EFFECT OF BASE OILS CHARACTERISTICS ON ATF PERFORMANCE

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Performance requirements for automatic transmission fluids have been changing to reflect the design changes of automatic transmission. The major purpose for these design changes is to improve fuel economy and drivability. The use of special base oils like API Group III and IV base oils has increased in order to formulate high performance ATF. In this study, the effect of base oils characteristics on ATF performance is investigated, mainly regarding differences in frictional characteristics with deterioration. Moreover, low-temperature fluidity, oxidation stability, and seal compatibility are also compared for four different ATFs. From the investigation, it was found that the use of Group III and IV base oils in ATF has several benefits in low temperature viscosity, oxidation stability and SAE No.2 friction characteristics.

Keywords: Base oils, Automatic Transmission Fluid, Friction Characteristics, Deterioration, Oxidation

1. INTRODUCTION

Recent trend in vehicle transmission designs has mainly been focused on energy saving and easy driving. Introduction of new designs and mechanisms simultaneously requires new high-performance lubricants for them, as they generally impose more severe conditions on lubricants.

In order to improve fuel efficiency of AT, requirements for ATF have become stringent regarding anti-shudder and torque capacity. Moreover, low-temperature fluidity and frictional characteristics are also important for the sake of easy driving. In addition, requirements for maintenance-free transmissions necessitate ATFs of high performance which can function without trouble for a long period under the conditions of high temperature and high shear, etc.

Therefore, it has been required to improve oxidation stability, shear stability, friction durability and seal compatibility. In order to formulate the high performance ATFs which can satisfy the recent requirements, additive formulation technology is very important especially for friction control but should be well balanced and optimized with base oils technology. Now, the use of high-quality base oils in ATFs is well established, particularly to improve low-temperature fluidity and oxidation stability, etc.

The effect of base oils characteristics on ATF performance is not fully understood, perhaps because the formulation of ATF is very complex and also different according to vehicle designs, operating conditions and properties of base oils and additives. Moreover, it is very difficult to separate factors influenced by base oils from the ones by additives as the deterioration process of ATF is very complicated during endurance performance tests.

Anyway, the following two factors are mainly related to the deterioration and performance of ATF: 1) depletion of additives and 2) deterioration of base oils. In this study, the effect of base oils characteristics on ATF performance is investigated, mainly regarding differences in frictional characteristics with deterioration. Moreover, low-temperature fluidity, oxidation stability, and seal compatibility are also compared for four different ATFs.

2. ATFS AND THEIR CHARACTERISTICS

ATFs are prepared with different base oils and their physico-chemical properties are determined with simple bench analysis. Deterioration of ATFs is conducted in both an oxidation bench tester and the SAE No.2 machine. Changes in the characteristics are followed up by sampling and analyzing the deteriorated oils. Deterioration in general oil performances is discussed in relation to the changes in the physico-chemical properties.

Table 1 Physico-chemical properties of four fresh ATFs used in the experiments

Properties	ATF-1	ATF-2	ATF-3	ATF-4	Dexron III Specification	Mercon Specification
Specific Gravity	0.8649	0.8605	0.8438	0.8309		
Kinematic Viscosity @40℃, cSt	37.65	36.73	33.42	29.41		
@100℃, cSt	7.670	7.647	7.382	6.836		Min. 6.8
Viscosity Index	179	184	196	204		
Brookfield Viscosity @-20℃,cP	1420	1570	1070	670	Max. 1,500	Max. 1,500
@-30℃,cP	5230	6140	2570	1520	Max. 5,000	
@-40℃,cP	26500	44250	9360	4150	Max. 20,000	Max. 20,000
Pour Point, ℃	-47.5	-45.0	-52.5	< -52.5		
Aniline Point, ℃℃	100.8	106.6	115.0	119.8		
TAN, mgKOH/g	0.78	←	←	←		

2.1 Preparation of lubricants

Physico-chemical properties of four fresh ATFs used in the experiments are summarized in Table 1. ATF-1, 2, 3 and 4 were blended at the same treat rate with an additive package which satisfies the requirements of GM Dexron III and Ford Mercon and is composed of anti-oxidant, anti-wear agent, dispersant, detergent and modifiers of friction and viscosity, etc. However, the base oils in them are different for each ATF. As shown in Table 2, various base oils, BO-1, 2, 3 and 4, are blended at the same treat rate for each ATF, respectively. All the base oils are 100 neutral grade with viscosity of about 4 cSt at 100°C but they are different each other in the quality and classified as Group I, II, III and VI, respectively, according to the recent API base oil classification.

Table 2 Properties of base oils

API Base Oil Group	I	II	III	IV
Properties	BO-1	BO-2	BO-3	BO-4
Specific Gravity	0.864	0.855	0.834	0.819
Kinematic Viscosity @ 40℃, cSt	20.08	20.20	19.57	17.10
@100℃, cSt	4.13	4.15	4.23	3.86
Viscosity Index	106	107	122	127
Flash Point, ℃	220	214	218	224
Pour Point, ℃	-10	-10	-15	-57
Sulfur, wt%	0.58	0.03	0.00	0.00
Aromatics by HPLC, vol%	27.7	3.5	0.6	0.0
Aniline Point, ℃	100	105	113	115

2.2 Low-temperature fluidity and seal compatibility

Low-temperature fluidity is very important because high viscosity at low temperature could cause slow operation of transmission and poor startability of torque converter. As shown in Table 1, the low-temperature viscosities, determined at –20, -30, -40°C, are better with ATF 3 and 4 satisfying the requirements of Dexron III and Mercon. Figure 1 gives changes in low-temperature viscosities with decreasing temperature from –10 to -50°C, which were determined using a scanning Brookfield viscometer. The oil ATF-4 also gives the best low temperature fluidity, while ATF-3 is better than ATF-1 and 2.

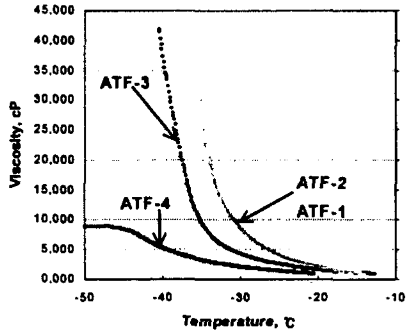


Fig.1 Low-temperature viscosities with decreasing temperature from –10 to -50°C

Because various seal materials are used in the hydraulic systems of automatic transmissions, seal compatibility of ATF is important for proper operation. With respect to six seal materials which satisfy the specification of Dexron III, their volume changes were determined after aging at 150°C for 70 hours. In Fig.2, their differences are compared among five oils including a reference oil REO, which satisfies the Dexron III specification. While the volume changes with ATF-1 and 2 are very similar to the REO, the ones with ATF-3 and 4 are considerably less than ATF-3 and 4. These results indicate that minor reformulation of base oils and/or additives is necessary for ATF-3 and 4.

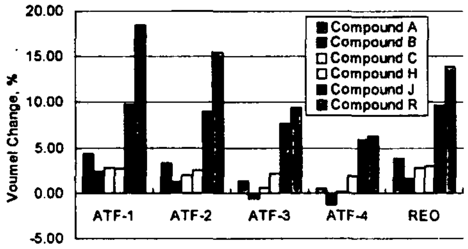


Fig.2 Volume change of six Dexron III materials with 4 ATFs and REO

2.3 Oxidation stability

Among the performances required for ATF, the oxidation stability is very important as over 70 % of automatic transmission failures were known to be related to fluid oxidation (1). As ATF undergoes deterioration during service under the oxidative conditions, sludge and varnish can be deposited on the transmission parts and deteriorated materials can corrode bearings and bushings and also harden the various elastomeric seals. Recent design changes make the fluid temperature even higher and it has been reported that fluid life is primarily limited by oxidation during severe service (2).

Oxidation processes in transmission can be simulated by a Ford method, ABOT (Aluminum Beaker Oxidation Test), only if the test conditions are carefully controlled (3). In order to evaluate oxidation stability, the test conditions, shown in Table 3, were selected, which are similar to ABOT method. During the deterioration process, we took samples and determined total acid number (TAN) and viscosity at 40 °C.

Table 3 Test conditions of Beaker Oxidation Test

Item	BOT	ABOT
Temp., ℃	155	155
Catalyst	Cu/Fe Wire	Aluminum Beaker Cu/Al Strip
Air, L/Hr	10	0.3
Oil Volume, ml	400	250
Time, Hr	432	300

As shown in Fig.3(a), TAN of ATF 1 and 2 increases steadily with increasing oxidation time but the increasing rate is higher with ATF 1 than with ATF 2. However, TAN of ATF 3 and 4 levels off at about 2 mg/KOH after 144 hours. This indicates that more oxidation products be generated with ATFs blended with conventional base oils, BO-1 and 2.

Viscosity at 40°C shows almost no changes until 288 hours for all the oils, as shown in Fig.3(b). After 360 hours, the viscosity increases rapidly with ATF-1 and 2 but stays unchanged with ATF 3 and 4.

3. FRICTIONAL CHARACTERISTICS

Frictional characteristics of ATFs are investigated through friction tests which are conducted using SAE No.2 machine with various lubricants, both fresh and deteriorated under different conditions.

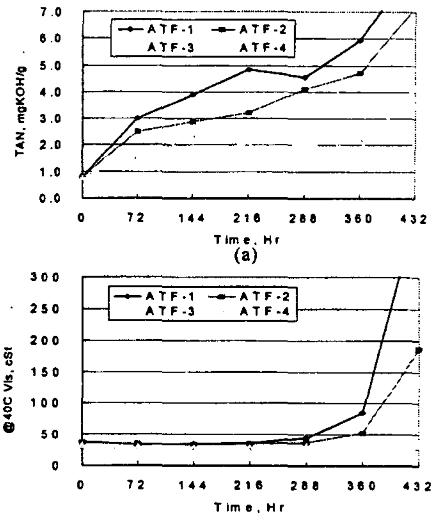


Fig.3 Beaker Oxidation Test results
(a) TAN change (b) Viscosity change

3.1 Experimental

A general view of the SAE No.2 machine is shown in Fig.4 and testing conditions in Table 4 are compared with other standard methods. This machine is often used in specification tests including Dexron III and Mercon.

The present experiments are different in its severity which can be defined as follows (4):

Severity Index

$$= \frac{(\text{Energy per Cycle}) \times (\text{Number of Cycles}) \times (\text{Fluid Temperature})}{(\text{Net Surface Area}) \times (\text{Fluid Volume})}$$

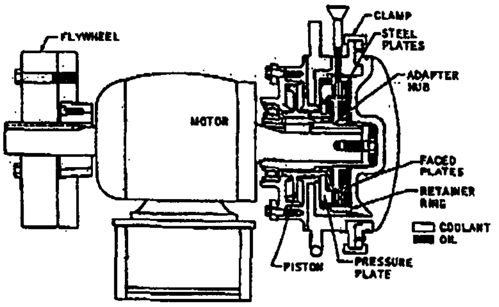
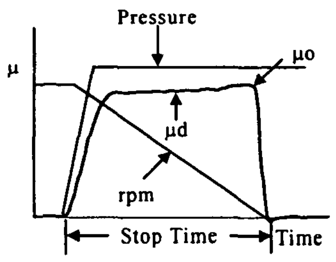


Fig.4. General view of SAE No.2 machine

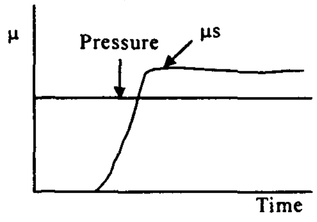
Table 4 Comparison of SAE No.2 test conditions

Item	Condition A	Condition B	GM Dexron III	Ford Mercon	JSAO
Friction Material	SD 1777X	←	SD 1777	SD 1777	SD 1777
Friction Material Size(o.d./i.d.), mm	127/104	←	125.4/90.5	133.4/98.8	126.5/105
Plate Arrangement(F= Friction Plate, S= Steel Plate)	S-F-S- S-F-S	←	S-F-S-S-F-S	S-F-S-S-F-S	S-F-S-F-S-F-S
Fluid Volume, L	0.30	←	0.65	0.30	0.60
Fluid Temperature, ℃	120	140	140	115	100
Energy, J	16,909	←	15,700	20,740	24,350
Inertia, kgm2	0.343	←	-	-	0.343
Dynamic Test Speed, rpm	3,000	←	3,600	3,600	3,600
Static(Breakaway) Test Speed, rpm	0.7	←	0.72	4.37	0.72
Apply Pressure, kPa	441	←	345	275	785
Gross Friction Area, mm2(per surface)	4,171	←	5,920	6,310	3,910
Groove Type	grooved	←	none	grooved	none
Net Friction Area, mm2	13,228	←	23,680	16,384	23,460
Cycle Length, s	30	←	20	20	30
Test Cycle	10,000	←	18,000	15,000	5,000
Test Duration, h	83.3	←	100	83.3	41.7
Energy per Total Net Friction Area, J/mm2	1.013	←	0.663	1.266	1.038
Energy per ATF Volume, J/L	56,400	←	24,200	69,100	40,600
Cumulative Energy Absorbed During Complete Test, kJ	169,090	←	282,600	311,100	121,750
Test Severity Index *	5.11	5.97	2.57	7.28	0.86
Catalyst(Metal Naphthenate)	-	*Cu/Fe* 40ppm	-	-	-

Figure 5 shows typical data taken from the machine, which include μs, μo, μd, μo/μd and stop time. During a run of 10,000 cycles, the friction data are continuously determined and oil samples are periodically taken for analysis.



Dynamic Mode



Static Mode

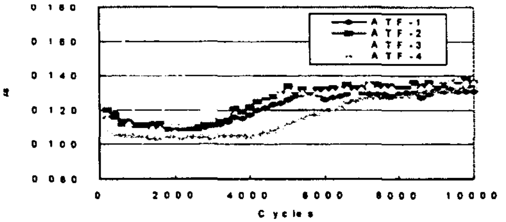
Fig.5 Typical data taken from SAE No.2

3.2 Effect of base oils and test conditions on friction characteristics

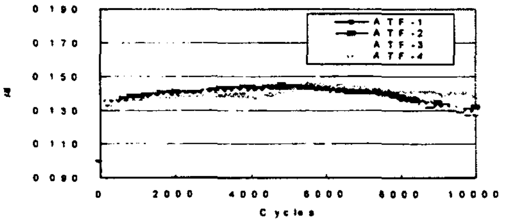
The variations of frictions μs and μd, the ratio μo/μd and stop time with testing cycles are shown in Figs.6(a)-(d) for experiments under the conditions A with four ATF 1-4, respectively. The data of each friction, the ratio and stop time in the figures are drawn from the original records at every cycle.

The static friction μs with ATF-4, Fig.6(a), shows considerable differences from other oils ATF 1-3. The friction of all the oils ranges from 0.11 to 0.12 at the initial and early stages. Then the friction increases gradually and exceeds 0.12 for ATF 1-3 after runs of about 3,000 cycles, but for ATF-4 after 6,000cycles.

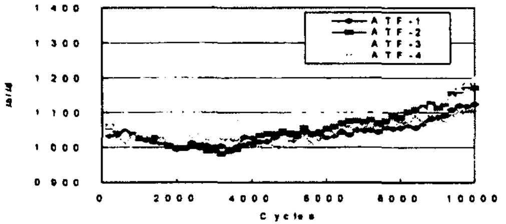
The dynamic friction μd stays at the same level for all the runs of 10,000 cycles and its behavior is basically the same for all the oils tested, as shown in Fig.6(b). Figure6(c) shows the changes in the friction ratio μo/μd with testing cycles. After slight decreasing at the initial stage, they increase slowly with cycles but stay at acceptable levels even at the end of the runs. The stop time also shows no considerable differences among the oils as shown in Fig.6(d).



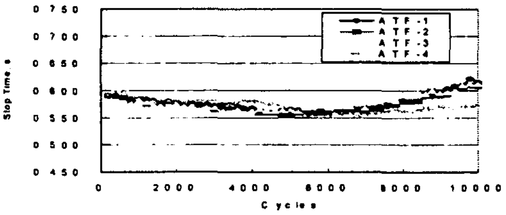
(a) μ-Static



(b) μ-Dynamic

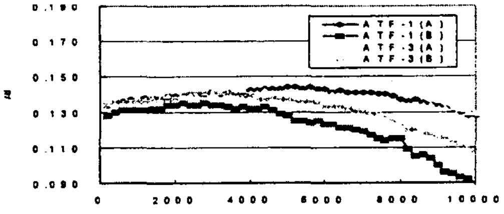


(c) μo/μd

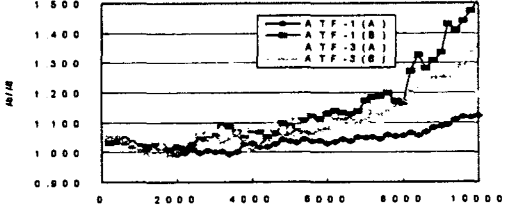


(d) Stop Time

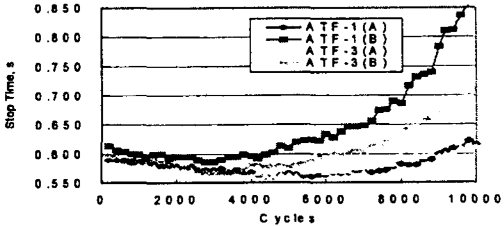
Fig.6 Test results of SAE No.2 by Condition A



(a) μ-Dynamic



(b) μo/μd



(c) Stop Time

Fig.7 Test results of SAE No.2 by Condition A and B

As the testing temperature 120 °C is not high enough to deteriorate the base oils and additives in the ATFs, it is considered that deterioration of oils is very mild even after the runs of 10,000 cycles. In order to increase the severity of test conditions, we increased temperature to 140°C and added soluble iron and copper catalysts to the level of 40 ppm.

As no changes were observed in static friction μs even under the conditions B, dynamic friction μd, the friction ration μo/μd and stop time are compared in Figs. 7(a)-(c). Even though differences were found among the oils at the conditions A, big differences exist between ATF-1(A) and ATF-1(B), between ATF-3(A) and ATF-3(B) and between ATF-1(B) and ATF-3(B). After about 5,000 cycles, ATF-1(B) and ATF-3(B) start to change with respect to all three parameters but the change are more severe with ATF-1(B).

As shown in Fig.8, the increase of total acid number is higher at the high temperature during the testing. This indicates that the increase of oxidation products in oils has correlation with deterioration of their friction characteristics.

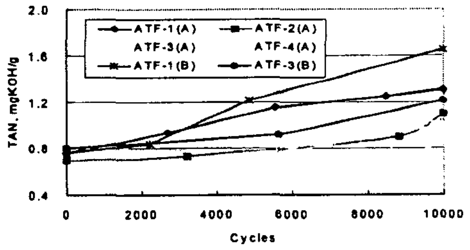


Fig.8 Change of TAN in SAE No.2 test

3.3 Effect of oxidation on friction characteristics

Fresh ATFs 1-4 was deteriorated for 72 hours at the conditions described in Table 3. The deteriorated oils are designated as OATFs 1-4, of which total acid numbers were 3.0, 2.5, 1.7, 1.5 mg/KOH, respectively.

Figures 9(a)-(c) show the changes of μd, μo/μd and stop time for OATFs 1-4. Clear differences exist between OATF 1.2 and OATF 3,4.

At the early stages of the runs, the frictional characteristics are almost the same for all the oxidated oils, but the differences between the two groups grow bigger and bigger with increasing cycles. From the fact that in spite of their different degree of oxidation the friction is almost the same at the initial stages of the runs for all the oils, it is clear that deterioration of friction materials is more important than the frictional property of deteriorated ATFs.

When TAN was determined after the runs, it decreased from 3.0 to 1.9, from 2.5 to 0.9 , from 1.7 to 0.8 and from 1.5 to 1.0mgKOH/g for OATF 1-4, respectively. These results indicate that oxidation products have deteriorated the friction surfaces and consumed during the runs. From the fact that increase in TAN was very little as discussed in Fig.8, the oxidation of oils is considered to be very mild during the runs under the conditions A.

4. CONCLUSIONS

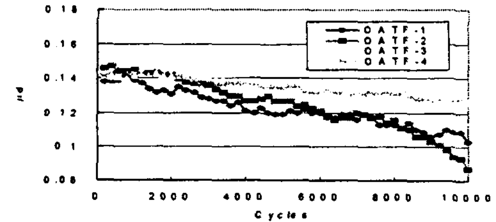
In this paper, in order to extend the understanding of the effect of base oils characteristics on ATF performance, low temperature viscosities, seal compatibility, oxidation stability and SAE No.2 test with several conditions were evaluated and following conclusions are obtained.

(1) Low temperature properties of ATFs within use of same additives are restricted by those of base oils

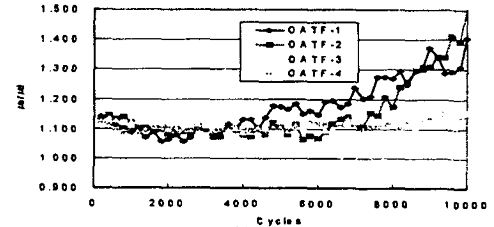
(2) Oxidation Stability of ATF-3 and 4 formulated with Group III and Group IV is better than that of ATF-1 and 2 formulated with Group I and II.

(3) In SAE No.2 test, frictional characteristics are similar under mild conditions among base oils, but under severe conditions frictional characteristics significantly different between high quality base oils and conventional base oils.

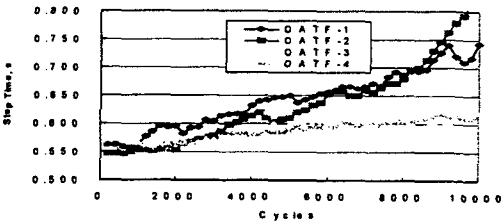
(4) For the better friction performance of AT, protection of friction surfaces is more important than the property of deteriorated oils themselves.



(a) μ-Dynamic



(b) μo/μd



(c) Stop Time

Fig.9 Test results of SAE No.2 of deteriorated ATFs by Condition A

5. REFERENCES

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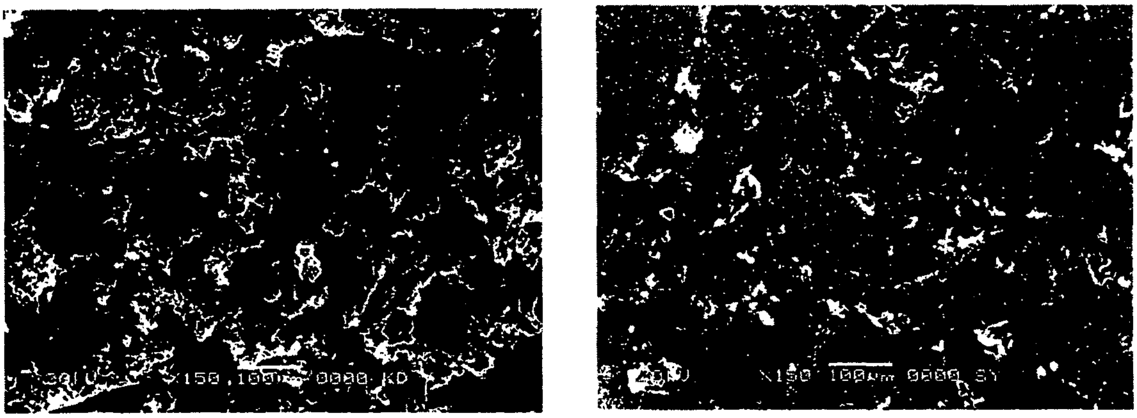
[Appendix]

Fig 10. SEM micrographs of friction plate after 10,000cycle of SAE No.2 test with the oxidated oils

(a) OATF-1 (b) OATF-2



(c) OATF-3 (d) OATF-4