Changes in the External Speed Characteristics of Chainsaw Engines with the Use of Mineral and Vegetable Oils

Alois Skoupy, Radomir Klvac, Seyedmohammad Hosseini

Abstract – Nacrtnak

Similarly to many other countries, the use of biologically degradable oils in forestry is also addressed by the Czech law. Several studies point out several technical problems regarding such regulations. It has not been demonstrated so far whether for example biologically degradable engine oils used for chain saw lubrication from mixture may be the cause of an excessive engine wear or deterioration of the combustion process and hence increased contamination of air inhaled by the operator. An experimental laboratory measurement was taken for the purpose of determining the external characteristics of a common chain saw engine at a brake stand, which enabled exact measurement of differences in engine output, fuel consumption and composition of exhaust gases (CO, CO₂, and HC), namely in dependence on the type of oil and the blending ratio. The results of the laboratory tests did not reveal any statistically significant differences between the oils in any of the measured criteria. The theory of workers based on practical experience that some oils may cause clogging of the fine fuel filter in the carburettor and that increased carbon sedimentation occurs in the engine exhaust duct was neither displaced by evidence, nor corroborated. Its refutation or confirmation would only be possible on the basis of a longer service test.

Keywords: biologically degradable engine oil, two-stroke engine, speed characteristic, composition of exhaust gases, laboratory testing

1. Introduction – Uvod

In order to reduce negative impacts of leakages from operational fuel charge of forest machines, several countries have taken the step of replacing mineral products by vegetable-based lubricants and fuels. These substances are expected to have much faster degradation characteristics in the natural environment.

Lauhanen et al. (1998), among others, assessed the possible effects of mineral oil on the forest environment in the course of several years. They calculated that during motor-manual felling of 200 m³ of merchantable timber volume per hectare a chain saw consumes 20 litres of lubricating oil, which leaks into the forest environment. Their overall estimate of the amount of such oil spilt into the forest environment in Finland amounts annually to 2 million litres. Wightman et al. (1999) evaluated and compared relative environmental impacts and socio-economic costs of several types of oil produced in the Great Britain from rape or on mineral basis in a model case study concerning oils for chain lubrication of chain saws with the use of the LCA (Life Cycle Assessment) and CBA (Cost Benefit Analysis) methods.

Only few authors analysed the impact of the exhaust gases composition of two-stroke engines according to the type of fuel or oil used to lubricate from mixture.

Apparently the adjustment of the carburettor should be carried out in full compliance with the prescribed conditions, and the engine should be kept at nominal running speed by working load and experience of the operators rather than by structural design of the engine, both affecting the quantity and composition of the exhaust gases. Idle speed (as well as maximum speed without loading) increases the proportion of incompletely combusted hydrocarbons – HC and CO (Wojcik and Skarzynski 2006).
Testing two-stroke engines for different types of fuel – aliphatic petrol with synthetic lubricating oil and traditional unleaded petrol in combination with mineral lubricating oil – proved that if a mixture of petrol with mineral oil is used, the content of hydrocarbons in the exhaust gases is 5–10 times higher compared to the synthetic mixture (Magnusson et al. 2000a). However, it is the type of used petrol rather than the lubricant oil that makes a significant difference (Magnusson et al. 2000b).

2. Material and methods – Materijal i metode

The first stage of the testing methodology for two-stroke engine lubricating oils used in chain saws and brush cutters was based on a simple comparison of the basic speed characteristics for engines of a specific type in using various oils with different blending ratios. External speed characteristics of the engine were designed in line with the applicable standards ČSN 30 2008 »Automobile engines – Tests at a brake stand« and ISO 7293 »Forest machinery – Portable chain saws – Engine performance and fuel consumption«.

The test compared the behaviour of torque, actual engine output, specific consumption and consumption per hour, engine temperature below the spark-plug and concentration values of CO, CO₂, and HC in exhaust gases under specific conditions.

All tests were carried out on a chain saw, whose engine can be characterized according to the following technical documentation:

⇒ engine type: reciprocating piston,
⇒ operating mode: ignition engine,
⇒ working cycle: two-stroke,
⇒ number of cylinders: 1,
⇒ arrangement: upright,
⇒ calibre: 50.0 mm,
⇒ stroke: 34.0 mm,
⇒ total cubic capacity: 66.7 cm³,
⇒ cooling – by air, crankshaft fan,
⇒ nominal speed: 8500 revs. per minute,
⇒ idle speed: 2500 revs. per minute,
⇒ centrifugal clutch switching speed: 3500 revs. per minute,
⇒ carburettor: floatless, TILLOTSON HS 234 A,
⇒ basic setting of the pilot jet: 1.0 revolution,
⇒ basic setting of the main jet: 1.0 revolution.

This engine was selected deliberately because no accurate and repeatable measurements would be attainable for smaller higher-speed engines under the given laboratory conditions (see below).

The following machines and apparatuses were used during the actual testing that took place in the testing lab for combustion engines at Brno Technical University:

⇒ electric eddy-current brake SCHENCK W 40,
⇒ thermometer THERM 5500 – 3,
⇒ exhaust gases analyser SUN SGA 9000 – measures the volume of CO, %, CO₂, % and HC, ppm,
⇒ calibrated vessel of 25 cm³ for measuring fuel consumption.

The chain saw required several modifications for adjusting it to the brake stand prior to the start of testing, which facilitated its firm fixing on a special clamping table. The following parts were removed from the chain saw:

⇒ front handgrip,
⇒ clutch case,
⇒ chain catcher,
⇒ centrifugal clutch,
⇒ chain tensioning pin,
⇒ oil pump,
⇒ spring-loaded handgrip part with the fuel tank and rear handgrip,
⇒ fuel inlet tube.

The chain saw had to be fitted with the following special parts required for its proper functioning:

⇒ control mechanism of the carburettor throttle valve,
⇒ GUFERO gasket ring in a special casing used to seal the crankcase.

Several parts of the chain saw had to be adjusted to allow for the installation of scanning sensors of the measuring instruments:

⇒ exhaust silencer was adjusted for sampling of exhaust gases; a hole was drilled in the silencer to which a tube fitting was soldered,
⇒ sealing below the ignition coil was modified for the connection of thermometer sensors.

After these modifications were completed, the fastening screws on the tested saw bar of the chain saw were firmly bolted to a specially adjusted test bench by two nuts. The chain saw was also fastened by the openings used for attaching the flexible elements of the antivibration system to prevent possible damage to the saw due to vibrations or other mechanical impacts during the test. The openings were reinforced crosswise by two spacers welded to a steel strip connected to the mandrel. Rotational movement of the chain saw along the crankshaft axis was forestalled by pins fastened in places where the complex chain saw construction (chiefly the engine block) allowed it. The chain saw was then connected to the
electric eddy-current brake SCHENCK W 40 by means of a transmission shaft over a fast coupling, expansion axial coupling and Hardy flexible coupling. An external fuel feed and external control of the throttle valve were connected to the chain saw. HOTTINGER sensor was used to measure the retarding force value required for the calculation of the engine torque.

The actual measurements were taken in the range between 4000 and 9000 revolutions per minute (each measurement was performed with a speed increase in steps of 1000 revolutions). During each measurement cycle, individual measurements were carried out when the values became stable. Each cycle was repeated four times. Arithmetic means were calculated for all monitored variables from individual measurement results. These were used for the calculation of the standardized variables (ČSN 30 2008) of the corrected actual torque, actual output, corrected actual output, fuel consumption per hour and specific fuel consumption.

The following formulas were used for the calculations:

\[ M_{t\text{ kor}} = M_t \frac{1013}{p_a} \left( \frac{273 + t_a}{273 + 20} \right)^0.5 , \text{Nm} \] (1)

Where:
- \( M_t \) measured torque, Nm
- \( p_a \) atmospheric pressure, hPa
- \( t_a \) air temperature, °C

\[ P_e = \frac{M_t \times n}{9550}, \text{kW} \] (2)

Where:
- \( M_t \) measured torque, Nm
- \( n \) engine revolutions, revs. per minute

\[ G_t = \frac{3.6}{V_{m,s}} V_t \frac{m_p}{m} \times \delta_p \cdot g \cdot h^{-1} \] (4)

Where:
- \( V_m \) volume of the measuring vessel, ml
- \( \delta_p \) fuel density, g/cm³
- \( t_m \) time necessary for consuming the volume \( V_{m,s} \), s

\[ g_e = \frac{G_t \times 1000}{P_e}, \text{g.kWh}^{-1} \] (5)

### 3. Results – Rezultati

The above method was used to determine the values of torque, air intake temperature, CO, CO₂ and HC concentration in the exhaust gases and the time required for the consumption of 25 ml of the fuel mixture. The values of the corrected torque, net and corrected outputs, fuel consumption per hour and specific consumption were calculated. The measured and calculated data were recorded in tables as shown in Table 1, where it can be seen that each measurement series was repeated four times for each oil type and blending ratio for the whole speed range.

The results of the Husqvarna 266 SE engine speed characteristics were subsequently subjected to statistical processing. Regression calculations were per-

**Table 1** Behaviour of HC concentration in exhaust gases

<table>
<thead>
<tr>
<th>Measurement</th>
<th>M_t</th>
<th>M_{t kor}</th>
<th>P_e</th>
<th>P_{e kor}</th>
<th>Time Vrijeme</th>
<th>( g_e )</th>
<th>( \delta_p )</th>
<th>%</th>
<th>%</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.6</td>
<td>3.64</td>
<td>1.51</td>
<td>1.53</td>
<td>60.88</td>
<td>1.050</td>
<td>696</td>
<td>19.6</td>
<td>1,000</td>
<td>4.70</td>
</tr>
<tr>
<td>2</td>
<td>3.7</td>
<td>3.74</td>
<td>1.55</td>
<td>1.57</td>
<td>61.04</td>
<td>1.047</td>
<td>676</td>
<td>19.5</td>
<td>1,000</td>
<td>4.63</td>
</tr>
<tr>
<td>4</td>
<td>3.7</td>
<td>3.73</td>
<td>1.55</td>
<td>1.56</td>
<td>61.11</td>
<td>1.046</td>
<td>675</td>
<td>20.6</td>
<td>1,007</td>
<td>4.58</td>
</tr>
<tr>
<td>4</td>
<td>3.7</td>
<td>3.73</td>
<td>1.55</td>
<td>1.56</td>
<td>61.18</td>
<td>1.044</td>
<td>674</td>
<td>20.5</td>
<td>1,007</td>
<td>4.51</td>
</tr>
<tr>
<td>Average Prosjek</td>
<td>3.7</td>
<td>3.71</td>
<td>1.54</td>
<td>1.55</td>
<td>61.05</td>
<td>1.047</td>
<td>680</td>
<td>20.1</td>
<td>1,004</td>
<td>4.61</td>
</tr>
</tbody>
</table>

**Used Oil – Uporabljeno ulje**

<table>
<thead>
<tr>
<th>Blending ratio – Omjer mješavine</th>
<th>2T/6</th>
<th>Engine: Husqvarna 266 SE – Tip motorne pile: Husqvarna 266 SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed – Brzina</td>
<td>4,000 revs./min – 4000 okr./min.</td>
<td></td>
</tr>
</tbody>
</table>
formed for the behaviour of individually measured variables for all six tested fuel mixtures. The behaviour of individual parameters depending on the engine speed was best expressed by the functions:

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5$$  \hspace{1cm} (6)

or

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4$$  \hspace{1cm} (7)

Only in the case of CO₂ concentration during the test of MOGUL TS oil mixture in combination with BA 90 petrol in the ratio of 1:40 the following function proved to be more suitable:

$$y = a_0 + a_1 \ln(x) + a_2 \ln(x)^2 + a_3 \ln(x)^3 + a_4 \ln(x)^4 + a_5 \ln(x)^5$$  \hspace{1cm} (8)

The specific coefficients of functions of approach, reached correlation indexes and extreme values of functions – i.e. the maxima during specified engine revolutions – were calculated on the basis of this formula. The minimum was expressed only in the case of specific fuel consumption.

The above stated dependencies were calculated from all of the measurement series. Mean error did not exceed 3% with the majority of criteria. Only the measurements of noxious substances emissions in exhaust gases usually showed higher mean error values; the mean error value for the CO₂ concentration once reached nearly 10%.

Further to the above statistical assessment results, it can be said that very good measurement repeatability was achieved and that the engine oils can be evaluated on the basis of the method that compares the speed characteristics.

It can be, therefore, stated that for example the torque value does not correlate with the blending ratio, while it seems that the lower the concentration of oil in the mixture, the lower the actual output. In comparison to the mixture containing the OA M6A oil, the maximum output in the case of the 2T/6 vegetable oil was generally lower, while it was higher when compared to the mixture with the MOGUL oil.

These and other possible dependencies can be established from the correlation matrices in shown in Tables 2 through 4.

The above tables show mutual correlation indexes between the engine speed, engine temperature and air intake temperature based on the type of used motor oils; the behaviours of noxious agent concentrations are assigned to the correlation indexes. The table for the 2T/6 oil also specifies the dependencies on the blending ratio and atmospheric pressure, which underwent significant changes during the measurements of these motive fluids.

It is particularly significant that CO₂ concentration depends more on the air intake temperature and on the engine temperature (in the case of the 2T/6 oil also on the air pressure) than on the engine speed. CO concentration is closely linked to engine temperature with all of the tested oils.

<table>
<thead>
<tr>
<th>OA M6A</th>
<th>Speed</th>
<th>Engine temperature</th>
<th>Intake temperature</th>
<th>CO concentration</th>
<th>CO concentration</th>
<th>CO concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.000</td>
<td>0.8140</td>
<td>0.0194</td>
<td>0.9155</td>
<td>0.4187</td>
<td>-0.9575</td>
</tr>
<tr>
<td></td>
<td>0.8140</td>
<td>1.0000</td>
<td>-0.0868</td>
<td>0.6867</td>
<td>0.7201</td>
<td>-0.7998</td>
</tr>
<tr>
<td></td>
<td>0.0194</td>
<td>-0.0868</td>
<td>1.0000</td>
<td>0.1153</td>
<td>-0.5303</td>
<td>-0.0864</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MOGUL TS</th>
<th>Speed</th>
<th>Engine temperature</th>
<th>Intake temperature</th>
<th>CO concentration</th>
<th>CO concentration</th>
<th>CO concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.000</td>
<td>0.9139</td>
<td>0.0639</td>
<td>0.8870</td>
<td>0.4352</td>
<td>-0.8605</td>
</tr>
<tr>
<td></td>
<td>0.9139</td>
<td>1.0000</td>
<td>0.0064</td>
<td>0.8277</td>
<td>0.6143</td>
<td>-0.8157</td>
</tr>
<tr>
<td></td>
<td>0.0639</td>
<td>0.0064</td>
<td>1.0000</td>
<td>0.1517</td>
<td>-0.5768</td>
<td>-0.3441</td>
</tr>
</tbody>
</table>
CO and HC concentrations are dependent on engine speed and – due to close dependence of the engine temperature on its speed – also on engine temperature.

It is rather surprising that the oil blending ratio does not significantly affect any of the noxious substances concentrations in exhaust gases.

Fig. 1 is the example of a graphic representation of the results, showing that with the increasing engine speed the combustion of the HC motive fluid improves with respect to the HC volume.

4. Conclusion – Zaključci

Evaluation according to changes in the external speed characteristics of engines at a brake stand is a standard assessment method during engine oil testing. Statistical evaluation revealed that a very good measurement repeatability was achieved by way of this method. The conclusions arising from the results specified in this paper are as follows:

⇒ engine torque value does not correlate with oil blending ratio in the fuel,
⇒ actual engine output probably drops with decreasing oil concentration in the fuel,
⇒ maximum output is lower when vegetable oils are used as opposed to mineral oils,
⇒ CO₂ concentration is more dependent on air intake and engine temperatures than on engine speed with all of the tested oils; air pressure is a significant factor in the case of BIO 2T/7 MIX oil,
⇒ CO concentration is closely linked to engine temperature with all of the tested oils,
⇒ CO and HC concentrations depend on engine speed and – due to very close dependence of the engine temperature on its speed – also on engine temperature,
⇒ blending ratio does not substantially affect the concentration of any of the monitored components of exhaust gases.

We believe that despite the achieved accuracy, the results do not correspond to generally held assumptions such as that the decreasing concentration of oil in the fuel causes the content of noxious agents in exhaust gases to fall and the engine output to grow. It is further surprising that the OA M6A oil, a traditional motor oil now only used for veteran cars, seemed to have the best qualities, while the MOGUL TS oil, a specially developed oil for two-stroke engines with high working loads, ranked worst. This was probably caused by the dependence on oil concentration rather than on its quality. It can be, therefore, stated that all of the tested fuel mixtures can be used for a trouble-free operation.
Acknowledgment – Zahvala

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5. References – Literatura


Sažetak

Promjene brzinskih značajki motora motornih pila pri uporabi mineralnih ulja i ulja biljnog podrijetla

U nastojanju da se smanji negativan utjecaj izlijevanja goriva iz spremnika šumskih strojeva više je zemalja počelo zamjenjivati mineralna goriva i ulja gorivima i uljima biljnog podrijetla koji se brzo razgrađuju u prirodi.

U Republici Češkoj, kao i u ostalim zemljama, uporaba je biorazgradivih ulja u šumarstvu propisana zakonima. Nekoliko studija ističe tehničke probleme vezane uz zakonske propise. Do sada nije istraživan utjecaj uporabe biorazgradivih motornih ulja u motornim pila na preciznost mjerenja razlika u radu motora, potrošnji goriva i komponenti ispod plinova (CO, CO2 i HC), ovisno o vrsti goriva i ulja.

Samo nekoliko autora istražuju sastav ispušnih plinova dvotaktnih motora i ulja na električnoj kočnici, što omogućuje precizna mjerenja razlika u radu motora, potrošnji goriva i sastavu ispušnih plinova (CO, CO2 i HC), ovisno o vrsti goriva i ulja.

Pri tome veći utjecaj na količinu ugljikovodika u ispušnim plinovima ima gorivo biorazgradivo. Pri tome veći utjecaj na količinu ugljikovodika u ispušnim plinovima ima gorivo biorazgradivo nego samo ulje (Magnusson i dr. 2000b).

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utvrđenim uvjetima. Uobičajena se metoda ispitivanja značajki motornoga ulja zasniva na promjeni brzinske
značajke motora na električnoj kočnici.

Metoda razumijeva mjerenje ovih vrijednosti: zakretni moment motora, broj okretaja motora, atmosferski tlak
zraka, temperatura zraka, obujam utrošene mješavine goriva i ulja, gustoća mješavine goriva i ulja te vrijeme
potrebno za utrošak određene količine mješavine goriva i ulja. Mjerenja su bila obavljeni u rasponu broja okretaja
motora od 4000 do 9000 min⁻¹. Svako se mjerenje četiri puta ponavljalo te je izražena aritmeška sredina za
vrijednosti mjerenja. Izrazi 1 do 5 korišteni su za izračun osnovnih veličina u istraživanju. U tablici 1 prikazani su
mjereni i izračunati podaci za različite vrste ulja i omjere mješavine goriva i ulja. Statističkim vrednovanjem
rezultata dokazana je vrlo velika mogućnost ponavljanja mjerenja s ovom metodom.

Rezultati istraživanja pokazuju da omjer mješavine goriva i ulja ne utječe na vrijednost zakretnog momenta
motora, a stvarna se snaga motora smanjuje sa smanjenjem koncentracije ulja u mješavini i s uporabom
biorazgradivih ulja u mješavini. Koncentracija je štetnih ispušnih plinova u pozitivnoj ovisnosti o temperaturi
motora i broju okretaja motora.

Utvrdjen je neznan utjecaj omjera mješavine na sastav ispušnih plinova, što je u suprotnosti s pretpostavkom
da se smanjenjem koncentracije ulja u gorivu postiže smanjenje štetnih tvari u ispušnim plinovima i povećanje
korisnosti motora. Nadalje je zanimljivo da ulje OA M6A, uobičajeno motorno ulje koje se rabi u starijim
automobilima, ima najbolju kakovost, dok se ulje MOGUL TS, posebno razvijeno za dvoaktne motore s velikim
opterećenjima, pokazalo najlošijim. Uzrok je tomu vjerojatno veći utjecaj koncentracije nego kakovost ulja na
dobivene rezultate. Prema navedenomu može se zaključiti o pouzdanosti uporabe svih ispitivanih mješavina goriva
i ulja u motornim pilama.

Ključne riječi: biorazgradiva motorna ulja, dvoaktni motor, brzinska značajka, sastav ispušnih plinova,
laboratorijsko ispitivanje

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