Degradation Mechanism of Water Contaminated Automatic Transmission Fluid (ATF) in Wet Clutch System

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1. Introduction

The effective life and performance of an automatic transmission fluid (ATF) is an essential aspect for a wet clutch system to maintain the stable friction characteristics and shudder free torque transfer for a given friction interface. Different operating conditions, ATF characteristics and presence of contaminants can greatly influence the clutch operation and system durability [1, 2]. Previous studies [3,4] showed that the antishudder behaviour and frictional reliability can be hindered by increasing friction and negative friction-velocity relationship, when different amounts of water has been added to the ATF. These [3, 4] friction tests were short term test, unable to clarify the effect of lubricant ageing in presence of water.

The aim of this paper is to inspect the impact of water presence on ATF degradation. Meanwhile the specific wet clutch parameter contributing to this increased and unstable frictional behaviour for water treated system is investigated as well.

2. Experimental Details

In this work the frictional response during long time clutch test for water contaminated ATF degradation is monitored along with the chemical or physical changes due to water presence. A standard paper based friction plate and the standard steel reaction plate were tested in a commercially available automatic transmission fluid (GM DEXRON®VI). This is the same clutch system as previously investigated in [4, 5].

2.1. Clutch friction test

To analyse the steady state friction and ageing of the ATF, the clutch plates were tested in a full scale test rig for different number of duty cycles (*Table 1*). The test parameters were chosen to fulfill the real clutch presented operating conditions. The test rig is a fully automated wet clutch test machine for a single clutch interface. Here the operating parameters like load, sliding speed, slip time, oil temperature can be controlled [4]. The details of the test profile are presented in Table 1. To get rid of the initial surface roughness, there was 500 cycles run-in period prior to the duty cycles. After additional 500 duty cycles of the reference test, 20 ml of distilled water (conc. 25000 ppm) was added for each water contaminated test.

According to Table 1 there was an additional test (for 500 cycles) with the contaminated used ATF (after 500 cycles regular test) and the uncontaminated used (after 500 cycles regular test) friction interfaces.

2.2. Static ageing test

To evaluate the interaction between ATF, paper based friction liner and water under static conditions, one friction plate was immersed in ATF and another plate in water contaminated ATF (5 ml distilled water in 200 ml ATF, conc. 25000 ppm) for 210 hours at 90°C in an oven [6].

Table 1   Test Profile

Friction test in full scale test rig				
Regular test	Run-in	Test ATF	No. of cycles	290 rpm, 5 kN, Slip time 5s, oil temperature 90 ºC
		ATF (800 ml)	500	
	Duty Cycles	ATF (800 ml)	500	290 rpm, 10 kN, Slip time 5 s, oil temperature 90 ºC
			5000	
			1000	
			500	
		ATF(800 ml)+ water (20 ml)	5000	
			1000	
			500	
Additional test		Used (after 500 cycles test) ATF (with water)	500	
Static ageing test				
ATF in oven		ATF (200 ml)		210 hrs at 90 ºC
		ATF+ water (5 ml)		210 hrs at 90 ºC

2.3. Post test analysis

After tests, the new and the tested lubricant samples were compared by using spectral analysis, thermogravimetric analysis and oxidation test. Additionally the viscosity of the fresh ATF (with and without water) was measured at 40°C and 85°C under

controlled stress using a standard Bohlin CVO 100 rheometer.

Infrared spectra were recorded on a Bruker Vertex 80v vacuum FTIR spectrometer equipped with a DTGS detector. All spectra were recorded at room temperature (~23°C) using the double side forward-backward acquisition mode. A total number of 128 scans were co-added and signal-averaged at an optical resolution of 4 cm^{-1} using a ZnSe Attenuated Total Reflection (ATR) crystal. The resultant interferogram was Fourier transformed using the Mertz phase correction mode, a Blackman-Harris 3-term apodization function, and a zero filling factor of 2.

To record spectra of the possible water-soluble additives, 10 volume-% water was added to fresh new ATF oil. The ATF-water emulsion was formed after ultra-sonication for 10 minutes. It was then centrifuged for 30 minutes at 20000 rpm implying that the micro emulsion separated into a water phase and an oil phase. The precipitate was further extracted by adding milli-Q water and subsequently it was centrifuged at 3000 rpm for 10 minutes to avoid any possible influence from the oil phase. A small part of the water fraction so obtained was transferred to an ATR crystal (ZnSe). The crystal with the deposited water phase was dried in a vacuum desiccator to evaporate water and the FTIR spectrum was recorded for the dry sample.

The thermal stability of the new and aged ATF (with and without water) was investigated with a Thermogravimetric (TGA) instrument over a temperature range between ambient and about 600°C in air atmosphere, at a rate of 10°C min^{-1}.

A qualitative linear voltammetry method (ASTM D6810/ASTM 6971) like 'RULER' (Remaining Useful Life Evaluation Routine) was used to compare the remaining antioxidants levels of the tested lubricant with the fresh ATF.

Prior to these analyses, the fresh new ATF containing water (2.5 volume-% or 25000 ppm) was mixed using an ultrasonic bath to achieve a homogenous emulsion and thereby a similar mobility under high pressure and temperature in the lubricant stream.

3. Results and Discussion

Fig. 1(a) shows the mean coefficient of friction (COF) at different number of cycles for the test of 5000 cycles with and without water. It indicates that the mean COF increased upon adding water to the ATF, which follows the same trend as observed previously [4, 5]. The increased friction level after water addition continues for around 600 cycles, then the friction drops gradually. As this test progresses the mean friction drops at a larger rate than for ATF without added water. This quick decline of friction after initial increased friction actually denotes wet clutch degradation. The other tests at a different number of cycles (1000 cycles) also showed the similar behaviour. Fig. 1(b) shows that after running for 500 cycles, the water contaminated ATF can also influence the friction behaviour of an uncontaminated clutch interface, so the friction enhancing effect of water disappears. On the other hand,

a rapid degradation occurred during longer test. These outcomes impose more to verify concerning the fresh and tested ATF (with and without water). The ATF (1.8 l/min flow rate) in the test rig mixed with the added water can form an emulsion and can change the viscosity. Table 2 shows that the measured dynamic viscosity at 40°C is rather high for the water contaminated ATF but at 85°C the viscosity is almost similar for fresh and water contaminated ATF. Since the operating temperature is a little higher (90°C), this might have a minor effect on the increasing friction at the clutch interface.

The RULER measurements show insignificant change for the new and tested ATF (with or without water). It can be assumed here that the antioxidants were not consumed during the test, even for ATF with water containing ATF. Since antioxidants are one of the key additives that protect the ATF from oxidation and ageing [2], the tested samples were not oxidized during test.
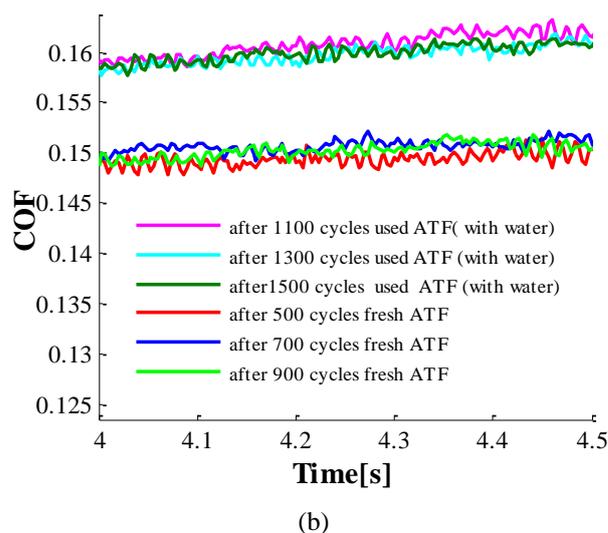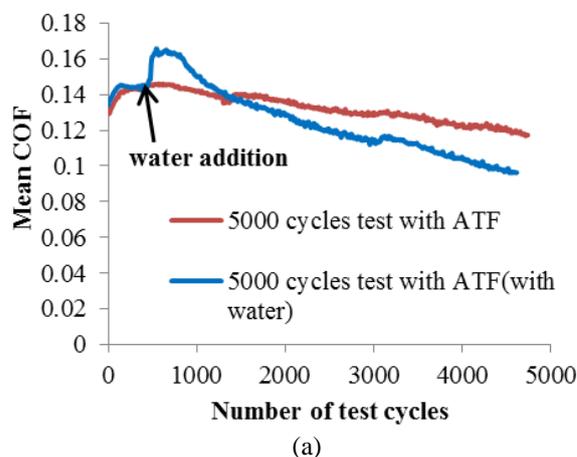

(a)

(b)

Figure 1 (a) Mean COF during ageing test, (b) Comparison of COF (during steady speed) for the repeated test, before and after adding contaminated ATF

This result is also confirmed by the TGA analysis (Fig. 2a) of the static aged ATF samples, where no specific change in thermal stability is noticed. Still the TGA analysis (Fig. 2b) shows that the used, contaminated ATF (after 5000 cycles) was less thermally stable compared to the pure ATF aged for the same time. Moreover, the presence of volatile water around 100°C is absent in the aged one. The comparatively unaffected static aged ATF (with water) sample indicates incomplete mixing of water and base oil.

Table 2 *Viscosity measurements at 40°C and 85°C for new ATF with and without water*

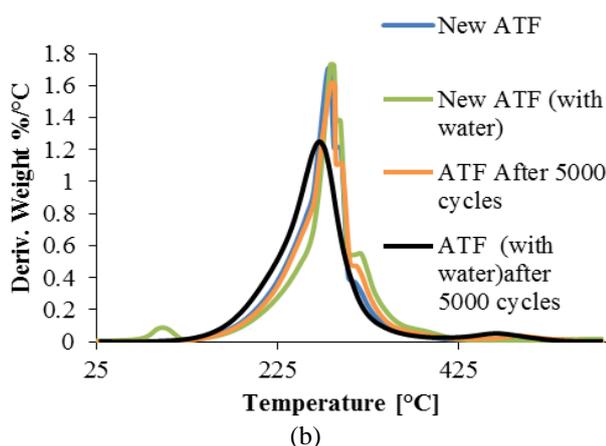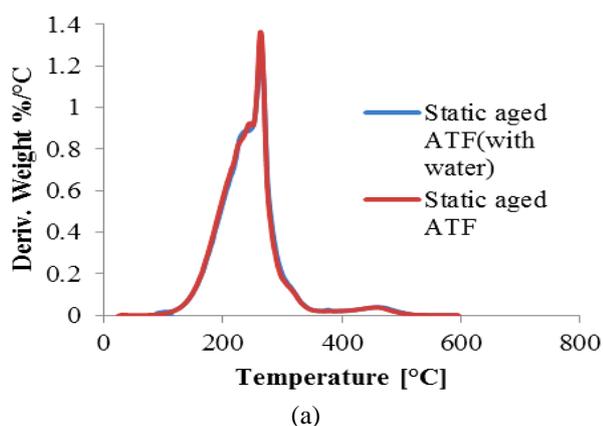| Temperature	Dynamic Viscosity[Pa-s]	
	w/o water	with water
40°C	0.0251	0.0272
85°C	0.0076	0.008

(a)

(b)

Figure 2 TGA analysis for (a) static aged ATF (with and without water), (b) the new and tested ATF

The FTIR spectra (Fig. 3a) of the new ATF and the water containing ATF samples show absorption bands at 1735 cm⁻¹ and 1707 cm⁻¹ in the 1715 ±100 cm⁻¹ range due to the presence of carbonyl groups [8]. The band at 1707 cm⁻¹ is shifted to 1703 cm⁻¹ for fresh ATF contaminated with water simultaneously as the half

width of the band was increased, indicating hydrogen bonding interaction between the carbonyl and water. An extra band was also observed at 694 cm⁻¹ beside the methylene in-phase rocking mode at 722 cm⁻¹ (see Fig. 3b) for the fresh and water contaminated (after 1000 cycles) ATF samples. The origin of this extra band will be the subject of further investigation. Usually commercial synthetic ATFs are composed of poly alpha olefin (PAO), ester and additives. Therefore, the interaction between water and polar ester groups or polar additives will be interesting. Especially the stretching vibration mode of the polar functional groups should be sensitive to the wet clutch operating pressure and temperature [7].

Water as a polar compound can interact with polar additives like surfactants, detergents, and friction modifier. Although the extracted and dried fraction from the centrifuged ATF/water emulsion (10 volume-% water) will increase the concentration of water soluble additives on the surface of the ATR crystal, it should be emphasized that additives in solution and additives in dry state may not show identical IR spectra. However, dominant absorbance bands of the possible additives in ATF can be seen in the spectrum of the water extract (Fig. 4), which were hidden behind the dominant base oil spectra in the spectrum of the water contaminated new ATF. The carbonyl bands between 1700 and 1730 cm⁻¹ were, however, also observed in spectra recorded for water contaminated new ATF. The spectra also showed possible OH- bending at 1404 cm⁻¹ and bending vibration of methyl groups at 1380 cm⁻¹. There are also prominent bands in the 1150-1000 cm⁻¹ range, which possibly corresponds to phosphate (PO_4^{3-}) compounds [9, 10]. However, one important result from our FTIR investigation of the water contaminated base oil is the fact that additives in the base oil are shown to accumulate in the water phase of the water in ATF emulsion formed upon adding water. The next challenge will be to compare the layers formed on friction and reaction plates before and after addition of water.
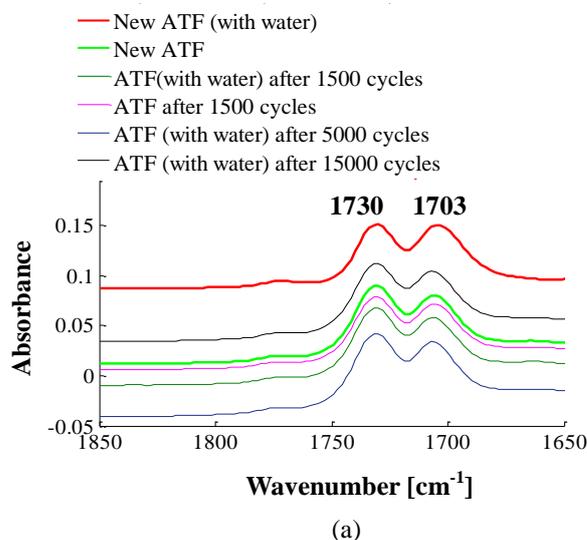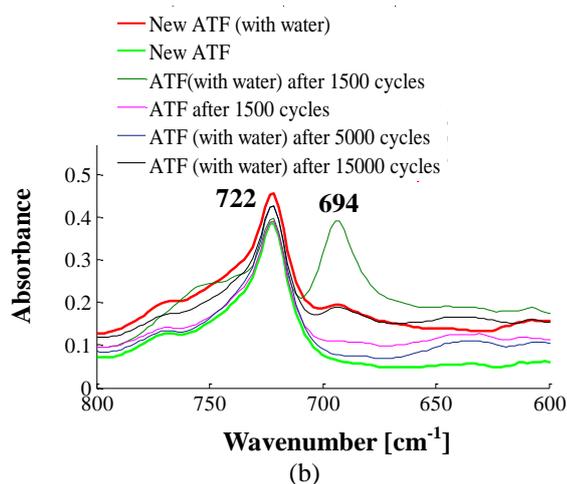

(a)

Figure 3 FTIR spectra of: (a) new ATF with 2.5 vol^m % water (top), new ATF, and ATF after tests showing the carbonyl stretching region and (b) spectra of tested compounds in the spectral region between 800 and 600 cm⁻¹.

Figure 3 FTIR spectra of: (a) new ATF with 2.5 vol^{m} % water (top), new ATF, and ATF after tests showing the carbonyl stretching region and (b) spectra of tested compounds in the spectral region between 800 and 600 cm^{-1}.
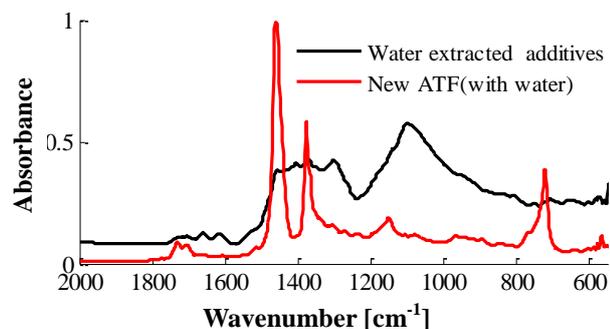

Figure 4 A comparison between FTIR spectra of the new ATF and the water extracted additives

4. Conclusions

This paper has presented an experimental approach to evaluate water contaminated ATF degradation. This might also help to detect the particular reason of increasing friction for water addition in the wet clutch system. The following conclusions can be drawn from this work:

- The levels of antioxidants were found to be stable for the tested cases and the dynamic viscosity was almost unchanged at high temperature. On the other hand, the thermal stability of the aged ATF showed the influence of water contamination.

- The study also provides a molecular insight into the effect of water on lubricant ATF degradation. The observed molecular interactions in the water extract and the spectral variance for water contamination, showed the effect of water on water-soluble lubricant additives and esters. This interaction might work here as the main friction-enhancing factor, where the formation of a tribofilm on the friction interface can be affected for the inaccessibility of the friction modifying additives.

- The FTIR spectra of the used ATFs indicated the absence of water in the lubricant after several thousand clutch engagements. This also confirms the friction data, where the increase in wet clutch friction level after water presence is relatively a short term occurrence for its service life.

- Though water treated clutches degrade more rapidly compared to uncontaminated ones, the insignificant ATF degradation for water presence itself should not be liable for the ultimate change in clutch durability. Still the water presence in the system and its interactions with the additives might degrade the friction interface fast as observed in the previous work [5] and consequently provides the quick frictional loss during service.

5. References

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