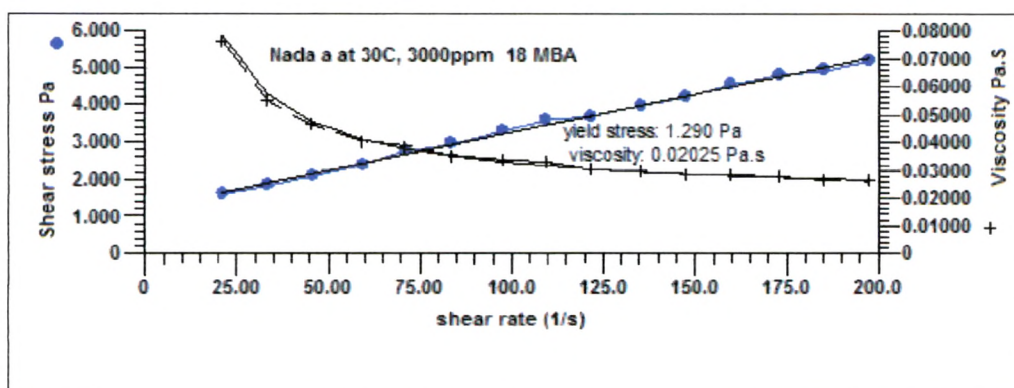


Fig 388 Nada with 3000 ppm of 18MBA

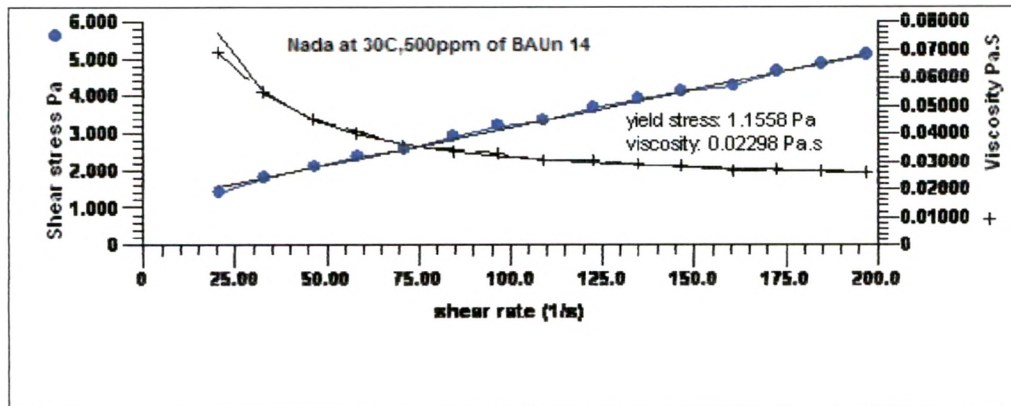


Fig 389 Nada with 500 ppm of BAUn 14

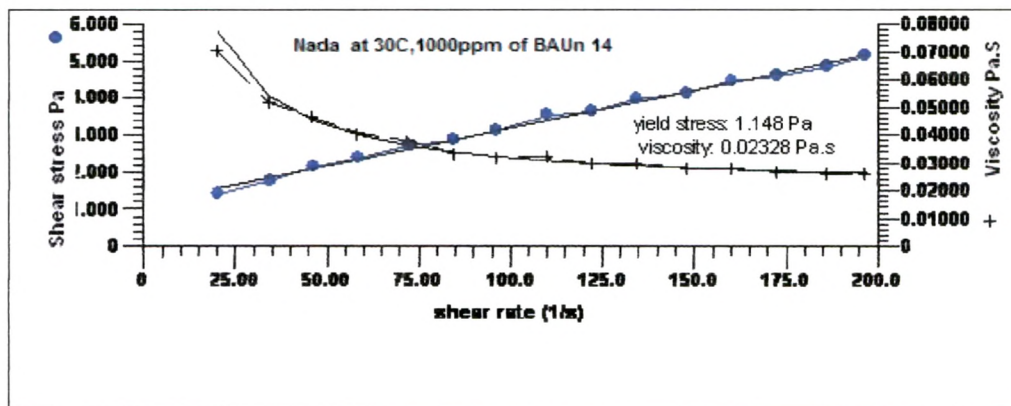


Fig 390 Nada with 1000 ppm of BAUn 14

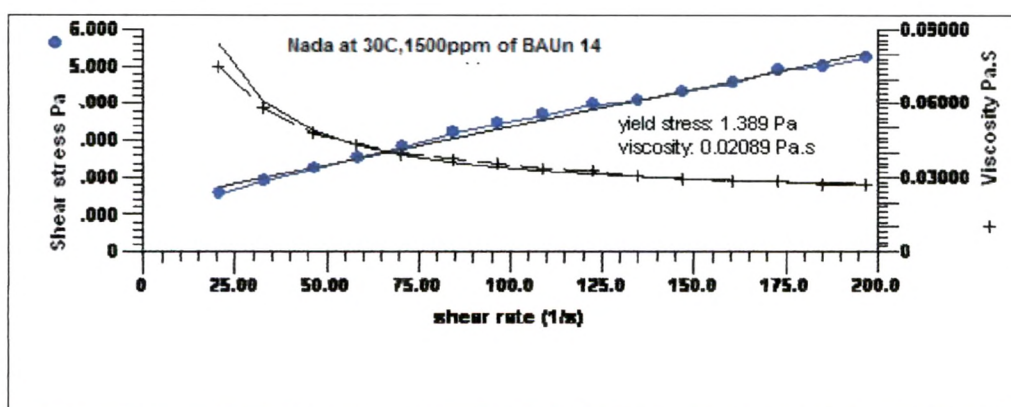


Fig 391 Nada with 1500 ppm of BAUn 14

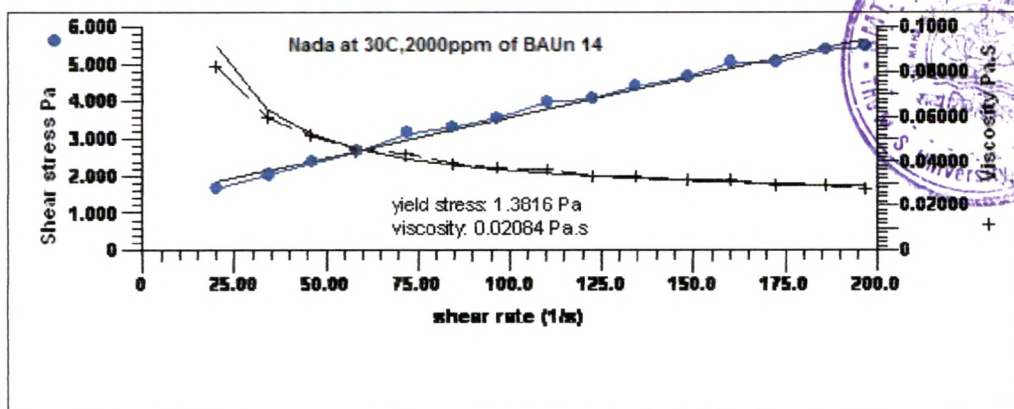


Fig 392 Nada with 2000 ppm of BAUn 14

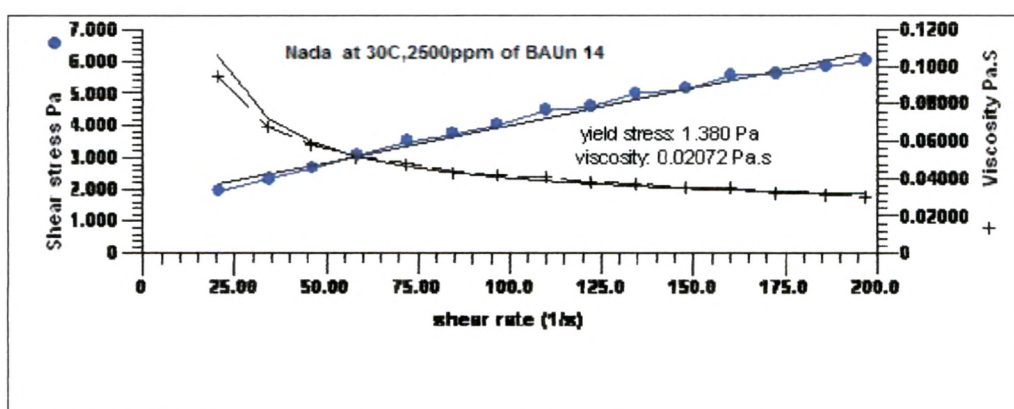


Fig 393 Nada with 2500 ppm of BAUn 14

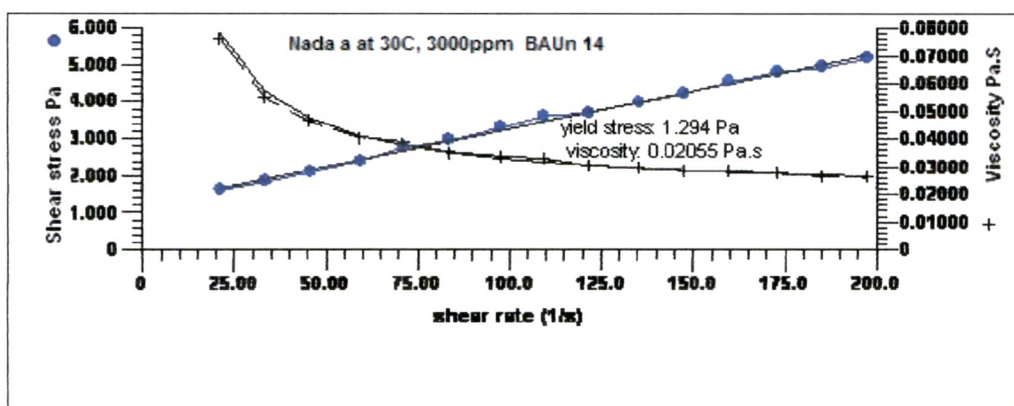


Fig 394 Nada with 3000 ppm of BAUn 14

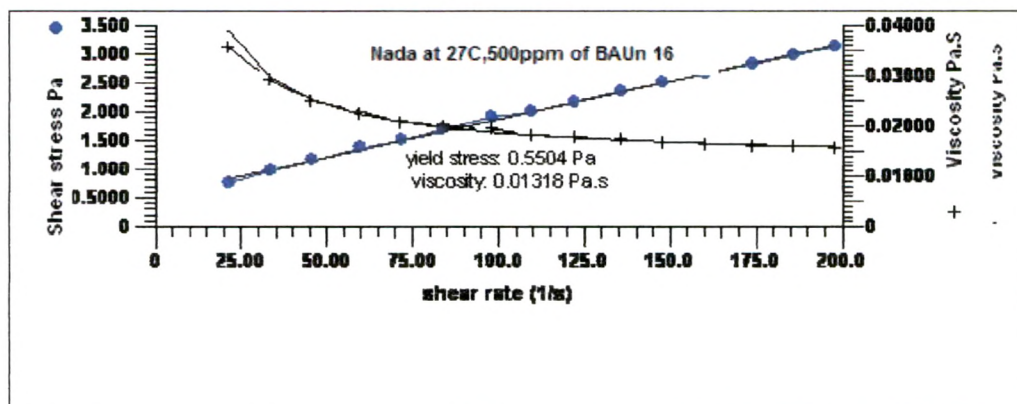


Fig 395 Nada with 500 ppm of BAUn 16

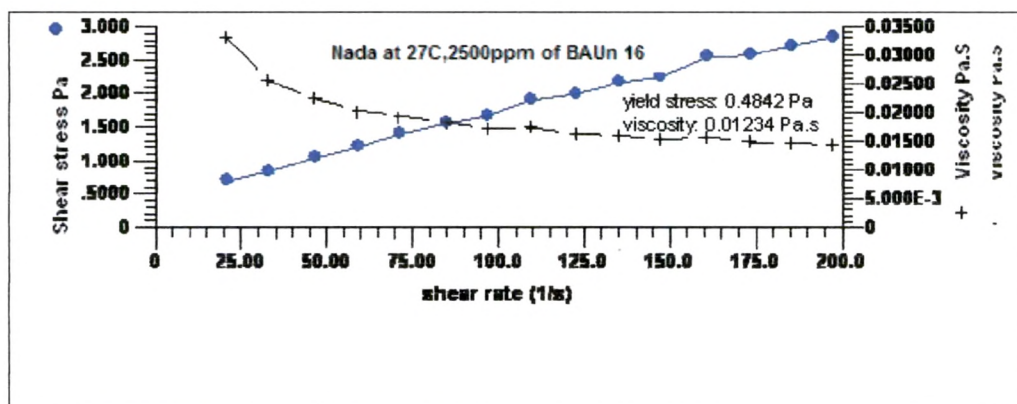


Fig 396 Nada with 2500 ppm of BAUn 16

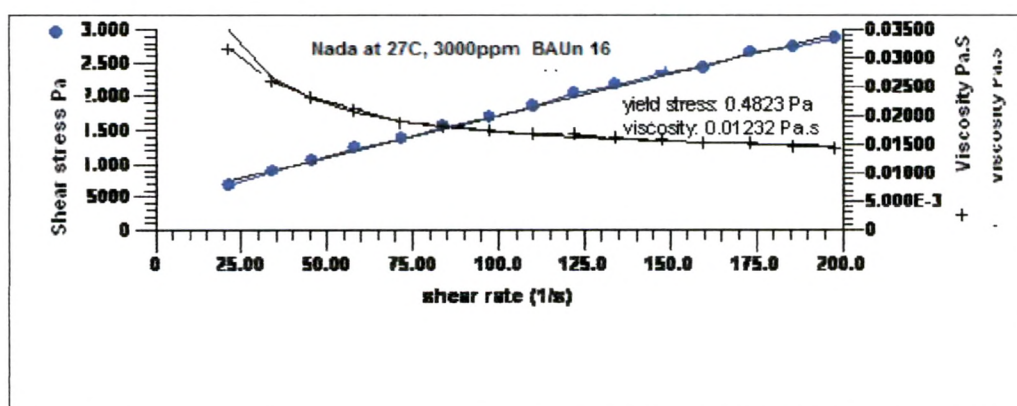


Fig 397 Nada with 3000 ppm of BAUn 16

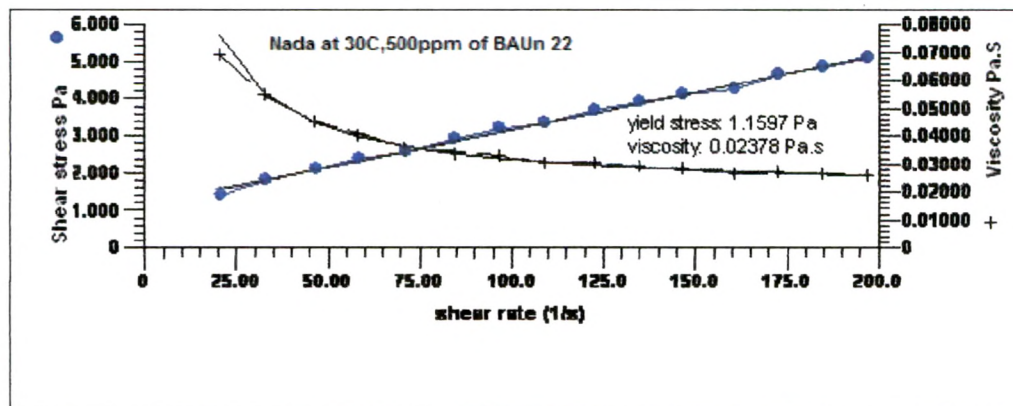


Fig 398 Nada with 500 ppm of BAUn 22

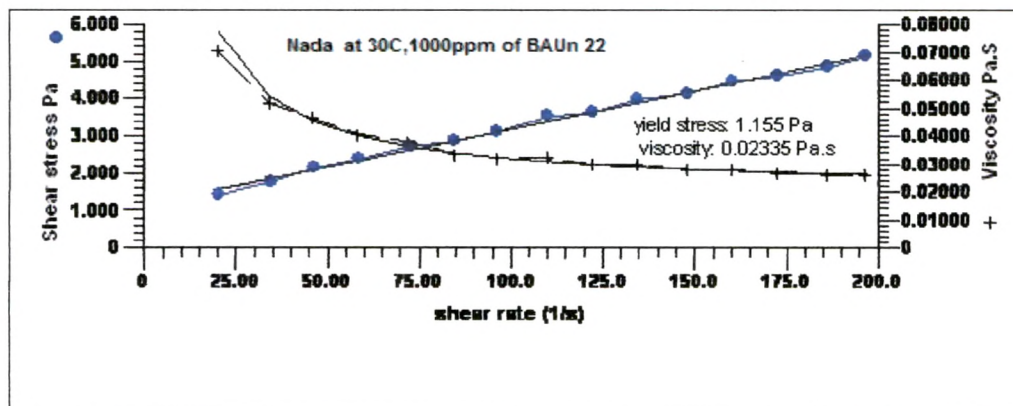


Fig 399 Nada with 1000 ppm of BAUn 22

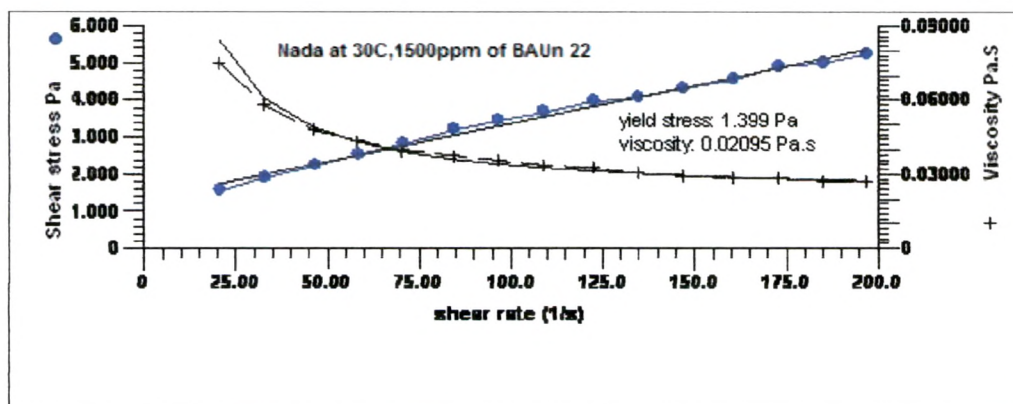


Fig 400 Nada with 1500 ppm of BAUn 22

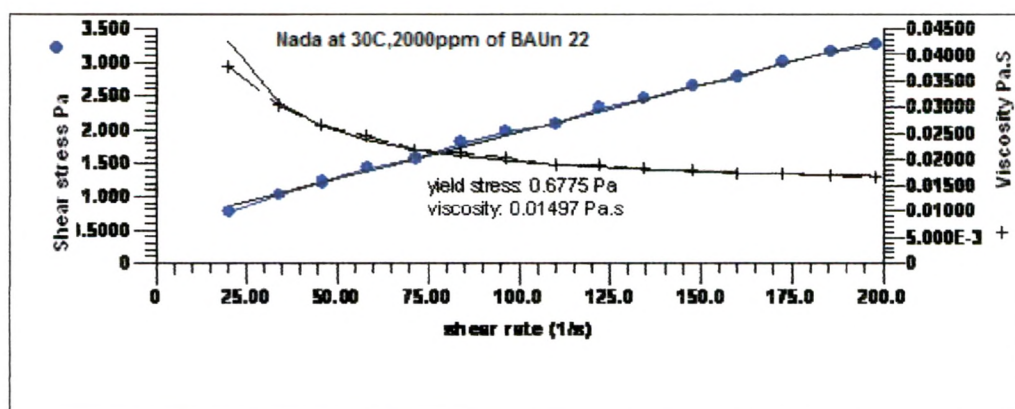


Fig 401 Nada with 2000 ppm of BAUn 22

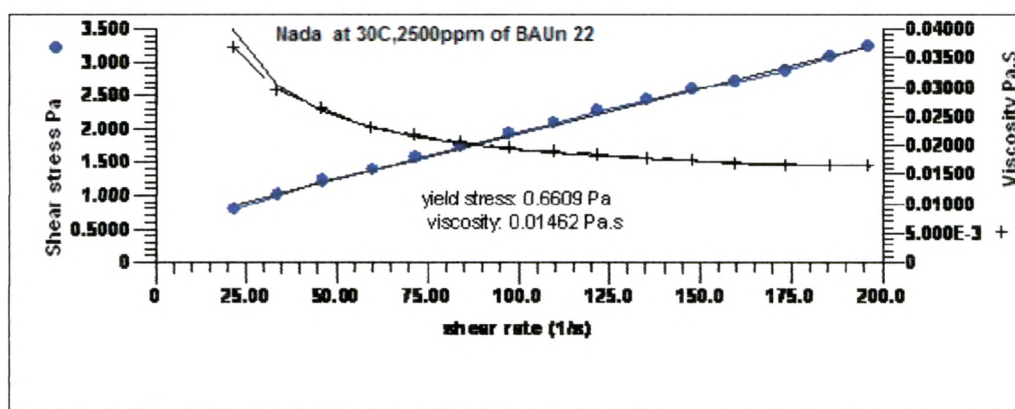


Fig 402 Nada with 2500 ppm of BAUn 22

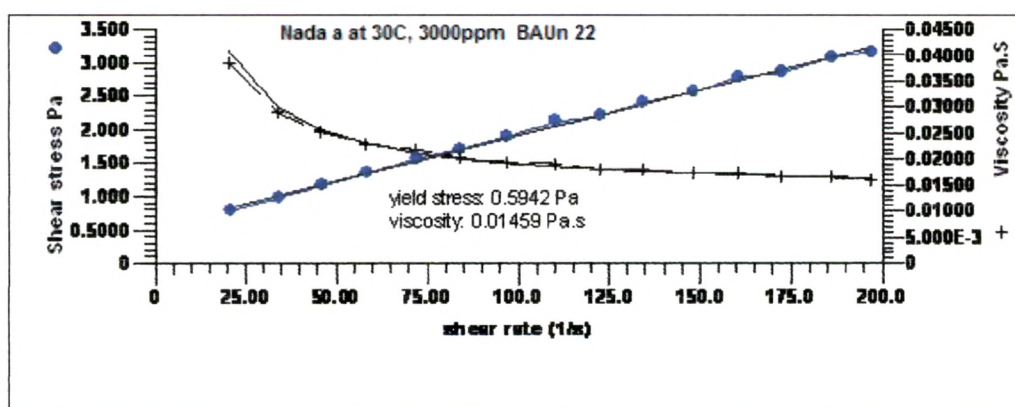


Fig 403 Nada with 3000 ppm of BAUn 22

4.3.5 Cold Finger Test on Nada crude:

Quantity required for running cold finger test is very high. So only selected doses were tried. But this test is very useful for implementation in field conditions for any PPD.

Volume taken: 800ml

Temperature gradient: 60 - 30°C

Sr.No	PPD Name	Dose (mg/l)	Wt. of deposit	% inhibition	M.P.of waxes °C	Wax content (%)
1	Blank	-	6.0		48	45
2	22 OA 22	2000	4.0	33.33	47	43
3	14 OA 14	2000	4.0	33.33	47	45
4	14 ABA	2000	3.0	50	44	41
5	16 ABA	2000	3.0	45.15	46	44
6	12 MBA	2000	2.5	75	44	40
7	14 MBA	2000	5.0	16.66	48	45
8	BAUn 16	2000	4.5	2.50	46	44
9	BAUn 14	2000	5.0	16.66	48	45

Table 58 Cold Finger Data for Nada crude oil

4.1.7 Discussion:

Pour point

Physico-chemical properties of Nada crude shows it a medium density crude oil and is highly waxy in nature as having 31% wax in neat sample. Viscosity of the neat crude measured below and above pour point of the crude. The viscosity is quite high at pour point i.e 33°C is 282cps and yield stress is reported 21 as seen in the Fig:278. Crude oil is not very highly susceptible to wax deposition but it observed from the experimental experience that this crude gives a very sharp pour point. If the temperature decrease rate is smooth it deposit slowly and does not form hard deposits but if the is somewhat higher then it also shows much tendency towards deposition. Pipe line deposit of Nada was also studied for its chemical composition. Pour Point Results are summarized in the Table 52. Waxes present in the deposit are more than 87%, oil is only 6%. Melting point of the deposit is 95°C is also quite high. So it is

clear from the deposit study that with the 31% of waxes in neat oils the deposition occurs to a great extent from well head to the pipeline end. Four series of the additives naming n ABA, nOA n, n MBA and nBAUn were prepared and tested on Nada crude from 500-3000 ppm. Pour point results of the Nada crude with all the doses of PPD's are summarized in Table 53. 8 ABA to 12 ABA has given the same as neat crude i.e 33°C, 16 ABA has decreased the pour point of Nada oil to 21°C. Again 18 ABA has given 33 °C.

It is observed that 10 OA 10 has increased the pour point to 36°C, 14 OA 14 has given pour point of Nada oil 27 °C . 16 OA 16 has given 33°C, only 22 OA 22 has been found effective in decreasing the pour point to 27°C. 6MBA- 10 MBA are not found effective in this crude. 12 MBA has decreased to 24°C. 16 MBA has also decreased to 21 °C. 18 MBA is not effective. BAUn 16 has been found effective to reduce pour point to 27 °C with all the doses (500,1000,1500,2000,2500 and 3000ppm). Studies repeats the same trend as in gandhar crude as there is no change in pour point with the increase in the dose of the additive. Here in case of Nada crude it has been observed that additives with C₁₆ side alkyl chain are mainly effective showing the presence of C₁₆ carbon chain in the waxes of Nada crude. Rest of the chains co-crystallizes with the waxes and added no effect in the pour point depression.

Rheological properties

All the four series synthesized flow improvers are evaluated for low temperature performance for Nada crude oil with and without additive treatment. Firstly pour point was detected and then the sample was taken for rheological studies with all the doses i.e from 500ppm to 3000 ppm. Studies on all the doses were possible because of the high sensitivity of TA Rheometer. The rheograms of the evaluated additives on the crude are given in the Figures 275 to 403 and results of rheological studies are summarized in Table 54 to 57.

Figure 275 to 285 shows the rheograms for the neat Nada crude oil. Viscosity and yield stress data is summarized in Table 51. It is clear from the data that viscosity of Nada neat crude is 282 cps at pour point i.e at 33°C and is recorded 33 cps at 50°C. When the temperature is subsequently decreased to 20°C it gives very high viscosity i.e 955cps which reveals that as the temperature increases, the viscosity of the oil decreases and vice versa. Same is case with yield stress also. In the Table 51 it is seen

that that yield stress of Nada neat crude at 20°C is 82 Pa and at it decreases to 2.9Pa at 50°C. Crude behaves like Newtonian above the cloud point ie 54°C. So viscosity and yield stress follows the same trend in neat conditions. Figure 284 shows comparison of the rheological behavior of neat Nada oil at different temperatures. This rheogram is recorded between shear rate and shear stress. Fig 285 is the temperature ramp at constant shear rate i.e 10 sec^{-1} . It gives the information about the change in viscosity of the crude oil from high to low temperature. Pour point and cloud point can be recorded with highly precise investigation of this rheogram.

Table 54 shows the viscosity and yields stress results with different doses(500-3000ppm) of the prepared(6 ABA - 18 ABA8) C_6 to C_{18} alkyl chain length additives of Diester of Poly(n-alkyl acrylate-co-maleic anhydride)dibenzylate. In this series almost additives has given good result from 500 to 3000 ppm. Viscosity ranges from 43 cps to 20 cps only and yield stress from 2.9 to 1.22 showing almost Newtonian behavior of the crude with these additives. Revealing that these alkyl chain lengths derivatives are able to dissolve the crude oil waxes and can keep them in solution form decreasing their molecular sizes.

Table 55 shows the viscosity and yields stress study results with different doses (500-3000ppm) of the prepared (6 OA 6 -22 OA 22) C_6 to C_{22} alkyl chain length additives of Diester of Poly(n-alkyl oleate-co-maleic anhydride)dialkylate. OA series has also behave as the ABA compounds. Viscosity remained in the range 43 to 14 cps. And yield stress is in the range 2.5 to 0.5 Pa. All the doses are quite effective in Nada crude oil.

Table 56 shows the rheology results of Alkyl chain length from(8 MBA – 18 MBA8) C_6 - C_{18} of Diester of Poly(n-alkyl methacrylate-co-maleic anhydride)dibenzylate. (6 MBA – 8 MBA) additives have less effect on viscosity and yield stress. As the side chain length increases the effectiveness of the additives has also increased and reduced the viscosity to 20 cps with 300ppm of 18 MBA and yield stress to 1.2 Pa. Results are quite encouraging . So the additives prepared in laboratory are useful in solving the wax deposition problem in Nada field

Table 57 shows the rheological results of Nada crude oil with the different doses(500-3000ppm) of BAUn 10 additives i.e Diester of Poly(benzyl undecylenate-co-maleic anhydride)didecylate. Pour point with these additives has been explained in the above

discussion. It is very clear from the table 58 that those carbon chains which has decreased pour point also has subsequently improved the flow behavior of the crude oils, they have decreased viscosity and yield stress of the oil at ambient temperatures. It is clear from the table 57 that as the alkyl chain length increases from C₁₀ to C₂₂ (BAUn 10 - BAUn 22) the viscosity and yield stress are decreased in a way improving flow behavior towards Newtonian side. BAUn 10 has given viscosity 289cps at 500ppm and decreased to 281cps with 3000ppm though the pour point remained the same in all the doses. Same is the case with yield stress, it is 21 Pa at 500ppm and becomes 19 Pa at 3000ppm following the viscosity trend. It reveals that the additives on increasing concentrations though there is no change in pour point but very much helpful in decreasing wax deposition property of the crude and improving flow behavior of the crude. BAUn 22 has decreased viscosity to 23 cps at 500cps and lowered to 14 cps at 3000ppm. It gives yield stress 1.5 to 0.5Pa from 500ppm to 3000ppm showing that crude has become highly flowable at higher concentrations.

Figure 275 to 403 shows the experimental results of Rheological studies of Nada crude with all the doses of synthesized polymers. Figures are self explanatory. Experimental results can easily be extended towards field applications for solving day to day problem.

Cold Finger Test:

All synthesized Chemical additives evaluated for pour point and rheology for the doses of 500ppm to 3000ppm. But in case of cold finger tests only those additives which have given very good results in the above studies are evaluated. Neat crude oil of Nada has given wax deposit of 6 grams showing a very high wax deposition tendency in pipeline and well head. When the Nada crude was treated with 2000ppm(medium) dose of 22 OA 22 and 14 OA 14 additives in separate bottles and experiment were run the deposition has decreased to 4gm respectively. Results are summarized in Table 58 In the same contest 2000ppm of 14 ABA and 16 ABA is tried and it has been observed that depositional tendency has decreased to almost 50% as the weight of the deposit has decreased from 6 gm to 3 gm. Further 12 MBA and 14 MBA has reduced to 2.5 and 5 gm respectively. In case of BAUn 16 and BAUn 14 deposit

weight has been decreased to 4.5 gm. So it is clear from the Table 58 that 12 MBA additives are also useful as wax dispersants in the Nada oil field.

It is very clear from all the studies that if the solutions suggested that is the pour point depressants synthesized for these particular field and which are decreasing the pour point of the crudes to the extent 15 °C can easily be use in field conditions.