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TRACTOR'S ENGINE EFFICIENCY AND EXHAUST EMISSIONS' RESEARCH IN DRILLING WORK

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Abstract. This paper provides an overview of possibilities for determining tractor's engine load, fuel consumption and exhaust emissions in real operating conditions. The use of accumulated database in tractor's electronic control modules for the analysis of engine load, fuel consumption and exhaust emissions is analysed. The methodology for analysis of engine power, speed and exhaust emissions' dependencies, also for analysis of engine exhaust emissions is presented. This paper presents testing results of the unit combined of tractor "Massey Ferguson MF 6499" and drilling machine "Vaderstad Rapid" by engine load, fuel consumption and exhaust emissions. Drilling process time, engine load, fuel consumption and exhaust emission components' distribution are presented in different engine speed and cyclic fuel injection modes. Test results are analysed separately for technological drilling and work processes at the headland. In the technological process of drilling, if the tractor engine speed and, correspondingly, the transmission gear ratio were reduced to get the set working speed, fuel consumption decreased, CO and CO_2 emissions varied slightly, but the NO_x increased significantly. Significant part of exhaust emissions occurred at headlands. The conclusion is that the fuel consumption and exhaust emissions, including harmful components, can be reduced only by complex optimization of technological processes and tractor operating modes.

Keywords: tractor, engine load, fuel consumption, engine speed, exhaust emissions, NO_x, CO, CO_2, environmental impact assessment, environment monitoring, environmental processes modelling.

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Introduction

Tractors are the main power machines in agriculture whose energy comes from the fuel burned in their engine. As total amount of powerful tractors, cars and other agricultural machinery is increasing, more and more various pollutants are emitted into the environment (Baltrėnas *et al*. 2008, 2004; Pérez-Martínez 2012; Szendro *et al.* 2012; Tretjakovas *et al.* 2012; Vaitiekūnas, Banaitytė 2007; Worldwide Emissions Standards 2011/2012). Fuel consumption and emissions during specific operations depend on engine speed and load characteristics. The engine load can be affected by various operation techniques, as well as by the transmission design and utilization of implements of various performance (Ashrafur Rahman *et al.* 2013; Negoižescu, Tokar 2013; Lindgren *et al.* 2010, 2011; Müllerová *et al*. 2011; Sendžikienė *et al.* 2012; Sirvydas *et al.* 2013). Farmers frequently have a goal, especially in the heavier work (ploughing, cultivation), to achieve maximum productivity, reduce fuel consumption, rather than make an adverse effect on the environment (toxic emissions).

Many studies were focused on environmental impact assessment and improvements in fuel consumption and efficiency of fuel utilization for specific tractors, vehicles and other machines (Grisso, Pitman 2010; Juostas, Janulevičius 2009; Pérez-Martínez 2012; Rakopoulos, Giakoumis 2009). Also, many studies were focused on engine exhaust emissions environment monitoring and measures for reduction of harmfulness of gases, i.e. reduction of emission of components that are harmful to the environment (Ashrafur Rahman *et al.* 2013; Lebedevas *et al.* 2010; Li *et al.* 2006; Lindgren, Hansson 2004; Lindgren *et al*. 2010, 2011). Most of the data for fuel

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consumption and environmental impact assessment today are obtained according to test data when the mode of engine is steady. During various field applications, engine speed and load characteristics are constantly changing. Hansson *et al*. (2003) and Lindgren *et al*. (2011) have found that fuel efficiency increases proportionally with increasing the engine load. Lindgren *et al.* (2010) studies have shown that emissions, when working with a mobile loader, significantly increased compared to the steady-mode test results. Speed selection in field work has a great influence on the efficiency of work and engine load, as well as fuel consumption and exhaust emissions. In the works of tillage cultivation, tractor operation principle "Gear up, speed down" gives significantly reduced fuel consumption (Grisso, Pitman 2010; Grisso *et al*. 2008). On the other hand, emissions of CO, NO_x and PM exhaust gases increased (Negoižescu, Tokar 2013; Li *et al*. 2006).

The result may be that using different management strategies and environmental processes modelling for machines and different machines' operating modes that are optimized for specific conditions, emissions may be affected to a large extent without affecting operation time or fuel consumption. This means that there is a potential for solving emissions problems. However, today we still lack of information about efficiency of tractor engines, fuel consumption efficiency and toxicity of exhaust emissions in specific field works of a particular tractor operation.

Purpose of the first part of the research is to develop methodologies and tools for data collection to determine the amount and harmfulness of engine exhaust emissions when tractor is working under natural conditions. The purpose of the second part of the tests is to investigate working performance and exhaust emissions for engine of the tractor in working conditions.

1. Methodology and methods

The main gas emission components of engine exhaust are as follows: NO_x *(nitrogen oxides),* PM *(particulate matter),* HC *(hydrocarbons),* CO *(carbon monoxide)* and CO_2 *(carbon dioxide).* In all cases, the CO_2 emission is directly dependent on fuel consumption. CO_2 emissions gradually increase with increasing of fuel consumption (An *et al.* 2012; Ashrafur Rahman *et al.* 2013). From ecological point of view, CO_2 gas is also dangerous because it traps heat on the surface of earth like a sort of shell. NO comprises about 90% of all nitrogen oxides in exhaust gases. The latter is formed where gas temperature is very high and there is sufficient amount of oxygen. When the combustion process is complete, the cycle temperature is higher, and then more NO is in the exhaust gases. When this process is not complete, more CO and HC are in exhaust gases. Harmful substances generated by diesel engines depend on the load and speed of the engine (McLaughlin, Layer 2003a; Lindgren *et al*. 2011; Lebedevas *et al*. 2012).

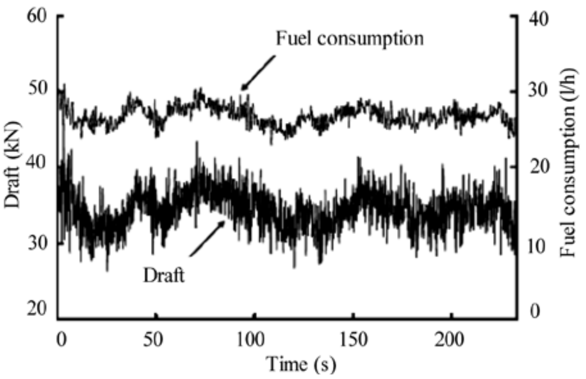


Fig. 1. Dependencies of traction force and fuel consumption and their interrelation in real-time soil preparation work (Li *et al.* 2006)

Environment monitoring of engine emissions in field conditions is an expensive and time consuming process, especially if operational strategies are studied. In addition, in field conditions it is almost impossible to directly measure and control all the variables affecting engine emissions (McLaughlin, Layer 2003a). Computer simulations and calculations are suitable for such studies. This requires a methodology, environmental processes modelling and data, where specific conditions are taken into account.

Analysis of data obtained in the field work tests (Li *et al.* 2006; McLaughlin, Layer 2003a) has showed that the fuel consumption curve for the tractor is very similar to the traction force curve (Fig. 1). In the results of a field work test by McLaughlin and Layer (2003b) hourly fuel consumption is very well reflected in the engine power curve.

Engine power is characterized by the product of tractor's traction force and speed. Fuel consumption can be expressed in mega-joules of traction power energy per litre of fuel ($MJ\ l^{-1}$) and dependence on time. Thus, the fuel efficiency, expressed in such a way, i.e. as a sum of efficiencies for the engine, transmission and traction power, is a measure of pure energy per unit of the fuel, when the tractor performs intended pulling activities under field conditions. If we compare the fuel consumption, fuel efficiency relatively depends on the traction force in conventional field work (Li *et al.* 2006).

Lebedevas *et al.* (2011) presented development of an algorithm for calculating energy characteristics of combustion products. The relation between fuel consumption and emissions is highly dependent on engine load (the acting torque) (Lindgren *et al*. 2011). Therefore, the reduction in fuel consumption can also reduce emissions. NO_x formation is closely related with the engine torque and combustion temperature which generally increases with the increase of engine speed and engine load (An *et al.* 2012; Asprion *et al.* 2013; Li *et al.* 2006). An *et al.* (2012) study shows that the engine idle speed of 800 rpm may also have a significant affect on the NO_X emission formation processes. Results of Li *et al.* (2006) and Bostic *et al.* (2009) tests for NO_x emissions very well reflect the curve of the traction force, but it is with increased emissions in the area of grater traction force and, correspondingly, at the higher engine loads (Fig. 2). The increase of NO_x emissions is treated as a result of increased need for fuel consumption and higher combustion temperatures when higher traction force is needed.

In test results of Li *et al.* (2006) and Bostic *et al.* (2009) exhaust gas temperature reflected the curve of traction force very well, but initially the temperature were low and temperature transition process lacked behind from the transition process of traction force (Fig. 3).

Bostic *et al.* (2009), Lebedevas *et al.* (2011), Junevičius *et al.* (2011) emulate engine performance from empirical relation between the engine speed, engine torque and fuel consumption, i.e. having at least two variables, the third can be derived. Tests of Hansson *et al.* (2003), Lindgren *et al.* (2010) and Bostic *et al.* (2009) showed that in the real field work fuel consumption and emissions cannot be accurately calculated if actual engine load in the field work is not taken into account. Tests of Lindgren *et al.* (2011, 2010) and Fathollahzadeh *et al.* (2010) showed a very high-frequency fluctuations in traction force and fuel consumption at different typical works. Such high-frequency fluctuations are normal for in-field use and depend on the soil surface roughness, which influences the tractor and the implement performance disparity and uneven depth of tillage. Therefore, using mathematical models, the load of the engine, fuel consumption, emissions, etc. can also be calculated with good accuracy only by possessing the data collected at high frequency.

Engines in older tractors and other machines have mechanically controlled fuel injection system. However, technical progress has led to wide introduction of new, electronically controlled engines with fuel injection systems. Electronic systems dynamically control engine parameters and manage its work (Mousazadeh 2013). Depending on the configuration, such motors can make rapid changes in engine speed and load conditions. Review of factors, affecting the fast changes in engine load and speed, were conducted by Rakopoulos, Giakoumis (2009). Sudden changes in engine load or speed are particularly relevant to tractors.

To test engine performance, exhaust harmfulness and emissions, tractor model "*Massey Ferguson MF 6499*" was selected. The histogram "ECU Load Profile" in microprocessors of tractors "Massey Ferguson" stores the operating parameters: working hours at particular

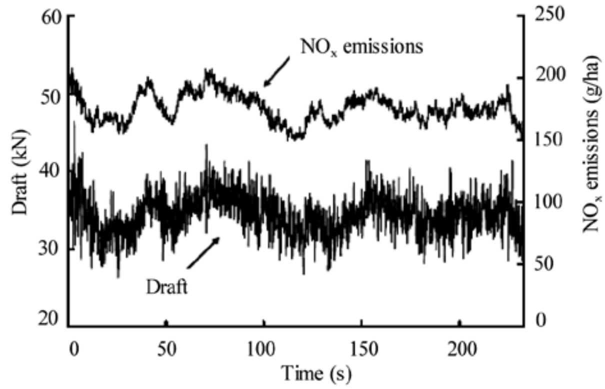


Fig. 2. Dependencies of traction force and NOx emissions and their interrelation in real-time soil preparation work (Li *et al.* 2006)

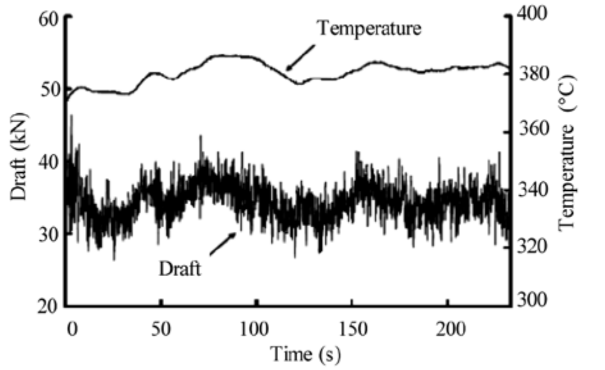


Fig. 3. Dependencies of traction force and combustion gas temperatures and their interrelation in real-time soil preparation work (Li *et al.* 2006)

engine speed and cyclic injection modes (Janulevičius *et al.* 2013, 2010a, b). Histogram and its table show the total tractor's operational periods, in seconds, in various engine modes. Modes of operation are divided by engine speed and the cyclic fuel injection. Histogram and the table show how long the engine of the tractor were operating at 700–900, 900–1100, 1100–1300, etc. rpm speed. It also shows how long the engine of the tractor were operating at the cyclic injection modes of 0–10, 10–20, 20–30, etc. mg.

From these histograms, recorded at the beginning and at the end of tested drilling, using methodologies proposed by Janulevičius *et al.* (2013, 2010a, b), engine torque, power, load factor and fuel consumption is calculated for all engine operating modes that are analysed in histogram. CO_2, CO and NO_x emissions during the tested drilling process were calculated using the following dependencies:

$$E_{(x)} = \frac{\varepsilon\ E_{(x,\,PPM)} \cdot \sigma_E \cdot \rho_E}{P}, \qquad (1)$$

where: $E_{(x)}$ is the emission of the engine exhaust gas component (x, i.e. CO_2, CO and NO_x), $gkW^{-1}h^{-1}$; $E_{(x,\,PPM)}$

is the emission of the engine exhaust gas component (x, i.e. CO_2, CO and NO_x), ppm; ε is the coefficient that evaluates the changes in engine load *(transient)*; σ_E is the gas flow, m^3h^{-1}; ρ_E is the gas density, kg $kmol^{-1}$; P is the engine power at various operating mode, kW.

$$\sigma_E = \frac{T_E + 460}{540} \sigma_O, \qquad (2)$$

where: σ_O is the flow of supplied fresh air, m^3h^{-1}; T_E is the temperature of exhaust gases, (F); Bostic *et al.* (2009) has proposed mathematical model for calculation of exhaust gas temperature.

$$\sigma_O = \frac{\upsilon_e \, n}{210,86} \eta_{\sigma_O}, \qquad (3)$$

where: υ_e is the engine displacement in cm^3; n is the engine speed, min^{-1}; η_{σ_O} is the volumetric efficiency coefficient of supplied air flow.

We can write the final equation for calculation of emissions of engine exhaust gas components (CO_2, CO and NO_x):

$$E0_{(x)} = \frac{\varepsilon E_{(x,\,PPM)} \, n \, \upsilon_e \, \eta_{\sigma_O} \, \rho_E \, A}{P} \left(\frac{T_E + 540}{1{,}139 \cdot 10^5} \right), \qquad (4)$$

where A is the performed engine work, kJ.

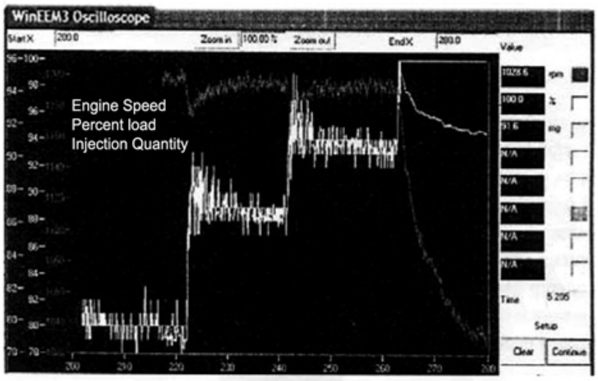


Fig. 4. Oscillogram of engine mode indicators (sample)

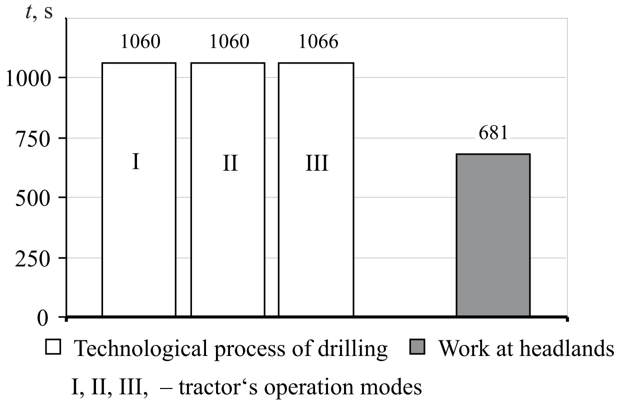


Fig. 5. Distribution of drilling process times between operating modes

$$A = P\,t, \qquad (5)$$

where t is the working hours, h.

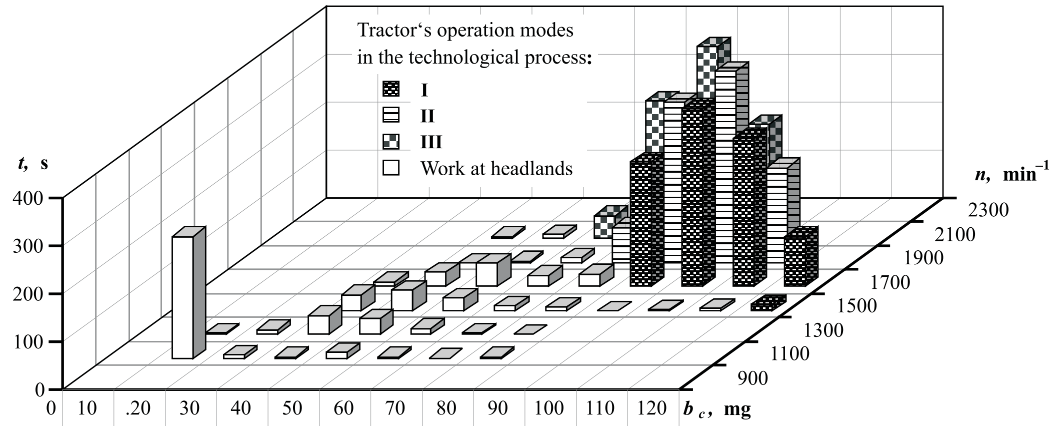
Emissions for separate components (CO_2, CO, NO_x, etc.*)* at specific engine operating modes can be determined from the "ECU Load Profile" histograms and the engine characteristics M, B_d, b_c, NO_x, CO, CO_2 = $f(n)$. These characteristics for the tractor "*MF 6499*" were compiled using a stand for the tractor's load via PTO shaft (tractor dynamometer (AW 400) on PTO test results) and standard test methodology (OECD Standard Code 2. 2011). In our case, the difference was that more parameters were measured and in much more points. In addition, oscillograms were recorded during each test (Fig. 4) to determine engine parameters, which could not be measured using the stand AW 400.

The variation of the engine speed (red curve), engine load (white curve) and fuel cyclic injection quantity (yellow curve) oscillograms (Fig. 4) during the test time were taken.

2. Results of the research

Engine performance and exhaust emissions tests were conducted during the drilling operations using the combination of tractor "Massey Ferguson MF-6499" and the drill "Vaderstad Rapid". For the test, a smooth, nearly even structures, loamy wheat-stubble field with a length of 403±7 m were selected. Before the test, the field were ploughed at 21±1 cm depth and cultivated at 10±1.5 cm depth. Soil moisture at a depth of 15 cm were 17.7±0.12%, soil hardness 0.58±0.11 MPa. During the studies, tractor slippage did not exceed 11% and theoretical speeds of 3.5±0.14 m s^{-1} were maintained. The selected speed were realized in three versions: I – gear 2b at engine speed of 1600 rpm; II – gear 2a at engine speed of 1800 rpm; III – gear 1d at engine speed of 2000 rpm. Figure 5 shows the distribution between the technological and auxiliary (work at headlands) working times in the analysed drilling process. Efficiency of working time for the unit τ = 0.824, productivity W – averagely about 4 ha h^{-1}.

Figure 6 shows the distribution of test time (3867 s) for the unit in the modes of engine speed and cyclic fuel injection. In this figure we can see the separation between the modes and their durations when the unit were making technological work and work at the headlands (in turns). In headland operating modes, large proportion of operational time apparently is concentrated in the mode of small engine speed (900–100 min^{-1}) and small quantities of cyclic fuel injection (10–20 mg). This mode took about 35% of full operational time at headlands, which accounted for 17.6% of total test time for drilling process. During the technological process of drilling, tractor engine were running in the modes when cyclic



900												
1100		255	7	3	13	3	1	3				
1300		3	10	40	33	13	3	1				
1500				33	43	26	10	7	0	1	4	13
1700				10	30	50	23	26	260	372	310	104
1900					0	3	10	74	335	453	198	
2100					5	9	47	287	494	238		
2300												

Fig. 6. Distribution of unit's working time period (3867 s) in the modes of engine speed (n) and cyclic fuel injection quantity (b_c)

fuel injection quantity were in the range of 60–120 mg. By reducing the engine speed and, correspondingly, the transmission ratio, cyclic injection quantities increased slightly to obtain the set working speed. The tested tractor's working mode III (gear 1d, engine speed 2000 rpm) were related with cyclic injection quantities in the range of 60–100 mg. Fuel injection quantity of 80–90 mg prevailed. Mode II (gear 2a, engine speed 1800 rpm) were related with cyclic injection quantities in the range of 70–100 mg. Fuel injection quantity of 90–100 mg prevailed. Mode I (gear 2b, engine speed 1600 rpm) were related with cyclic injection quantities in the range of 80–120 mg. Fuel injection quantity of 90–110 mg prevailed. The average time period for technological drilling process in all three tested modes was 1060 s.

Figure 7 shows fuel consumption during the test period of drilling. During the test period of drilling (3867 s) 28.1 kg of fuel were consumed. Part of that fuel, 26.05 kg (92.7%) were used for technological drilling process, and 2.05 kg (7.3%) were used for work at headlands.

Figure 8 shows the distribution of fuel consumption during the test time (3867 s) for the unit in the modes of engine speed and cyclic fuel injection. Fuel consumption, in relative terms, reflects the power of the engine and working hours in that mode (Janulevičius *et al.* 2010a; Li *et al.* 2006). In tractor mode I (gear 2b, engine speed 1600 rpm), 8.27 kg of fuel were consumed during the technological process of drilling that lasted 1060 s. In this mode the hourly fuel consumption was 28.1 kg/h. For the

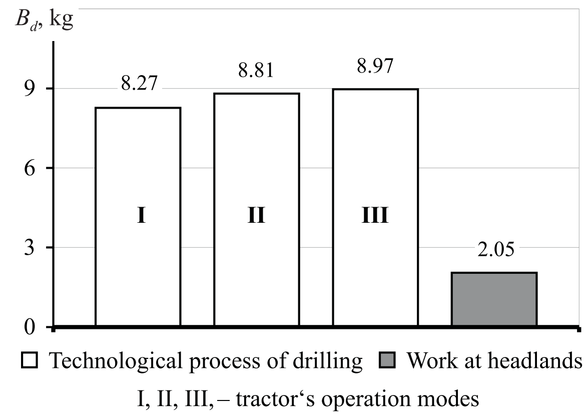
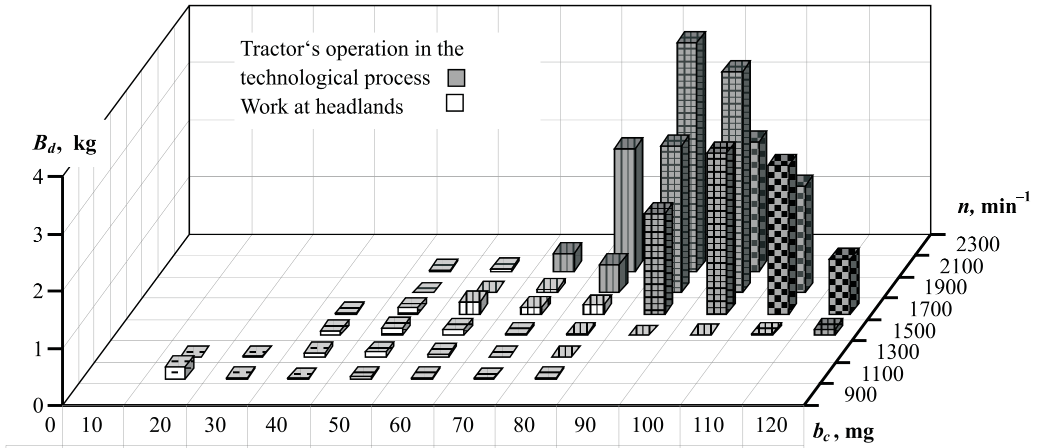


Fig. 7. Distribution of fuel consumption during the process of drilling test (3867 s) by the operating modes

similar technological drilling process, when tractor were in mode II (gear 2a, engine speed 1800 rpm), 8.81 kg of fuel were consumed during the period that lasted 1060 s. In this mode the hourly fuel consumption was 29.9 kg/h. For the technological drilling process (gear 1d, engine speed min 2000 rpm), 8.97 kg of fuel were consumed during the period that lasted 1066 s. In this mode the hourly fuel consumption was 30.3 kg/h. By reducing the engine speed and, correspondingly, the transmission ratio, hourly fuel consumption decreased to obtain the set working speed. Similar patterns of changes in fuel consumption were obtained by Grisso, Pitman (2010), Grisso *et al.* (2008), Lindgren *et al.* (2010, 2011). For the work at headlands 2.05 kg of fuel were consumed during



	10	20	30	40	50	60	70	80	90	100	110	120
900												
1100		0.20	0.01	0.01	0.03	0.01	0.00	0.01				
1300		0.00	0.01	0.08	0.09	0.04	0.01	0.00				
1500				0.08	0.14	0.10	0.05	0.03	0.00	0.01	0.03	0.11
1700				0.03	0.11	0.22	0.12	0.16	1.77	2.83	2.61	0.96
1900					0.00	0.02	0.06	0.50	2.56	3.87	1.88	
2100					0.02	0.05	0.31	2.15	4.20	2.26		
2300												

Fig. 8. Distribution of unit's fuel consumption during the test period (3867 s) in the modes of engine speed (n) and cyclic fuel injection quantity (b_c)

the process that lasted 681 s. In the headlands' mode the hourly fuel consumption was 10.84 kg/h.

In Figure 8 the modes of engine speed and cyclic fuel injection are marked by the size of engine load. Engine load is set by the extent of torque usage. From Figure 8 we can see that for the investigated drilling technological process, when engine speed were 2000 rpm and gear 1d were selected, the recommended engine load (load factor >0.8) lasted 22% of the total duration of that mode, while 78% of the time the engine load factor were in the range from 0.6 to 0.8. In mode II of the tractor, when engine speed were 1800 rpm and a gear 2a were selected, the recommended engine load (load factor >0.8) lasted 19% of the total duration of that mode, while 81% of the time the engine load factor were in the range from 0.6 to 0.8. And when engine speed were 1600 rpm and gear 1d were selected, the recommended engine load (load factor >0.8) lasted 39% of the total duration of that mode, while 61% of the time the engine load factor were in the range from 0.6 to 0.8. The lowest fuel consumption and the maximum engine load were while operating at 1600 rpm engine speed and when gear 2b was selected.

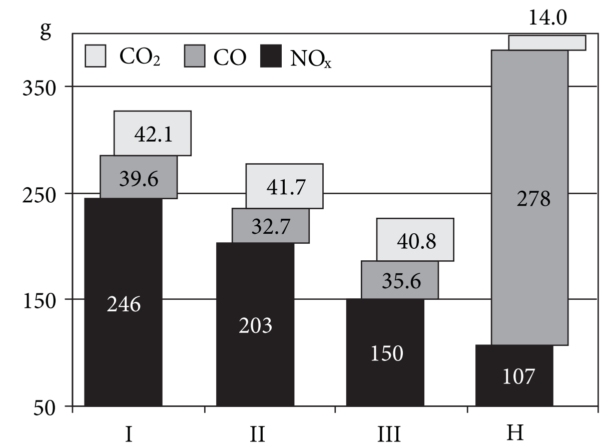
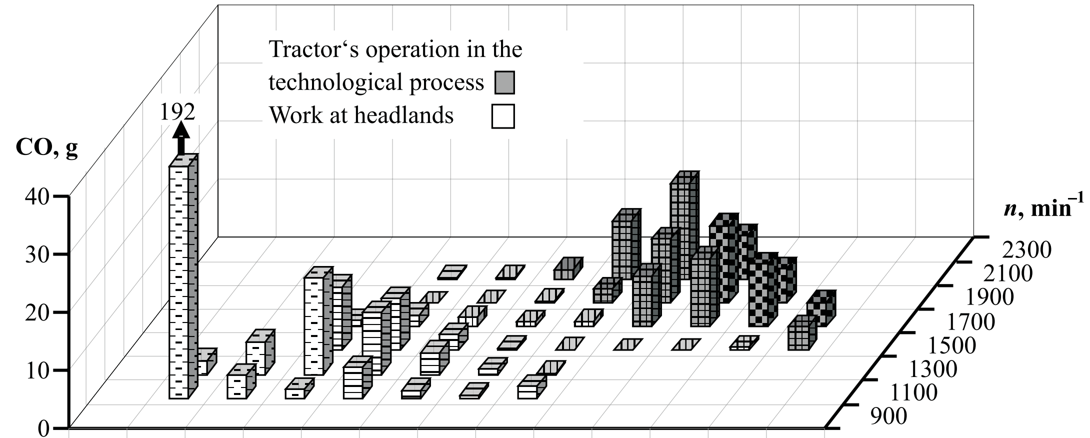


Fig. 9. Distribution of emitted combustion components CO, CO_2 and NO_x during the test period (3867 s) in the drilling process by operating modes; I, II, III – tractor's operation modes, H – mode at headland

While working at headlands, engine load factor were less than 0.4. About half of working time at headlands it were between 0.2 and 0.4, and the other half of the working time it were less than 0.2.

Figures 9, 10, 11 and 12 show the CO, CO_2 and NO_x emissions exhaust during the test period of drilling. During the drilling test period (3867 s), CO emission were approximately 386 g, CO_2 emission were 103 g and NO_x emission were 706 g. Part of these were for the technological process of drilling, namely: CO emissions – 108 g (28%), CO_2 – 124.6 10^3 g (90%) and NO_x – 600 g (85%). When working at headlands, CO emissions were 278 g (72%), CO_2 – 14 10^3 g (10%) and NO_x – 107 g (15%).

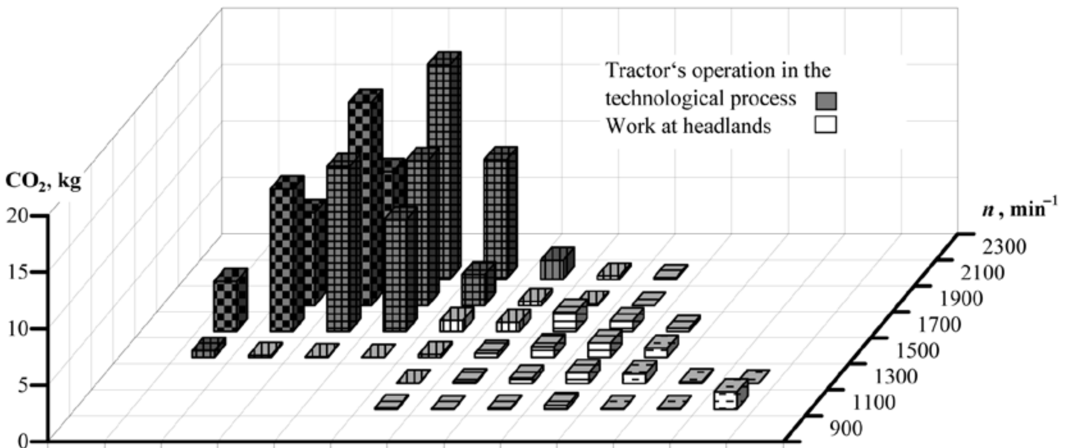
In the technological process of drilling, if the tractor engine speed and, correspondingly, the transmission gear ratio were reduced to get the set working speed, CO and CO_2 emissions varied slightly, but the NO_x emission increased significantly. In the technological process of drilling, when tractor were in mode III (gear 1d, engine



0	10	20	30	40	50	60	70	80	90	100	110	120	130
900													
1100		192.1	3.9	1.5	5.3	1.4	0.5	2.1					
1300		2.4	5.6	16.6	10.6	3.7	0.9	0.3					
1500				10.9	9.0	2.8	0.4	0.2	0.0	0.1	0.6	4.1	
1700				1.1	2.1	1.6	0.8	0.9	8.8	11.8	10.8	4.2	
1900					0.0	0.1	0.3	2.3	11.1	13.4	5.9		
2100					0.3	0.3	1.7	10.0	16.5	7.4			
2300													

Engine‘s load factor
- <0.2
- 0.2–0.4
- 0.4–0.6
- 0.6–0.8
- >0.8

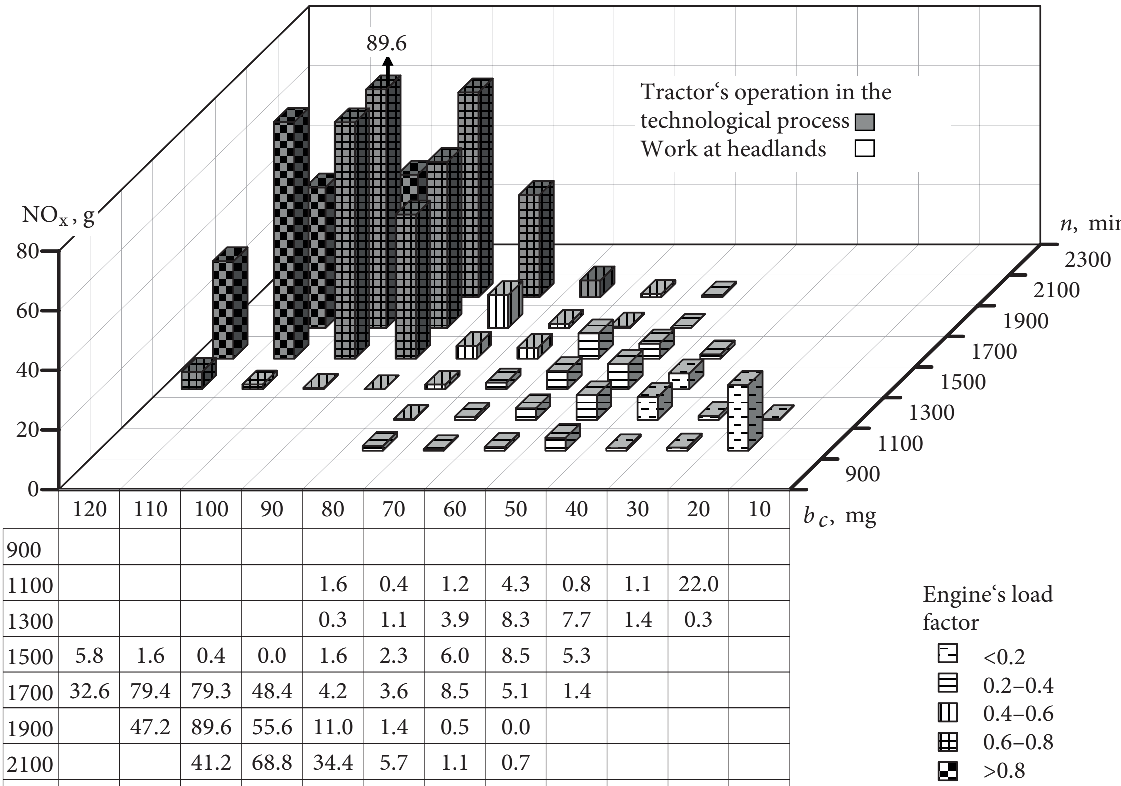
Fig. 10. Distribution of CO emissions during the test period of drilling (3867 s) in the modes of engine speed (n) and cyclic fuel injection quantity (b_c)



	130	120	110	100	90	80	70	60	50	40	30	20	10
900													
1100						0.15	0.04	0.11	0.35	0.06	0.08	1.54	
1300						0.04	0.13	0.46	0.95	0.85	0.14	0.03	
1500		0.60	0.19	0.06	0.00	0.25	0.37	0.93	1.28	0.82			
1700		4.41	12.60	14.60	9.86	0.97	0.82	1.70	0.94	0.27			
1900			8.21	17.98	12.81	2.72	0.36	0.12	0.00				
2100				9.55	18.98	10.58	1.69	0.31	0.17				
2300													

Engine‘s load factor
- <0.2
- 0.2–0.4
- 0.4–0.6
- 0.6–0.8
- >0.8

Fig. 11. Distribution of CO_2 emissions during the test period of drilling (3867 s) in the modes of engine speed (n) and cyclic fuel injection quantity (b_c)



	120	110	100	90	80	70	60	50	40	30	20	10
900												
1100					1.6	0.4	1.2	4.3	0.8	1.1	22.0	
1300					0.3	1.1	3.9	8.3	7.7	1.4	0.3	
1500	5.8	1.6	0.4	0.0	1.6	2.3	6.0	8.5	5.3			
1700	32.6	79.4	79.3	48.4	4.2	3.6	8.5	5.1	1.4			
1900		47.2	89.6	55.6	11.0	1.4	0.5	0.0				
2100			41.2	68.8	34.4	5.7	1.1	0.7				
2300												

Fig. 12. Distribution of NO_x emissions during the test period of drilling (3867 s) in the modes of engine speed (n) and cyclic fuel injection quantity (b_c)

speed 2000 min^{-1}), during the period of 1066 s NO_x emission were 150 g. Hourly NO_x emissions for this mode were 506 g h^{-1}. For the similar technological drilling process, when tractor were in mode II (gear 2a, engine speed 1800 rpm), NO_x emissions were 203 g during the period that lasted 1060 s. Hourly NO_x emissions for this mode were 680 g h^{-1}. During the technological process of drilling (gear 2b, engine speed 1600 rpm) NO_x emissions were 246 g during the period that lasted 1060 s. Hourly NO_x emissions for this mode were 836 g h^{-1}. Hourly NO_x emissions increased when engine speed and, correspondingly, transmission ratio were reduced to obtain the set working speed. When engine speeds were reduced from 2000 min^{-1} to 1600 min^{-1}, NO_x emissions increased from 506 g h^{-1} to 836 g h^{-1}. An hourly NO_x emission, when working at headlands, was approximately 566 g h^{-1}.

In the technological process of drilling, hourly CO emissions varied in the range from 110 to 134 g h^{-1}, and CO_2 emissions – from 138 to 143 kg h^{-1}. The highest CO emissions were in the work processes at headlands. The hourly CO emissions here reached 1470 g h^{-1}. In the diagram zone of low speed and low cyclic injection, the tractor most of the time (255 s) operated in the mode of 900–1000 min^{-1} and 10–20 mg of fuel injection. This mode corresponds the engine idling. From Figures 2 and 6 we can determine that in the process of drilling, when engine speeds were in the mode from 900 to 1100 min^{-1} and cyclic fuel injection from 10 to 20 mg, average hourly emissions of CO were 2710 g h^{-1}. Similar patterns of fuel consumption and amount of CO_2, CO, NO_x emission variations are also obtained by other scientists in their research works (An *et al.* 2012; Asprion *et al.* 2013; Li *et al.* 2006; Lindgren, Hansson 2004; Lindgren *et al.* 2010, 2011).

Conclusions

1. Tractor engine performance, fuel consumption and exhaust emission components can be evaluated by using information stored in the engine control microprocessor, where engine speed and fuel cyclic injection modes and periods are registered in detail. Such database in tractors "Massey Ferguson MF 6499" is called "ECU Load Profile."

2. For the tested drilling process, technological drilling work accounted for 82% of total working time, and work at the headlands accounted for 18% of total working time. In the drilling process fuel consumption was 26.2 kg h^{-1}. Of these, 92.7% accounted for the technological work, and 7.3% – for the work at headlands. Distribution of exhaust emissions' components in the

technological work and the work at headlands were as follows: NO_x – 84.8% and 15.2%; CO – 28% and 72%; CO_2 – 89.9% and 10.1%.

3. In the technological process of drilling, if the tractor engine speed and, correspondingly, the transmission gear ratio were reduced to get the set working speed, fuel consumption decreased, CO and CO_2 emissions varied slightly, but the NO_x increased significantly. After reducing the engine speed from 2000 min^{-1} to 1600 min^{-1}, hourly fuel consumption in the technological process of drilling decreased from 30.3 kg h^{-1} to 28.1 kg h^{-1}, and NO_x emissions increased from 506 g h^{-1} to 836 g h^{-1}.

4. Significant part of exhaust emissions occurred at headlands. The highest emissions were of CO – 1470 g h^{-1}. The mode of low engine speed (900–1100 min^{-1}) and small cyclic fuel injection quantity (10–20 mg) distinguished here; hourly emissions of CO in this mode were 2710 g h^{-1}, and this mode took 37.4% of working time at the headlands or 6.6% of total working time.

5. Fuel consumption and exhaust emissions, including harmful components, can be reduced only by complex optimization of technological processes and tractor operating modes.

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