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EVALUATING THE CARBON MONOXIDE EMISSION FROM CHAINSAW EXHAUST OUTLET

PROCJENA EMISIJE UGLJIČNOG MONOKSIDA IZ ISPUŠNOG OTVORA MOTORNE PILE

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SUMMARY

In many countries, two-stroke chainsaws have been actively used in forest operations. Chainsaw operators are exposed to harmful gases and particulates generated by the exhaust of the two-stroke hand-held chainsaw. In this study, carbon monoxide (CO) parts per million (ppm) exposure of operators working with a chainsaw at 1900-2000 revolutions per minute (rpm) was investigated by mixing oil-fuel at a ratio of Society of Automotive Engineers (SAE) 10W motor oil (2.5%) and 95-octane unleaded gasoline. To investigate the presence of CO at a short distance, the relationship between exposure time and distance from the source were divided into groups. The result of the statistical analysis has shown that the average amount of CO emitted from the chainsaw was 1683 ppm at a distance of 0 (±4 cm) cm, 343.6 ppm at a 10 cm distance, 252.3 ppm at a 20 cm distance and 86.5 ppm at a 30 cm distance. The analysis of variance, according to the distance, has shown the amount of CO (ppm) to be statistically significant ($p < 0.05$). If the chainsaw operator is working very close to the chainsaw, CO exposure will be observed, which translates to a negative impact on their health and work efficiency. Therefore, training should be conducted to increase the awareness of the proximity to the chainsaw and the operators and the importance of using personal protective equipment. In addition to training support, the use of the new generation of chainsaw engines should also be encouraged and promoted to minimize CO emissions.

KEY WORDS: Forestry, timber production, two-stroke gasoline engine, emissions exposure, carbon monoxide, operator health

INTRODUCTION
UVOD

In countries with difficult terrain conditions, chainsaws are commonly being used in forestry production activities. Chainsaws, have been used in forestry since the 1960s, are used effectively and efficiently in timber production for tree felling, removing branches, bucking and debarking (Eker et al. 2011; Gülci et al. 2016; Russell and Mortimer 2005). Further research is underway to develop alternative tools to chainsaws. Recent alternatives include the use of debarkers "moto-debarker" instead of the conventional chainsaw (Şefik and Eker 2019), and a chainsaw powered by a lithium-ion battery (Neri et al. 2018; 2022; Pandur et al 2021). However, to date, no alternative power saw system has been

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used that can compare to the high performance and pros of existing two-stroke hand-held chainsaws in timber production.

The chainsaw is used as an important forestry tool due to its powerful two-stroke engine, lightweight and ergonomic design, and continues to exist in timber production in mountainous terrains. Although these powerful tools are very useful and ergonomic, they are full of rules to be considered in terms of occupational health and safety. Hence, considering the intensity of the use of chainsaws in forestry, research on occupational health and the effects of chainsaws on operators has been growing (Iftime et al. 2022).

There are various factors that affect the health and safety of chainsaw operators working in open areas and difficult terrain conditions. According to the International Labor Organization (ILO), in terms of occupational health and safety, forestry activities pose among the highest risks and most hazardous in terms of accidents (Acar and Şentük 1999; ILO 2011). As a result, legislation and research on worker health and safety issues began to become more and more important. In this way, it has become a priority to make sure that workers operate in safe and healthy conditions; preventing or minimizing exposure to occupational accidents or occupational diseases (Acar and Üçüncü 2020).

In the area of operator health and safety, the noise (Tunay and Melemez 2008; McLain et al. 2021; Akay et al. 2022), dust (Dimou et al. 2020), and vibration (Tunay and Tuna 2015; Landekić et al. 2020), and the risk of musculoskeletal disorders (Cheța et al., 2018) that forest workers are exposed to while using chainsaws are the important research topics. Exposures and their effects have been observed and confirmed through previous research. Chainsaw operator exposure to the exhaust gases of chainsaws with two-stroke engines, which use fossil-derived fuels, is one of the most critical issues because the chainsaw operator exposed to the exhaust gas may face respiratory diseases. (Iftime et al. 2022).

In recent years, detailed studies have been conducted on dust and gas exposure related to other forest production tools (such as chainsaws) (Leszczyński 2014; Hooper et al. 2017; Marchi et al. 2017; Dimou et al. 2019; Dimou et al. 2020; Taş and Akay, 2022). Neri et al. (2016) evaluated the exposure of harmful gases emitted by chainsaws in different fuel types to polycyclic aromatic hydrocarbons (PAH) and BTEX (benzene, toluene, ethylene, and total xylene). Volckens et al. (2007) investigated the values of carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (NO), hydrocarbons (HC), particulate matter (PM2.5), and sulfur dioxide (SO_2) produced by different amount of fuel mixtures used in two-stroke engines such as chainsaw. The main adverse effects suffered by chainsaw operators are vibration and noise, as well as exposure to carbon monoxide in the emitted exhaust gases (Arnold and Parmigiani 2015). Due to the incomplete combustion process of a two-stroke engine with internal combustion, different amounts of CO gas are produced. In other words, the combustion process in a two-stroke engine may not be fully realized, and as a result, CO and CO_2 gases are expected to be emitted from exhaust outlet in different concentrations. Therefore, it is critical to understand the CO exposure limit, which is an odorless, tasteless, colorless, and short-lived harmful gas that exists in various gases discharged from the exhaust (EU 1995).

Although new brands or engines have been developed for chainsaws, traditional two-stroke engine powered saws are still very commonly used in logging operations (not only logging, cut to length, pruning and peeling but also winching) in many countries. In previous studies, the measured values of exhaust gas released when cutting the trees with different brands of chainsaws were presented. CO exposure measurement studies conducted on chainsaw operators estimated different concentration values and limits. According to Leszczyński (2014), the short-term exposure value is determined to be 110 ppm (127 mg/m^3). In another study, the operator's short-term exposure to CO with a chainsaw was determined to be 120 ppm (Baldauf et al., 2006). Operators of chainsaws may be exposed to high concentrations (400 ppm) of CO in a short period of time (Bünger et al. 1997). A recent study conducted by Dimou et al. (2019) indicated that the average CO concentration of three different types of chainsaws in the operator's breathing zone reached 88.32 ppm in open area.

This study evaluated and measured the amount of CO that an operator might inhale when temporarily approaching an idling chainsaw when the chain brake is open. Hence, the carbon monoxide exposure value of the chainsaw operator from the exhaust gas was measured at different distance intervals up to 30 cm. An electronic gas sensor was used to obtain short-time interval CO ppm values from close-range distances from exhaust in an open area.

MATERIAL AND METHOD
MATERIJAL I METODA

Study Area – *Područje istraživanja*

This study was conducted in a pine plantation in the southern part of the campus (Figure 1), Kahramanmaras Sutcu Imam University (KSU), located in the Avsar campus in the eastern Mediterranean region of Türkiye. Measurements were done outdoors under normal weather conditions with gentle slope. The study area, which has a typical Mediterranean climate, has an altitude of 550 m. The measured air temperature, wind speed and relative humidity of work environment were at 28°C, 0.2-1 m/s and 68%, respectively.

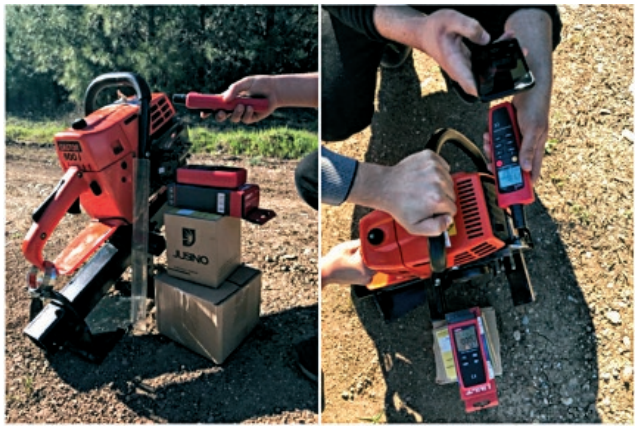
Figure 1. Study area
Slika 1. Područje ispitivanja

Figure 2. Experimental study design of measuring CO from very close to the exhaust of chainsaw
Slika 2. Dizajn eksperimentalne studije mjerenja CO vrlo blizu ispuha motorne pile

Used Equipment and Features – *Rabljena oprema i značajke*

In this study, the exhaust gas of a chainsaw was measured on the Castor 600i. The engine power is 2.2 kW and the engine volume is 59 cm^3, which belongs to the light class chainsaw (Table 1). For safety reasons, the guide bar and cutting chain of the chainsaw were separated from the body. An iron frame mechanism was used to keep the chainsaw stable during work (Figure 2).

CO measurements were carried out with a low-cost Uni-T Ut337A brand CO meter. The CO meter gives measurement results in ppm (Table 2). The instrument used in the measurement does not have the ability to automatically save the measurements. If the maximum CO value exposed during the measurement exceeds the exposure limit specified according to a short-term exposure limit (STEL) and a time-weighted average (TWA), the measurement tool will issue a luminous warning.



Uni-T UT373 is a mini tachometer was used to measure the rotation speed of engines and other technical equipment. Uni-T UT373 is a digital tachometer, which displays the measurement results in revolutions per minute (rpm) (Table 3).

Table 1. General specification of Castor 600i chainsaw
Tablica 1. Opće specifikacije motorne pile Castor 600i

Engine displacement/ Zapremina motora	59 cm^3
Engine power / Snaga motora	2.2 kW
Ignition plug / Svjećica za paljenje	Electronic RCJ7Y / Elektronički RCJ7Y
Tank volume / Volumen spremnika	550 cm^3
Weight / Masa	5.9 kg

Table 2. Technical specifications of the CO meter
Tablica 2. Tehničke karakteristike jeftinog CO mjerača

Sensor range / Raspon senzora	0-1000ppm
Resolution / Rezolucija	1 ppm
Sensor accuracy / Točnost senzora	±5% or 5 ppm
Respond Time / Vrijeme odgovora	<60s
Sensor / Senzor	Electro-chemical / Elektrokemijski
Sample mode / Način uzorka	Dispersive / Disperzivan

Table 3. Technical specifications of mini digital non-contact laser tachometer
Tablica 3. Tehničke specifikacije mini digitalnog beskontaktni laser tahometra

Range / Raspon	10.0 – 9999.9 rpm
Accuracy / Preciznost	±(0.04%+2)
Sensor type / Vrsta senzora	Photodiodes and laser tubes / Fotodiode i laserske cijevi
Battery / Baterija	3 x 1.5V batteries (AAA) / 3 x 1,5V baterije (AAA)
Target distance / Ciljna udaljenost	50 mm – 200 mm

A tachometer was used to show the engine speed during operation. Chainsaw fuel was supplied from a company that is in easy access to operators, has a widespread gas station and offers fuel analysis to consumers. The type of SAE 10W synthetic engine oil recommended by the chainsaw manufacturer was used. Again, the mixture ratio of the 1 part oil to 40 parts petrol was prepared with the help of a scale at recommended values. The measurement was started after 15 minutes of warm-up to reach the desired temperature.

METHOD
METODA

In this study, the proximity of the chainsaw operator to the chainsaw is considered during working on the slopes (Figure 3). The measurement values of CO were sampled at the shortest possible distance ±4 cm, 10 cm, 20 cm and 30 cm away from the exhaust outlet of the chainsaw considering the head location of chainsaw operator. Measurement studies were carried out on the upper part of the first exit point of the exhaust gas.

The idling speed of the chainsaw was constantly tried to be kept between 1900 and 2200 rpm. Measurements were made by reading data directly from the electronic gas sensor display. Fifteen minutes of measurements were taken for each distance interval between the chainsaw and the operator. For each measurement distance, the duration of measurement was 15 minutes, and the sampling interval was one second. Therefore, the total measurement time for

Figure 3. The moment of exposure to emitted exhaust gases from the chainsaw for an operator using low-standard work safety equipment (a: tree felling with chainsaw, b: debarking with chainsaw)
Slika 3. Trenutak izloženosti emisiji ispušnim plinovima iz motorne pile za operatera koji koristi zaštitnu opremu niskog standarda (a: rušenje stabla motornom pilom, b: skidanje kore motornom pilom)

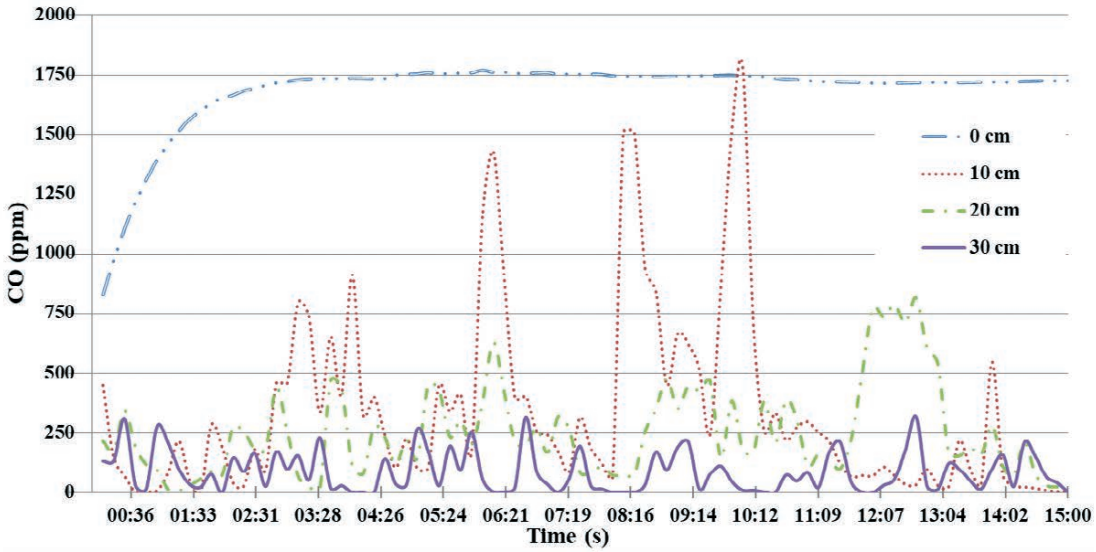


Figure 4. Characteristics of CO exposure to chainsaw operator
Slika 4. Karakteristike izloženosti rukovatelja motornom pilom CO

Table 4. Data groups
Tablica 4. Grupe podataka

Main groups / Glavne skupine	Distances (cm) / Udaljenosti (cm)	Subgroups (minute) / Podskupine (minuta)
1	0	5 10 15
2	10	5 10 15
3	20	5 10 15
4	30	5 10 15

all four distances was one hour. A total of 360 sample measurement values were obtained by taking the arithmetic mean of the values of each 10 seconds for the measurement period (Figure 4). The data of carbon monoxide from the chainsaw's exhaust was measured while the engine was idling at each measurement. Display screen of measuring instrument were recorded using a cell phone camera (Figure 2). The recorded measurements were read from the video recording screen and were tabulated in MS Excel in the office environment.

Statistical analysis – *Statistička analiza*

The amount of CO emitted from the exhaust of the chainsaw is divided into 4 main classes according to the distance and 12 subgroups according to the exposure time (Table 4). Then, the relation between the amount of CO of the chainsaw and the distances and the exposure time was examined with a One-Way ANOVA at a significance level of 0.05. The difference between the averages was evaluated by Duncan's multiple comparison test. To study the relationship between variables, statistical calculations were performed by using the SPSS software package using Pearson correlation test (SPSS 2012).

RESULTS
REZULTATI

Results of variance analysis indicated to significant differences between the operator's distance to CO gas and the amount of CO gas exposure. In addition, CO exposures showed a statistically homogeneous distribution ($p<0.05$). While the average CO gas exposure was the highest (1683.04 ppm) at 0 cm = 1, it gradually decreased as the distance increased (Table 5). According to Duncan's multiple comparison test results, the operator was exposed to CO gas at the highest rate (1693.04 ppm-D) at 0 cm. As the distance increases, the average amount of CO exposed have decreased from 10 cm (343.58 ppm-C) to 20 cm (252.34 ppm-B) and 30 cm (86.49 ppm-A), respectively. The operator was exposed to CO gas at a minimum close-range distance of 30 cm.

There is a significant difference between distance and CO exposure time at the 95% confidence level. According to the results of the analysis of variance, the amount of CO gas in the first 10 minutes (Group 2) was the highest when exposed to CO gas at 0 cm (Table 5). The same happens when exposed from a distance of 10 cm. In the first 5 minutes, the operator was exposed to the lowest amount of CO gas from 20 cm, but as time increases, the amount of CO gas increase. Considering the CO exposure measurements at a distance of 30 cm from the exhaust outlet, the CO emissions of the chainsaw were higher in the first 5 minutes, while the average amount of CO decreased after the first 5 minutes (Table 6). The reason why the amount of gas exposure decreases in the opposite direction as time increases is because the measurement is carried out under open weather conditions and is affected by wind speed. According to Duncan's multiple comparison test results, the operator can be exposed to CO equally and at the highest rate (F) in groups 2 and 3, while groups 12, 11, 10, 6 and 7 were exposed to CO at the same degree and at the lowest rate (A) (Table 6).

A correlation test was also conducted to determine the relationship between the distance to exhaust and the amount of CO exposed and the duration of exposure (Figure 5). According to the results, it is found that there is a very strong

Table 5. Variance analysis results between the operator's distance to chainsaw exhaust and the amount of CO exposure
Tablica 5. Rezultati analize varijance između operatera i motorne pile te količini izloženosti CO

Distance group / Grupa udaljenosti	N	Mean / Prosjek	Std. Deviation / Std. Odstupanje	Duncan Analysis / Duncan Analiza	Minimum / Najmanje	Maximum / Najviše
1	90	1683.04	162.48	D	826.00	1769.00
2	90	343.58	393.85	C	1.00	1784.00
3	90	252.34	192.86	B	8.00	813.00
4	90	86.49	85.42	A	.00	316.00

Table 6. The result of the One-Way ANOVA analysis of the difference between the time the operator is exposed to carbon monoxide and the amount of exposure

Tablica 6. Rezultat jednosmjerne ANOVA analize razlike između vremena u kojem je operater bio izložen ugljičnom monoksidu i količine izloženosti

Subgroup / Podskupina	N	Mean / Prosjek	Std. Deviation / Std. Odstupanje	Duncan Analysis / Duncanova Analiza	Minimum / Najmanje	Maximum / Najviše
0 cm – 5 min	30	1575.87	250.21	E	826.00	1754.00
0 cm – 10 min	30	1751.90	7.03	F	1742.00	1769.00
0 cm 15 min	30	1721.37	7.43	F	1713.00	1743.00
10 cm – 5 min	30	265.97	252.01	CB	1.00	911.00
10 cm – 10 min	30	621.57	507.82	D	62.00	1784.00
10 cm 15 min	30	143.20	164.13	A	3.00	696.00
20 cm – 5 min	30	172.27	129.39	BA	8.00	468.00
20 cm – 10 min	30	281.07	149.19	CB	71.00	629.00
20 cm 15 min	30	303.70	254.83	C	21.00	813.00
30 cm – 5 min	30	99.07	90.69	A	.00	308.00
30 cm – 10 min	30	83.53	87.45	A	1.00	314.00
30 cm 15 min	30	76.87	79.07	A	.00	316.00

statistical inverse relationship between distance and CO exposure (-0.80**). As the distance increases, the CO exposure decreases. A statistically strong relationship was found between exposure time and exposure at a distance of 0 cm (x_2) and 20 cm (x_4) to CO gas (x_2=0.37** and x_4=0.28**), and an inversely insignificant relationship was found between exposure time and exposure at a distances of 10 cm (x_3) and 30 cm (x_5). In short, although the amount of exposure to CO gas was the lowest at a distance of 0 cm and 20 cm in the first 5 minutes, it was observed to increase with time. Contrary to 0 cm and 20 cm, the statistical results of the trend are different at 10 cm and 30 cm. It can be considered that the measurement at a distance of 10 cm and 30 cm is due to the wind factor (air flow) effect caused by the open air and the sensitivity of the measuring instrument.

Generally, chainsaw operators perform work of felling trees in difficult terrain conditions. In the process of felling trees, sometimes operators may approach the chainsaw in a short period of time to enter the breathing zone. There may be high CO exposure limits at that time. Therefore, a large amount of CO exposure detect in a short period of time during the work period in forest.

DISCUSSION
RASPRAVA

In the present study, when 15 minutes of average measurement data were obtained every 10 seconds from a distance of 10 cm, 20 cm and 30 cm, an average CO exposure of 227±5% ppm was observed for short periods of time. When determining the concentration or limit value of CO exposure in the work environment, differences may occur. Due to the wind speed and direction, the posture of the worker, the environmental barriers, the measurement technology, the type of fuel, and engine technologies, CO exposure limits can be different.

It is necessary to evaluate the health problems caused by the operator who uses the chainsaw being exposed to CO and other factors (such as noise, vibration, dust and other chemicals) (Golmohammadi and Darvishi 2020). On the other hand, chainsaw operators who use low-standard work safety equipment are more likely to suffer from chronic fatigue than manual hauling workers (Yovi and Yamada 2019). CO exposure, which is another important factor for chronic health problems, needs more attention and comprehensive study. The results of comprehensive evaluation and medical tests can prove the level of impact of the chainsaw operator exposure to CO. Within the scope of this study, we used a low-cost CO meter to perform a 15-minute measurement at a distance of 30 cm and less. The results showed that the operator exposure to CO was higher than the legal limit for short-term exposure (EU 1995). Besides, among the instantaneous measurements are high-level CO exposure measurements, which can be very harmful for human health (Table 4, 5). In measurements made in open area, it was found that the operator could be exposed to higher values close

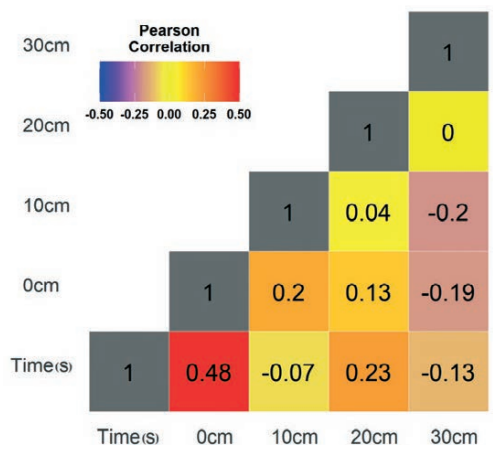


Figure 5. Summary of correlation test results

Slika 5. Sažetak rezultata testa korelacije

to the exhaust (30 cm) for a short period of time. Chainsaw operators do not have special personal protective equipment to prevent momentary exposure to carbon monoxide during forestry work. Therefore, it is appropriate to increase the level of knowledge of chainsaw operators about CO and other gasses exposure (Taş and Akay, 2022).

Environmental factors (such as temperature, humidity and wind) have an effect on the concentration of harmful gases emitted from the exhaust (Hooper et al. 2017; Dimou et al. 2019). Tight enclosure in the forest or weather conditions that limit the operator's work area will further increase the amount of short-term CO exposure (Nilsson et al. 1987; Bünger et al. 1997). It has been observed that the wind direction in the study area is not constant, and wind from different directions can affect the flow direction in the air and the gas released from the exhaust (Figure 4). Therefore, chainsaw operators are necessary to pay attention to the working position and the wind direction to reduce the CO exposure. Using a carburetor suitable for the chainsaw and always cleaning the air filter will reduce CO exposure (Wójcik and Skarżyński 2006). Considering that the production technology of the chainsaw used in this study is relatively old, compared with the chainsaw of the new technology, it may generate a lot of harmful gas emissions. However, chainsaws with new engine technology, engine maintenance and the type of fuel used are effective against increasing of harmful gases emitted by exhaust gas (Neri et al. 2016; Calcante et al. 2018).

Due to the use of a low-cost CO meter that performs integer measurements, precise decimal-level measurements could not be made at this study. Besides, it should be taken into account that the absence of chainsaw guide bars and cutting chains in the design of this study would have an impact on the results. In forest conditions, using a more professional gas meter would increase the budget of research. However, multi-dimensional analysis can also be performed by obtaining real-time data on environmental factors such as relative humidity, wind speed, and wind directions as well as CO measurement. Considering the data obtained from this study, the emission of CO from the exhaust of an idling two-stroke engine chainsaw is high enough to affect the health of operator.

CONCLUSIONS AND SUGGESTIONS
ZAKLJUČAK I PRIJEDLOZI

During the timber production work, the chainsaw operator should not approach the idling chainsaw up to a distance of 30 cm and 20 cm in a way that it enters the personal breathing zone. The CO exposure generated by the chainsaw under idling (1900 to 2200 rpm) reaches a high value in a short time. When cutting the trees or stopping for more than 10 seconds for control purposes, the operator must not approach the idling chainsaw in a way that it enters the personal breathing zone. Otherwise, the operator may be exposed to high CO for a short period of time. The chainsaw operator, who works very close to the chainsaw, is exposed to an average CO of 1683.04±5% ppm at a 0 cm distance, 343.58±5% ppm at a 10 cm distance, 252.34±5% at a 20 cm distance, and 86.49±5% ppm at a 30 cm distance. CO exposure decreases with increasing distance from the chainsaw. Analysis of variance, correlation analysis and homogeneity analysis were found to be statistically significant ($p<0.05$).

Evaluating air flow direction as a guiding factor for the work environment will be a preventive factor for immediate high-value CO exposure. If the operator of the chainsaw cannot be prevented from being as far as 30 cm from the chainsaw, it is absolutely necessary to wear a special mask (personal protective equipment) to prevent from the CO gas. If it is not possible to wear a mask, at least two operators should be employed alternately during working hours. If there is only one chainsaw operator in the work environment, the frequency of breaks should be increased. In addition, not only education but also research on other energy types should be promoted, which will replace fossil-based fuels as fuel for two-stroke engines. By accounting for the CO emissions, it will be possible to contribute to health and safety of operators, while increasing the efficiency of production.

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SAŽETAK

U mnogim zemljama motorne pile sa dvotaktnim benzinskim motorom aktivno se koriste u šumama. Rukovatelji motornom pilom izloženi su štetnim plinovima i česticama koje su sastavni dio ispušnih plinova takvih motornih pila. U ovoj studiji, istraživana je izloženost operatera ugljičnom monoksidu -CO- (ppm) prilikom rada s motornom pilom u režimu rada od 1900-2000 okretaja u minuti (o/min). Pri istraživanju je kao pogonsko gorivo korištena mješavina bezolovnog benzina od 95 oktana i motornog ulja gradacije SAE 10W u iznosu od 2%. Kako bi se istražila prisutnost CO na malim udaljenostima, odnos između vremena izloženosti i udaljenosti do izvora emisije podijeljen je u skupine. Rezultat statističke analize pokazao je da je prosječna količina CO emitirana iz motorne pile bila 1683 ppm na udaljenosti od 0 cm (±4 cm), 343,6 ppm na udaljenosti od 10 cm, 252,3 ppm na udaljenosti od 20 cm i 86,5 ppm na udaljenosti od 30 cm. Analiza varijance prema udaljenosti pokazala je da je količina CO (ppm) statistički značajna ($p<0,05$). Ako rukovatelj motornom pilom radi vrlo blizu motorne pile, primijetit će se izloženost CO, što se smatra negativnim utjecajem na njihovo zdravlje i radnu učinkovitost. Stoga treba provesti obuku kako bi se povećala svijest o blizini motorne pile i rukovatelja te o važnosti korištenja osobne zaštitne opreme. Uz podršku pri obuci, korištenje nove generacije pogonskih motora motornih pila također treba poticati i promicati kako bi se emisije CO svele na minimum.

KLJUČNE RIJEČI: Šumarstvo, proizvodnja drva, dvotaktni benzinski motor, izloženost emisijama, ugljični monoksid, zdravlje operatera