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

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Abstract – Nacrtak

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, CO_2, 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 m^3 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, CO_2 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 cm^3,
⇒ 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, %, CO_2, % and HC, ppm,
⇒ calibrated vessel of 25cm^3 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:

⇒ corrected torque $M_{t\,kor}$ (Standard: ČSN 30 2008)

$$M_{t\,kor} = M_t \frac{1013}{p_a} \times \left(\frac{273 + t_a}{273 + 20} \right)^{0,5}, \text{Nm} \quad (1)$$

Where:

M_t measured torque, Nm

p_a atmospheric pressure, hPa

t_a air temperature, °C

⇒ actual output P_e (Standard: ČSN 30 2008)

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

Where:

M_t measured torque, Nm

n engine revolutions, revs. per minute

⇒ corrected actual output $P_{e \times kor}$ (Standard: ČSN 30 2008)

$$P_{e \times kor} = P_e \frac{1013}{p_a} \times \left(\frac{273 + t_a}{273 + 20} \right)^{0,5}, \text{Nm} \quad (3)$$

⇒ fuel consumption per hour G_t (Standard: ČSN 30 2008)

$$G_t = 3,6 \times \frac{V_m \times \delta_p}{t_m}, \text{k} \cdot \text{gh}^{-1} \quad (4)$$

Where:

V_m volume of the measuring vessel, ml

δ_p fuel density, g/cm^3

t_m time necessary for consuming the volume V_m, s

⇒ specific fuel consumption g_e (Standard: ČSN 30 2008)

$$g_e = \frac{G_t \times 1000}{P_e}, \text{g} \cdot \text{kw}^{-1} \quad (5)$$

3. Results – *Rezultati*

The above method was used to determine the values of torque, air intake temperature, CO, CO_2 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

Tablica 1. *Izmjerene i izračunate vrijednosti brzinskih značajki*

Measurement *Mjerenja*	M_t	$M_{t\,kor}$	P_e	$P_{e\,kor}$	Time *Vrijeme*	g_p	m_p	Air temp. *Temp. zraka*	Air press. *Tlak zraka*	Engine temp. *Temp. motora*	CO	CO_2	HC
	Nm	Nm	kW	kW	s	kg.h^{-1}	g.kWh^{-1}	°C	hPa	°C	%	%	ppm
1	3.6	3.64	1.51	1.53	60.88	1.050	696	19.6	1,000	140	4.70	3.47	3,150
2	3.7	3.74	1.55	1.57	61.04	1.047	676	19.5	1,000	140	4.63	3.21	2,940
4	3.7	3.73	1.55	1.56	61.11	1.046	675	20.6	1,007	140	4.58	2.81	2,773
4	3.7	3.73	1.55	1.56	61.18	1.044	674	20.5	1,007	140	4.51	2.78	2,791
Average *Prosjek*	3.7	3.71	1.54	1.55	61.05	1.047	680	20.1	1,004	140	4.61	3.07	2,914

Used Oil – *Uporabljeno ulje* 2T/6 Engine: Husqvarna 266 SE – *Tip motorne pile: Husqvarna 266 SE*

Blending ratio – *Omjer mješavine* 1:40 Speed: 4,000 revs./min – *Brzina:* 4000 okr./min.

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:

$$y = a_0 + a_1 \times x + a_2 \times x^2 + a_3 \times x^3 + a_4 \times x^4 + a_5 \times x^5 \quad (6)$$

or

$$y = a_0 + a_1 \times x + a_2 \times x^2 + a_3 \times x^3 + a_4 \times x^4 \quad (7)$$

Only in the case of CO_2 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:

$$y = a_0 + a_1 \times \ln(x) + a_2 \times \ln(x)^2 + a_3 \times \ln(x)^3 + a_4 \times \ln(x)^4 + a_5 \times \ln(x)^5 \quad (8)$$

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 CO_2 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 CO_2 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 2 Correlation matrix for the OA M6A oil
Tablica 2. *Međusobni odnosi značajki za ulje OA M6A*

OA M6A	Speed *Brzina*	Engine temperature *Temperatura motora*	Intake temperature *Temperatura radnoga prostora*	CO concentration *Koncentracija CO*	CO concentration *Koncentracija CO*	CO concentration *Koncentracija CO*
Speed – *Brzina*	1.0000	0.8140	0.0194	0.9155	0.4187	–0.9575
Engine temperature *Temperatura motora*	0.8140	1.0000	–0.0868	0.6867	0.7201	–0.7998
Intake temperature *Temperatura zraka*	0.0194	–0.0868	1.0000	0.1153	–0.5303	–0.0864

Table 3 Correlation matrix for the MOGUL TS oil
Tablica 3. *Međusobni odnosi značajki za ulje MOGUL TS*

Mogul TS	Speed *Brzina*	Engine temperature *Temperatura motora*	Intake temperature *Temperatura zraka*	CO concentration *Koncentracija CO*	CO concentration *Koncentracija CO*	CO concentration *Koncentracija CO*
Speed – *Brzina*	1.0000	0.9139	0.0639	0.8870	0.4352	–0.8605
Engine temperature *Temperatura motora*	0.9139	1.0000	0.0064	0.8277	0.6143	–0.8157
Intake temperature *Temperatura zraka*	0.0639	0.0064	1.0000	0.1517	–0.5768	–0.3441

Table 4 Correlation matrix for the 2T/6 oil
Tablica 4. *Međusobni odnosi značajki za ulje 2T/6*

2T/6	Speed *Brzina*	Blending ratio *Omjer miješavine*	Engine temp. *Temp. motora*	Intake temp. *Temp. zraka*	Air pressure *Tlak zraka*	CO concentration *Koncentracija CO*	CO_2 concentration *Koncentracija* CO_2	HC concentration *Koncentracija HC*
Speed – *Brzina*	1.0000	0.0000	0.8666	0.0796	0.0000	0.8781	0.4604	–0.8730
Blending ratio *Omjer miješavine*	0.0000	1.0000	–0.0441	–0.1202	0.0000	0.0144	–0.1589	–0.1874
Engine temperature *Temperatura motora*	0.8666	–0.0441	1.0000	0.1045	0.0352	0.7593	0.5782	–0.7549
Intake temperature *Temperatura zraka*	0.0796	–0.1202	0.1045	1.0000	0.9431	0.1435	–0.5843	–0.3447
Air pressure *Tlak zraka*	0.0000	0.0000	0.0352	0.9431	1.0000	0.0809	–0.6698	–0.3063

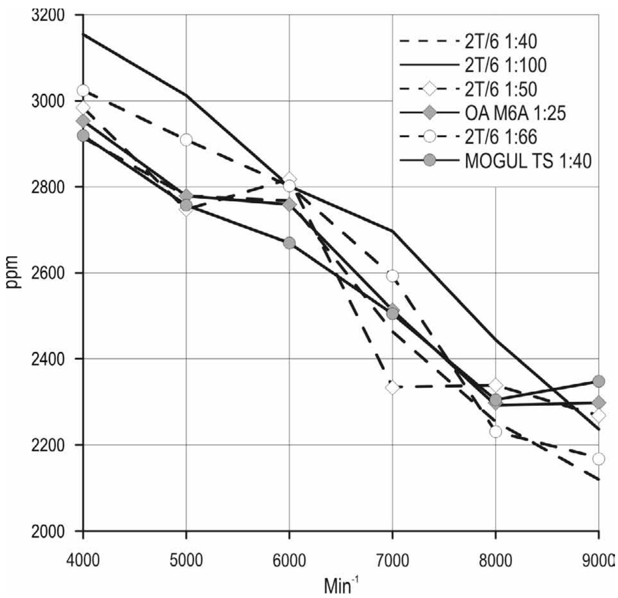

Fig. 1 Behaviour of HC concentration in exhaust gases
Slika 1. *Kretanje koncentracije HC-a u ispušnim plinovima*

CO and HC concentrations are dependent on engine speed and – due to close dependence of the engine temperature on its speed – also on the 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,

⇒ CO_2 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.

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Sažetak

Promjene brzinskih značajki motora motornih pila pri uporabi mineralnih ulja i ulja biljnoga 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 biljnoga 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 pilama na pretjerano trošenje dijelova motora i pogoršanje sagorijevanja koje povećano onečišćuje zrak i radni okoliš operatera. Zbog toga su obavljena pokusna laboratorijska mjerenja za utvđivanje značajki uobičajenih motora motornih pila na električnoj kočnici, što omogućuje precizna mjerenja razlika u radu motora, potrošnji goriva i sastavu ispušnih plinova (CO, CO_2 i HC), ovisno o vrsti ulja i omjeru miješanja ulja i benzina.

Samo nekolicina autora istražuje sastav ispušnih plinova dvotaktnih motora prema vrsti goriva ili ulja koje se u mješavini koristi za podmazivanje. Prazan hod, jednako kao i najveći broj okretaja motora bez opterećenja, povećava omjer nepotpuno sagorjelih ugljikovodika – HC i CO (Wojcik i Skarzynski 2006). Magnusson i dr. (2000a) ispitivanjem dvotaktnih motora s različitim vrstama goriva (alifatski benzin sa sintetičkim uljem za podmazivanje i uobičajeni bezolovni benzin s mineralnim uljem) utvrđuju da je upotrebom mješavine benzina i mineralnoga ulja količina ugljikovodika u ispušnim plinovima 5 – 10 puta veća u usporedbi s mješavinom goriva i sintetičkoga ulja. Pri tome veći utjecaj na količinu ugljikovodika u ispušnim plinovima ima uporabljeno gorivo nego samo ulje (Magnusson i dr. 2000b).

Prva je faza u istraživanju ulja za podmazivanje dvotaktnih motora motornih pila i motornih kosa bila temeljena na jednostavnoj usporedbi brzinskih značajki motora određenoga tipa pri uporabi različitih ulja i različitih omjera mješavine.

Brzinske su značajke motora određivane prema zahtjevima važećih normi ČSN 30 2008 »Automobile engines – Tests at a brake stand« i ISO 7293 »Forest machinery – Portable chain saws – Engine performance and fuel consumption«.

Ispitivanjem su uspoređeni zakretni moment motora, trenutna snaga motora, specifična i satna potrošnja goriva, temperatura motora na svjećici i vrijednost koncentracije CO, CO_2 i HC u ispušnim plinovima pod *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 obavljena u rasponu broja okretaja motora od 4000 do 9000 min^{-1}. Svako se mjerenje četiri puta ponavljalo te je izražena aritmetička 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 zakretnoga 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.

Utvrđen je neznatan 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 kakvoću, dok se ulje MOGUL TS, posebno razvijeno za dvotaktne motore s velikim opterećenjima, pokazalo najlošijim. Uzrok je tomu vjerojatno veći utjecaj koncentracije nego kakvoće 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, dvotaktni motor, brzinska značajka, sastav ispušnih plinova, laboratorijsko ispitivanje

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