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Test of pure rape-seed oil suitability for lubrication of cutting system of chainsaw

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Abstract: *Test of pure rape-seed oil suitability for lubrication of cutting system of chainsaw.* The aim of the tests presented was to compare the temperature of the cutting system and cutting efficiency achieved when using pure rape seed oil and Pilarol oil (reference oil), for the sake of assessment of the usability of biodegradable rape-seed oil for lubrication of cutting system. The temperatures were measured with the use of a thermal imaging camera. The measurements were made with an electric chainsaw by Stihl, lubrication with rape-seed oil and Pilarol oil, dedicated to chainsaw (reference oil). It was concluded that given the insignificant differences in guide bar temperature and machining performance, pure rape-seed oil can be used for lubrication of cutting system.

Key words: chain saw, lubrication, cutters, cutting efficiency, guide bar heating

INTRODUCTION

About 90% of wood in Poland is obtained with the use of chainsaw [Kusiak 2012, Wójcik 2014], with the remaining 10% being cut with high-performance machining centres, such as harvesters. Although their use entails many risks [Brzózko and Skarżyński 2014], saws are still popular because of the high costs of purchase of machining centres [Nurek 2013]. As the relatively low purchase prices of new chainsaw make their replacement every 2 or 3 years affordable [Zychowicz 2009], fairly new machines are used, consistent with applicable standards for ergonomics and environmental safety. What chainsaw and harvesters have in common is that they both use a saw chain and have an open saw lubrication system, which means that once used, the oil is ejected on the ground and into the forest.

As assessed by different researchers, from 3.5 up to 4.5 million l of oil is used annually in the process of obtaining wood for lubrication of cutting system [Laurow 1999, Wojtkowiak 2004, Więsik 2005]. This much oil pollutes the environment. If the mineral oil used is not soil degradable (or old), the forest gets polluted with such oil. Wojtkowiak [2004] concluded that there were no significant counterindications against using vegetable oils for lubrication of cutting system. Commercial cutter lubrication oils that are available for sale, produced based on vegetable oils, are enriched by improvers which are not neutral to the environment and increase the price of the oil.

Among the methods of assessment of mechanical losses induced by friction is through measurement of the cutter temperature. As a result of friction between the saw and the guide bar's race, both elements get heated up. The nose of the guide bar is particularly exposed to heating, as here the temperature changes are the most dynamic, depending on the conditions in which the device is used. This is probably due to the significant friction force load from the saw (which moves in changing directions) and distance from the oil feeding site [Maciak 2009]. Guide bar's races heat up as well, due to the loss of energy to friction between the race and the chain saw [Wojtkowiak 2004].

The temperature of the cutting system also depends on the preliminary tension of the saw. The higher the saw tension, the higher the temperature, i.e. the friction-related energy losses [Maciak 2009].

Reduced intensity of lubrication of saw induces temperature growths, which is due to the less intense heat evacuation from the cutters by the greasing oil and increased friction. Nordfjell et al. [2007] proved in their research that if the oil flow intensity reaches 2 $cm^3 \cdot min^{-1}$, the guide bar temperature is by several degrees higher than at 6 $cm^3 \cdot min^{-1}$. Additionally, the growth of the guide bar's temperature is strictly connected with the duration of the machining [Wojtkowiak 2004]. Several research confirm that during the cutting process, the temperature initially rises whereupon it remains stable at a certain level. If the process is lengthy, the guide bar keeps heating up, but there are no longer any big temperature jumps. The heating time depends on the conditions in which the saw is used [Wojtkowiak 2004, Maciak 2009].

In his research of 2004, Wojtkowiak achieved the maximum temperature of guide bar of 105°C using mineral oils, while with pure rape-seed oil it was 94°C. As can be seen, the temperature was lower, where the cutting system were lubricated with rape-seed oil.

Nordfjell et al. [2007], in turn, proved that no significant differences between the maximum temperature of the cutting system were produced with the use of the two oils (rape-seed oil and mineral oil).

An important parameter to be used for comparing the saw's operation in different conditions is the cutting efficiency per area, i.e. the quotient of the lateral area of the kerf and the time of cutting. The parameter is considered to be one of the crucial parameters defining chain saw use. Additionally, cutting efficiency can also be affected by other factors such as engine parameters, chain saw parameters, saw's linear speed, the type and properties of wood, skills and experience of the operator, preliminary tensioning of the saw, kerf height or cutter greasing intensity [Górski 1993, Więsik 2005].

The aim of the research was to compare the temperature of the cutting system and cutting efficiency achieved with the use of pure rape-seed oil and Pilarol oil (used for reference).

MATERIAL AND METHODS

The tests were performed in two different seasons of the year. The first series was carried out in summer, with out--door temperature of ca. 23°C, while the second one was performed in winter, at ambient temperature of about 0°C. The tests were performed with a chainsaw Stihl MSE 180C fitted with a single-phase motor (rated voltage: 230V; horsepower: 1.8 kW). The chainsaw's weight (without the guide bar) equals 3.5 kg. The chainsaw is fitted with an automatic lubrication system, and the oil tank capacity equals 0.2 l. The tests were carried out with an electric chainsaw, since, unlike petrol chainsaws, it has no elements prone to high heating, such as a cylinder or attenuator, which could interfere with temperature measurements with a thermal imaging camera.

The chainaw has been fitted with a 14-inch long RolloMatic guide bar with a star-shaped sprocket and a Picco Micro chain saw, 3/8 P; drive link thickness of 1.3 mm, and 25 cutting links. The saw chain was tensioned in such a way that after a 20 N load was put on the saw, at the midpoint of the guide bar's length, the distance between the lower edge of chain links and the guide bar race equalled 5 mm.

Newly-cut oak wood logs were used for the testing, with absolute moist content (in relation to dry mass) of 56.12% (summer) and 47.03% (winter).

Moist content was determined with the use of a RADWAG WPS 210 S moisture analyser. Weighing accuracy equalled 0.01%. During the tests, the wood was placed on a trestle and immobilised with a belt. The diameter of the logs machined ranged from 24 to 26.5 cm.

Thermograms of the cutting system were made with a thermal imaging camera, VIGOcam v50. The camera is fitted with a detector of 384 × 288 pixels (which converts radiation into electric signal), with a single pixel sized 35 × × 35 μm. Thermal resolution of the device equal 0.07°C. Accuracy of the camera measurements equals ±2°C of ±2% of the measurement range. The guide bar's thermograms were analysed in the THERM 2.29.3 software, which enables the deciphering of the minimum, maximum and average temperature of the cutters. The software attached is suitable for analysing the thermograms obtained. To do this, histograms of the percentage of individual temperatures in the overall surface of the guide bar were made.

The tests were performed with an ordinary cooking rape-seed oil and Pilarol, i.e. oil dedicated to chainsaws, which was used for reference. Table 1 shows the parameters of the oils used.

The rape-seed oil used for the tests was a 100% biodegradable, ordinary cooking oil bought at one of the stores of a large retail chain. Pilarol oil, which is recommended for chain saws, is produced based on deeply refined mineral oil with improvers added (www.orlenoil.pl).

TABLE. Parameters of oils used in the tests [Wojtkowiak 2004]

Properties	Rape-seed oil	Pilarol oil
Kinematic viscosity at 100°C [$mm^2 \cdot s^{-1}$]	7.96	9.35
Kinematic viscosity at 40°C [$mm^2 \cdot s^{-1}$]	75.6	64.9
Viscosity index	212	122
Flash-point [°C]	225	242
Flow temperature [°C]	–30	–31

The summer and the winter tests were carried out using the same method. Three measurement series were performed for each oil, 20 kerfs in a series. According to the preliminary measurements, such a number of series was enough to stabilise the cutter temperature. The results show the average values from three series of measurements.

Wood diameter was measured before each series of tests with a section gauge, with accuracy of 0.5 cm. The diameter was measured in two perpendicular planes. The average value was assumed for kerf area calculations. The machining time of each kerf was measured with a stop-watch (accuracy: 0.01 s). The time was measured from the start of the machining process until the separation of the element from the log. A photo of the cutters was made after each kerf with the thermal imaging camera. The machining direction was perpendicular to the wood fibres. The saw was sharpened and the cutters were cooled to ambient temperature between individual series of measurements. The cutting efficiency per area – W (defined as the quotient of the lateral area of the kerf and the time of cutting) was calculated based on the following formula:

$$W = \frac{\pi \cdot d^2}{4 \cdot t} \quad [cm^2 \cdot s^{-1}]$$

where:
d – wood diameter [cm];
t – time of cutting [s].

The results obtained were compared and subjected to statistical analysis in Statistica v. 10. Statistical analysis was to calculate average, standard deviations and the statistical significance of differences between data sets. The level of significance $\alpha = 0.05$.

RESULTS AND DISCUSSION

Based on the analysis of the thermograms obtained, it can be concluded that in each case, the highest temperatures were recorded on the guide bar's race and nose. Figure 1 shows a comparison of maximum and average temperatures of the cutting system after 20 kerfs, made with the use of rape-seed oil and Pilarol oil.

During the summer measurements, made with the use of rape-seed oil, the maximum temperature of the cutting system was slightly higher than when

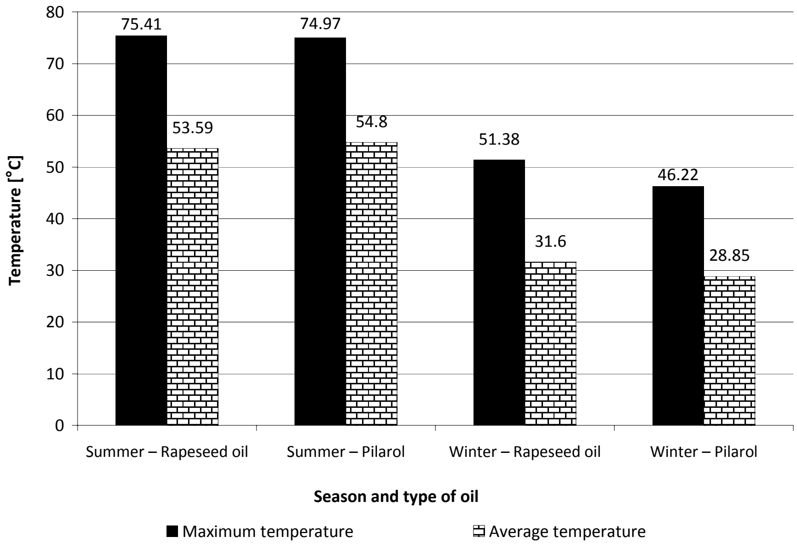

FIGURE 1. Comparison of maximum and average temperatures of the cutting system after 20 kerfs

Pilarol oil was used, but the difference between the temperatures equalled only 0.44°C. Average temperatures of the cutters for both oils were quite similar in summer, but the average temperature recorded on the guide bar was by 1.21°C lower when rape-seed oil was used. Nevertheless, the statistical difference between both values was insignificant ($P = 0.78$).

In winter, lower maximum and average guide bar race temperature was obtained with Pilarol, with the respective differences between the two oils amounting to 5.16 and 2.75°C. Although the difference between average temperatures was still insignificant ($P = 0.53$), it was higher than in summer.

Figures 2 and 3 show the percentage share of individual temperatures in the guide bar's surface after 20 kerfs.

In winter, where rape-seed oil was used for lubrication (Fig. 2) the biggest area within the guide bar (29%) was the area within the range between 15 and 24°C, with 26% reaching 24–33°C. Temperatures ranging from 33–41°C and 41–50°C covered both 22%. Only 1% of the area reached the temperature of 50–59°C.

Where Pilarol oil was used for lubrication in winter (Fig. 2), 36% of the guide bar area was within a temperature range between 15 and 24°C. Temperatures of 24–33°C were recorded within 27%, while 33–41°C on 24% of the guide bar surface. When used with Pilarol, the saw developed slightly lower temperatures than with rape-seed oil. With rape-seed oil, temperatures between 15 and 24°C covered an area which was by 7% smaller than with oil dedicated to saws. With

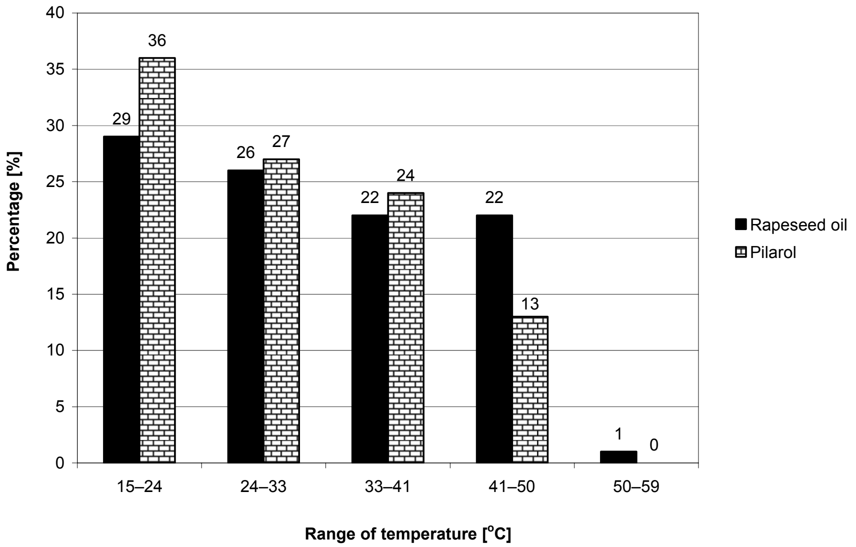

FIGURE 2. Percentage share of individual temperature ranges in the guide bar's surface in winter, for rape-seed oil and Pilarol

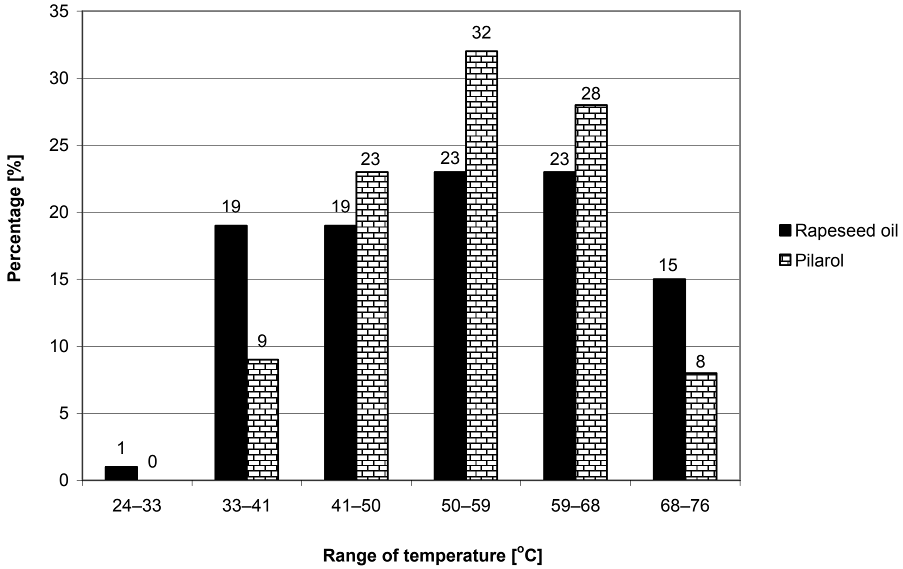

FIGURE 3. Guide bar surface with individual temperature ranges for lubricated with rape-seed oil and Pilarol oil in summer

both oils, temperatures of 24–33°C were reported on a similar surface area, with a difference of 1% only (26% for rape-seed oil, 27% for Pilarol). The share of surfaces with temperatures 41–50°C, in turn, differed significantly: 22% for rape-seed oil and 13% for Pilarol.

Where Pilarol was used in winter, a bigger portion of the guide bar surface had lower temperatures and a smaller portion of the surface was characterised by higher temperatures, when compared to rape-seed oil. These differences, however, do not disqualify rape-seed oil as a saw cutter greaser. The maximum and average temperature of the guide bar did not differ much (the difference was 5°C for maximum temperatures and ca. 3°C for average temperatures), and the temperatures reached by guide bars lubricated with rape-seed oil were not too high and their level was comparable as for Pilarol. While analysing the chart in Figure 2, it can be noted that the guide bar surface heated up more evenly, when rape-seed oil was used.

When rape-seed oil was used for lubrication of cutting system in summer (Fig. 3), the biggest part of the bar surface, i.e. 23%, was within the range of 50–59°C, while 23% was between 59 and 68°C. In summer, higher temperatures were reported across the entire surface of the cutting system, which is logical, as the ambient temperatures were higher.

Where Pilarol was used for lubrication in summer (Fig. 3), the prevailing portion of the guide bar surface (32%) reached the temperature of 50–59°C. By using rape-seed oil in the same testing conditions, a bigger portion of surfaces between 68 and 76°C was reported than with the use of Pilarol, by 15 and 8%, respectively. In summer, a bigger percentage of bar surfaces with higher temperatures was obtained with Pilarol. The biggest difference, of 9%, was reported for the temperature range 50–59°C, which covered 23 and 32% of the guide bar surface for rape-seed oil and Pilarol, respectively. For lower temperature ranges (33–41°C), the surface of the cutters with such temperatures was bigger by 10% than with the use of Pilarol-greased cutters.

The higher percentage of surfaces with lower temperatures, obtained with rape-seed oil, favours its selection. No significant temperature differences were discovered within the bar surface, as it heated up evenly. With Pilarol, in turn, there were broader surfaces with higher temperatures, and the bar heated rather unevenly. The difference between the maximum bar temperatures (Fig. 1) for both oils tested was insignificant. Average temperatures for the entire guide bar surface were similar, but still, lower values were obtained with rape-seed oil.

Table 2 shows a comparison of the cutting efficiency obtained in summer and in winter with lubrication of cutting system with different types of oil. In summer, higher cutting efficiency (51.13 $cm^2 \cdot s^{-1}$) was obtained with rape-seed oil. For Pilarol, the value equalled 48.02 $cm^2 \cdot s^{-1}$. The difference was statistically significant. In winter, higher cutting efficiency was in turn obtained with Pilarol (50.47 $cm^2 \cdot s^{-1}$) than with rape-seed oil (47.31 $cm^2 \cdot s^{-1}$). The difference was statistically significant too.

TABLE 2. Cutting efficiency per area – comparison

Season of the year	Type of oil used	Average machining performance [$cm^2 \cdot s^{-1}$]	Standard deviation [$cm^2 \cdot s^{-1}$]
Summer	rape-seed oil	51.13	1.08
	Pilarol	48.02	1.09
Winter	rape-seed oil	47.31	1.88
	Pilarol	50.47	1.23

On warm days, it is good to use rape-seed oil to grease saw cutters, as the difference between the maximum and average temperatures of the guide bar were insignificant, while cutting efficiency was higher when Pilarol was used. In winter, however, the average cutting efficiency for Pilarol was only by 6% higher and there were no significant changes in temperatures.

Some researchers [Wojtkowiak 2004] maintain that the use of pure rape-seed oil has a negative impact on cutting system's durability. The cause of wear is friction. Which results in an increase in the temperature of the cutting system. In the described studies, no excessive heating of the cutting system was found when using pure rape-seed oil. Influence use of pure rape-seed oil on the cutting system durability requires further investigation.

The authors did not conduct research on differences in durability of the cutters for the two oils. Such tests should nevertheless be performed to verify the results obtained by other researchers, and unambiguously confirm the suitability of rape-seed oil for lubrication of cutting system.

SUMMARY AND CONCLUSIONS

1. When rape-seed oil was used for lubrication of cutting system, the guide bar reached slightly higher maximum temperatures than with Pilarol, in the same working conditions. Differences between average temperature values were not statistically significant.
2. The guide bar heated up more evenly when rape-seed oil was used than with Pilarol.
3. The highest temperature was recorded on the guide bar's nose.
4. In summer, the cutting efficiency was higher when rape-seed oil was used for lubrication of cutting system saw, while in winter, higher cutting efficiency was obtained with Pilarol.
5. As the differences in guide bar's temperatures and cutting efficiency were insignificant, it can be concluded that pure rape-seed oil can be successfully used for lubrication of cutting systems, especially in summer.
6. Durability tests of the saw chain are recommended in order to unambiguously confirm suitability of pure rape-seed oil for their lubrication.

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Streszczenie: *Badanie przydatności oleju rzepakowego bez dodatków uszlachetniających do smarowania układów tnących pilarek.* W artykule przedstawiono wyniki badań mających na celu ocenę możliwości użycia biodegradowalnego oleju rzepakowego do smarowania układów tnących pilarek łańcuchowych. Badania polegały na porównaniu temperatur osiąganych przez prowadnicę pilarki oraz wydajności skrawania pilarki. Do pomiaru temperatury układu tnącego wykorzystano kamerę termowizyjną. Badania prowadzono na pilarce elektrycznej marki Stihl z użyciem oleju rzepakowego bez dodatków uszlachetniających oraz oleju dedykowanego dla pilarek Pilarol, który był olejem porównawczym. W wyniku badań stwierdzono, że nieznaczne różnice uzyskiwanej temperatury prowadnicy i wydajności pozwalają wnioskować, że czysty olej rzepakowy może być stosowany do smarowania układów tnących pilarek.

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