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# EMISSION AND COMPOSITION OF EXHAUST GASES BY NEW CHAIN SAWS PRODUCED BY HUSQVARNA AND STIHL

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**Abstract.** Both the composition and harmfulness of exhaust gases emitted by the two-stroke engine of new Husqvarna and Stihl chain saws have been discussed in the paper. The research carried out on six chain saws (three chain saws from each of the manufacturers), with a different engine capacity, at several stages of work.. Moreover, possibilities of reduction and limitation of fumes emission are presented. As a result of the analysis of the research it has been stated that: the swept capacity of the two-stroke engine of a chain saw does not influence the size of the produced exhaust gases, and differences between the models and firms are not large. The work of a chain saw in the idle running causes a considerably higher emission of hydrocarbons (HC) than at other stages of work. And thus its work in low gear should be limited to the indispensable minimum; an increase of oxygen ($O_2$) quantity in the air-fuel mixture lowers the quantity of emitted carbon monoxide (CO). This phenomenon is connected with the suitable regulation of the chain saw carburettor.

**Key words:** chain saws, exhaust gases, two-stroke engine, gas emission, exhaust gas composition

## INTRODUCTION

In spite of the considerable technical progress in the field of the mechanization of logging woods, the general application of chain saws in Polish conditions will be continued in the years to come. It is basically connected with both low purchase and utilization costs when compared with the so-called multipurpose machines (processors and harvesters). The above-mentioned machines are characterized by considerably higher efficiencies, but at the same time meaningfully higher costs of obtaining wood when compared with chain saw wood logging. This fact alongside with low concentrations of felling sites in Poland (which prevail in the country) makes the utilization of the expensive equipment unprofitable, and so chain saws still stay the only alternative.

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A doubtless advantage of the modern chain saws is their engine. Generally speaking this is the internal-combustion two-stroke engine with a spark-ignition, characterized by a simplicity of its construction, fairly small sizes and weight and relatively low production costs. Apart from the above-mentioned factors and the parameters such as the swept capacity and power; the engine of the chain saw can be also characterized by means of its exploitation indexes such as:

– the power index, related to the engine capacity – high, i.e. above 45 kW/cm$^3$,

– the mass index, related to the power or engine capacity – low, i.e. below 0.115 kg/cm$^3$ [Wójcik 2002].

The chain saws engines are naturally not devoid of certain defects. First of all their low heat efficiency and high emission of harmful hydrocarbons are the problems to consider. They are caused by the unburned air-fuel mixture forcing its way through the escape channel. The immediate contact of the operator with the outlet of exhaust gases from the engine of chain saws creates a certain threat to the worker's health. It should be either eliminated or limited to some extent which seem rather impossible.

## EXHAUST GASES

Exhausts are an inseparable product of the chain saw engine operation (combustion). Gases, which can be divided into two groups, are their component:

– non-toxic gases,

– toxic gases.

Harmless gases include mainly nitrogen ($N_2$), oxygen ($O_2$), carbon dioxide ($CO_2$) and water vapour ($H_2O$). While harmful gases include carbon monoxide (CO), the entire group of nitric oxides ($NO_x$), hydrocarbons (HC), sulphur dioxide ($SO_2$) and other sulphur compounds converted to hydrogen sulphide ($H_2S$). Providing a high quality fuel (sulphur free compounds) is used, the exhaust gases should not contain this chemical element, and the average composition of gases emitted by a two-stroke engine would be as presented in Figure 1.

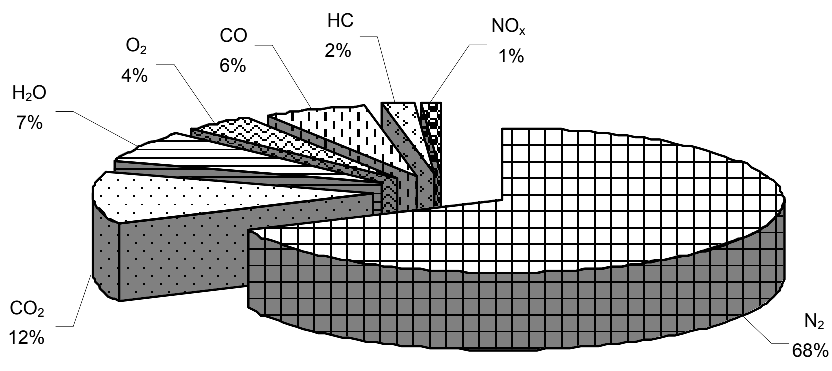



Fig. 1. Composition of exhaust gases emitted by two-stroke engine of chain saw [Różański and Jabłoński 2001]

Rys. 1. Skład spalin emitowanych przez silnik dwusuwowy pilarki spalinowej [Różański i Jabłoński 2001]

The share of harmless gases in the exhausts reaches about 90%. Nevertheless, the toxic compounds which take the remaining about 10%, especially carbon monoxide (CO – 6%), non-burnt hydrocarbons (HC – 2%) and nitric oxides ($NO_x$ – 1%), create a serious, both ecological and ergonomic, problem.

The amount of harmful toxic components, permitted in the operator's environment, has been defined by the decree of the Minister of Labour and Social Policy of 29 November, 2002 [Rozporządzenie... 2002], and described by the standards in force in particular countries. Methods of measurements are described in PN-EN ISO 8178 – 1, 2, 4 of January 1999.

According to the above mentioned decree, the highest admissible concentration (so-called NDS) of harmful compounds in the operator's environment amounts to:

– carbon monoxide (CO) – 30 mg/m$^3$,
– nitric oxides ($NO_x$) – 5 mg/m$^3$,
– sulphur dioxide ($SO_2$) – 2 mg/m$^3$,
– hydrocarbons (HC) – 100 mg/m$^3$.

When many toxic components act simultaneously in the operator's environment, the so-called sum of relative values is determined; this should not exceed 1, according to the formula:

$$\sum_{i=1}^{n} \frac{q_i}{NDS_i},$$

where:

$q_i$ – value of i-factor, mg/m$^3$,
$NDS_i$ – highest admissible concentration of i-factor, mg/m$^3$,
n – number of toxic factors in operator's environment.

Admissible concentrations of toxic gases in exhausts of chain saws [Hoβ et al. 1997] have been recorded to be exceeded in majority of cases. The unfavourable influence of fumes can be eliminated applying special fuels without polycyclic hydrocarbons or introducing a suitable regulation of the chain saw carburettor. It facilitates the reduction of carbon monoxide emission [Emmerich and Burger 1993, Różański and Jabłoński 2001, Wójcik 2003]. However, the research conducted by Komuński [1995] proves there is no permanent threat caused by carbon monoxide in the zone of the operator's respiration. The threat can be multiplied though by: unfavourable wind direction and speed, as well as its lack, local conditions, compaction of the stand, chain saw poor technical conditions, usage of too rich fuel mixtures, and the maladjustment of the carburettor. Also Forbrig [1988] recorded an insignificant threat to the operator with carbon monoxide and nitrous oxide at the correct regulation of the carburettor.

However, determination of harmful compound contents in the environment of the chain saw operator is very difficult. Therefore, particular limits of these compounds are described in the norms published by special agencies entitled to set up different regulations and acts. In the USA such rules were established by two agencies: Environmental Protection Agency (EPA) and California Air Resources Act (CARB), while in Europe by the European Commission in charge of the environmental protection. In Table 1 admissible values are presented of toxic compounds in exhaust gases according to EPA and CARB standards.

Table 1. Admissible values of tonic compounds in exhaust gases according to EPA and CARB [Różański and Jabłoński 2001]
Tabela 1. Dopuszczalne wartości związków toksycznych w spalinach według normatywów EPA i CARB [Różański i Jabłoński 2001]

| Standard Norma | Years Lata obowiązywania | Engine capacity Objętość skokowa silnika | HC | $NO_x$ | CO | Solid particles Cząstki stałe |
|---|---|---|---|---|---|---|
| | | $cm^3$ | $g \cdot kWh^{-1}$ | | | |
| CARB 1* | 1995-1999 | < 20 | 295 | 5.36 | 805 | |
| | | 20-50 | 241 | 5.36 | 805 | |
| | | > 50 | 161 | 5.36 | 402 | |
| EPA 1** | from 1998 – od 1998 | < 20 | 295 | 5.36 | 805 | |
| | | 20-50 | 241 | 5.36 | 805 | |
| | | > 50 | 161 | 5.36 | 603 | |
| CARB 2* | from 2000 – od 2000 | | 72 | | 526 | 2 |
| EPA 2** | from 2002 – od 2002 | > 50 | 196 | | 805 | |
| | from 2003 – od 2003 | | 148 | | 805 | |
| | from 2004 – od 2004 | | 99 | | 805 | |
| | from 2005 – od 2005 | | 50 | | 805 | |
| | from 2004 – od 2004 | > 50 | 143 | | 603 | |
| | from 2005 – od 2005 | | 119 | | 603 | |
| | from 2006 – od 2006 | | 96 | | 603 | |
| | from 2007 – od 2007 | | 72 | | 603 | |

*Valid in Kalifornia State.
**Valid in other States of USA.
*Obowiązujące w stanie Kalifornia.
**Obowiązujące w pozostałych stanach USA.

According to European rules, the admissible values are the same as in EPA and CARB standards (EPA 1 from September 2002 to 2007, EPA 2 from 2007 to 2010). These are weighted values, with consideration to toxic gases emission both at work and idling stages.

## MATERIAL AND METHODS

The composition of combustion gases emitted by chain saw engines was investigated by means of the stationary analyser of combustion gases "Crypton 290" having the parameters shown in Table 2.

The research was carried out on the turn of March and April 2004 (windless weather, slightly cloudy sky, temperature 20°C) on the area of The Faculty of Production

Table 2. Specification of exhaust-gas analyser "Crypton 290"
Tabela 2. Dane techniczne analizatora spalin „Crypton 290"

| Parameter<br>Parametr | Range and accuracy of measurement<br>Zakres wielkości i dokładność pomiaru |
|---|---|
| CO | 0-9.99%, accuracy ± 0.06%, repeatability ± 0.03%<br>0-9,99%, dokładność ± 0,06%, powtarzalność ± 0,03% |
| HC | 0-9999 ppm, accuracy ± 11 ppm, repeatability ± 5 ppm<br>0-9999 ppm, dokładność ± 11 ppm, powtarzalność ± 5 ppm |
| $CO_2$ | 0-20.00%, accuracy ± 0.40%, repeatability ± 0.20%<br>0-20,00%, dokładność ± 0,40%, powtarzalność ± 0,20% |
| $O_2$ | 0-25%, accuracy ± 0.20%, repeatability ± 0.10%<br>0-25%, dokładność ± 0,20%, powtarzalność ± 0,10% |
| Engine revolutions<br>Obroty silnika | 0-9999 rpm, possible engine selection: conventional, DIS type or Wankel rotary piston type<br>0-9999 obr·min$^{-1}$ z możliwością wyboru silnika konwencjonalnego, silnika typu DIS lub silnika Wankla |
| Oil temperature<br>Temperatura oleju | 0-120°C |
| Coefficient Lambda<br>Współczynnik Lambda | from 0.34 to 1.70, possible selection fuel<br>od 0,34 do 1,70 z możliwością wyboru rodzaju paliwa |
| Time of heating<br>Czas nagrzewania | 5 min |
| Time to actuation<br>Czas zadziałania | 6 s without pipe<br>10 s with pipe 8 m long<br>6 s bez węża<br>10 s z wężem o długości 8 m |
| Operational temperature<br>Temperatura pracy | +2 do +50°C |
| Moisture content<br>Wilgotność | 0-85% |
| Altitude<br>Wysokość pracy | from –300 m to +2100 m a.s.l.<br>od –300 m do 2100 m n.p.m. |
| Power<br>Zasilanie | ≈220 V (110 V), 50/60 Hz |
| Power requirement<br>Pobór mocy | 170 W |
| Overall dimension<br>Wymiary gabarytowe | 485 × 386 × 175 mm |
| Weight<br>Masa analizatora | 16.5 kg |

Engineering. The measuring sampler was placed in the outlet of the chain saw combustion gases suppressor and joined with the combustion gases analyser by means of a 8 m long pipe.

Six professional chain saws of various engine capacities were tested. The Husqvarna saws were represented by: H 346 XP (45 $cm^3$), H 357 XP (56.5 $cm^3$) and H 372 XP (70.7 $cm^3$), while the Stihl saws by: MS 260 (48.7 $cm^3$), MS 280 (54.2 $cm^3$) and MS 440 (70.7 $cm^3$).

Research passed for every model in The research was carried out at five different stages of work for each of the models and the analyser's results were read every 10 seconds:

a) idle running (engine rotational speed n = 2500 rpm, exhaust gas temperature t = 64-76°C),
b) work without load (n = 8000-9000 rpm, t > 120°C),
c) work without load (n = 12 000 rpm, t > 120°C),
d) cross-cutting of round log 1 (d = 14 cm, n = 5000-10 500 rpm, t > 120°C),
e) cross-cutting of round log 2 (d = 25 cm, n = 5000-10 500 rpm, t > 120°C).

The chain saw engine rotational speed was measured with the use of non-contact rotational counter DET-302.

The wear of the investigated chain saws was slight; proper adjustments were applied, before the measurements, in agreement with the operator's manual. The fuel mixture was prepared according to the manufacturer's recommendations of lead-free petrol of octane number 95 and the two-stroke engine TE class oil.

Four basic exhaust gas components were analysed: carbon monoxide (CO), carbon dioxide ($CO_2$), oxygen ($O_2$) and hydrocarbons (HC).

## RESULTS AND DISCUSSION

### The participation of the carbon monoxide (CO), the carbon dioxide ($CO_2$) and oxygen ($O_2$) in exhaust gases

Figures 2-4 present the findings of the percentage share of carbon monoxide (CO), carbon dioxide ($CO_2$) and oxygen ($O_2$) in exhausts emitted by each chain saw at different stages of work. The saws were paired depending upon similar swept capacity. During idle running work the percentage share of carbon monoxide (CO) for the investigated models, is approximately at a similar level and oscillates within 3.3-5%, as far as carbon dioxide ($CO_2$) is concerned; the percentage value of this relationship amounts to about 3%. Whereas, the oxygen ($O_2$) content at this stage of work oscillates within 12 and 15%. At the moment of increasing of the rotational speed (from about 2500 rpm to 8000-9000 rpm and further to 12 000 rpm), during the engine's operation without load, the percentage share of oxygen slowly starts falling, approximately by half, to about 3-6%. Simultaneously the participation of carbon monoxide increases abruptly and at the rotational speed of 8000-9000 rpm it oscillates between 7-8%, and at approximately 12 000 rpm reaches 8-9%. The higher percentage share of this component is, in this particular case, due to a shortage of oxygen in the process of the air-fuel mixture combustion. At the same time the participation of harmless carbon dioxide increases proportionally to the decrease of oxygen in the released exhausts.

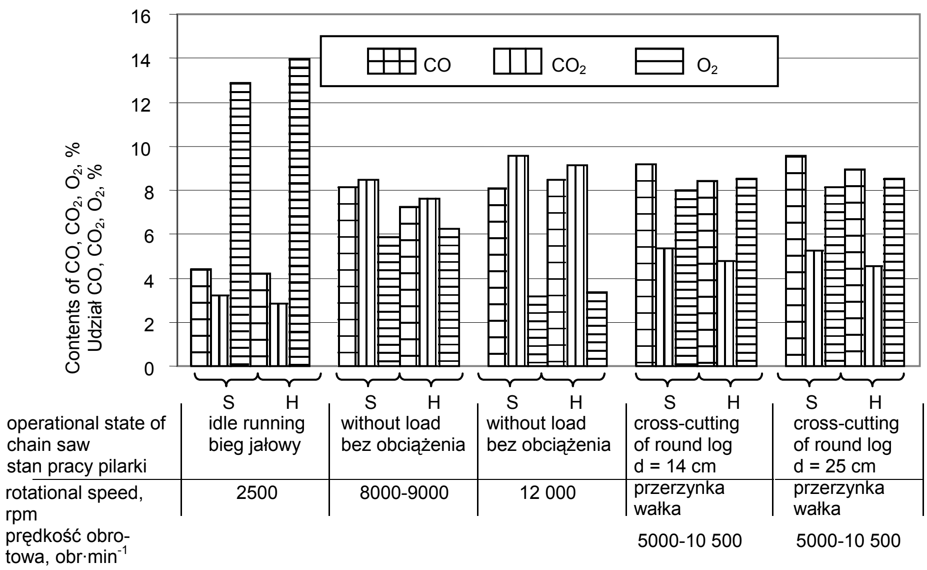



Fig. 2. Percentage of CO, $CO_2$ and $O_2$ in Husqvarna (H) chain saw of $V_s$ = 45 $cm^3$ and Stihl (S) of $V_s$ = 48.7 $cm^3$ at various operational stages
Rys. 2. Procentowy udział CO, $CO_2$ i $O_2$ dla pilarki spalinowej Husqvarna (H) o $V_s$ = 45 $cm^3$ i Stihl (S) o $V_s$ = 48,7 $cm^3$ w różnych stanach pracy

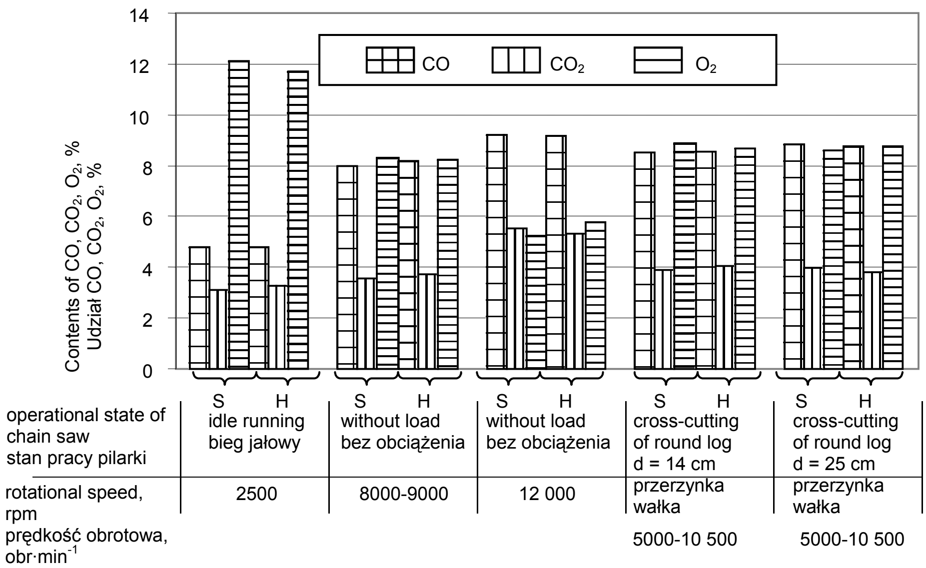
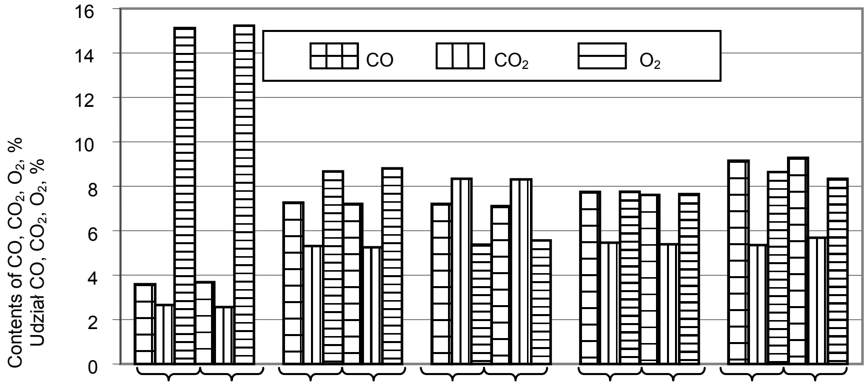



Fig. 3. Percentage of CO, $CO_2$ and $O_2$ in Husqvarna (H) chain saw of $V_s$ = 56.5 $cm^3$ and Stihl (S) of $V_s$ = 54.2 $cm^3$ at various operational stages
Rys. 3. Procentowy udział CO, $CO_2$ i $O_2$ dla pilarki spalinowej Husqvarna (H) o $V_s$ = 56,5 $cm^3$ i Stihl (S) o $V_s$ = 54,2 $cm^3$ w różnych stanach pracy



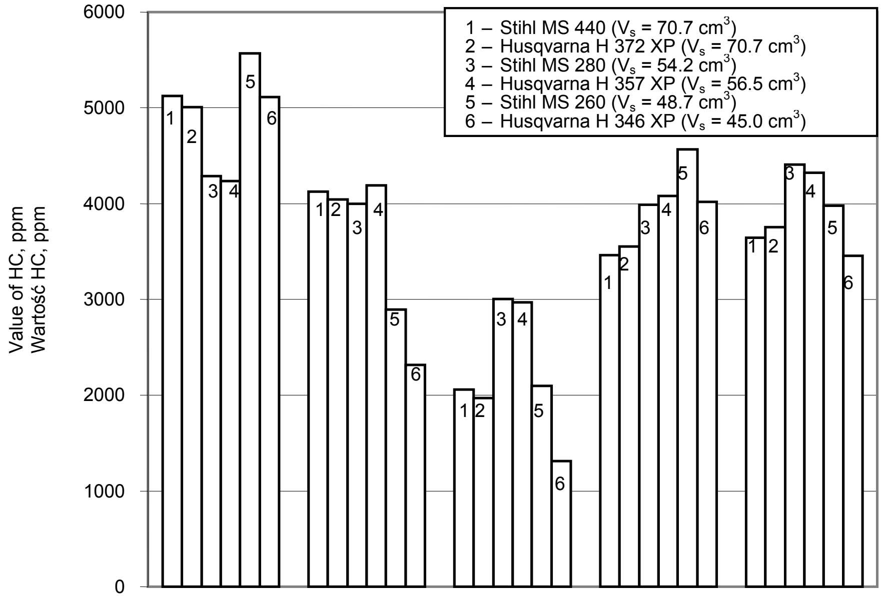

| | S H | S H | S H | S H | S H |
|---|---|---|---|---|---|
| operational state of chain saw<br>stan pracy pilarki | idle running<br>bieg jałowy | without load<br>bez obciążenia | without load<br>bez obciążenia | cross-cutting of round log<br>d = 14 cm | cross-cutting of round log<br>d = 25 cm |
| rotational speed, rpm<br>prędkość obrotowa, obr·min$^{-1}$ | 2500 | 8000-9000 | 12 000 | przerzynka wałka<br>5000-10 500 | przerzynka wałka<br>5000-10 500 |

Fig. 4. Percentage of CO, $CO_2$ and $O_2$ in Husqvarna (H) chain saw of $V_s$ = 70.7 cm$^3$ and Stihl (S) of $V_s$ = 70.7 cm$^3$ at various operational stages
Rys. 4. Procentowy udział CO, $CO_2$ i $O_2$ dla pilarki spalinowej Husqvarna (H) o $V_s$ = 70,7 cm$^3$ i Stihl (S) o $V_s$ = 70,7 cm$^3$ w różnych stanach pracy

When the chain saw engine works under load i.e. during cross-cutting of round logs of definite diameters, the situation is different. A further slow increase of the percentage share of carbon monoxide is observed, to approximately 8-9%, and as a result of the decreased quantity of carbon dioxide from approximately 8% to about 4-5%, the participation of oxygen reaches about 8-9%. It can be explained by the fact that the oxygen contained in the air, delivered to the combustion chamber of the chain saw engine by the carburettor, as a result of a fairly high variable rotational velocity of the engine during cross-cutting (5000-10 500 rpm), will not manage to enter into the reaction with carbon. It can be also observed that during cutting there are situations when the saw engine operates at the rotational velocity close to the speed of the clutch disconnection and the cutting itself does not take place (rotational velocity decreases alongside with performing saw cuts or as a result of the guide bar jams), then the participation of oxygen is considerably higher than at the other stages of work (approx. 13-14%).

**The content of hydrocarbons (HC) in exhaust gases**

The main source of hydrocarbons in exhaust gases is the unburned fuel and prior cutting out of the engine cylinder flame [Różański and Jabłoński 2001]. An equally serious source of these compounds are fuel vapours coming from the carburettor, the fuel tank and resulting from leaks of the fuel supplying system. Additionally, after their penetration through the exhaust system to the atmosphere, they create, with atmospheric oxygen, nitrogen compounds (nitrates, aldehydes, peroxides, and ozone which creates the so-called photochemical smog [Różański and Jabłoński 2001].




| operational state of chain saw<br>stan pracy pilarki | idle running<br>bieg jałowy | without load<br>bez obciążenia | without load<br>bez obciążenia | cross-cutting of round log d = 14 cm<br>przerzynka wałka | cross-cutting of round log d = 25 cm<br>przerzynka wałka |
|---|---|---|---|---|---|
| rotational speed, rpm<br>prędkość obrotowa, obr·min$^{-1}$ | 2500 | 8000-9000 | 12 000 | 5000-10 500 | 5000-10 500 |

Fig. 5. Value of HC emission for chain saws with different swept capacities of the engine at various operational stages
Rys. 5. Wielkość emisji HC dla pilarek spalinowych użytych do badań o różnych pojemnościach skokowych silnika w różnych stanach pracy

As far as hydrocarbons are concerned (Fig. 5), it ought to be noticed that the higher rotational velocity of the engine, without load, the lower the value i.e. from about 5500 to 1500 ppm, which can be explained in terms of the process of the more effective removal of the unburned fuel from the cylinder, resulting from the faster movement of piston. It can be thus concluded that leaving of the chain saw engine working on idle running is undesirable and, if it is well-motivated due to a longer passage from one tree to another, it is advisable to switch off the saw.

When the saw engine works under load (during cross-cutting), the emission of hydrocarbons significantly increases when compared to the degree of the emission while working at high revolution without load and stays at the level of approximately 3500--4500 ppm. This can be compared to the work of chain saw at the rotational speed of 2500 rpm (idle running), or work without load at n = 8000-9000 rpm. And also in this situation the increase of the emission of this compound is connected with the rotational velocity changes of the chain saw engine (2500-10 500 rpm).

## CONCLUSIONS

Piston swept-capacity of the two-stroke chain saw engine does not determine the amount of exhaust gas emission; it rather depends on the techniques of work and operational skills of the worker who should keep the speed of the engine at the level with providing for the lowest emission of injurious components of exhaust gases.

Idle running chain saw operation brings about a considerably higher emission of hydrocarbons (HC) than at other operational stages, thus, it should be limited exclusively to the necessary minimum, and in some cases it is recommended to stop the engine.

Increasing the amount of oxygen ($O_2$) in the fuel-air mixture decreases the content of carbon monoxide (CO), which results from the adequate adjustment of the chain saw carburettor and keeping the air filter in clean state.

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Rozporządzenie Ministra Pracy i Polityki Socjalnej z dnia 29 listopada 2002 roku w sprawie ilości toksycznych składników, które mogą znaleźć się w otoczeniu operatora i które zagrażają jego zdrowiu [Ordinance of Minister of Labour and Social Policy of 29 November 2002 in the matter of the quantity of toxic components which can be found in the environment of the operator and which threaten his health]. 2002. Dz. U. nr 217, poz. 1833 [in Polish].

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## EMISJA I SKŁAD SPALIN NOWYCH PILAREK SPALINOWYCH FIRMY HUSQVARNA I STIHL

**Streszczenie.** W artykule omówiono skład i szkodliwość spalin emitowanych przez silnik dwusuwowy nowych pilarek spalinowych firmy Husqvarna i Stihl. Autor przedstawił badania przeprowadzone na sześciu pilarkach (po trzy pilarki każdej z firm), o różnej objętości skokowej silnika, w kilku stanach pracy oraz podał możliwości zmniejszenia i ograniczenia emisji gazów spalinowych. W wyniku analizy badań stwierdzono, że: objętość skokowa dwusuwowego silnika pilarki spalinowej nie decyduje o wielkości emisji spalin, a różnice między modelami i firmami są niewielkie; praca pilarki na biegu jałowym powoduje znacznie większą emisję węglowodorów (HC) niż w innych stanach pracy, stąd należy ograniczyć jej działanie na wolnych obrotach do niezbędnego minimum; zwiększenie ilości tlenu ($O_2$) w mieszance paliwowo-powietrznej zmniejsza ilość emitowanego tlenku węgla (CO), co wiąże się z odpowiednią regulacją gaźnika pilarki.

**Słowa kluczowe:** pilarki spalinowe, gazy spalinowe, silnik dwusuwowy, emisja gazów, skład spalin

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