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DEGRADATION OF ECOLOGICAL ENERGY CARRIERS UNDER CYCLIC PRESSURE LOADING

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The presented work investigates the degradation of an ecological energy carrier in the form of changes in its properties, which was subjected to dynamic loading through a test device in laboratory conditions. The primary goal was to describe the degradation process itself in terms of obtained data through the analysis of kinematic viscosity, water content, acidity number, and X-ray spectrometry. The process was focused on monitoring the values of increase in contaminants and monitoring the values of changes that occurred in case of additives. The ecological energy carrier in the form of transmission-hydraulic fluid was cyclically loaded in a time interval of 200 working hours, while a time interval of every 25 working hours was used when a sample was taken and subsequently analysed. From the obtained data, it can be concluded that during the degradation process, there were no significant changes in the observed properties of the liquid, chemical composition, or additives. For this reason, further measurements of the ecological energy carrier were subsequently carried out. The influence of the given energy carrier on the change in the flow rate of a new type of hydraulic pump with external gearing was also monitored.

Keywords: X-ray spectrometry; laboratory test equipment; simulation of operating conditions; ecological energy carrier; dynamic loading

Due to the increased consumption of hydraulic fluids in machinery working often in ecologically sensitive environments, there is a significant increase in the requirements for the qualitative properties of these carrier media. The individual properties of hydraulic fluids are mainly affected by temperature and pressure. If temperature rapidly increases, it can have a very negative effect on the hydraulic fluid in terms of a change in the value of kinematic viscosity, or the occurrence of various chemical reactions (Dalla Lana and De Negri, 2006). Some of these properties directly impact the individual components of the environment. One of these properties is biological degradability, which must be ensured in every liquid working in agriculture, forestry, or in areas considered critical from an environmental point of view. In case of biological degradability, the parameters of environmental persistence and ecotoxicity are monitored. They determine the ability of the given fluid to resist the components of the environment, as well as the value by which the hydraulic fluid damages individual components of the environment (Casoli et al., 2018). Hydraulic mechanisms are relatively complex machine mechanisms, the individual elements of which are significantly influenced by the state of the transmission fluid. In addition to the already mentioned impact on the environment, the technological development of these mechanisms is therefore focused on increasing the transmitted power, reducing energy consumption, etc. The importance of research into the degradation of ecological energy carriers is also confirmed by Tkáč et al. (2008), Majdan et al. (2016a, 2016b), and Tulík et al. (2016), who researched the degradation of working fluids together with the influence of operational load on changes in their individual properties. Halenár and Kuchar (2017) state that it is necessary to have all the information related to the individual properties of operating fluids, which are expected to be used as a carrier medium in hydraulic mechanisms.

This paper is focused on monitoring the changes in the properties of ecological energy carriers. In practice, they are used in transmission-hydraulic systems working in ecologically sensitive environments, where the impact of operating fluids on individual components of the environment is relatively significant. To optimize the testing time of the ecological energy carrier, accelerated exams have been used. In this case, operating conditions were simulated in the hydraulic circuit under cyclic pressure loading for 200 working hours. After the end of the measurement process, individual samples taken at the

intervals of every 25 working hours will be subjected to an analysis of the physicochemical properties of the used working fluid, but in addition, there will be an evaluation of the effect of the tested working fluid on the technical condition of the used hydraulic pump. The development of similar laboratory equipment, on which such tests can be performed, is very important, as evidenced by Turza and Kopiláková (2011), Zastempowski (2013), Hujo et al. (2017), and Hujo et al. (2016). To reduce emergency situations and various undesirable situations that may occur during the working process of the hydraulic mechanism, it is very important to use the tribotechnical diagnostics of oils. By means of tribotechnical diagnostics, it is possible to detect the contamination of the hydraulic fluid, while it is contamination that accelerates the degradation process of operating fluids (Helebrant et al., 2001). The objective is to replace the previously used laboratory equipment with a new one (SpectroCube) to obtain more complex results of elemental analysis of elements, which can be used as a source of information in the design process of new filter devices.

Material and methods

Ensuring the correct function of the hydraulic fluid as well as ensuring its effective care is conditioned by the selection

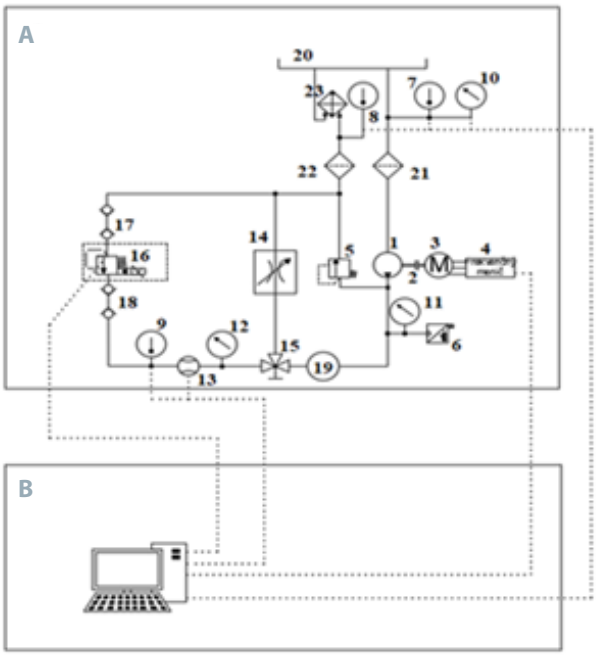


Fig. 1 Hydraulic diagram of the primary circuit with the designation of its elements
A – hydraulic circuit; B – control and evaluation circuit; 1 – hydrogen generator; 2 – clutch; 3 – electric motor; 4 – frequency converter; 5 – pressure valve; 6 – TSI pressure sensor; 7–9 –thermometer; 10–12 – pressure gauge; 13 –flow meter; 14 – throttle valve with stabilization; 15 – three way valve; 16 – electrohydraulic proportional valve; 17–18 – quick coupling; 19 –measuring points for evaluating liquid indicators; 20 – tank; 21–22 –filter; 23 –cooler

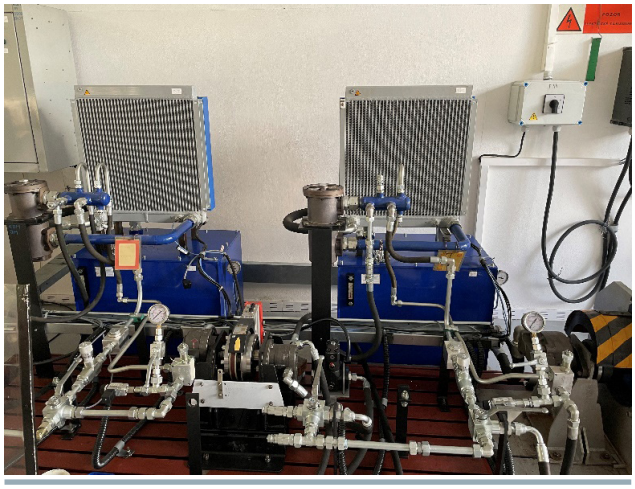


Fig. 2 View of the laboratory testing device

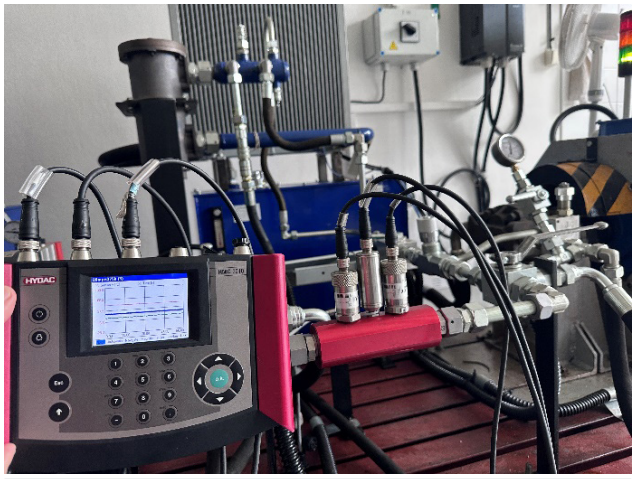


Fig. 3 View of measurement sensors connection

of a suitable methodology for testing operating fluids with monitoring of their pollution level. The laboratory test equipment, on which the individual measurements described in this publication were performed, was designed for the purpose of conducting tests of ecological energy carriers. The design and construction process of the given laboratory test equipment was based on the individual points listed in the SAE J745 technical standard. Specifically, the laboratory test equipment consists of two hydraulic circuits, which allows performing simultaneous testing of two different hydraulic fluids (Hujo et al., 2017). During the measurement, only one hydraulic circuit was used, since one type of hydraulic fluid was measured. In Fig. 1, it is possible to see the hydraulic diagram of the primary circuit, marked A, of the laboratory test equipment and the control-evaluation circuit, marked B. This diagram shows the individual hydraulic elements of the circuit, which are necessary for its correct, safe, and reliable operation. A real view of the laboratory test equipment can be seen in Fig. 2.

During the measurement itself, combined sensors are used (Fig. 3), through which important operational parameters can be simultaneously recorded – pressure, temperature, and flow. For data transmission and acquisition,

Table 1 Physicochemical properties of the Shell Naturelle HF-E 46 fluid

Parameter	Unit	Value
ISO-VG grade	–	46
Density at 15 °C	$kg \cdot m^{-3}$	921
Viscosity at 40 °C	$mm^2 \cdot s^{-1}$	47.2
Viscosity at 100 °C	$mm^2 \cdot s^{-1}$	9.41
Viscosity index	–	188
Flash point	°C	322
Pour point	°C	-42
Biodegradability according to OECD 301B	%	>60
Biodegradability according to CEC L-33-A 93	%	90
Water hazard level	–	0

these sensors are connected to an Hydac recording unit. It is a device Hydac HMG 3010, which enables the measurement of the above-mentioned quantities:

a) flow value in the range of 6–60 $dm^3 \cdot min^{-1}$,
b) pressure value in the range of 0–40 MPa,
c) temperature value in the range of 20–95 °C.

In this case, the ecological energy carrier used for the investigation of the degradation process was Shell Naturelle Fluid HF-E 46, an ecological transmission-hydraulic fluid. It is a synthetic biodegradable transmission-hydraulic fluid with a low ecotoxicity value, which predetermines it for use in hydraulic systems of machines working in exposed environments with a wide range of working temperatures. Selected physicochemical properties of the tested liquid are listed in Table 1 (Whlubricants, 2013).

The transmission-hydraulic fluid was measured through cyclic loading. According to the methodology used, it is necessary to observe the input parameters of measurement. In this case, it is the working temperature of the monitored liquid (90÷95 °C) and operating speed (1600 rpm). The measurement process will be completed after 200 hours, which corresponds to the value of 480,000 cycles. One cycle consists of three intervals, namely:

a) load interval – action time 0.50 s and loading at a pressure of 22.5 MPa, which corresponds to 90% of the set pressure value;
b) limit pressure loading interval – action time 0.50 s and loading at a pressure of 18.5 MPa, which corresponds to 60% of the maximum pressure value;
c) unloading interval – duration of action 0.50 s and load at a pressure of 0 MPa.

After working for 25 hours, which corresponds to the value of 60,000 cycles, the process of taking a sample of the tested transmission-hydraulic fluid will be started, which will then be subjected to analyses. In our case, the analysed samples will be taken in the time interval of 0, 100, and 200 working hours. Through these analyses, information about the overall condition of the liquid will be obtained. An important finding will be whether there is contamination by foreign substances from the surrounding environment, or whether contaminants are formed as a result of ageing. The equipment used during the analysis process is specially designed for the needs of:

– analysing the kinematic viscosity at 40 °C using the Spectro VISC Q^{300} device (Fig. 4),
– analysing the water content and acidity number (TAN) using FluidScan Q1000 (Fig. 5),

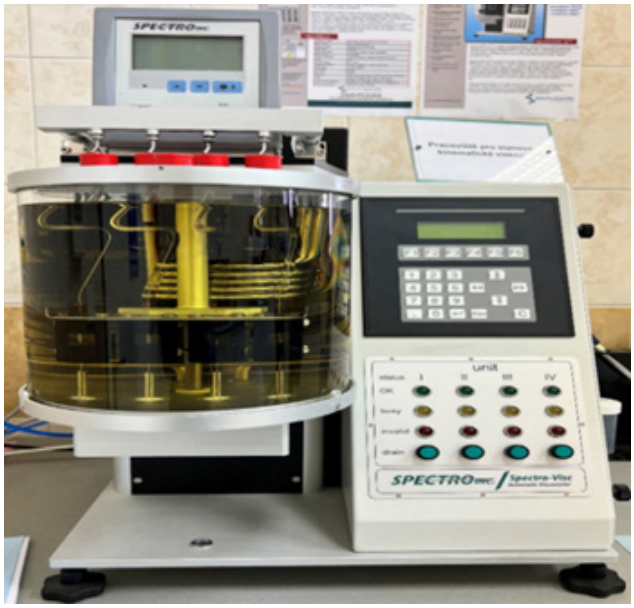


Fig. 4 Spectro Visc Q300

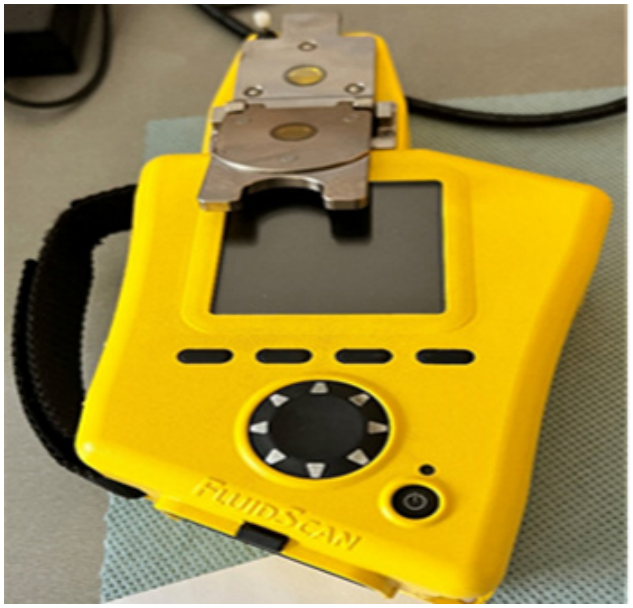


Fig. 5 FluidScan Q1000



Basic SpectroCube parameters
Detector: Silicon Dry Detector (SDD)
Dimensions (H × W × D): 380 × 520 × 540 mm
Weight: 48 kg
Power supply: 95–120 V/200–240 V, 50/60 GHz
Measuring chamber (H×W×D): 155 × 400 × 320 mm
Power consumption: 120 W
Computer system: PC with Win 10 (min.)
Analysis: fundamental parameters of FP + elemental analysis of alloys

Fig. 6 SpectroCube with its basic parameters

– analysing the chemical composition using SpectroCube (Fig. 6).

A significant added value in this case will be the use of a SpectroCube device. It is an energy-dispersive X-ray fluorescence spectrometer that works on the same principle as Spectroil Q100. Through this equipment, the analysis of chemical elements using spectrometry can be performed; however, it uses X-rays for this purpose. A great advantage is the ability to analyse up to 8 samples simultaneously, while the analysis of 1 sample takes approximately 10 minutes. The analysis of liquids takes place according to the steps established by the ASTM D7751 standard.

Results and discussion

In the process of analysing the physicochemical properties, a total of three samples of the taken transmission-hydraulic fluid were used. The first of the analyses carried out was the kinematic viscosity test at 40 °C, using the Spectro VISC Q^{300} device. The reference sample, 0 hours worked, showed a value of kinematic viscosity at 40 °C equal to 47.48 $mm^2 \cdot s^{-1}$. The limit value of viscosity is determined based on the ISO 15380 standard, which sets the maximum change in kinematic viscosity at the limit of ±10%. As can be seen from the obtained values in Table 2, the value of kinematic viscosity, based on the increasing number of hours worked, gradually increased. The only recorded anomaly occurred in the sample after 75 working hours, where it is possible to see a decrease in the value of kinematic viscosity in comparison with the previous value of kinematic viscosity for the sample after 50 working hours. When comparing the value of kinematic viscosity measured for the reference sample and the value of kinematic viscosity obtained for the sample after 200 working hours, the value increased by a total of 6.61%. It can be concluded that the total increase expressed as a percentage did not exceed the maximum limit set by the ISO 15380 standard. Figure 6 shows the behaviour of kinematic viscosity at 40 °C together with the maximum and minimum limit set by the standard. The graphic display of individual values of kinematic viscosity is shown in Fig. 7 together with the maximum and minimum limits determined by the mentioned standard.

The second analysis performed was the analysis to determine the total water content and acidity number, since both analyses can be performed using a single device. From the analysis of water content after working for 200 hours, a zero concentration was found. The reason for this conclusion may be the fact that measurement was performed in laboratory conditions, with operating temperature of the examined liquid 90–95 °C. The ASTM D664 standard sets the limit values for acidity number in the range of 1.0–5.0 mg $KOH \cdot g^{-1}$. In this case, samples taken in the range of 0–200 working hours were analysed. The obtained values are listed in Table 3. From the obtained data, the value of acidity number after working for 200 hours was 1.90 mg $KOH \cdot g^{-1}$; therefore, the value of acidity number of the investigated liquid is within the range established by the above-mentioned standard. The total increase in acidity number when comparing the reference sample and the sample after working for 200 hours represented a value of 0.14 mg $KOH \cdot g^{-1}$. Figure 7 shows the increase in acidity number in the time interval of 200 working hours, together with the limits established by the ASTM D644 standard. Figure 8 presents the evaluation of total acid number.

Table 2 Evaluation of kinematic viscosity at 40 °C after 200 hours worked

Number of hours worked, *t* (h)	Kinematic viscosity at 40 °C *v* ($mm^2 \cdot s^{-1}$)
0	47.48
25	49.19
50	49.75
75	48.01
100	49.44
125	50.02
150	50.27
175	50.17
200	50.62

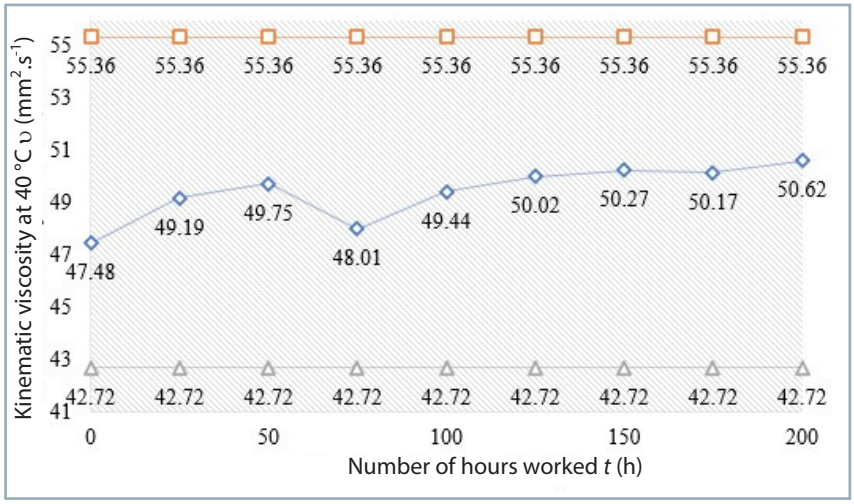


Fig. 7 Graphic representation of kinematic viscosity at 40 °C

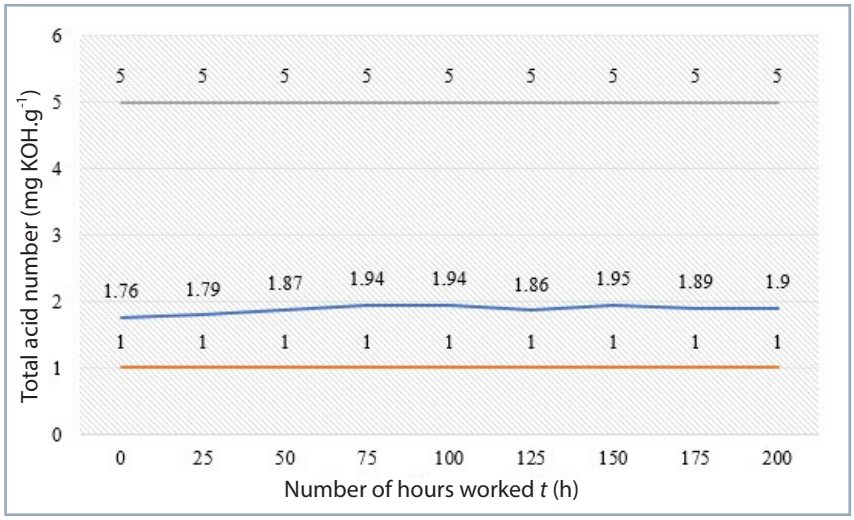


Fig. 8 Graphic representation of the evaluation of total acid number

Table 3 Evaluation of total acid number after 200 hours worked

Number of hours worked, *t* (h)	Total acid number (mg KOH·g^{-1})
0	1.76
25	1.79
50	1.87
75	1.94
100	1.94
125	1.86
150	1.95
175	1.89
200	1.90

Finally, the analysis of the chemical composition of investigated transmission-hydraulic fluid using the SpectroCube device was performed. In this case, the analysis of hydraulic fluid samples taken at time intervals of 0, 100, and 200 working hours was performed. The reason for choosing these specific time intervals was that we were interested in the concentration of chemical elements at the beginning of the measurement process, after 50% of working hours, and at the end of the measurement process. In this analysis, the focus was on a total of ten chemical elements: silicon (Si), phosphorus (P), potassium (K), calcium (Ca), iron (Fe), copper (Cu), zinc (Zn), tin (Sn), barium (Ba), and lead (Pb). The data obtained through this analysis are shown in Table 4.

Chemical elements were evaluated from the point of view of contaminants and additives. As can be seen from the obtained results, the highest increase was recorded for lead and potassium, which can be considered as contaminants in this case. Even though in their case there was the most significant increase in concentration compared to the reference sample, it can be concluded that the limit values set by the ASTM D6595 standard were not exceeded. In terms of monitoring the activation of chemical elements acting as additives in the examined transmission-hydraulic fluid, there was a decrease in the value of calcium and zinc. It is possible to conclude that these elements were activated due to operating conditions (increased temperature and pressure) and fulfilled their function in terms of additional chemical elements that serve to protect the given liquid. According to Deuster and Schmitz (2021), ecological hydraulic fluids offer great potential, mainly due to their thermal properties. Fluids that are included in the HEES (hydraulic environmental ester synthetic) category have a viscosity index value in the range of 150–220, while the viscosity index of mineral oil fluids is around 100. According to Pochi et al. (2020), a total of up to 23% of hydraulic fluids end up in the natural environment. According to the DIN EN 16 807 standard, ecological liquids must contain at least 25% renewable components. The biodegradability of ecological energy carriers reaches

Table 4 Evaluation of energy-dispersive X-ray fluorescence spectrometry

Chemical element	Analysed sample of transmission-hydraulic fluid		
	0 h (mg·kg^{-1})	100 h (mg·kg^{-1})	200 h (mg·kg^{-1})
Silicon	26.9	30.1	30.3
Phosphorus	39.5	29.3	26.3
Potassium	0.9	0.9	1.1
Calcium	6.4	2.7	2.7
Iron	2.0	2.0	2.0
Copper	0.23	0.7	0.7
Zinc	4.14	1.19	1.2
Tin	0.5	0.7	0.6
Barium	0.9	0.6	0.9
Lead	0.52	0.56	0.67

a value of up to 90% already within the first three weeks. This is a relatively high value compared to mineral energy carriers, where degradability is only 36%. Stojilković and Kolb (2016) consider the use of ecological energy carriers to be the right choice in agricultural machines, since during their use, there is direct contact with individual components of the environment. When comparing the results achieved by us with the results of Pochi et al. (2020), it can be concluded that the ecological transmission-hydraulic fluid is suitable for use in the hydraulic mechanisms of machines working in an ecologically sensitive environment. From the analysis carried out and subsequent data obtained, new hydraulic fluids already have some pollution in the form of a small number of contaminants. However, their quantity is reduced during operation through the function of filter devices. This fact was confirmed in our case as well, which makes it possible to confirm that the hydraulic fluid showed slight pollution from the beginning. A common phenomenon that occurs during the operation of hydraulic equipment is the activation of additional chemical elements in the form of additives. This phenomenon also occurred in our case, where it is possible to observe a decrease in the values of calcium and zinc with the increasing number of hours worked. In normal practice, this is an important phenomenon that needs to be monitored, because through these findings, appropriate time interval for changing the hydraulic fluid, or, in some cases, the time interval for refilling some of the additives, can be determined. Some elements in hydraulic fluid can appear in the form of a contaminant, but also in the form of an additive. Silicon is usually considered an additive, but in our case, it appears to be a contaminant (surface particles).

Conclusion

Even though ecological energy carriers show a high value of biodegradability, which is considered one of the most important properties of these liquids today, they do not always achieve the necessary properties required for the safe and reliable operation of the hydraulic equipment. For this reason, our research was expanded to include research into individual changes in the required properties of transmission-hydraulic fluids, as well as monitoring the influence of the used transmission-hydraulic fluid on individual hydraulic elements of the given device. A decisive factor that can significantly affect the service life of hydraulic fluids, in addition to their chemical composition, is the balance of operating conditions, or their pollution. Pollution is an undesirable process that accelerates the degradation processes of ecological energy carriers, while it can also affect their physical and chemical properties. From this point of view, we evaluated qualitative parameters – kinematic viscosity, total acid number, water content, and chemical composition. Based on the evaluation of results obtained by experimental measurements, it can be concluded that the individual parameters by which the qualitative properties of the investigated transmission-hydraulic fluid were evaluated, did not exceed the limit values specified by the ASTM D6595 standard.

References

ASTM D664: 2019. Standard test method for acid number of petroleum products by potentiometric titration.

ASTM D6595: 2022. Standard test method for determination of wear metals and contaminants in used lubricating oils or used hydraulic fluids by rotating disc electrode atomic emission spectrometry.

ASTM D7751: 2021. Standard test method for determination of additive elements in lubricating oils by EDXRF analysis.

CASOLI, P. – CAMPANINI, F. – BEDOTTI, A. – PASTORI, M. – LETTINI, A. 2018. Overall efficiency evaluation of a hydraulic pump with external drainage through temperature measurements. In Journal of Dynamic Systems, Measurement, and Control, vol. 140, no. 8, article no. DS-17-1191. DOI: https://doi.org/10.1115/1.4039084

DALLA LANA, E. – DE NEGRI, V. 2006. A new evaluation method for hydraulic gear pump efficiency through temperature measurements. In SAE 2006 Commercial Vehicle Engineering Congress & Exhibition, SAE Technical Paper 2006-01-3503, 10 pp. DOI: https://doi.org/10.4271/2006-01-3503

DEUSTER, S. – SCHMITZ, K. 2021. Bio-based hydraulic fluids and the influence of hydraulic oil viscosity on the efficiency of mobile machinery. In Sustainability, vol. 13, no. 14, article no. 7570. DOI: https://doi.org/10.3390/su13147570

DIN EN 16807: 2016. Liquid petroleum products – Bio-lubricants – Criteria and requirements of bio-lubricants and bio-based lubricants.

HALENÁR, M. – KUCHÁR, P. 2017. Research of biodegradable fluid during operating test. In MendelNet 2017, vol. 24, pp. 784–789.

HELEBRANT, F. – ZIEGLER, J. – MARASOVÁ, D. 2001. Technical Diagnostics and Reliability I. Tribodiagnostics. Ostava : VSB – Technical University of Ostrava, 154 pp. ISBN 80-7078-883-6 (In Czech)

HUJO, Ľ. – JABLONICKÝ, J. – TKÁČ, Z. 2017. Design of an Innovative Laboratory Simulation Device for Testing Hydrostatic Transducers and Hydraulic Fluids. Nitra : Slovak University of Agriculture in Nitra, 180 pp. ISBN 978-80-552-1645-4 (In Slovak)

HUJO, Ľ. – TKÁČ, Z. – TULÍK, J. – KOSIBA, J. – UHRINOVÁ, D. – JÁNOŠOVÁ, M. 2016. Monitoring of operation loading of three-point linkage during ploughing. In Research in Agricultural Engineering, vol. 62, no. 1, pp. 24–29. DOI: https://doi.org/10.17221/10/2015-RAE

ISO 15380: 2018. Lubricants, industrial oils and related products (class L) – Family H (Hydraulic systems) – Specifications for hydraulic fluids in categories HETG, HEPG, HEES and HEPR.

MAJDAN, R. – ABRAHÁM, R. – KUČERA, M. – HAAS, P. 2016a. Analysis of the effect of loading process on tribological system properties. In Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, vol. 64, no. 3, pp. 825–833.
DOI: https://doi.org/10.11118/actaun201664030825

MAJDAN, R. – TKÁČ, Z. – ABRAHÁM, R. – SZABÓ, M. – HALENÁR, M. – RÁŠO, M. – ŠEVČÍK, P. 2016b. Proposal for filtration system for biodegradable lubricants in agricultural tractors. In Agronomy Research, vol. 14, no. 4, pp. 1395–1405.

STOJILKOVIĆ, M. – KOLB, M. 2016. Tribological properties of biodegradable universal tractor transmission oil. In Tribology in Industry, vol. 38, no. 2, pp. 229–234.

SPECTRO. 2022. SpectroCube – ED XRF Spectrometer for the analysis of precious metals. In Spectroaps, pp. 3. Available at: https://www.spectroaps.sk/wp-content/uploads/spectrocube_brochure_SK_low.pdf

TKÁČ, Z. – DRABANT, Š. – MAJDAN, R. – CVÍČELA, P. 2008. Testing stands for laboratory tests of hydrostatic pump of agricultural machinery. In Agricultural Engineering, vol. 54, no. 4, pp. 183–191. DOI: htpps://doi.org/10.17221/704-RAE

TULÍK, J. – HALENÁR, M. – KUCHÁR, P. – JÁNOŠOVÁ, M. 2016. Comparison of conventional hydraulic fluid with biodegradable fluid on the basis of laboratory test of durability. In Traktori I Pogonske Mašine, vol. 21, no. 1, pp. 64-70. ISSN 0354-9496.

TURZA, J. – KOPILÁKOVÁ, B. 2011. Combined stand for measuring hydraulic elements. In Hydraulics and pneumatics – a magazine for hydraulics, pneumatics and automation technology, vol. 27, no. 1–2, pp. 60–64.

POCHI, D. – FANIGLIULO, R. – BISAGLIA, C. – CUTINI, M. – GRILI, R. – FORNACIARI, L. – BETTO, M. – PARI, L. – GALLUCCI, F. – CAPUZZI, L. – SAGLIANO, A. – PALMIERI, F. – CHIATTI, G. 2020. Test rig and method for comparative evaluation of conventional and bio-based hydraulic fluids and lubricants for agricultural transmissions. In Sustainability, vol. 12, no. 20, article no. 8564.
DOI: https://doi.org/10.3390/su12208564

SAE J745: 2019. Surface vehicle standard – Hydraulic power pump test procedure.

WHLUBRICANTS. 2013. Shell Naturelle HF-E 46. Whlubricants Technical Data Sheet. Available at:
https://whlubricants.com/files/products/naturelle-fluid-46.pdf

ZASTEMPOWSKI, M. 2013. Test stands with energy recovery system for machines and hydraulic transmissions. In Journal of Research and Applications in Agricultural Engineering, vol. 58, no. 2, pp. 182–191. Corpus ID: 109688180.