Agronomy Research **16**(S1), 968–976, 2018
https://doi.org/10.15159/AR.18.103

Experimental research on compatibility of mineral and biobased hydraulic oils

A. Birkavs* and R. Smigins

Latvia University of Life Sciences and Technologies, Faculty of Engineering, Motor Vehicle Institute, 5 J.Cakstes blvd, LV3001 Jelgava, Latvia
*Correspondence: aivars.birkavs@llu.lv

Abstract. The use of biobased hydraulic oils becomes more popular in the different industries, but especially in agriculture machinery. This is stimulated by the fact that significant amount of hydraulic oils effluence in the environment and therefore leaves a negative impact to the ecosystem. Besides of that, the part of sold hydraulic oils grows and now forms approximately 15% of total oil consumption amounts worldwide (Nagendramma & Kaul, 2012).
The aim of this research was to study the compatibility of the comercially produced mineral and biobased hydraulic oils, identify viscosity of a different mixtures in the entire work temperature range, as also changes of anti-frictional properties. Two different oils and three mixtures were tested. Special hydraulic experimental apparatus was established for visual observation of fluid properties. Sliding friction bench was used for the comparision of friction properties.
The results showed that change of the working pressure and temperature of the hydraulic oil in the various mixtures of mineral and biological hydraulic oils do not change its original appearance. It was observed that the highest viscosity 71 $mm^2 s^{-1}$ and worst anti-friction properties is for the 50% mix of mineral and biologial hydraulic oil at 20 °C ambient temperature.

Key words: biobased, mineral, hydraulic oil, compatibility.

INTRODUCTION

Nowadays hydraulic systems are found in a variety applications realizing most significant work converting mechanical power in hydraulic power. The modern aviation, heavy industry and agricultural machinery is no longer inconceivable without the built-in hydraulic systems. The main advantages of modern hydraulic systems are simple structure, light weight and easy maintenance and installation. One of the main component of such systems is hydraulic fluid the aim of which is transmit and distribute forces based on its main advantage over other materials – incompressibility. The importance of hydraulic fluids is very essential as they play a key role in operation and protection of main components of hydraulic system, which is working on high temperatures and pressures. Insufficient protection could lead to a shorter maintenance intervals and expensive problems due to an increased wear, tear, cavitation and corrosion. Manufacturers of such systems usually specify the type of hydraulic liquid based on characteristics of equipment operation, necessary pressure, and expected temperatures in the system and outside of it. Therefore hydraulic liquids have many properties and characteristics, which should be known to ensure correct system operation.

Most popular hydraulic liquids are mineral based oils due to its lower costs and availability, as also synthetic lubricants mainly developed to perform high temperature ranges in aviation and military equipment (Paredes et al., 2014). Although synthetic oils have eco-friendly characteristics and have better impact on environment compared to mineral based oils, the main disadvantage of all oils is effluence in environment mainly due to a damaged hydraulic systems. It results with effluence of about 20–30% of all sold amount of hydraulic oil. This is the quantity of oil, which poses a serious threat to the ecosystem, especially if the oil is used in protected nature areas. Besides of that, professional mechanics and also other technical specialists are exposed to these oils mainly by dermal contact promoting irritation of skin. As some researches have shown that mineral based oils have possible carcinogenic effect, than substitution of such oils would be valuable for those people who have a risk to be in contact with it practically every day. Such replacement could be done by biological or renewable oils. In that case there exists a term – 'Green Tribology', which discusses a concept of this area and its relation to the other ones formulating 12 principles, where one of them is biodegradable lubrication, connected with the use of biodegradable and environment friendly lubricants (Nosonovsky & Bhushan, 2010). Lubricants, which are based on different renewable oils (corn, soybean, etc.) usually have an excellent lubricity compared to mineral based oils, but they have also insufficient thermal and oxidative stability which makes oil polymerization to a plastic-like consistency (Mannekote & Kailas, 2009). This problem could be resolved by different chemical modifications of oil or usage of additives.

Biobased oil is a lubricant, containing of at least 95% (by weight) base fluid and not more than 5% (by weight) additives and having derived carbon ratio at least 70% from renewable materials. It cannot contain mineral oil, as well as toxic, carcinogenic, mutagenic, teratogenic or environmentally hazardous additives. In general 62% of the total exploitable renewable natural resources which are used for the production of oil are plants containing oil (rape, sunflower seeds, palm trees, etc.), 33% of the total renewable raw materials used by wood waste, but 5% is algae, bacteria and genetically modified plants (Bart et al., 2013). Biobased hydraulic oil can be used both in stationary and mobile equipment. The total share of it is growing rapidly and these oils starting to replace mineral based hydraulic oils. Although it is not mandatory to use organic oils separate vehicle users have already tried and understood the opportunities it offers, thus preserving the environment from pollution.

Studies done before do not confirm any negative impact of biobased hydraulic oil on hydraulic system. The experiments did not show any signs of increased wear of the oil pump that might indicate on the poor anti-friction properties of the hydraulic oil. There was not found aeration or cavitation due to a high viscosity (Bart et al., 2013).

For example, Kassfeldta (Kassfeldta & Daveb, 1997) was tested one mineral based hydraulic oil and three environmentally adapted hydraulic oils, from which there were two mixtures of vegetable base oil and synthetic esters, and the last was based on synthetic esters only. Researchers determined lubricant capability properties by measurements of the capability of each oil to build a film in an elastohydrodynamic contact. The results showed that environmentally adapted oils at 40 °C give a thicker film than the mineral oil, but at 80 °C there is no significant difference between the different types of oil in their capability to build a lubricating film (Kassfeldta & Daveb, 1997).

Other researchers (Silva et al., 2015) conducted the study, the purpose of which was to develop new hydraulic biolubricants based on vegetable oils and to investigate their tribological behavior under conditions of boundary lubrication. The tribological performance of the developed lubricants was analysed in an HFRR apparatus. Researchers have found that biobased oils have satisfactory tribological properties, which were considered as a potential hydraulic oils for replacing mineral based hydraulic oils (Silva et al., 2015).

Another study (Paredes et al., 2014), which was realized to analyse potential industrial applicability of vegetable bases, realizing research with two mineral and two biobased hydraulic oils. Viscosity measurements have been carried out at three temperatures: 313.15 K, 343.15 K and 363.15 K and a pressure up to 250 MPa. In case of behaviours of the four liquid oils, they have found that the oils with a vegetable base should offer better energy efficiency due to the thinner protective layer they grant specially at low temperatures therefore extending life cycle of hydraulic systems (Paredes et al., 2014).

Based on the literature, the choice of hydraulic oil is dependent on the type of hydraulic system, operating temperature range, working and natural conditions, as well as the pump type, working pressure and environmental considerations. In case of the use of hydraulic oil, the oil viscosity is important to the specified temperature range. The lower viscosity means the system is less inert throughout the operation. On the other hand, the viscosity must be sufficiently large to ensure safety and lubrication of the lubrication pump and other moving parts. Knowing the range of operating temperature and changes of the viscosity depending on the temperature of the proposed oil, it is possible to choose exact oil for the hydraulic system.

The aim of this research was to carry out a practical study on the compatibility of the mineral and biobased hydraulic oils in hydraulic systems of tractors, as also trying to understand if there will be any advantages or disadvantages in case of mineral oil change to biobased oil. In that case it is important to understand if the hydraulic system must be cleaned before biobased oil use, identify viscosity changes of a different oil mixtures in the entire work temperature, detect how fast each oil is heated at the same working conditions, as also identify changes of anti-frictional properties. All these issues have a direct impact on productivity of tractor units, as also on different operations: loading, lifting, floating, etc.

MATERIALS AND METHODS

Experiments were realized using two different oil types and three mixtures. There was used a mineral based *46 HLP* hydraulic oil produced by LIQUI MOLY and characterized as a high performance hydraulic oil with optimal anti-wear properties and excellent oxidation resistance and operating intervals. As a biobased hydraulic oil was chosen *Agra Utto Bio* produced by AVIATICON. This oil is characterised as universal tractor transmission oil, contains ester and additive, and it confirm to the API GL4 class. The main parameters of both oils are reflected in the Table 1.

Table 1. Main parameters of the used oils

Parameters	HLP 46	Agra Utto Bio
Density, 15 °C	0.880 g mL^{-1}	0.903 g mL^{-1}
Viscosity, 40 °C	46 mm^2 s^{-1}	46.50 mm^2 s^{-1}
Viscosity, 100 °C	6.7 mm^2 s^{-1}	10.00 mm^2 s^{-1}
Viscosity index	97	211
Flash point, °C	226	230
Pour point, °C	-25	-41
Neutralisation number, mg KOH g^{-1}	0.5	4.7
Solubility	Insoluble in water	NA
Degradability	Not readily biodegradable	Biodegradable

*NA – not available.

All used oils and mixtures prepared for the tests are as follows: 1 – mineral based hydraulic oil with 0% addition of biobased hydraulic oil (marked as 'M + 0% Bio'); 2 – mineral based hydraulic oil + 25% addition of biobased hydraulic oil (marked as 'M + 25% Bio'); 3 – mineral based hydraulic oil + 50% addition of biobased hydraulic oil (marked as 'M + 50% Bio'); 4 – mineral based hydraulic oil + 75% addition of biobased hydraulic oil (marked as 'M + 75% Bio'); 5 – biobased hydraulic oil with 0% addition of mineral based hydraulic oil (marked as 'Bio + 0% M'). Prepared mixtures can be seen in Fig. 1.

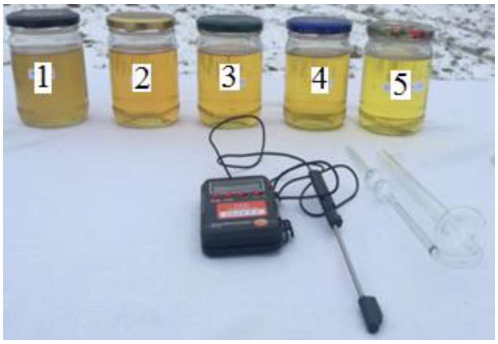

Figure 1. Samples of tested oils and created mixtures.

Oil heating measurements

Special hydraulic experimental apparatus was established by the authors for the visual observation of mixtures of mineral and biobased hydraulic oils at different operating temperatures (Fig. 2.).

Figure 2. Special hydraulic experimental apparatus established for the tests.

It consists from all necessary units to perform a pressure in the system as it would be in real working conditions. The main components of the system could be seen in Fig. 3. Electric motor, with rotation frequency 1,480 rpm^{-1}, was used to drive a pump. In addition, the safety valve was used operating a little before the maximum pressure of the pump (240 bar) is reached.

The procedure to determine condition of the oil is as follows. After switching of electric motor, it is verified if the hydraulic line is fully filled up with oil and if there is no any leakage. The next step – reduction of adjustable throttle aperture have been started activating stopwatch and registering and controlling pressure and temperature of the oil, as also looking for visual changes. Once the oil is warmed up to 65 °C, the square of the aperture of adjustable throttle is increased and control of the pressure, temperature and visual changes is continued. After an hour of such operation the aperture of adjustable throttle is fully opened and all necessary parameters have been registered once more.

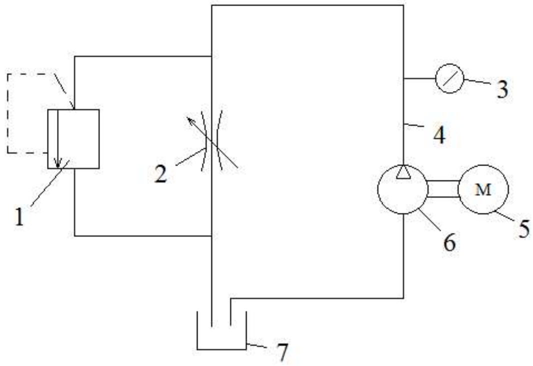

Figure 3. Technical scheme of special hydraulic experimental apparatus established for the tests: 1 – safety valve; 2 – adjustable opening throttle; 3 – gauge; 4 – hydraulic line; 5 – electric motor for hydraulic station operation; 6 – oil pump; 7 – return reservoir.

Based on the operation principles of established hydraulic experimental apparatus, it is possible to regulate operation pressure in hydraulic system till 240 bars and assure the hydraulic oil temperature changes from -10 °C to 100 °C. Besides the visual observations, the temperature measurements were realized in order to find out the mixture, which heats faster at the same operation conditions. The tests were performed at ambient temperature 0 °C and air relative humidity 80%.

Viscosity measurements

Viscosity measurements of oils and their mixtures were realized using glass capillary viscometer VPZ – 4, which is intended for the determination of kinematic viscosity of liquids. Preparation for experimental work (washing and drying of viscometer) based on standard procedures. For the realization of experiment was used also manual air baster, stopwatch, thermometer, calibrated flask. Viscosity measurements were performed under field conditions in the temperature range from – 15 °C to +20 °C.

Friction measurements

Sliding friction bench was used for the comparison of friction properties (Fig. 4.). In order to ensure the full functioning of the bench, in addition there was used multimeter, torque wrench, stopwatch. Experiments were carried out under laboratory conditions at ambient temperature (+19 °C). For the operation of the bench there were used a 12 V battery and multimeter switched in electric circuit for the control of the amperage (A). Unused friction bricks and the roller was prepared for the tests. Friction block was changed after the usage of each oil mixture. Bricks and the roller was cleaned before check of each oil sample. In order to determine the anti-friction characteristics, 10 Nm load was applied to torque wrench and amperage was controlled. The aim was to determine the changes of the amperage at the same load and then measure the size of the wear on the block.

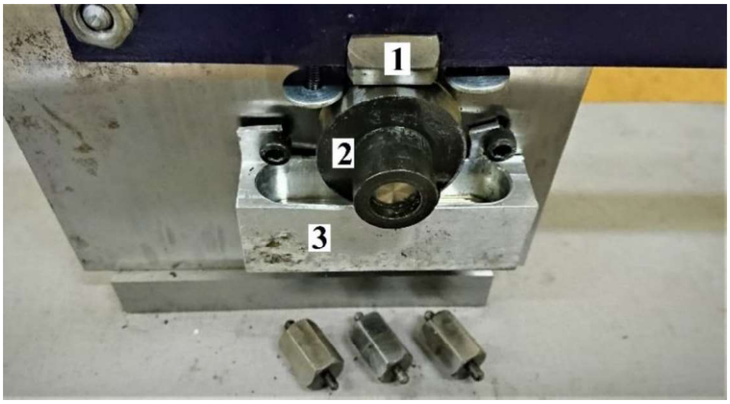

Figure 4. Side view of sliding friction test bench with friction blocks used in the tests: 1 – friction block; 2 – steel disc; 3 – oil reservoir.

RESULTS AND DISCUSSION

During testing conditions realized in hydraulic experimental apparatus, similar to those which is possible to get in hydraulic system of agricultural machinery, was observed that mineral and biobased hydraulic oils are practically compatible. There was not observed any visual changes in the oil mixtures during regulation of operation pressure of hydraulic experimental apparatus and the temperature of the oil mix in it. Besides of that there was not also observed any changes in its original appearance.

Tests have showed that mineral based oil warms faster than biobased oil. For example, biobased hydraulic oil achieved maximal testing temperature about 60 second later than the mineral one. Oil mixtures have very similar results to mineral oil with small difference based on the amount of added biobased additive. This could be connected with the molecular structure of biobased oil, which is slightly different from the mineral oil. Mineral oil molecules have tendency to radically change its size based on the impact of temperature. While the biobased oil molecules does not change its size so radically, and therefore biobased oil viscosity under temperature influence don't change so quickly (Nathan et al., 2012). Heating curves of hydraulic oils and its mixtures could be seen in Fig. 5.

Technical characteristics of both oils shows that pour point of mineral based oil is -25 °C, but for biobased oil – only at -41 °C (Table 1). Based on these characteristics can be deduced that the results of the experiments carried out at the -10 °C will show a drastic difference, but obtained data showed that biobased oil viscosity at this temperature is 206.1 mm^2 s^{-1}, but mineral oil viscosity is 190.0 mm^2 s^{-1}, but other oil mixtures based on the growing of organic oils impurity showed viscosity gradually reduction till the biobased oil viscosity.

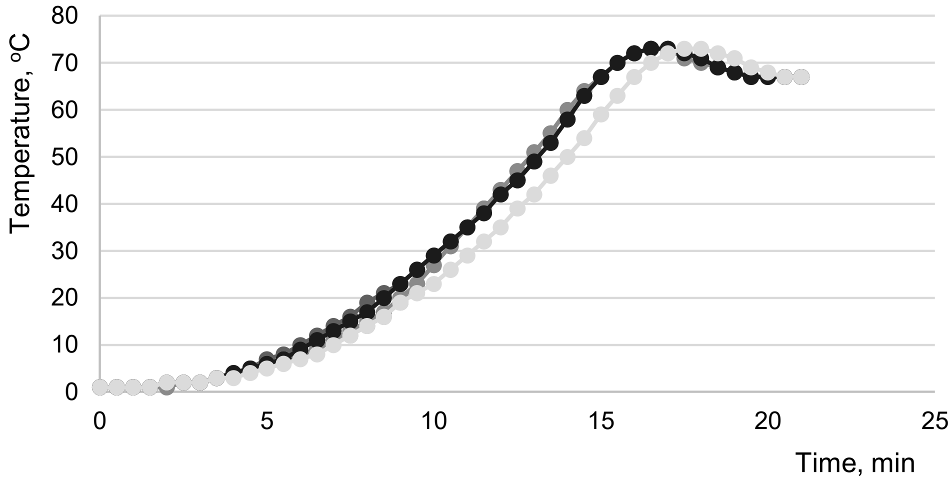

Figure 5. Heating curves of hydraulic oils and its mixtures: M + 0% Bio – ; M +25% Bio – ; M +50% Bio – ; M +75% Bio – ; Bio + 0% M – .

The increase in temperature showed decrease of distinction. The measurements taken at 20 °C showed mineral oil viscosity about 71.84 $mm^2 s^{-1}$, but the biobased oil viscosity at 65.86 $mm^2 s^{-1}$. Comparison of the viscosities of the hydraulic oil and its mixtures can be seen in Fig. 6.

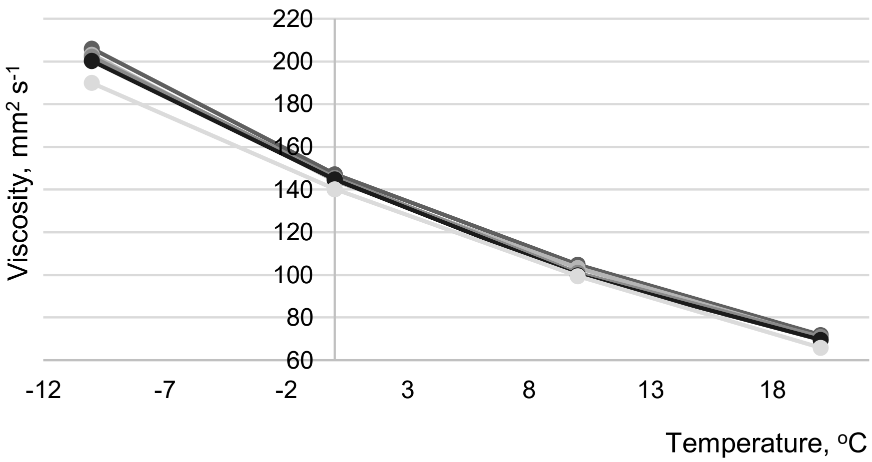

Figure 6. Viscosity curves of hydraulic oils and its mixtures: M + 0% Bio – ; M +25% Bio – ; M +50% Bio – ; M +75% Bio – ; Bio + 0% M – .

It should be noted that oil specification indicates that hydraulic fluid contains anti-abrasive additives, but it does not guarantee that the oil will protect parts from the increased wear. This parameter is important as due to a bad anti-friction properties there is possible increased wearing of all devices involved in hydraulic system. Experimental results of the mixtures using sliding friction bench is showed in Fig. 7. Data showed that biobased hydraulic oil have the best protection of hydraulic system from wearing, but

50% mixture with mineral based oil have the worst antifriction characteristics. It could be explained by chemical reaction between main components of oils, which are not compatible and therefore such mixture has shown largest wear zone. As it is seen, such situation is mainly observed for mixtures, where biobased oil concentration is larger than 50%. Wear zone for separate oils – weather it mineral or biobased – is very similar.

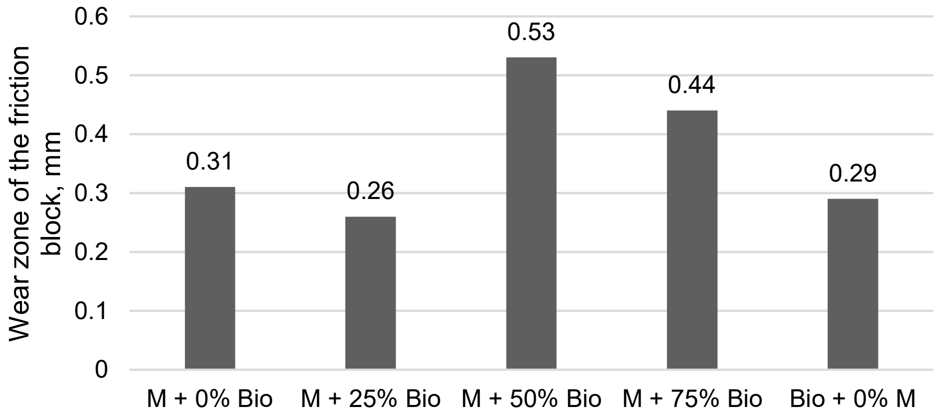

Figure 7. Graph of the wear zone of friction blocks for different oil types and their mixtures.

In general, the characteristics of the biobased hydraulic oils is good enough for use in hydraulic systems of the vehicles, as also oil mixture (M + 25% Bio), as has been shown, can ensure normal operation of hydraulic systems.

CONCLUSIONS

Based on the research of all oil mixtures it could be concluded that mineral based and biobased hydraulic oils are compatible as there was not observed any visual changes in the oil mixtures during regulation of operation pressure and simulating of real working conditions in the hydraulic system. Research on the viscosities of hydraulic oils at one and the same temperature did not show rapid changes based on the different percentage of admixture of biobased oil. Largest difference of viscosities of mineral based oil over biobased oil was observed only at –10 °C. Increasing the percentage of biobased hydraulic oil, viscosity of a mixture decreased. Besides of that, experimental results using the sliding friction bench showed that the worst anti-friction properties and the largest wear occurred using mineral based hydraulic oil by 50% and 75% biobased oil addition, but the smallest wear occurred using hydraulic oil with 25% organic additive. Therefore only small amount of biobased oil addition can ensure acceptable wear and a positive impact on environment. Usage of large mixtures are not recommended.

REFERENCES

Bart, J.C.J., Gucciardi, E. & Cavallaro, S. 2013. *Biolubricants: science and technology.* Woodhead Publishing Limited, 944 pp.

Kassfeldta, E. & Daveb, G. Environmentally adapted hydraulic oils. *Wear* **207**, Issue 1–2, 41–45. DOI:10.1016/S0043-1648(96)07466-2

Mannekote, J.K. & Kailas, S.V. 2009. Performance evaluation of vegetable oils as lubricant in a four stroke engine. In: *Proc. 4th World Tribology Congress*. Kyoto, Japan, 6–11 September, pp. 331.

Nagendramma, P. & Kaul, S. 2012. Development of ecofriendly/biodegradable lubricants: An overview. *Renewable and Sustainable Energy Reviews* **16**, 764–774.

Nathan, S. Mosier, M. & Ladisch, R. 2012. *Modern Biotechnology.* United States of America: Willey, 433 pp.

Nosonovsky, M. & Bhushan, B. 2010. Green tribology: principles, research areas and challanges. *Phil. Trans. R. Soc. A* **368**, 4677–4694. DOI: 10.1098/rsta.2010.0200

Paredes, X., Comunas, M.J.P., Pensado, A.S., Bazile, J.P., Boned, C. & Fernandez, J. 2014. High pressure viscosity characterization of four vegetable and mineral hydraulic oils. *Industrial Crops and Products* **54**, 281–290.

Silva, M.S., Foletto, E.L., Alves, S.M., Dantas, T.N.C. & Dantas Neto, A.A. 2015. New hydraulic biolubricants based on passion fruit and moringa oils and their epoxy. *Industrial Crops and Products* **69**, 362–370. DOI: 10.1016/j.indcrop.2015.02.037