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Krzysztof LEW
Paweł WOJEWODA
Janusz LUBAS

Combustion Engines
Polish Scientific Society of Combustion Engines

The analysis of the impact of the storage period of engine and transmission oil on operational properties

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The purpose of the research presented in this article was to determine the impact of the storage period of engine and transmission oils on their operational properties. The prolonged storage of oils leads to a series of physicochemical changes that can significantly affect their lubrication efficiency. Changes such as reduced viscosity, changes in density, and deterioration in lubricity can lead to increased wear of the engine, transmission, and other mechanical components. The study included samples of new and five-year-old engine and transmission oils, as well as engine oil after the break-in period (with a mileage of approximately 800 km). The SAE 10W40 oil after use in an internal combustion engine shows a significant reduction in scuffing resistance (approximately one-third lower scuffing load compared to new and old oil). Long-term five-year storage also slightly reduces its scuffing resistance at higher temperatures. In contrast, long-term storage of SAE 30 oil significantly decreases its scuffing resistance across both tested temperature ranges (by about 20%). Storage time did not significantly alter the viscosity index of SAE 10W40, whereas old SAE 30 oil showed a slightly better index than new oil.

Key words: *oil samples, lubricity, viscosity, density, aging process*

1. Introduction

Engine oils play a crucial role in ensuring the proper functioning and durability of internal combustion engines, particularly modern units that operate under increasingly demanding conditions. Their primary function is to lubricate moving mechanical components, protect against wear, corrosion, and overheating, with precisely adjusted viscosity being one of the key parameters determining the effectiveness of lubrication [7–9, 13, 14, 16].

Studies, such as the analysis of Marinol RG 1240 oil in the Cegielski-Sulzer 3AL25/30 engine, demonstrate that lubricating properties undergo dynamic changes, initially improving with ageing (even a threefold increase in anti-scuffing load capacity). However, this beneficial effect gradually decreases with the accumulation of contaminants [11]. Oil degradation is a multistage process that accelerates under harsh operating conditions, such as high temperatures, intense loads, or fuel dilution [12, 17, 18]. However, changes in oil properties occur not only during operation but also during long-term storage, posing an additional challenge for supply chains and end users [6, 11, 13, 14, 16].

A comprehensive assessment of the condition of the oil requires considering both the initial benefits of oil maturation and the negative effects of contaminant accumulation. Monitoring parameters such as viscosity, base number (TBN), acid number (TAN), and thermal stability are essential [1, 3, 5, 16]. Excessively low viscosity increases oil consumption and harmful emissions, while excessively high viscosity complicates cold starts and increases fuel consumption. However, viscosity alone is insufficient for a full assessment of oil condition: advanced analytical methods such as FTIR spectroscopy or TAN / TNB balance analysis are necessary [1, 5, 16].

The results of long-term storage studies (up to 5 years) of engine and gear oils revealed significant changes in their operational properties, including, for example, a 30% decrease in anti-scuffing resistance in SAE 10W40 oil used at 40°C [2–5, 13, 16]. These observations confirm that optimal oil management requires customised selection and replacement strategies, taking into account both operating and storage conditions. Insufficient monitoring or excessively long oil change intervals can lead to faster engine wear, failures, and reduced lifespan [7, 10, 12, 15].

This article combines an analysis of oil ageing processes under engine operation with an evaluation of the impact of long-term storage on oil properties, providing practical recommendations for the automotive industry in the context of increasing efficiency and environmental requirements. An important part of this work is the analysis of changes in the anti-seizure properties of engine oils after working in sliding pairs of combustion engine and long-term storage. The results obtained in the study provide an important suggestion regarding possible changes to the composition of oil during storage time, which can often be a long time from the production of oil to its use.

2. Measuring equipment and test methodology

2.1. Measuring equipment

The determination of the density, viscosity and lubricity of the oils selected for the tests was performed using research equipment that is part of the facilities of the Laboratory of Operational Materials at the Department of Motor Vehicles and Transport Engineering.

The density measurement of the oils was conducted using the DMA 4500 M apparatus (Fig. 1), which has the following parameters:

– Measurement range: density from 0 to 3 g/cm³, temperature from 0 to 90°C
– Accuracy: 5×10^{-5} g/cm³, 0.03°C
– Sample volume: min. 1 ml.

To measure the kinematic viscosity of the selected oils, the automatic Herzog HVU 482 apparatus was used, based on the Ubbelohde viscometer (Fig. 2). This device is characterised by the following key parameters:

- Temperature range for measurements: from –40 to +100°C
- Measurement range: depending on the capillary used, 1 to 50 000 mm²/s
- Thermostatic system: external, with a temperature regulation range of –80 to +20°C
- Temperature stabilisation accuracy: ±0.01°C.

This apparatus allows measurements to be performed in accordance with the following standards: PN-EN ISO 3104, ASTM D445, ASTM D2270, and DIN 51562.

Fig. 1. DMA 4500 M apparatus for density determination

Fig. 2. HVU 482 apparatus for determining kinematic viscosity

To evaluate the lubricity of the tested oils, a four-ball T-02U apparatus was used (Fig. 3), which consists of a testing machine and a measurement control system. The mechanical part of the apparatus is composed of a housing, a drive unit, a load unit for the friction assembly, a ball holding unit, and a base.

The friction assembly consists of three stationary lower balls clamped in a holder and an upper ball mounted in a rotating spindle (500 rpm). The test elements are standardised bearing balls with a nominal diameter of 1/2", made of bearing steel ŁH15 with a hardness of 60–65 HRC. The mechanical system enables a linear increase in the load on the friction assembly during the test (loading rate: 408.8 N/s).

Fig. 3. View of the test stand for lubricity evaluation with the T-02U four-ball apparatus

2.2. Test methodology

Basic parameters tests, that is, density, viscosity, and lubricity, were carried out for five oil samples (Fig. 4). The specifications of the oils tested are given in Table 1. One of them was a sample of "new" semi-synthetic SAE 10W40 engine oil, and for comparison, a sample of 5-year-old oil of the same grade, both unused and used during the break-in period of a 1.3 dm³ naturally aspirated spark ignition (SI) engine (mileage approx. 800 km). The next two samples were mineral SAE 30 oils, one new and the other after five years of storage. Both oils were unused. The selected oils are commonly used in older and newer generations of combustion engines, which allows for determining the area of application of these oils in selected engine designs and evaluating their impact on the operation and wear processes of lubricated friction pair elements.

Tests of selected anti-scuffing oil parameters (scuffing load) and (pressure of seizure) were performed using the T-02U four-ball apparatus at oil temperatures of 40 and 100°C (standard practice for calculating viscosity index from kinematic viscosity at 40°C and 100°C – international standard D2270-24) (Fig. 3). The recorded test curves allowed for the determination of (Scuffing load) and (Pressure of seizure) according to the methodology provided by the equipment manufacturer (parameter determination scheme shown in Fig. 6) [11].

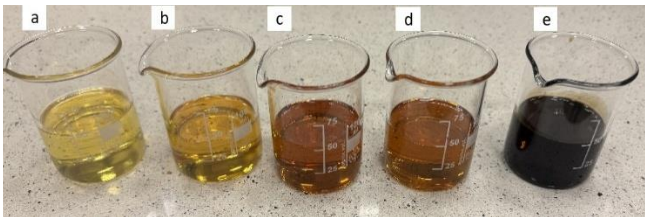

Fig. 4. Tested oil samples: a) SAE 30 old, b) SAE 30 new, c) SAE 10W40 old, d) SAE 10W40 new, e) SAE 10W40 used

The viscosity measurement device was controlled using dedicated HLIS 32 computer software (Fig. 5), with measurements performed using an NIR-type capillary (in accordance with the ASTM D 2162 standard).

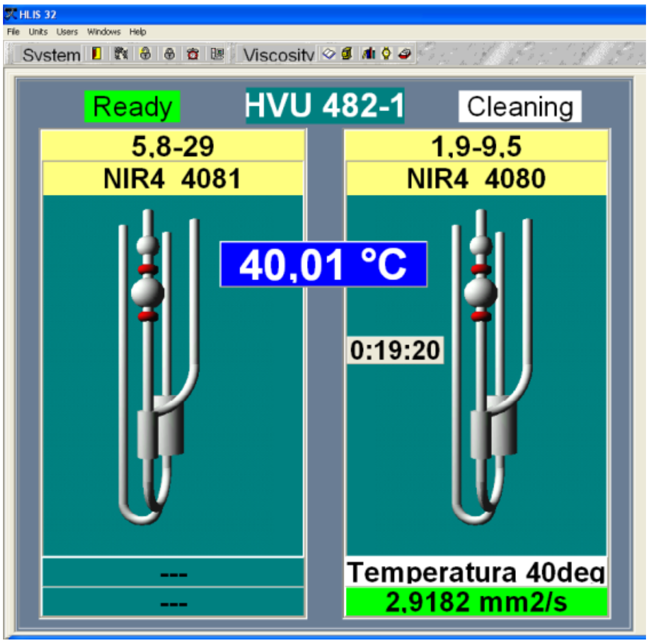

Fig. 5. HLIS 32 software windows with capillary identification and device status

Table 1. Characteristics of oil [19–21]

Lubricant	SAE 10W40	SAE 30
Parameter	Value	Value
Kinematic viscosity at 40°C [mm^2/s]	102.5	No data
Kinematic viscosity at 100°C [mm^2/s]	15	10.9
Viscosity index	153	91
	High performance Technosynthese® lubricant specially designed for cars powered by gasoline or diesel engines, naturally aspirated or turbocharged, indirect or direct injection. Standards: ACEA A3/B4, API SERVICE SN/CF	Mineral engine oil without additives (may contain depressants to lower the pour point). Application: in devices that do not require refined oil. Standards: PN-73/C-96085, API: SA, SAE: 30

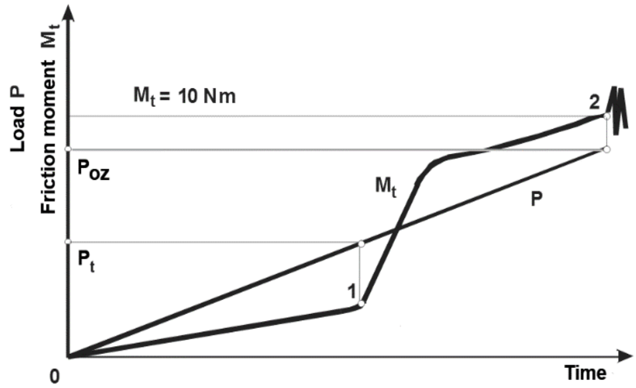

Fig. 6. Method for determining the scuffing load (P_t) and the seizure limit load (P_{oz}) [11]: 1 – point corresponding to the scuffing initiation, 2 – point corresponding to the seizure

3. Results and discussion

Oil tests revealed significant changes in anti-seizure properties, characterised by scuffing load (Fig. 7) and pressure of seizure (Fig. 8 and Table 2).

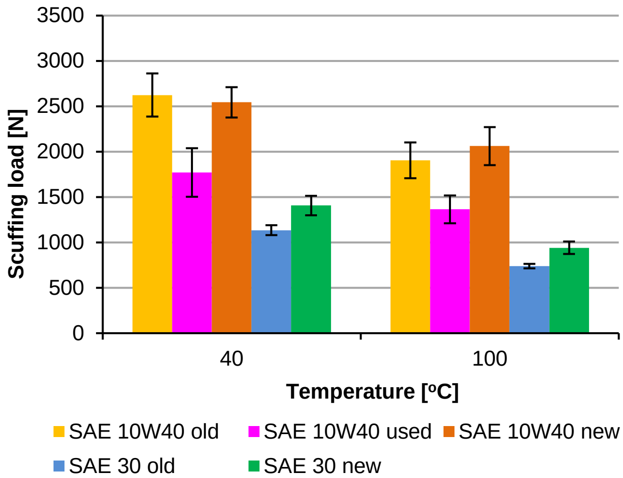

Fig. 7. Scuffing load of oil at temperatures of 40 and 100°C

The scuffing load values of the tested oils are significantly influenced by the temperature and the state of their wear. SAE 10W40 oil tests reveal substantial differences depending on the wear condition: for oil used in an internal combustion engine, a significant decrease in scuffing load (by approximately one-third compared to old and new oil) was observed at 40°C (Fig. 7). On the contrary, the comparison between old and new oil shows only a 3% difference in scuffing load, with higher values for old oil.

At 100°C, the scuffing load decreases by approximately 30% for old oil, 25% for used oil, and 20% for new oil. In particular, at this temperature, the new SAE 10W40 oil exhibits the highest resistance to the onset of scuffing initiation (~8% higher than the old oil), while the lowest resistance (at 40°C) was observed for engine-used oil (~34% lower than the new oil). For SAE 30 oil, new samples showed ~20% higher resistance to scuffing initiation than old samples at both 40°C and 100°C. Comparative analysis indicates nearly twice better anti-scuffing properties for SAE 10W40 versus SAE 30 oil (Fig. 7).

The pressure of seizure p_{oz} was calculated from the seizure limit load determined from the friction torque curves under increasing load at 40°C and 100°C (Table 3). Calculations demonstrate favourable tribological properties of the used SAE 10W40 oil, which exhibits nearly double the anti-seizure resistance of old/new oils at both temperatures (Fig. 8). New and old SAE 10W40 oils show comparable seizure load values. For SAE 30 oil, new samples had ~10% higher seizure load than old samples at 40°C, with marginal differences at 100 °C. The higher temperature reduced the seizure load by ~8% (old) and 18% (new).

In particular, SAE 30 oil showed ~30% lower seizure resistance than SAE 10W40 for both new and old states (Fig. 8).

Table 2. Pressure of seizure p_{oz}

Pressure of seizure p_{oz} [N/mm^2]						
Temperature	40 °C			100 °C		
Sample number	1	2	3	1	2	3
SAE 10W40 old	238.20	264.42	240.10	252.46	244.80	266.77
	Ø	247.57		Ø	254.68	
	σ	14.62		σ	11.15	
SAE 10W40 used	543.32	484.28	494.67	449.73	434.08	464.36
	Ø	507.42		Ø	449.39	
	σ	31.52		σ	15.14	
SAE 10W40 new	242.36	252.09	261.15	253.32	256.58	273.02
	Ø	251.87		Ø	260.97	
	σ	9.40		σ	10.56	
SAE 30 old	180.16	189.42	192.65	157.82	174.44	182.34
	Ø	187.41		Ø	171.54	
	σ	6.48		σ	12.52	
SAE 30 new	195.26	196.06	226.41	158.66	182.44	164.00
	Ø	205.91		Ø	168.37	
	σ	17.76		σ	12.48	

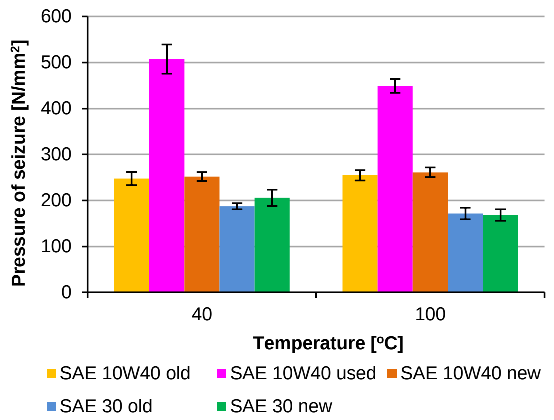

Fig. 8. Pressure of seizure of oil at temperatures of 40 and 100°C

The important key parameters for characterizing oil useful properties are kinematic viscosity and viscosity index (Fig. 9 and 10). At 40°C, the highest kinematic viscosity was measured for the new SAE 30 oil at approximately 100.5 mm²/s, while the lowest value was recorded for the old SAE 30 oil of the same grade, showing a 30% difference between these two oil conditions (Fig. 9).

For SAE 10W40 oil, the highest kinematic viscosity values were obtained for new oil (93.9 mm²/s), followed by old oil (87.8 mm²/s), and engine-used oil (72 mm²/s). At 100°C, the highest kinematic viscosities were measured for SAE 10W40 oil at 13.2, 12.1, and 13.9 mm²/s for old, used, and new oil, respectively. In comparison, SAE 30 oil showed lower values of 8.9 and 10.7 mm²/s for old and new oil.

Comparison of measured kinematic viscosity values with those specified in the oil data sheets revealed that for SAE 10W40 oil, viscosity was lower by 8.7 mm²/s at 100°C and 1.1 mm²/s at 40°C, while for SAE 30 oil, it was lower by 0.2 mm²/s at 100°C (Table 3).

Table 3. Kinematic viscosity

Temp. [°C]	SAE 10W40 old	SAE 10W40 used	SAE 10W40 new	SAE 30 old	SAE 30 new
	Kinematic viscosity [mm^2/s]				
40	87.8	72.0	93.9	69.5	100.5
100	13.2	12.1	13.9	8.9	10.7

Table 4. Viscosity index

SAE 10W40 old	SAE 10W40 used	SAE 10W40 new	SAE 30 old	SAE 30 new
Viscosity index				
151	166	152	102	89

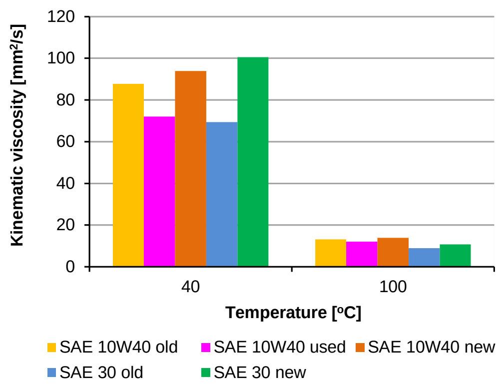

Fig. 9. Kinematic viscosity of oil at temperatures of 40 and 100°C

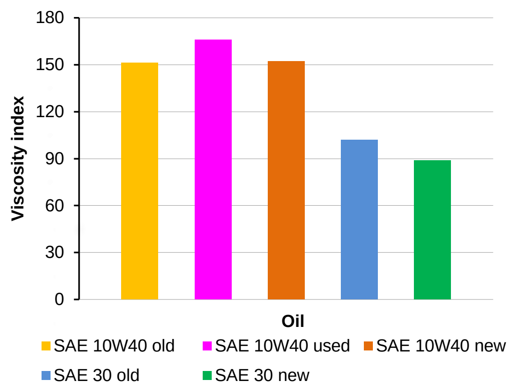

Fig. 10. Viscosity index of oil

Due to the minimal values of measurement uncertainties on the order of tenths of a unit, the error bars are not visible on the graphs in the adopted scale (Fig. 9 and 10).

The viscosity index calculations revealed the highest value for used SAE 10W40 oil (166), followed by lower and similar values for new and old oils of the same grade (152 and 151 respectively) (Fig. 10). For new SAE 30 oil, the viscosity index was 41% lower compared to new SAE 10W40 oil and 32% lower for old oils. The difference between new and old SAE 30 oils was approximately 13%.

Comparison of measured viscosity index values with those specified in the oil technical data sheets showed comparable results, with the SAE 10W40 being 1 unit lower and the SAE 30 being 2 units lower (Table 4).

The influence of temperature on the density of engine oils constitutes a crucial factor in evaluating their suitability for use in kinematic friction components of internal combustion engines operating under variable thermal conditions. Analysis of the graph (Fig. 11) showing density variations as a function of temperature for different SAE oil grades (SAE 10W40: new, used, old; and SAE 30: new, old) revealed a clear decreasing density trend with increasing temperature, characteristic of liquids.

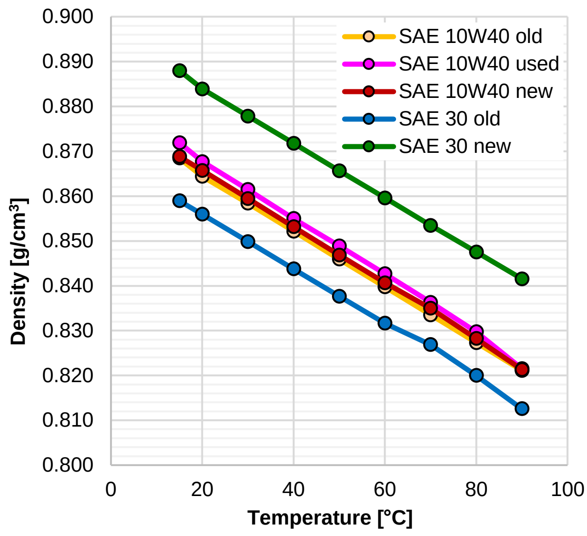

Fig. 11. Engine oil density [g/cm^3]

SAE 30 new oil is characterised by the highest density (from 0.888 g/cm³ at 15°C to 0.842 g/cm³ at 90°C). The new and old SAE 10W40 oil achieve similar values throughout the range, from 0.869 g/cm³ (15°C) to 0.821 g/cm³ (90°C), while its used version ranges from 0.872 to 0.821 g/cm³, slightly higher than previous versions. The lowest density is exhibited by old SAE 30 oil, whose density drops from 0.859 to 0.812 g/cm³.

Analysis of density changes in SAE 30 and SAE 10W40 engine oils as a function of temperature and their technical condition revealed noticeable differences for the oils tested. In the case of SAE 30, a decrease in density was observed in the old oil compared to the new one, ranging from 3.11% to 3.44% in the temperature range of 15 to 90°C, clearly indicating oil degradation due to ageing. The greatest differences were observed at higher temperatures, which may suggest a deterioration in the lubricating properties of the oil during engine operation under high temperature conditions.

For SAE 10W40 oil, the differences between the new, old, and used states were much smaller, ranging from 0.02% to 0.17%, which may indicate its higher density stability during use.

Actual trends in the changes in friction moment for the tested oils as a function of increasing continuous load on the friction pair (Fig. 12 and 13). The analysis of the friction moment trends showed that for the selected oils, seizure of the friction pair occurs at a load of 10 Nm [11] (according to the ITeE Standard). This applies to SAE 10W40 old oil (40°C, Fig. 12a), SAE 30 old and new oils at 40°C and 100°C (Fig. 12d, e and Fig. 13d, e).

However, in the case of SAE 10W40 old oil at 100°C (Fig. 13a) and SAE 10W40 used and new oils at 40°C and 100°C (Fig. 12b, c and Fig. 13b, c), the seizure of the friction pair occurred below 10 Nm [11].

The tests conducted demonstrated the need for careful lubricant selection. SAE 10W40 oil used in an internal combustion engine changed its operating properties, including due to fuel and exhaust gases entering the combustion chamber from the oil pan through piston ring leaks, the accumulation of contaminants resulting from the action of detergent-dispersant additives, and wear products of the engine friction pairs. These changes can reduce the scuffing load of used SAE 10W40 oil, as new SAE 10W40 oil enables the formation of a more durable boundary layer that protects the friction pair components from the beginning of the scuffing process (Fig. 7). The reverse relationship occurs in the case of scuffing resistance tests. The calculated values of the pressure of seizure are higher when the friction pair is lubricated with used SAE 10W40 oil (Fig. 8). Additives in engine oil, including anti-wear and anti-seize additives are activated during operation in an internal combustion engine as a result of chemical reactions occurring in the oil as a result of tribochemical processes, which may explain the increase in the pressure of seizure of used oil compared to new oil; additionally, oxidation processes occurring during the operation of the oil in the engine generate surface-active organic impurities, forming a boundary layer on the metal surface, improving the lubricating properties of the engine oil [2–5, 13, 16]. Storage factors affect the properties of engine oil and can lead to oil degradation, resulting in a deterioration of its lubricating, protective, and operational properties. Temperature, humidity, and air access are among the most important factors affecting changes in oil properties during long-term storage. These factors can cause oil oxidation and viscosity degradation or reduced corrosion protection, deposit formation, and additive precipitation, as well as reduced oil film durability [14].

4. Conclusions

Long-term storage of oils (5 years) leads to significant changes in their physicochemical properties, including viscosity, density, and scuffing resistance, although the degree of degradation depends on the type of oil.

Based on the test results of the engine oils, the following conclusions can be drawn:

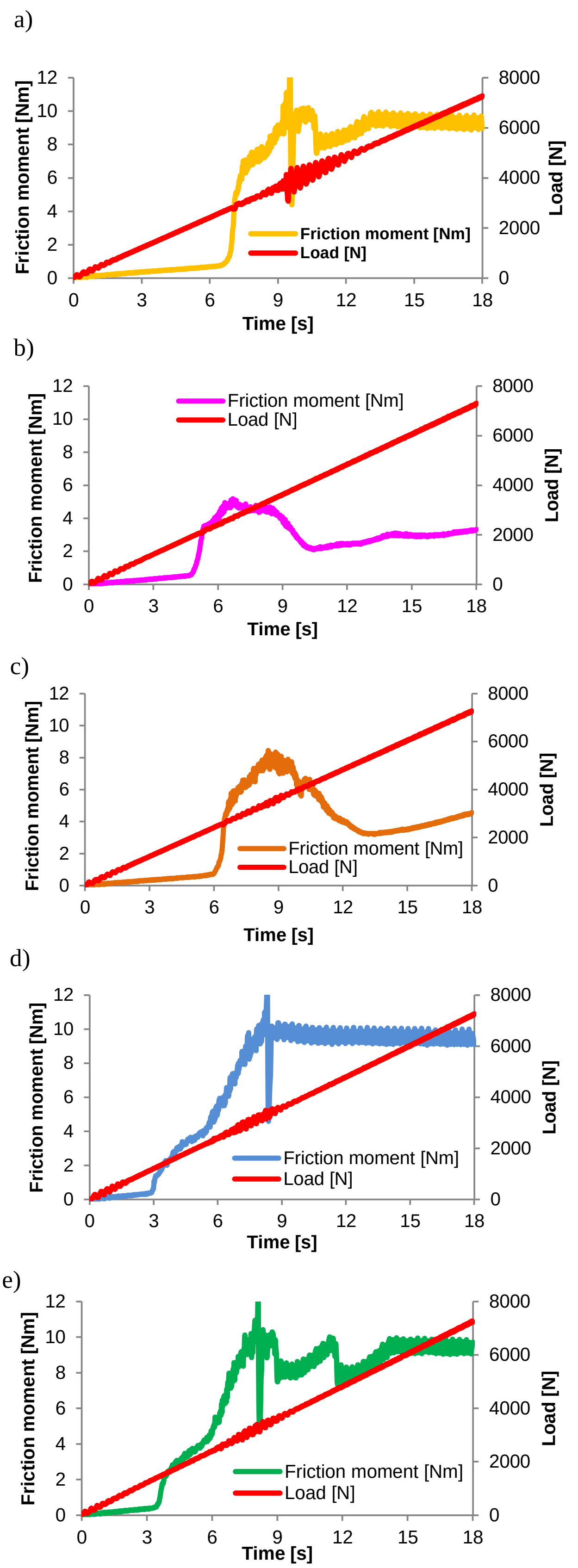

Fig. 12. Friction moment curve obtained under continuous load conditions of oil at temperatures of 40 °C: a) SAE 10W40 old, b) SAE 10W40 used, c) SAE 10W40 new, d) SAE 30 old, e) SAE 30 new

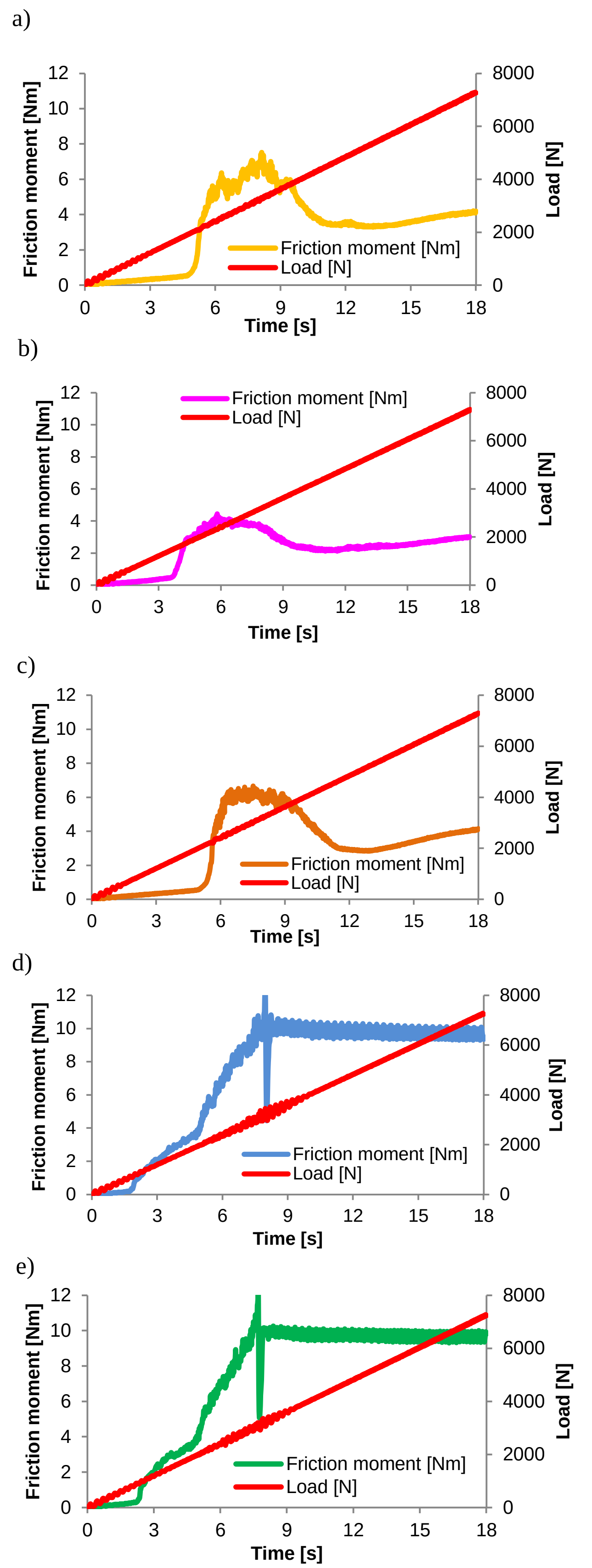

Fig. 13. Friction moment curve obtained under continuous load conditions of oil at temperatures of 100 °C: a) SAE 10W40 old, b) SAE 10W40 used, c) SAE 10W40 new, d) SAE 30 old, e) SAE 30 new

1. SAE 10W40 oil after use in an internal combustion engine shows a significant reduction in scuffing resistance (approximately one-third lower scuffing load compared to new and old oil). Long-term five-year storage also slightly reduces its scuffing resistance at higher temperatures. In contrast, long-term storage of SAE 30 oil significantly decreases its scuffing resistance across both tested temperature ranges (by about 20%).
2. Lubricating the friction zone with used SAE 10W40 oil increases scuffing resistance by nearly 50% compared to the new and old oil (particularly at lower temperatures). However, storage time has no significant effect on seizure pressure (this applies to both tested temperatures).
3. Kinematic viscosity measurements revealed notable changes at 40°C, where the new SAE 30 oil has the highest viscosity among all oils tested, while prolonged storage caused it to exhibit the lowest viscosity. For SAE 10W40 oil, the highest viscosity was measured in new oil, with a significantly lower value in engine-used oil and a slightly lower value after 5 years of storage.
4. SAE 10W40 oil has the most favourable viscosity index, while the new SAE 30 oil has the lowest. Storage time did not significantly alter the viscosity index of SAE 10W40, whereas old SAE 30 oil showed a slightly better index than new oil.

It would be advisable to modify the composition of SAE 30 oils (e.g., by adding anti-oxidant and anti-wear additives) to enhance their storage durability.

Further research on the impact of short-term use (break-in period) on oil properties would be beneficial, as it could optimise oil change intervals. The development of oil condition monitoring systems (e.g., real-time quality sensors) could help more accurately determine the optimal oil replacement time, especially for oils prone to ageing.

The study confirms that storage time and operating conditions significantly affect oil properties, with SAE 10W40 being more resistant to degradation than SAE 30. The findings have important industrial implications, highlighting the need for proper oil selection and monitoring of condition. Future research should focus on optimising oil formulations and developing methods for quality assessment during storage and operation.

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Krzysztof Lew, DEng. – Faculty of Mechanical Engineering and Aeronautics at Rzeszow University of Technology, Poland.

e-mail: *klew@prz.edu.pl*

Paweł Wojewoda, DEng. – Faculty of Mechanical Engineering and Aeronautics at Rzeszow University of Technology, Poland.

e-mail: *pwojewod@prz.edu.pl*

Janusz Lubas, DSc., DEng. – Faculty of Mechanical Engineering and Aeronautics at Rzeszow University of Technology, Poland.

e-mail: *lubasj@prz.edu.pl*