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EFFECT OF CONTAMINANTS ON THE LIFETIME OF HYDRAULIC BIOOILS AND SYSTEMS

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Abstract

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The extensions of service-lives regarding hydraulic fluids is gaining prominence due to several considerations including environmental pollution, conservation of natural resources and the economic benefits associated with extended service-life. The presented methods for testing the durability and oxidation stabilities of hydraulic fluids can be simultaneously used in two ways. Firstly for comparing different hydraulic biooils and for selecting more adequate oils with higher oxidation stabilities and longer service lifetimes and secondly for the development of a prognostic model for an accurate prediction of an oil's condition and its remaining useful lifetime, which could help to extend the service life of the oil without concerns about damaging the equipment.

Keywords: hydraulic fluids, oil degradation, ageing tests, catalysts

INTRODUCTION

The development of modern hydraulic components is aimed at increasing the transmitted power, reducing the energy intensity, minimizing the environmental pollution and increasing the technical lifetime and machine reliability (Tkáč, *et al.* 2014; Majdan *et al.* 2014; Lovrec and Tič, 2014). The hydraulic fluid is always considered as a major component in a hydraulic system. The fluid can be regarded as the system blood, an element that connects the whole parts together. A good hydraulic fluid should have the following characteristics: power transmission with minimum loss, lubrication of surfaces moving against each other, corrosion protection of metal surfaces and transporting and transferring heat from heat source back to reservoir or heat exchanger (Mendoza *et al.*, 2011; Valach *et al.*, 2013).

Currently, around 50% of the all lubricants sold worldwide end up in the environment via total loss applications, volatility, spills or major accidents. (Rudnick and Erhan, 2006; Salimon *et al.* 2012).

Such environmental problems enforce the forestry and agriculture to use more environmentally friendly lubricants. Particularly the use of environmentally friendly lubricants is essential in water treatment, forestry, agriculture and recreation zones. The driving forces for that are various legislations and Eco Labels: The European Eco-label, The German „Blue Angel“, Nordic countries „White Swan“, Austrian ecolabel, Canadian „EkoLogo“ a.o. (Mang and Dresel, 2007).

The basic requirements for an environmentally acceptable hydraulic fluid are not only high biodegradability and low eco-toxicity, but also that the fluid performance guarantees satisfactory operation in the most demanding hydraulic components. However, to present good performance over long periods of operation, the physico-chemical properties of the fluid must remain stable (Kumbár and Dostal, 2013a). These properties include good performance at high and low temperatures, oxidation stability, thermal stability, shear stability, wear protection, demulsibility, low foaming tendency and good filterability (Kučera and Rousek, 2008; Rhee, 2011; Kumbár and Dostal, 2013b).

Ageing tests can analyse which properties are affected, and to what extent they are affected by the different ageing conditions. Accordingly, in this article, new information obtained from commercial biodegradable fluids under the influence of common contaminants (water, mineral oil, copper solid particles, and oxygen) present in current hydraulic systems has been investigated. Based on oxidation and hydrolytic stability tests, ageing of biodegradable fluids are analysed, and the influence of contaminants is described.

MATERIALS AND METHODS

The procedure and tasks of this research are shown in Fig. 1. The goal of the laboratory tests was to determine how the contaminants can influence ageing of the fluids as well as to obtain information on the effects observed on applying different concentrations and combinations of contaminants (mineral oil, solid copper particles and water). An analysis of the influence of contaminants on biodegradable fluids was carried out through oxidation tests and hydrolytic stability tests.

Fig. 2 shows factors that can provoke ageing mechanisms such as oxidation, polymerization, cracking, and hydrolysis, which modify the fluid's properties and consequently decrease the fluid usability (Theissen, 2009; Bekana *et al.* 2015).

According to Murrenhoff and Schmidt 2002, the most important ageing mechanism is oxidation. Regarding the causes of ageing, Schmidt and Murrenhoff 2003 observed that a combination of high pressure and high temperature leads to a significant increase in the viscosity and total acid number (TAN), which prevents the fluid from performing its tasks properly.

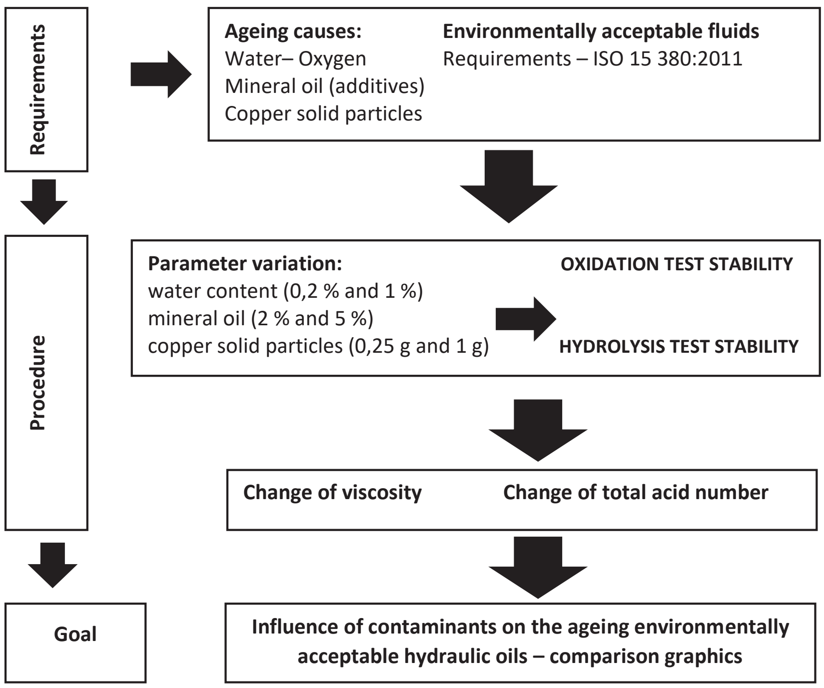
For this purpose, two different biodegradable fluids were used in the laboratory tests on based synthetic esters complying with the HEES specifications in ISO 15380. In this paper, they are identified as BIO A and BIO B. Tab. I shows their relevant properties.

Oxidation Stability Test

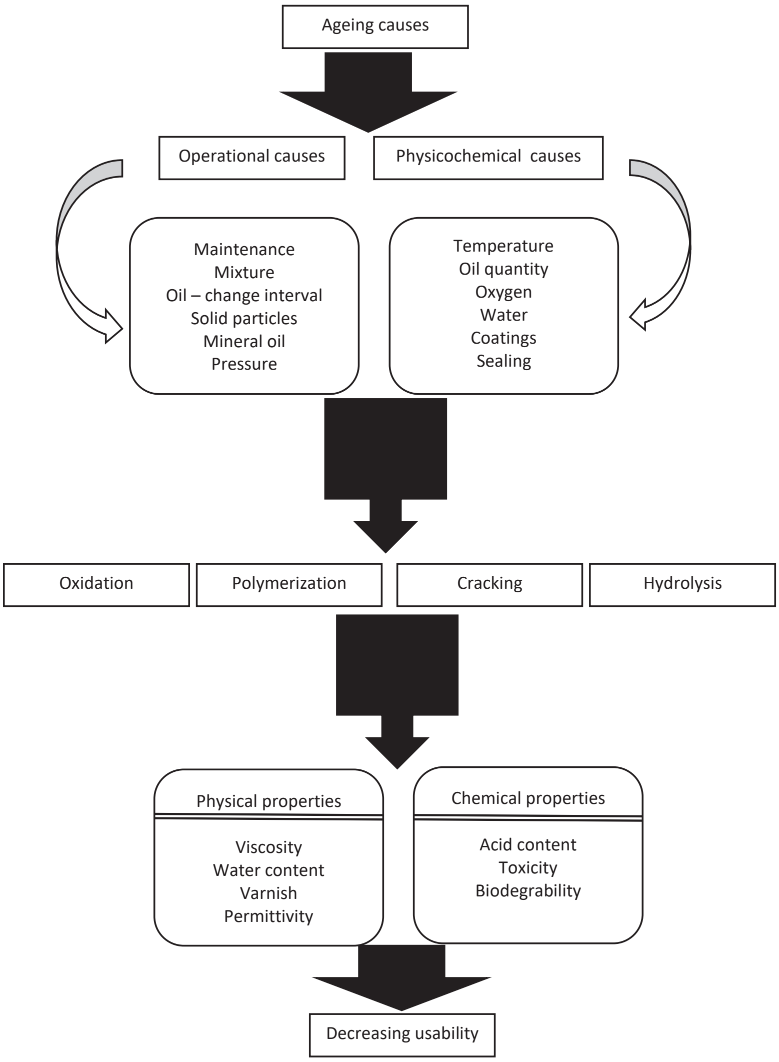
The oxidative stability of all the lubricants was evaluated using a rotary bomb oxidation test (RBOT), see Fig.3. According to ASTM test method D-2272:11, RBOT test should be carried out in the presence of water and a copper catalyst coil at 120 °C in dry conditions. In the RBOT test an oxygen-pressure vessel is charged to 620 kPa and rotated axially in an oil sample bath. The pressure of the vessel is continuously recorded. The RBOT time is the time at which a pressure decrease of 175 kPa from the maximum pressure is achieved.

Hydrolytic Stability Test

Factors that influence hydrolysis are primarily water content, temperature, and retention time of water in the fluid. Furthermore, the presence of metals significantly affects hydrolytic action.



1: *Investigation strategy*



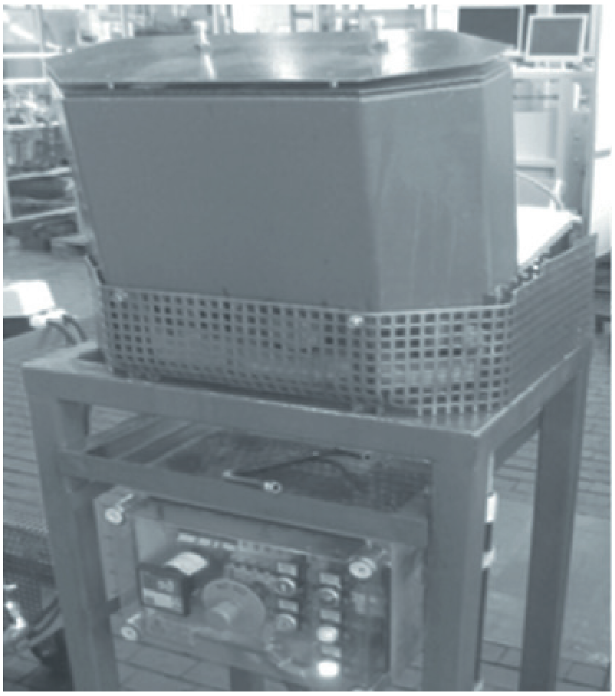
2: *Causes and effects of ageing (Sourse: Asaff et al., 2014)*

I: *Tested fluids used in the experiments*

Fluid	Kinematic viscosity at 40 °C [$mm^2.s^{-1}$]*	Biodegradability OECD 301 [%]
BIO A	45.43	>60
BIO B	49.07	>90

*Experimental measurement

3: *Oxidation stability test: RBOT bench (Source: ASTM D2272-11)*



4: *Hydrolytic stability test: test bench (Source: ASTM D2619-09)*

The hydrolytic stability of the reference fluids was tested according to ATSM D2619-09. For the test, a fluid sample (75 g) was placed into a glass jar enclosed in a stainless steel container with 1% of water and left there for a specific period, in this case for 72 hours. The stainless steel container stands in a heating bath that can be set to the desired temperature (93 °C), see Fig. 4. At the end of the test, layers are separated and insolubles are weighed. Weight change of the copper is measured. Viscosity and acid number changes of fluid are determined.

RESULTS AND DISCUSSION

Influence of the Contaminants on Viscosity and TAN after the Oxidation Test

Viscosity is one of the most important properties of hydraulic fluids, and also an early indicator of ageing. The acidity of fluids as expressed by the total acid number (TAN) is of interest because it indicates the degree of fluid oxidation. Results for these parameters are presented in Figs. 5 and 6. Experimental values of kinematic viscosity and total acid number with statistics for oxidation stability test are given in Tab. II and Tab. III.

According to Fig. 5, the maximum increase in the viscosity of Fluids A and B was 4% for all contaminants. In Fig. 6, it is also possible to observe that the presence of water in high concentrations and of solid copper particles increasing total acid number in both oils.

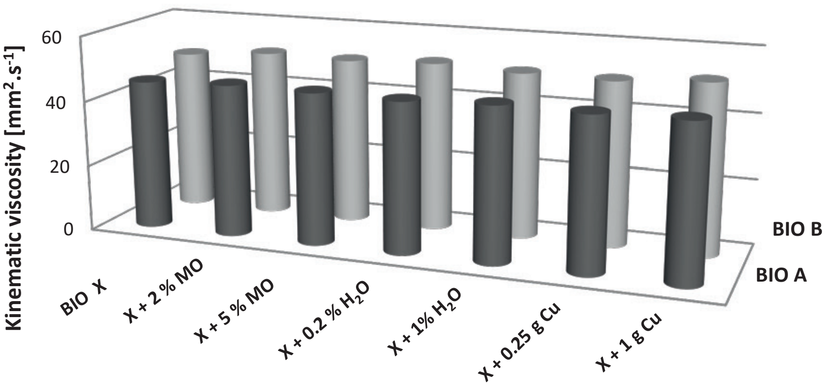
Influence of the Contaminants on Viscosity and TAN after the Hydrolysis Test

The hydrolysis resistance of hydraulic fluid is a significant issue, as strong acids may ultimately be formed in the fluid and cause corrosion in components of the circuit. A low influence of the contaminants on viscosity after the hydrolysis test is observed in Fig. 7.

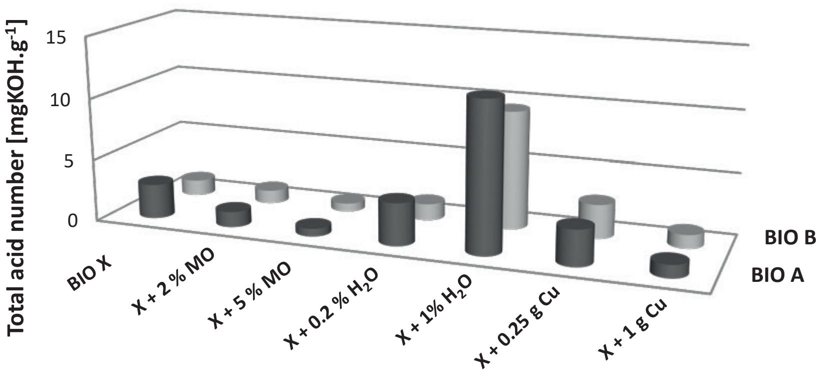
In relation to the influence of the contaminants on the TAN after hydrolysis, Fig. 8 shows that the presence of contaminants (water, mineral oil, or copper) exerts a significant influence on acid production in the fluids. Experimental values of kinematic viscosity and total acid number with statistics for hydrolysis test are given in Tab. IV and Tab. V.

Regarding the causes of ageing, Murrenhoff and Schmidt 2002 observed that a combination of high pressure and high temperature leads to a significant increase in the kinematic viscosity and total acid number (TAN), which prevents the fluid from performing its tasks properly. They further state that high temperature affects the fluid properties more than high pressure.

The contamination of biodegradable hydraulic fluids with mineral oils has been discussed by Theissen 2009, who showed that the degree of deterioration is not correlated to the amount of mineral oil added but instead to the amount of metals introduced through additives present in some mineral oils. The general impact of catalysts on the oxidation stability of environmentally acceptable fluids was studied by Murrenhoff and Schmidt 2003. Their investigations showed that, according to oxidation test results, the significant impact of catalyst contaminants on the oxidation stability is strongly dependent on the ratio between the catalyst surface area and the amount of fluid.



5: *Influence of the contaminants on kinematic viscosity after the oxidation test*



6: *Influence of the contaminants on TAN after the oxidation test*

II: *Experimental values of kinematic viscosity for oxidation stability test*

Test oil	Kinematic viscosity [$mm^2.s^{-1}$]	Test oil	Kinematic viscosity [$mm^2.s^{-1}$]
BIO A	45.43 ± 0.05	BIO B	49.07 ± 0.08
BIO A + 2 % MO	46.38 ± 0.07	BIO B + 2 % MO	51.06 ± 0.10
BIO A + 5 % MO	46.16 ± 0.07	BIO B + 5 % MO	50.63 ± 0.01
BIO A + 0.2 % H_20	45.79 ± 0.02	BIO B + 0.2 % H_20	51.61 ± 0.09
BIO A + 1 % H_20	46.85 ± 0.03	BIO B + 1 % H_20	50.57 ± 0.03
BIO A + 0.25 g Cu	46.52 ± 0.08	BIO B + 0.25 g Cu	50.23 ± 0.06
BIO A + 1 g Cu	47.02 ± 0.04	BIO B + 1 g Cu	51.89 ± 0.02

*Note: Data represents mean values ± standard deviations.

III: *Experimental values of total acid number for oxidation stability test*

Test oil	TAN [mg $KOH.g^{-1}$]	Test oil	TAN [mg $KOH.g^{-1}$]
BIO A	2.78 ± 0.05	BIO B	1.27 ± 0.03
BIO A + 2 % MO	1.23 ± 0.09	BIO B + 2 % MO	1.09 ± 0.05
BIO A + 5 % MO	0.62 ± 0.02	BIO B + 5 % MO	0.67 ± 0.02
BIO A + 0.2 % H_20	3.42 ± 0.02	BIO B + 0.2 % H_20	1.34 ± 0.05
BIO A + 1 % H_20	12.03 ± 0.05	BIO B + 1 % H_20	9.55 ± 0.05
BIO A + 0.25 g Cu	2.89 ± 0.01	BIO B + 0.25 g Cu	2.74 ± 0.04
BIO A + 1 g Cu	1.03 ± 0.06	BIO B + 1 g Cu	1.09 ± 0.02

*Note: Data represents mean values ± standard deviations. TAN, total acid number

CONCLUSION

Numbers and various methods are used to evaluate the thermal stability and antioxidant properties; some are specific for a type of lubricants. Nevertheless, all these methods attempt to simulate the oxidation phenomena at various operating conditions and in various mechanical components. They are all more or less based on the same principle. The oil ageing depends on:

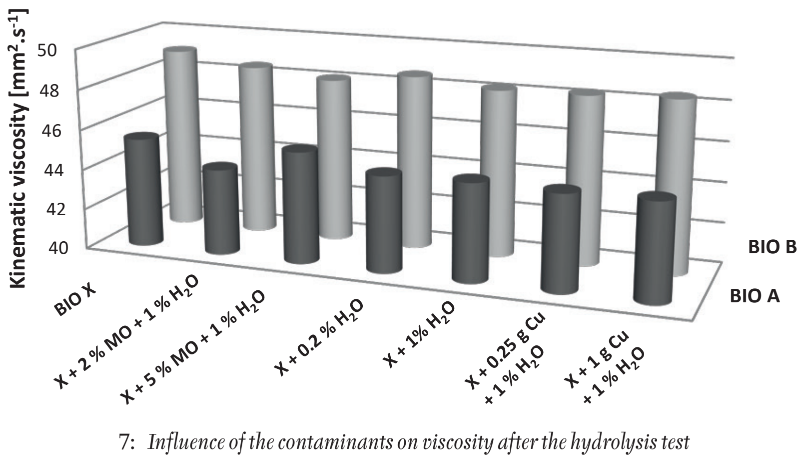
- The thermal stress : temperature higher or lower
- The air or oxygen at a flow rate higher or lower or a static pressure of air or oxygen;
- The presence or not of metal catalysts; this may be massive metals or of metals introduced into the lubricant solution to be tested as naphtenates;
- The presence or not of water;

The evaluation of the oxidation stability is determined by the follow-up of some parameters:

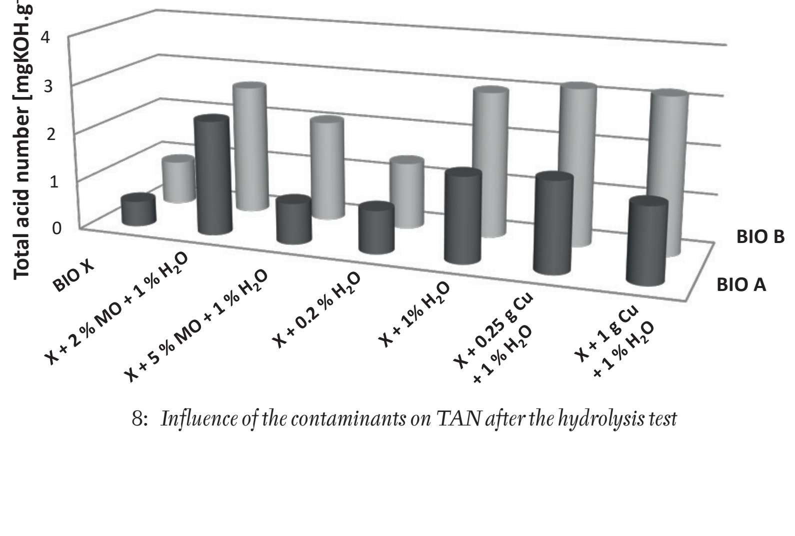
- The evolution of the characteristics of the fluid (viscosity, acidity, additives depletion, metals concentration from the catalysts, peak area increase (carbonyle peak by IR spectrometry) ;
- The volatile acidity;
- The evaluation of the corrosion on metal specimen including the weight loss;
- The quantification and appearance of unsoluble materials coming from oxidation (deposits, sludge, varnish);
- The pressure drop as indication for the induction time

According to the test results, it is initially possible to note the positive influence of the mineral oil on the oxidation stability of the biodegradable fluids, in contrast to the influence of water and copper. The effect of copper particles (as contaminant) on the oxidation stability of the fluids is not dependent on the amount of copper present. The results clearly show that a water content higher than 1% can considerably affect the oxidation and hydrolysis stability of the biodegradable fluids.

For all fluids analysed, the trend of the change in TAN resulting from oxidation is generally in the same direction as that resulting from hydrolysis. This implies that the conditions (type of contaminant) that exert a negative influence on oxidation stability also exert a significant influence on hydrolysis, both effects are expressed in the terms of an increase in the total acid number.



7: *Influence of the contaminants on viscosity after the hydrolysis test*



8: *Influence of the contaminants on TAN after the hydrolysis test*

IV: *Experimental values of kinematic viscosity for hydrolysis test*

Test oil	Kinematic viscosity [$mm^2.s^{-1}$]	Test oil	Kinematic viscosity [$mm^2.s^{-1}$]
BIO A	45.43 ± 0.07	BIO B	49.07 ± 0.05
BIO A + 2 % MO + 1 % H_20	44.26 ± 0.01	BIO B + 2 % MO + 1 % H_20	48.51 ± 0.02
BIO A + 5 % MO + 1 % H_20	45.52 ± 0.04	BIO B + 5 % MO + 1 % H_20	48.15 ± 0.03
BIO A + 0.2 % H_20	44.75 ± 0.02	BIO B + 0.2 % H_20	48.63 ± 0.02
BIO A + 1 % H_20	44.83 ± 0.03	BIO B + 1 % H_20	48.26 ± 0.03
BIO A + 0.25 g Cu + 1 % H_20	44.74 ± 0.02	BIO B + 0.25 g Cu + 1 % H_20	48.33 ± 0.04
BIO A + 1 g Cu + 1 % H_20	44.81 ± 0.02	BIO B + 1 g Cu + 1 % H_20	48.47 ± 0.05

*Note: Data represents mean values ± standard deviations.

V: *Experimental values of total acid number for hydrolysis test*

Test oil	TAN [mg $KOH.g^{-1}$]	Test oil	TAN [mg $KOH.g^{-1}$]
BIO A	0.52 ± 0.04	BIO B	0.91 ± 0.02
BIO A + 2 % MO + 1 % H_20	2.36 ± 0.06	BIO B + 2 % MO + 1 % H_20	2.68 ± 0.03
BIO A + 5 % MO + 1 % H_20	0.84 ± 0.02	BIO B + 5 % MO + 1 % H_20	2.08 ± 0.03
BIO A + 0.2 % H_20	0.88 ± 0.02	BIO B + 0.2 % H_20	1.87 ± 0.04
BIO A + 1 % H_20	1.74 ± 0.06	BIO B + 1 % H_20	2.98 ± 0.03
BIO A + 0.25 g Cu + 1 % H_20	1.83 ± 0.04	BIO B + 0.25 g Cu + 1 % H_20	3.19 ± 0.04
BIO A + 1 g Cu + 1 % H_20	1.53 ± 0.03	BIO B + 1 g Cu + 1 % H_20	3.18 ± 0.04

*Note: Data represents mean values ± standard deviations. TAN, total acid number

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