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Exhaust Gases from Skidder ECOTRAC 140 V Diesel Engine

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Abstract: During forest harvesting operations, exhaust emissions from forest vehicles are released at different levels depending on several variables. This pollution released into the atmosphere is considered one of the main anthropogenic factors that negatively affect forest ecosystems. In this study, we analyzed exhaust emissions from a skidder diesel engine during various engine loads. Measurements were done on an ECOTRAC 140 V skidder with the water-cooling diesel engine and a built-in catalyst with an SCR system. The composition and amount of exhaust gases (CO, CO_2, O_2, NO_x,) at different loads of the diesel engine of the skidder and engine temperature were measured using a MAHA MET 6.3 measuring device. The amount of exhaust gases was analyzed in relation to the engine speeds, engine temperatures, and the European emission standards for engines used in nonroad mobile machinery (NRMM). Influences of catalyst systems and recommendations for more environmentally friendly forest harvesting practices are addressed. With the engine unloaded, the amount of CO_2 increased when engine speed was increased, while other amounts of exhaust gas decreased. During the cold start, the concentrations of hydrocarbons and nitrogen compounds were high. The composition of the exhaust gas was affected by the exhaust reduction system installed in the tractor and the amount of the exhaust gas was dependent on the engine load. The skidder engine met the requirements of the exhaust gas standards EPA/COM IIIB Tier 4 (I) under which it is declared. With a load engine during winch operation (2300 rpm), NO_x amounts mostly exceed the limit values of the standard. Exhaust emissions can be reduced at various operating levels by utilizing the most environmentally friendly technologies and following the correct procedures, such as warming the engine up to operating temperature prior to operation and operating in the most favorable mode with optimal speed. The regular reduction of exhaust limit values to newer stages of the standard therefore leads to the continuous development of engines and forest vehicles in general.

Keywords: skidder; winch; emissions; engine loads; European standards NRMM

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1. Introduction

One of the main anthropogenic factors that negatively affect forest ecosystems is the pollution released into the atmosphere, including the pollution generated by the propulsion engines of vehicles and machines. Air, as a fundamental component of the biosphere, is a carrier of various pollutants in the form of gases, dust, and aerosol, and its quality has a significant impact on the forest ecosystem [1].

For each product or service, a certain amount of primary fuel sources is consumed and CO_2 emissions are released into the environment. The impact of any technology (system) or product on the environment may be assessed using a life cycle analysis (LCA), which can be used to identify input and output data [2]. Klvac et al. [3] analyzed energy consumption through life cycle analysis in a fully mechanized timber harvesting system; they argued that the most significant amount of energy is consumed in the form of propellants up to 80%, while the remaining 20% represents the energy needed to manufacture, repair, and maintain the machines. The above-mentioned authors claim that larger machines generally achieve higher productivity as well as lower fuel consumption per unit of production, which is the main reason that they are being built larger in size. A similar result was obtained by Pandur et al. [4], which indicated the amount of fuel energy consumption as 86% in a partially mechanized system of timber harvesting in lowland pedunculate oak woods (felling and bucking using a chainsaw, extracting using a forwarder). Forest harvesting techniques and technologies account for a significant share of the total greenhouse gases emitted into the atmosphere. Based on the statistics, Athanassiadis [5] stated that, in Sweden, harvesting and extracting operations account for one percent of CO_2 and one point six percent of NO_x compounds emitted.

In 1997, in order to minimize the pollution of working machinery, the first Euro standard for machinery that does not operate on public roads was adopted [6]. This significantly affected the further development of internal combustion engines [7]. Over the last 20 years, engine exhaust emissions from agricultural and forest machines have been significantly reduced in accordance with the applicable EU legislation. Today, the modern tractor emits approximately 95% less nitrogen oxides (NO_x) and particulate matter (PM) in relation to a comparable machine twenty years ago [8]. The Euro stage V standard [9] is currently enforced and is even stricter in terms of harmful exhaust gases and particulate matter emitted in diesel engines. Therefore, manufacturers of internal combustion engines are upgrading their engines to make exhaust emissions as climate-friendly as possible. Scientists are also developing propellants with a more favorable environmental impact with regards to exhaust gases. This regulation makes the EU's environmental requirements for agricultural and forest machines the strictest in the world and requires major changes in tractors and forest machines since all of these vehicles need to have new, cleaner propulsion engines installed. Compliance to new emission regulations is one of the main differences between the features of old machines and machines that are currently being introduced to the market [10].

During forest harvesting operations, exhaust emissions from forest vehicles are released to varying degrees depending on terrain conditions, wood species, management methods, operator performance, and type of machines used in the process. Tavankar et al. [11] observed a higher amount of emissions in moist soil conditions over steep slope gradients. With an expected increase in the level of timber harvesting coupled with greater levels of mechanization, we can expect higher levels of total fuel use as well as exhaust emissions in future harvesting operations. Emissions of a specific forest vehicle engine mainly depend on engine speed and load. Various driving methods and the usage of implements such as bogie tracks or wheel chains can affect the engine load and increase (or decrease) fuel consumption in certain work conditions.

Janeček and Adamovský [12] concluded that the emissions of greenhouse gases (CO_2, SO_2, HC, and NO_x compounds) in timber harvesting processes have been significantly lower in the past few years compared to a decade earlier. They state that the main reason for the reduction of emissions is the improved design of the propulsion engines of existing machinery and equipment in combination with optimized timber harvesting operations.

Skidding operations emitted large amounts of greenhouse gases, mainly CO_2 ($2.23\ \mathrm{kg/m^3}$). Within the skidding time elements, loaded and empty travel produced the highest amounts of emissions (52% and 23%, respectively) [13].

Emissions-wise, modern machines are expected to have more controlled fuel and lubricant use engines to comply with regulatory concerns of carbon dioxide emissions in the atmosphere and their contribution to climate change [10]. Under ideal thermodynamic conditions, only harmless components such as nitrogen (N_2), water vapor (H_2O), oxygen (O_2), and carbon (IV) oxide (CO_2) would be released with the complete combustion of diesel fuel [14]. However, there are numerous reasons (air–fuel ratio, ignition timing, turbulence in the cylinder) which cause incomplete combustion and the formation of many harmful gases. Harmful components of exhaust gases include carbon (II) oxide (CO), hydrocarbons (CH), sulfur (IV) oxide (SO_2), nitrogen oxides (NO_x) and compounds, soot, and smoke [15].

In order to reduce harmful exhaust gases, new systems for the diesel engines' exhaust gases are being developed. At this time, there are four reworked exhaust systems used individually or in combination with others.

The Diesel Oxidation Catalyst (DOC) consists of a monolithic substrate whose honeycombs are coated with metal and packed in a stainless steel container. The honeycomb structure, with numerous small parallel channels, has a highly catalytic area of contact with the exhaust gases. The exhaust gases of a diesel engine contain sufficient amounts of oxygen for the reactions. The concentration of O_2 in the exhaust gases of a diesel engine varies from 3% to 17%, depending on the engine load. Catalyst activity increases with temperature. An exhaust temperature of at least 200 °C is required for the light-off of the catalyst. At elevated temperatures, the conversions depend on the size and design of the catalyst, and can be greater than 90%.

The exhaust gas recirculation (EGR) valve is used in SUI engines used in working machinery. The EGR valve works by diverting 5 to 15% of the exhaust gases from the engine back to the engine through the intake manifold for recombustion in the cylinders. Therefore, the emission of nitrogen oxides is reduced and the recirculation ensures that the combustion temperature does not exceed 1800 °C, which is optimal for combustion. If the temperature elevates further, nitrogen oxides are formed. In order for the exhaust gas recirculation valve to work well, the engine must be properly warmed up. During usual operations, emissions are reduced by as much as 30%. Today, most modern engines utilize this type of valve in order to meet environmental standards that are becoming increasingly demanding every year.

The particulate filter (DPF), or soot filter, is a filter designed for diesel engines and has become a standard component for working machinery engines to meet the Euro exhaust gas standards. The particulate filter belongs to the system which reduces harmful gases from the engine, and its function is to retain soot particles that would otherwise be released into the environment through the exhaust system.

Selective Catalytic Reduction (SCR) is one of the most advanced technologies for reducing greenhouse gas emissions produced by leading European commercial vehicle manufacturers. This type of technology is the only one that enables simultaneous reduction of exhaust emissions and optimization of engine operation and fuel consumption. It is a well-known fact that high emissions of nitrogen oxides are the result of incomplete combustion of fuel in the engine. Selective catalytic reduction using a reducing agent in the form of a 32% solution of urea in distilled water (AdBlue) treats the exhaust gases in the catalyst. A precisely determined amount of the urea solution is injected through the nozzles into the exhaust gas stream where hydrolysis occurs, and then into the catalyst, which is where the transformation of nitrogen oxides to molecular nitrogen (N_2) and water (H_2O) occurs.

Many previous studies have calculated exhaust emissions of forest machines based on fuel consumptions. In our study, we performed direct measurements of exhaust gasses from a skidder diesel engine during various engine loads in laboratory conditions. The amounts of exhaust gases were analyzed in relation to the engine speeds, engine temperatures, and the European emission standards for engines used in nonroad mobile machinery (NRMM). Influences of catalyst systems and recommendations for more environmentally friendly forest harvesting practices are addressed. Our research represents the initial phase of determining the energy consumption of the skidder and the development of measurement methods based on the amounts of exhaust gases and fuel consumed during machine operation.

2. Materials and Methods

A skidder is defined as a self-propelled, articulated forest vehicle for skidding trees or parts of trees. Skidding is a process of removing entire trees or parts of trees (trunk, wood assortment) from the felling and site processing to the roadside landing. In most countries of Central and South-Eastern Europe, the use of skidders is the most common method of timber extraction. It was estimated that these countries have a fleet of 8370 skidders [16]. Lundback et al. [17] stated that in the European Union, at least 40% of the total harvested wood, or more than 100 million m^3 per year, is extracted with skidders. In the forests of the hilly area and mountainous area of Croatia, skidders with a winch, weighing up to 10 tons, are primarily used for timber extraction from regular felling of broadleaves and selective felling of coniferous species. Approximately 55% of the total timber assortments are extracted by skidders using a winch [18].

In our study, we performed an analysis of diesel engine exhaust gases at different loads and at different engine speeds. Measurements were performed on an ECOTRAC 140 V skidder (Figure 1.), manufactured by Hittner d.o.o. the Republic of Croatia, Bjelovar, powered by a water-cooled Cummins diesel engine and a built-in catalyst with an SCR system (Table 1). A two-drum, hydraulically driven winch with a nominal tractive force of 2 × 100 kN was mounted on the skidder.

Figure 1. Skidder ECOTRAC 140 V.

Table 1. Technical specifications of the ECOTRAC 140 V skidder engine.

Engine	**Cummins Inc.; QSB4.5**
Engine cooling	Water cooling
Number of cylinders	4 in-line cylinders
Working volume	4500 cm^3
Rated power	104 kW at 2000 min^{-1}
Torque	622 Nm at 1500 min^{-1}
Exhaust gas standards	EPA/COM IIIB Tier 4(I)

The MAHA MET 6.3 exhaust gas analyzer was used to measure the exhaust gas concentration. The device consists of a measuring unit with a protective housing for transport, an exhaust emission probe, a temperature measuring probe, and a device for measuring the engine speed (Table 2). The device is able to measure the concentration of the following exhaust gas components: carbon (II) oxide (carbon monoxide, CO), carbon (IV) oxide (carbon dioxide, CO_2), hydrocarbons (HC), oxygen (O_2), nitrogen (II) oxide (nitrogen monoxide, NO), and nitrogen (IV) oxide (nitrogen dioxide, NO_2). The exhaust emissions measured with the gas analyzer are given in volume percent (vol%) and parts per million (ppm). Along with the measurement of the exhaust gas concentrations, the device records the parameters of the vehicle engine (engine speed and engine temperature). Exhaust gas concentration measurements were performed under test conditions on an unloaded tractor at various engine speeds, from engine idling up to the maximum engine speed. Exhaust gas measurements of the loaded engine using the winch were also performed. The MAHA MET 6.3 mobile exhaust gas analyzer was mounted inside the skidder, and the exhaust gas sample was fed to the analyzer through a sampling probe inserted into the exhaust pipe. The measurement of the concentrations of HC, CO, and CO2 was done with the nondispersive method using an infrared sensor NDIR (nondispersive infrared), while concentrations of O_2 and NO_x were measured with an electrochemical sensor. Together with the measurement data, the system recorded the engine speed with the MTG-300 EVO RPM Counter and the engine oil temperature using an oil temperature sensor that was inserted instead of an oil level dipstick and connected directly to the MAHA MET 6.3 gas analyzer. The entire rig was connected to a laptop, which was used to record data with the corresponding MAHA software (Figure 2). To measure the exhaust gases of a loaded engine, a winch rope was connected to a dynamometer anchored to the ground. The dynamometer used was the HBM model U1, capable of measuring tensile force up to 100 kN. The engine was loaded by pulling a winch rope that was anchored to the ground, and the traction force was recorded with a dynamometer.

Table 2. Specifications of the MAHA MET 6.3 measuring device.

Measured Variables	Measurement Range	Measurement Accuracy	Measurement Principle	Resolution (Accuracy)	Response Time
HC (hexane)	0–2000 ppm	±4 ppm abs./3% rel.	NDIR (infrared spectrometry) Nondispersive infrared sensor	1 ppm vol.	3.5 s
HC (propane)	0–4000 ppm	±8 ppm abs./3% rel.			
	4001–10,000 ppm	±5% rel.			
	10,001–30,000 ppm	±10% rel.			
CO	0.00–10.00 vol.%	±0.02% abs./±3% rel.		0.01 vol.%	
	10.00–15.00 vol.%	±5% rel.			
CO_2	0.00–16.00 vol.%	±0.3% abs./±3% rel.			
	16.01–20.00 vol.%	±5% rel.			
O_2	0.00–25.00 vol.%	±0.02% abs/1% rel.	Electrochemical	0.01 vol.%	5 s
NO_x	0–5000 ppm vol.	32–120 ppm	Electrochemical	1 ppm vol.	5 s
Temperature	0–150 °C			1°	
Engine rpm	400–8000 min^{-1}			1 min^{-1}	

For the measurement results to be comparable with the European standard, it was necessary to transform them to the same units of measurement. European emission standards for engines used in new nonroad mobile machinery (NRMM) have been structured as gradually more stringent tiers known as Stage I to V standards. According to these standards, the amount of exhaust gases is expressed in g/kWh.

Previous studies have reported a relationship between vehicle emission concentration (vol%; ppm) and specific fuel consumption (g/kWh) [19–21]. This relationship is defined by Equation (1).

$$EP_i = EV_{i,d} \times \left(\frac{M_i}{M_{Exh,d}} \times \frac{m_{Exh,d}}{P_{eff}} \right) = EV_{i,w} \times \left(\frac{M_i}{M_{Exh,w}} \times \frac{m_{Exh,w}}{P_{eff}} \right) \quad (1)$$

EP_i, Pollutant mass, i, referenced to P_{eff} (g/kWh);
$EV_{i,d}$, Exhaust emission value of components on dry basis, i, as volume share (ppm);
$EV_{i,w}$, Exhaust emission value of components on wet basis, i, as volume share (ppm);
M_i, Molecular mass of the components, i, (g/mol);
$M_{Exh,d}$, Molecular mass of the exhaust gases on dry basis (g/mol);
$M_{Exh,w}$, Molecular mass of the exhaust gases on wet basis (g/mol);
$m_{Exh,d}$, Exhaust mass flow of the exhaust gases on dry basis (kg/h);
$m_{Exh,w}$, Exhaust mass flow of the exhaust gases on wet basis (kg/h);
P_{eff}, Power output (kW).

Figure 2. Measurement rig.

The empirical constant is taken from previous research [19–21] as follows:

$$k_d = \frac{m_{Exh,d}}{P_{eff}} = 3873\ g/kWh \tag{2}$$

$$k_w = \frac{m_{Exh,\ w}}{P_{eff}} = 4160\ g/kWh \tag{3}$$

Using the empirical constant from Equations (2) and (3), Equations (4) and (5) were derived.

$$EP_{i,d}(g/kWh) = \frac{EV_{i,d}(ppm)}{1 \times 10^6} \times \left(\frac{M_i}{30.21(g/mol)}\right) \times 3873(g/kWh) \tag{4}$$

$$EP_{i,w}(g/kWh) = \frac{EV_{i,w}(ppm)}{1 \times 10^6} \times \left(\frac{M_i}{28.84(g/mol)}\right) \times 4160(g/kWh) \tag{5}$$

The MAHA MET 6.3 exhaust gas analyzer measures the concentration of all exhaust gases on a dry basis; therefore, Equation (4) was used for the calculation. Using the above equation the general conversion from emission gas concentration (ppm) to specific fuel consumption (g/kWh) is summarized as follows:

$$CO(g/kWh) = 35.910 \times CO(\%\ Vol.) \tag{6}$$

$$\mathrm{HC(g/kWh)} = 1.779 \times 10^{-3} \times \mathrm{HC(ppm)} \tag{7}$$

$$\mathrm{NO_x(g/kWh)} = 5.898 \times 10^{-3} \times \mathrm{NO_x(ppm)} \tag{8}$$

3. Results and Discussion

In order to analyze the amount of exhaust gases, the engine speed range was divided into 100 $\mathrm{min^{-1}}$ steps. For each individual step, the average values of all exhaust gas components (CO, CO_2, HC, O_2, NO, NO_2, and NO_x) and the average engine temperature were calculated (Table 3). In addition to the values obtained for each engine speed, the average values of the exhaust gases with the loaded engine using a winch were also calculated.

Table 3. Average exhaust gas values of the unloaded engine.

Engine rpm	Average of CO [% Vol.]	Average of CO_2 [% Vol.]	Average of O_2 [% Vol.]	Average of HC [ppm]	Average of NO [ppm]	Average of NO_2 [ppm]	Average of No_x [ppm]
750	0	2.83	16.74	3.25	400.75	125.5	526.25
800	0	2.5825	17.3425	3	309	84.75	393.75
900	0	2.5225	17.445	0.75	273.75	51.75	325.5
1000	0	2.825	16.8525	0.25	339.5	63.5	403
1100	0	2.86	17.1175	1.5	246	36.25	282.25
1200	0	3.325	16.195	1.5	255	46	301
1250	0	3.58	15.815	4	254.5	52	306.5
1300	0	3.7425	15.6875	1.75	177.25	53.75	253.5
1400	0	3.9325	15.3025	0.75	144	55.25	199.25
1500	0.0025	3.995	16.645	0.75	65.25	28.25	93.5
1600	0.005	4.41	14.57	1.25	101	57.25	158.25
1700	0	4.445	14.9625	0.5	79.5	50	129.5
1800	0.0025	4.5175	15.0475	0.25	69.25	47	123
1900	0.005	4.675	14.505	0.25	72.5	52	124.5
2000	0	4.64	14.49	0	72.5	50.5	123
2100	0	4.8275	14.17	0.25	82.5	61.75	144.25
2200	0	4.8775	15.255	0.25	77	61.75	138.75
2300	0	4.6675	14.3725	1.25	78	65.25	143.25

The results demonstrated changes in the amount of exhaust gases in relation to the engine speed. When increasing the unloaded engine speed, the concentration of carbon dioxide (CO_2) was increased, and the concentration of oxygen (O_2) was decreased (Figure 3). Oxygen and carbon dioxide are inversely proportional, which is to be expected since better combustion causes more oxygen consumption and more carbon dioxide production, and vice versa [22]. Carbon monoxide (CO) was almost nonexistent; negligible quantities were recorded at 1500 and 1600 rpm and at 1800 and 1900 rpm (Table 3). CO appears during incomplete combustion and when there is an increased amount of fuel in the mixture, referred to as a "rich mixture". Diesel engines are engines that use a "lean mixture", with a higher air–fuel ratio; therefore, the formation of CO is reduced to a minimum [15].

All nitrogen compounds (NO, NO_2, and NO_x) showed a declining trend, where increasing the unloaded engine speed reduces the concentrations of said compounds (Figure 4). Nitrogen compounds are formed under conditions of increased temperature and pressure, and with an increased concentration of oxygen in the mixture (lean mixture) which reacts with nitrogen [21]. Therefore, the concentration of nitrogen compounds should increase with the increase of engine speed and temperature; however, our observations indicated the opposite result. The highest values of nitrogen compounds measured on an unloaded engine occured at lower engine speeds and at lower temperatures. The concentration of nitrogen compounds decreased with the increase of temperature (Figure 5). This was because the engine had just started and had not reached its operating temperature; therefore, the exhaust catalyst had not warmed up sufficiently. This is referred to as a "cold start". The catalyst must be heated to a minimum of 300 °C in order for catalytic reactions to take place. The catalyst operates at its optimal level when its cartridge is exposed to a temperature of 400 to 800 °C [23]. For example, during a NEDC (New European Driving Cycle) from cold conditions with a total duration of ~1200 s, the exhaust temperature is typically below the catalyst light-off level for over 200 s, and reaches its minimum operating temperature of about 300 degrees only after 850 s [24]. Previous research showed that insufficient temperature levels significantly impair the efficiency of the catalyst, and that the catalyst itself has a greater impact on exhaust emissions than the changes in combustion of fuel. The difference in the concentration of harmful exhaust gases with and without catalytic converters is greater than the difference in the concentration of harmful exhaust gases in different engine operating modes [25].

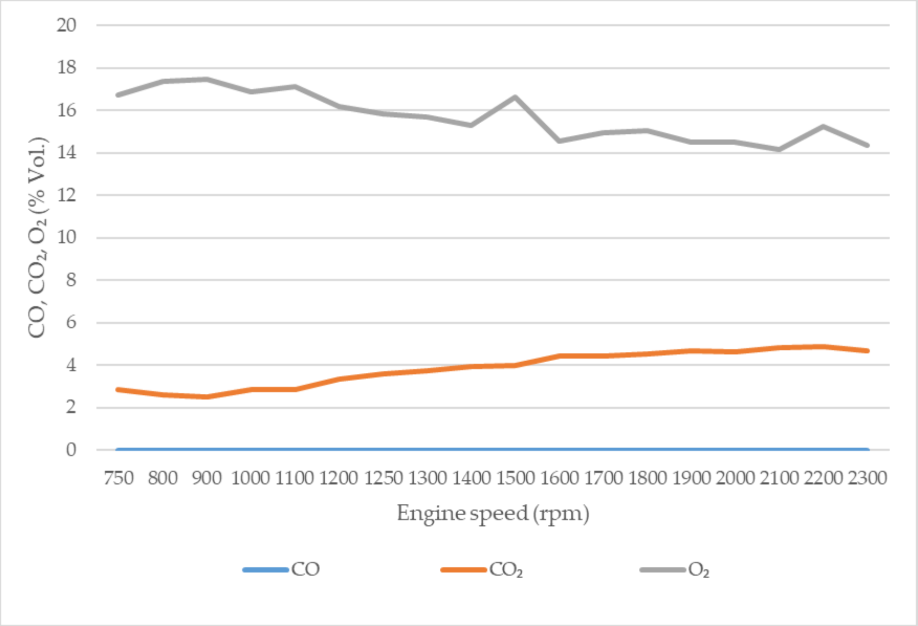

Figure 3. Changes in CO, CO_2, and O_2 in relation to the engine speed.

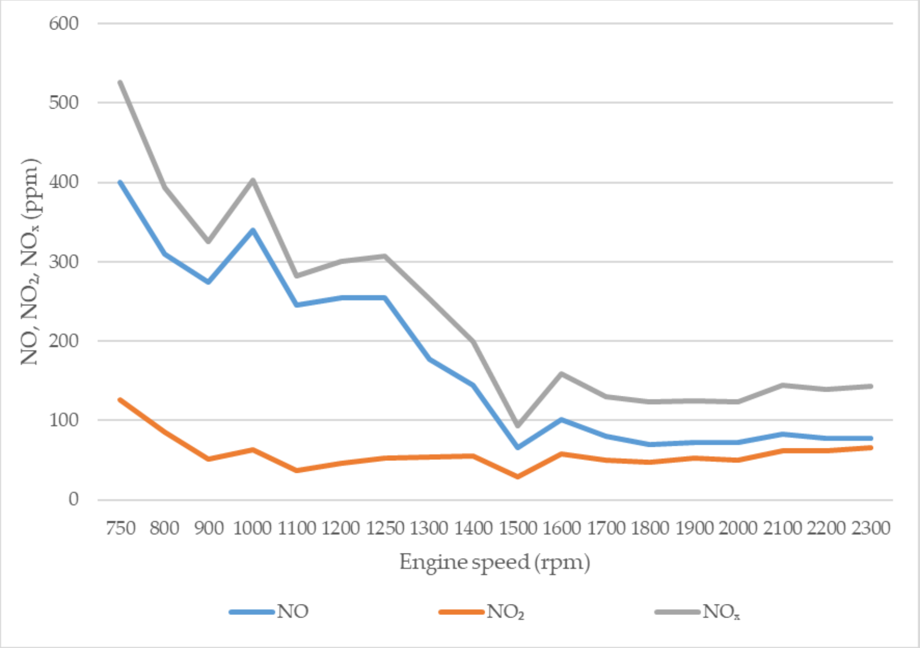

Figure 4. Changes in NO, NO_2, and NO_x concentrations in relation to the engine speed.

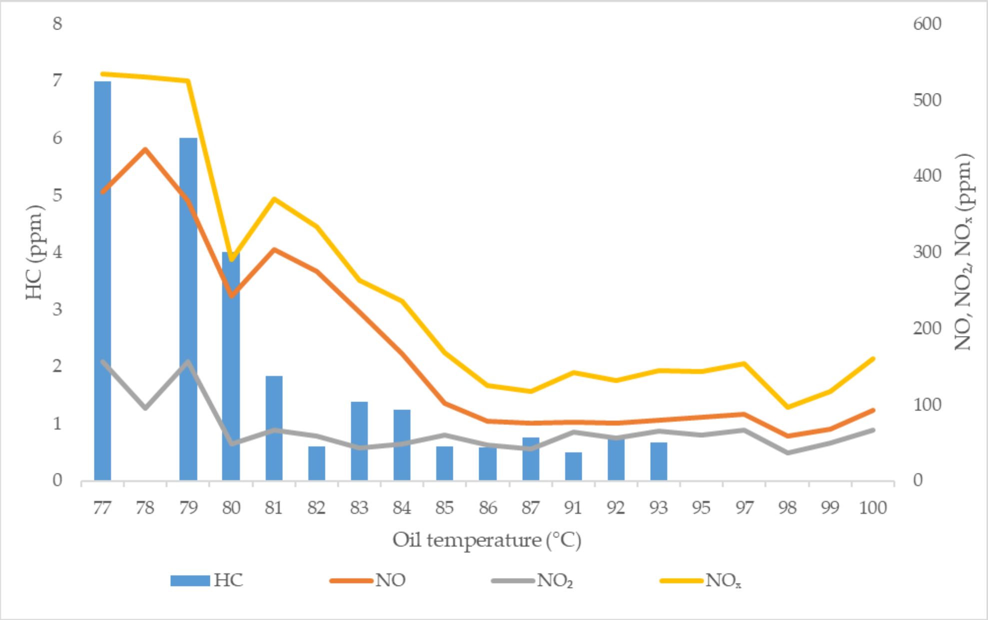

Figure 5. Changes in HC, NO, NO_2, and NO_x concentrations in relation to engine temperature.

The concentration of hydrocarbon compounds (HC) had no continuous upward or downward trend and showed no dependence on engine speed. It was found that changes in the concentration of HC compounds in an unloaded engine are most influenced by engine temperature (Figure 5). The highest HC concentrations appeared at lower starting temperatures, when the engine was not yet sufficiently warmed up. When starting an engine, a rich mixture in which the oxygen content is reduced is used, resulting in an incomplete combustion, and the appearance of unburned fuel (HC) in exhaust gases [12].

The use of a winch increased the amount of nitrogen compounds (NO, NO_2, and NO_x), which is correlated with the engine load (Figure 6). It should be noted that the changes in exhaust gas concentrations do not overlap with the engine load in the graph; however, we were able to observe a shift. This is due to the mode of operation of the measuring device where the engine speed is registered and recorded instantaneously; in order to measure the concentration of each gas, there is a delay period required for the exhaust gases to reach the sensor from the exhaust pipe. The engine speed increased under load, and the concentrations of nitrogen (NO_x) compounds also increased, which was not the case with an unloaded engine. Trends in changes in the oxygen (O_2) and carbon dioxide (CO_2) concentrations followed the same laws, as was the case with an unloaded engine.

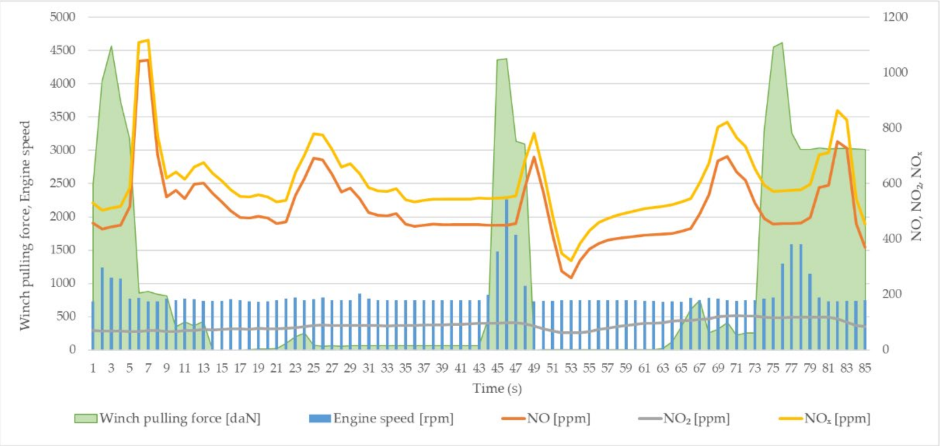

Figure 6. Change in the concentration of nitrogen compounds during engine load.

The exhaust gas values were converted into grams per kilowatt hour in order to compare them to the limit values of the EPA/COM III standard. Due to the extremely small measured values, the amount of carbon monoxide was not considered. Values of considered HC were well below the applicable standard limit (Figure 7).

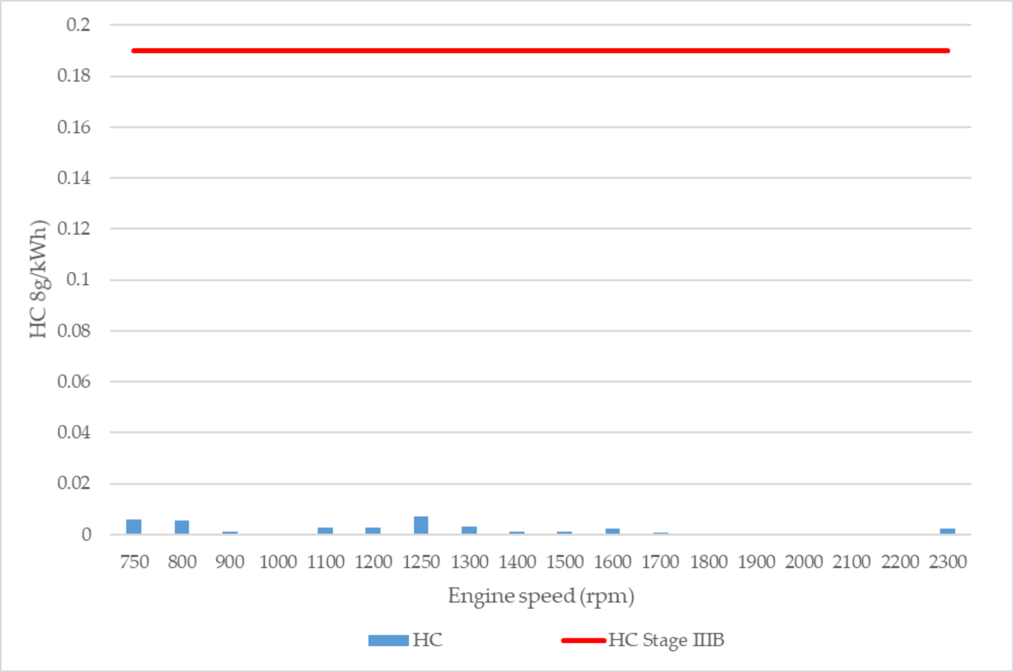

Figure 7. Comparison of HC depending on engine speed with EPA/COM IIIB standard.

NO_x levels were below the standard limit in the entire engine speed range (Figure 8). The amount of NO_x was very close to the limit value at the lowest engine speeds, which is a consequence of the cold start of the engine when the catalyst system has not reached the operating mode.

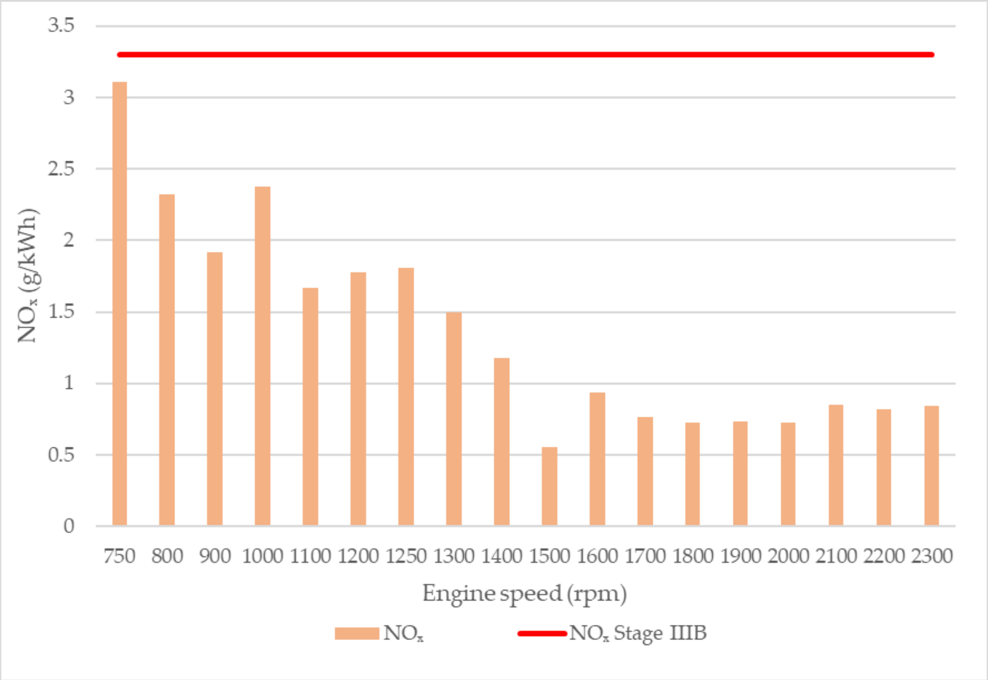

Figure 8. Comparison of NO_x depending on engine speed with EPA/COM IIIB standard.

During winch operation with a loaded engine, NO_x amounts mostly exceed the limit values of the standard. Even when a pulling force of only half the rated power of the winch was applied, the values of the NO_x amounts exceeded the limit values. The highest values are twice the limit values of the standard (Figure 9). Similar results were reported by Egúsquiza et al. [26]. Under heavy load condition of the engine, due to an increase in fuel supply, the combustion duration is longer, the cylinder temperature is high, and NO_x emissions are heavy. In their research of exhaust emissions of heavy-duty vehicle diesel engines, Sun et al. [27] came to the realization that when the engine load increases from 400 Nm to 3113 Nm with an engine speed at 1400 min^{-1}, the concentration of NO_x emissions rises fivefold.

Figure 9. Comparison of NO_x during engine load with EPA/COM IIIB standard.

High concentrations of NO_x and soot occur during heavy operation of diesel engines in working machines and forest vehicles. Our study was conducted on an older skidder diesel engine that met the EPA/COM IIIb standard, but the newer stages of the exhaust gas standards brought a drastic reduction of the limit values of NO_x and soot concentrations. Based on our results, it could be concluded that NO_x concentration needs to be further reduced through the development of new engines and improvements to catalyst systems, but it is necessary to further measure the amount of soot particles in the engine operating conditions under load.

4. Conclusions

In this paper, we present aspects of exhaust gas testing of the ECOTRAC 140 V skidder in the conditions of an unloaded engine and an engine under load. The composition of the exhaust gases was affected by the exhaust reduction system installed in the tractor, and the amount of exhaust gases depended on the engine load. We found that the concentrations of individual exhaust gas components were many times higher with a loaded engine. During the cold start, the concentrations of hydrocarbons and nitrogen compounds were high because the catalyst did not heat up enough to reach operating temperature.

The exhaust emission test was carried out on a skidder engine that, according to the results, meets the requirements of the Exhaust gas standards EPA/COM IIIB Tier 4 (I) under which it is declared.

The regular reduction of exhaust limit values to newer stages of the standard therefore leads to the continuous development of engines and forest vehicles in general.

Exhaust testing of diesel engines in working machines is very important. Reducing exhaust emissions requires a constant search for new solutions in the field of internal combustion engine construction and new methods for testing. The results obtained in the research confirm that it recommended to also test engines in real operating conditions because they provide data that are impossible to obtain in laboratory conditions.

Exhaust emissions can be reduced at various operating levels by utilizing the most environmentally friendly technologies and following the correct procedures, such as allowing the engine to warm up to operating temperature before operation and operating in the most favorable mode with optimal engine speed.

The development of methods for the determination of the energy consumption of different types of forest vehicles performing different work tasks under different terrain conditions is a very important topic of scientific research in the field of forestry engineering. These data could be used as a basis for the development of hybrid and electric forest vehicles.

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