SHEAR STABILITY OF MULTIGRADE ENGINE OILS—

Institute of Petroleum Fleet Tests

DS 49 S-1

AMERICAN SOCIETY FOR TESTING AND MATERIALS

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on the Shear Stability of Fluids

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I. SUMMARY

Two car fleet programs sponsored by the Institute of Petroleum (I.P.) were conducted on ten ASTM Reference Oils as part of an ASTM program to study methods of evaluating the shear stability characteristics of polymer containing oils. The results obtained from one fleet consisting of conventional cars, i.e., cars having separate oil charges for their engines and their gear boxes, agreed well with the average results from six U.S. car fleets. A second fleet, made up of cars having a common oil charge for the gear boxes and the engine crankcases, sheared the reference oils substantially more than the other fleets. Viscosity loss results from the second fleet correlated poorly with those from all shear stability bench tests and with results from the other fleets.

II. INTRODUCTION AND BACKGROUND

In 1969, ASTM R&D Div. VII B-1 Subsection on the shear stability of crankcase oils initiated a program "to study ways of evaluating the shear stability of polymer-containing oils under conditions closely related to service". Since then, 13 ASTM Reference Oils (ARO's) were formulated and evaluated in six United States car fleets and in a variety of bench tests. These results are summarized in ASTM data series report, DS49, published in early 1973.(1)*

The current report summarizes data from two fleets which were used in tests conducted by the Institute of Petroleum members recently. One fleet was made up of cars which used the same oil charge in both the engine and the transmission (hereafter referred to as integral gear box cars). The other fleet was of conventional design. Both fleets had seven cars and each fleet evaluated seven of the 13 ARO's although the seven were not the same oils in each case.

*Numbers in parentheses designate references at the end of report.

Regression analyses were conducted to determine how well the various fleets agreed and to see if any of the bench tests could satisfactorily predict an oil's shear stability as determined with the integral gear box car fleet.

III. PROGRAM

Test Oils - The ten SAE 10W/40 ARO's used in the two European fleets are shown in Table 1 along with their V.I. improver type. The average 210 and 100 F new oil viscosities determined by seven participants (six I.P. participants plus laboratory P) are compared to those determined by laboratory "P", which was the only laboratory that determined the viscosities of both the base oils and the finished blend. In addition, the viscosities with and without the V.I. improvers are shown along with the 0 F Cold Cranking Simulator viscosities of the finished blends.

Car Fleets - The data on the two car fleets are summarized in Table 2. The test lab which ran each car is listed along with the vehicle make, model, number of cylinders, cubic inch displacement (CID), mileage at start of test, test date and estimated oil consumption rate.

Test Designs - The two fleet tests were conducted using the two 7X4 Incomplete Latin (Youden) Square test designs[2] shown in Table 3. Although each car evaluated only four oils, this design allows each viscosity loss to be corrected for car severity effect as was done with the U.S. fleet data. These calculations are shown in Appendix Tables B-1 through B-4.

IV. EXPERIMENTAL DATA

Fleet Viscosity Data - The field viscosity data submitted by each sample processor are shown in Appendix Tables A-1 through A-4. Each oil sample was stripped in accordance with the revised* procedure. In most cases at least two different laboratories stripped the used oil samples taken from each car and reported the results. An oil (ARO-100) containing 5% mineral spirits was supplied to each oil sample processor to check their stripping procedures. If the processor could not strip all of the diluent out of the sample without removing the light ends of the oil, their data were questioned and, if not satisfactorily re-run, discarded.

The average viscosity losses obtained for each oil in each phase of the program are shown in Tables 4 and 5 at both 210 and 100 F.

Appendix Tables B-1 through B-4 show the statistical treatment of field data for each I.P. fleet and the viscosity losses for each temperature. Section 1 of each table shows the average viscosity losses for each car in each phase of the program. Section 2 shows the average viscosity losses obtained for each oil in each car. Section 3 shows the steps in calculating the correction for car effects. The corrected average viscosity losses are underlined. The uncorrected averages are also shown for comparison. Section 4 shows Analysis of Variance results which determine whether or not the phase, car and oil effects were significant.

V. RESULTS AND DISCUSSION

I.P. Fleets versus U.S. Fleet Data - The corrected average viscosity losses obtained with each of the two I.P. fleets are compared to the corrected U.S. Six-Fleet average in Table 6. Fleet B, the conventional fleet produced viscosity losses which were essentially the same as the six U.S. fleets. The U.S. Fleets' results, which were summarized in ASTM DS-49, showed that oil thickening occurred to varying degrees and a satisfactory correction could not be made. In view of the high degree of correlation between the U.S. fleets and

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*Procedure revised April 14, 1971 (see page 42, DS-49).

I.P. fleet B, it is probable that oil thickening occurred here also. However, the degree of thickening for the two I.P. Fleets is not known because no single graded oils were evaluated. The substantially higher shearing severity of the integral gear box Fleet A, is apparently due to the additional shearing which takes place in the transmission.

Results of regression analyses between the various fleets are shown in Table 7. These results show that Fleet B data correlate* very well with the U.S. six-fleet average. In contrast, Fleet A results do not correlate well with the other fleets.

<u>Bench Test Data versus Fleet A Data</u> - Since Fleet A was quite different in its shear severity, it was selected for comparison with all of the available bench and laboratory engine test results. The viscosity losses are shown in Table 8. In order to determine the degree of correlation between the bench tests, laboratory engine tests, and Fleet A results, regression analyses were conducted. These results are shown in Table 9. The data in all cases show that the integral gear box cars shear the oils substantially more than any of the bench tests or laboratory engine tests. None of the bench or laboratory engine tests gave a satisfactory correlation. In addition, the intercepts are unreasonable high (2.4 to 4.0 cSt).

<u>Bench Test Data versus Fleet B Data</u> - Since Fleet B data are very similar to the U.S. six-fleet average, correlation comparisons presented in Table 10 were made using only the best** viscosity loss data from each type of bench test. Correlation results from linear regression analyses of the best

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* For a perfect linear correlation the standard error of estimate must be "zero" and the correlation coefficient must be "one". It is also desirable, but not essential, for the intercept to be "zero" and the slope to be "one".

** Best in this case denotes the highest correlation coefficient with U.S. six-fleet data.

bench test data versus fleet data, U.S. and B, are shown in Table 11. Note that the U.S. fleets' correlation results are similar to those reported in DS-49 even though only seven ARO's were included instead of the 12 or 13 ARO's in the other analysis.

In all of the laboratory bench tests, the Fleet B results correlated somewhat better than U.S. six-fleet results. In laboratory engine tests, Fleet B correlation coefficients were equivalent to or slightly poorer than U.S. fleet results.

Precision of Program (Both Fleets A & B) - This program was designed so that the precision of the viscosity determination method, the stripping procedure and the car's ability to shear test oils repeatably could be determined.

The pooled reproducibility standard deviation for fresh oil at 210 F was 0.06 cSt. This value was calculated from the fresh oil viscosities of the 10 AROs determined by seven laboratories. The data from the eighth lab were omitted from the analysis because several of their results were outliers. The calculated fresh oil viscosity determination reproducibility is as follows:

$$\text{Reproducibility} = \sigma_R \cdot \sqrt{2} \cdot t_{41} = 0.06 \times 1.414 \times 2.02 = 0.17 \text{ cSt.}$$

Where: σ_R is the reproducibility standard deviation

t_{41} is the student t @ the 95% confidence level and 41 degrees of freedom.

The ASTM reproducibility in percent is calculated by dividing reproducibility by the average oil viscosity.

Therefore:

$$\text{Reproducibility \%} = \frac{0.17}{15.04} \times 100 = 1.13\%$$

The reported reproducibility for the ASTM D-445 method is 0.70%.

The pooled reproducibility standard deviation obtained for the combined stripping operation and viscosity determinations at 210 F was determined to be 0.17. This value was calculated from the results shown in Appendix Tables A-1 and A-2 where two different laboratories stripped the same used oil samples and determined their viscosities at 210 F. The calculated reproducibility of the combined operation is as follows:

$$\text{Reproducibility (Combined)} = \sigma_{R_c} \cdot \sqrt{2} \cdot t_{48} = 0.17 \times 1.414 \times 2.01 = 0.49 \text{ cSt}$$

When this reproducibility is compared to the reproducibility obtained with the fresh oil viscosity determinations alone, it indicates that about 0.46 cSt of the reproducibility was contributed by the stripping operation. The data from any lab that did not strip ARO-100 (the oil which contained 5% mineral spirts) so that its 210 F viscosity was within specified limits were omitted from the analyses. One laboratory's data were omitted on this basis.

The car fleet program included some repeat tests by adding a fifth phase to the original program. This fifth phase consisted of re-evaluating the shear stability of several test oils in the same cars in which they were run previously. This part of the program was added to establish an independent measure of a car's ability to shear the test oils repeatably. The pooled repeatability standard deviation was calculated to be 0.29 cSt from the Phase V and matching data shown in Appendix Tables A-1 and A-2 after one outlier[4] was omitted. This standard deviation includes the stripping and viscosity determination variations in addition to the repeatability or a car's shearing ability. The calculated repeatability of the combined operation is as follows:

$$\text{Repeatability (Combined)} = \sigma_{R_c} \cdot \sqrt{2} \cdot t_{7} = 0.29 \times 1.414 \times 2.37 = 0.97 \text{ cSt.}$$

CONCLUSIONS

- Cars in the I.P. fleet test which used separate sumps for their engines and gear boxes, although different in displacement and in average engine speed, gave virtually identical average viscosity losses for multigrade oils as the U.S. fleets.

- Cars in the I.P. fleet test having a common sump for the engine and the transmission sheared multigrade oils more severely than those having separate sumps.

- Current bench tests do not adequately predict the viscosity loss behavior of multigrade oils in integral gear box engines.

- A bench test that is suitable for predicting viscosity loss performance of multigrade oils in U.S. fleets should also be adequate for predicting viscometric performance in most other conventional cars with separate sumps for their gear boxes and engines.

REFERENCES

1. Shear Stability of Multigrade Crankcase Oil - Establishment of Field Data and Correlation with Laboratory Engine and Bench Test Results DS-49 ASTM 1973.

2. W. G. Cochran and G. M. Cox, "Experimental Designs", Second Edition, Page 523 Incomplete Latin Square - Plan 13.2 John Wiley and Sons, Inc., 1962, N.Y.

3. A. W. Talbot, W. A. Wright, and H. I. Morris, "A Bench Scale Engine Test for Shear Stability of Multigrade Engine Oils", SAE Paper 730485, presented at Detroit, Michigan, May 1973, SP-382.

4. Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants, Spring 1973 Edition, Page 37, Paragraph 5.6.

TABLE 1

VISCOSITIES OF ASTM REFERENCE OILS

ARO Oil No.	V.I. Improver Type	SAE Viscosity Grade	210°F Viscosity, cSt. 7-Lab. Avg.* Finished Blend	210°F Viscosity, cSt. Lab. P Finished Blend	210°F Viscosity, cSt. Lab. P Without V.I. Improvers	210°F Viscosity, cSt. Lab. P Polymer Contributed	100°F Viscosity, cSt. Finished Blend 7-Lab.Avg.	100°F Viscosity, cSt. Finished Blend Lab P	CCS Viscosity @ 0°F, cP Finished Blend Lab P
101	Polymethacrylate-1	10W/40	15.07	15.05	5.71	9.34	86.36	86.19	2040
102	Polymethacrylate-2	10W/40	14.99	15.02	5.83	9.19	85.98	85.93	2030
103	Polyisobutylene	10W/40	15.03	15.02	4.84	10.18	97.59	98.09	1970
104	Olefin Copolymer-1	10W/40	14.96	14.96	6.15	8.81	109.02	108.9	1960
105	Vinyl Copolymer	10W/40	14.93	15.05	5.67	9.38	83.99	84.54	1930
106	Polyacrylate	10W/40	14.96	15.01	5.65	9.36	76.40	76.95	1940
107	Polyalkylstyrene	10W/40	15.19	15.15	5.49	9.66	97.91	97.58	2000
108	Olefin Terpolymer	10W/40	14.98	15.00	5.47	9.53	104.73	105.1	1880
109	Styrene Polyester	10W/40	15.25	15.23	5.36	9.87	90.27	90.81	1940
110	Olefin Copolymer-2	10W/40	15.04	15.00	5.19	9.81	104.54	104.4	1950

* Six I.P. Laboratories Plus Laboratory P.

TABLE 2

TEST VEHICLE CHARACTERISTICS - INSTITUTE OF PETROLEUM FIELD TEST

Vehicle No.	Test Lab.	Vehicle Make	Vehicle Model	Engine		Mileage at Start	Date of Test		Est. Oil Consump. Rate Miles/qt.
				Cyl.	CID		Start	Finish	
				FLEET A					
1	A	BLMC*	1100(HT/I)**	4	67	50,870	6/70	12/70	1,920
2	C	Peugeot	204 (HT/I)**	4	69	12,562	8/70	7/71	1,500+
3	B	BLMC*	1100(HT/AI)**	4	67	59,119	6/70	5/71	2,000+
4	I	BLMC*	Mini (SW/I)**	4	52	46,548	6/70	8/70	1,500+
5	A	BLMC*	1800 (HT/I)**	4	110	16,287	7/70	3/71	2,020
6	H	BLMC*	1300 (S/I)**	4	80	7,196	6/70	10/70	2,400+
7	G	Peugeot	204 (HT/I)**	4	69	19,185	1/72	8/72	1,500
				FLEET B					
1	A	Vauxhall	Viva (HT)**	4	71	25,560	7/70	2/71	1,560
2	D	Rootes	Rapier (HT)**	4	105	27,991	6/70	11/70	1,400
3	B	Volkswagen	1200 (HT)**	4	73	48,777	7/70	11/72	800
4	E	Ford	Cortina (S)**	4	97.5	21,298	8/70	11/70	1,600
5	F	Ford	Cortina (SW/A)**	4	97.5	10.057	7/70	9/70	-
6	F	Ford	Zephyr (HT/A)**	V6	183	41,343	7/70	9/70	-
7	I	Triumph	1300 (HT)**	4	79.5	31,267	6/70	8/70	1,500+

* British Leyland Motor Company

** S - 2 or 4 door sedan
HT- 2 or 4 door hard top
SW- Station Wagon

A - Automatic Gear Box
I - Integral Gear Box

TABLE 3

I.P. FIELD TEST DESIGNS

FLEET A					FLEET B				
Car	ARO No. Used in Phase				Car	ARO No. Used in Phase			
No.	I	II	III	IV	No.	I	II	III	IV
1	104	103	108	109	1	104	105	106	107
2	110	108	109	101	2	110	106	107	101
3	103	109	101	102	3	105	107	101	102
4	108	101	102	104	4	106	101	102	104
5	109	102	104	110	5	107	102	104	110
6	101	104	110	103	6	101	104	110	105
7	102	110	103	108	7	102	110	105	106

TABLE 4

VISCOSITY LOSS RESULTS FROM I.P. FIELD TESTS

(FLEET A)

ARO Oil No.	210°F Avg. Viscosity Losses, cSt.				100°F Avg. Viscosity Losses, cSt.			
	Phase I	Phase II	Phase III	Phase IV	Phase I	Phase II	Phase III	Phase IV
101	3.16	3.40	2.97	3.44	15.02	16.32	13.27	16.87
102	5.17	5.19	4.51	4.08	27.35	25.60	21.80	20.22
103	3.67	4.41	4.80	4.48	19.15	29.62	32.35	29.79
104	4.07	3.97	5.55	4.53	32.41	32.00	45.77	34.65
108	4.86	5.84	5.20	4.49	36.41	44.53	40.04	33.18
109	3.62	2.85	3.24	3.37	15.25	10.97	15.58	18.14
110	3.92	3.33	2.80	4.67	27.93	25.61	22.27	36.83

TABLE 5

VISCOSITY LOSS RESULTS FROM I.P. FIELD TESTS

(FLEET B)

ARO Oil No.	210°F Avg. Viscosity Losses, cSt.				100°F Avg. Viscosity Losses, cSt.			
	Phase I	Phase II	Phase III	Phase IV	Phase I	Phase II	Phase III	Phase IV
101	0.78	2.25	1.30	3.25	0.06	9.98	4.58	15.18
102	2.68	3.45	3.71	2.44	12.12	15.17	17.62	8.71
104	2.46	1.31	2.07	2.70	18.71	10.11	14.95	21.43
105	3.79	4.49	3.74	3.24	19.43	19.62	14.56	12.32
106	3.98	3.86	4.76	4.04	12.48	10.73	15.74	12.83
107	2.26	1.11	2.95	3.32	10.87	1.44	18.35	20.85
110	1.41	0.60	-0.38	0.22	9.95	4.36	-4.76	0.84