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INFLUENCE OF THE WEAR OF SPRAY NOZZLE TIPS ON EXHAUST GAS TOXICITY IN DIESEL ENGINES

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Summary. the following scientific work presents results of research into concentration of toxic compounds in exhaust gas from S-4003 tractor engines as well as theoretical correlations (regression equations) for research sets of injector spray nozzle tips of average wear rate. The research was carried out in an engine's brake hall at two rotational speeds of the engine within full engine load range. A mass spectrometer was used to determine the level of toxic compounds in exhaust gas. Wear of the spray nozzles was found with hydraulic method.

Key words: spray nozzle tips, wear, exhaust gas toxicity, tractor engine.

INTRODUCTION

With the development of motorization the atmosphere becomes more and more polluted with exhaust gas. More than 50% of the pollution comes from car engines. A lot of effort is now put into finding ways of powering engines with biofuels. The authors [Lotko 2000, Piekarski and Wawrzosek 2002, Szlachta 2002, Wasilewski 2006, Zając et al. 2008] and other researchers found that using that type of fuel in diesel engines is ecologically beneficial.

The pollution of the environment is closely connected with the technical condition of injection apparatus in diesel engines, especially of precise pairs (pressing elements and shut-off valves of injection pumps as well as injector spray nozzle tips). These pairs wear out mainly due to the presence of abrasive pollutants in fuel [Krasowski 1990, Lejda 1989].

The spray nozzle is the most delicate part of the injector and is actually its only part of low durability. This is because of extreme conditions it works in. High pressure, high temperature and high working speed cause quick wear of both the needle and the housing. The wear of the conical needle face and its housing results in leaks of unatomized fuel and hot exhaust gas penetrating the inside of the nozzle. This leads to the appearance of carbon sediments that fill the orifices of the spray nozzle or reduce its tightness. Apart from the coking of the nozzle, untight needle and housing faces cause changes in the doses of fuel and in the initial injection pressure. An increased clearance in the conductive part of the spray nozzle lowers the injection pressure and makes way for exhaust gas, which causes coking and, possibly, jamming of the needle. Not blocked by the needle, unatomized fuel leaks through the housing of the nozzle. This leads to a rise in the temperature of exhaust gas. The engine lets out smoke, fuel consumption increases and the spray nozzle wears out fast.

Worn out and damaged spray nozzles or pump's press sections cause problems with an engine's start-up, lack of power, excessive fuel consumption, increased toxicity and smoking of the engine. Apart from the wear of injection apparatus, also regulation settings influence the performance of Diesel engines, especially the injection advance angle [Bocheński 1990, Ćwikła et al. 2001, Falkowski et al. 1989, Oyudo 1990, Wasilewski 2004, Wasilewski 2008].

This work presents the results of research into levels of CO and HC in a tractor engine depending on injector's spray nozzle tips wear level.

DESCRIPTION OF THE RESEARCH STAND AND RESEARCH METHODOLOGY

The subject of research is four-cylinder compression-ignition engine S-4003 of the farm tractor Ursus C-360 assembled on a dynamometric stand in the engine brake hall of the Department of Power Industry and Vehicles, University of Life Sciences in Lublin. The tested engine has got the combustion system with direct fuel injection to the toroidal chamber in the piston. The diagram of the test stand is presented in Fig. 1.

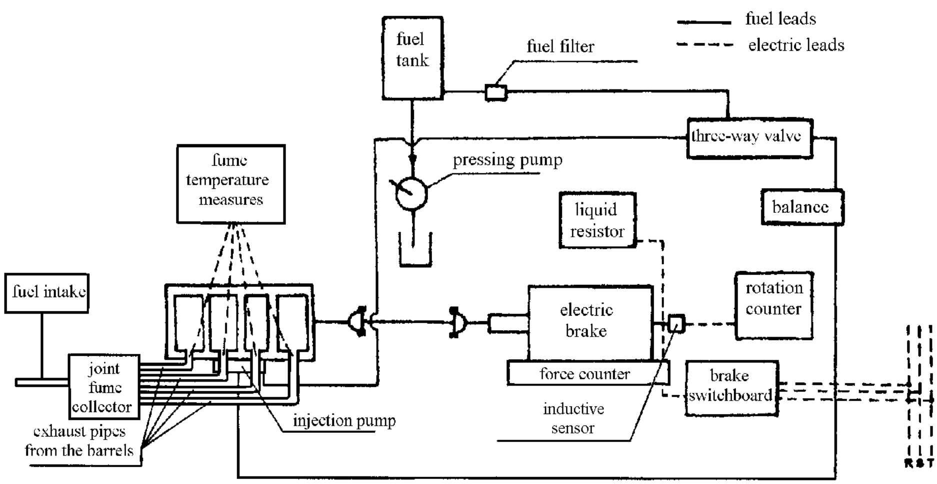


Fig. 1. The diagram of the test stand

The main element of the dynamometric stand is an electric brake of the type K1 – 136 B – E (alternating current generator), which also served for the starting of the tested engine. The rational speed of the engine was measured by means of an inductive sensor cooperating with a digital counter of the type N05.

The wear of DSL150.A2 spray nozzle tips was determined according to their hydraulic tightness, by means of measuring the time of pressure fall of fuel (diesel oil, relative viscosity E_{20} = 1,25°E and density γ_{20} = 0,828 kg/dm^3 at 20 degrees Celsius) supplied to the spray nozzle, within 15-to-10 MPa measuring range. The research was carried out on PRW-3 injector tester. The tested spray nozzle was then mounted in the housing of a brand-new injector, which was set at 17,5 MPa opening pressure, according to the engine instruction manual. Moreover, leakage on the nozzle was measured as well as its spraying efficiency. On the basis of the measurements two sets of spray nozzles (Table 1) were singled out to be used in stand tests.

Table 1. Research sets of spray nozzles

Spray nozzle wear	Spray nozzle (also fuelled cylinder) number	15-to-10 MPa pressure fall time [s]	Leakage at 15 MPa over 10 seconds	Spraying efficiency
New spray nozzles	1	26,8	No leakage	High
	2	28,2		
	3	27,3		
	4	27,9		
Spray nozzles – 100% of wear	1	3,6	a drop forms	No typical injection sound, presence of drops of fuel in the sprayed fuel stream, changes in its density and symmetry
	2	1,7	dripping	
	3	2,5	dripping	
	4	2,2	dripping	

Exhaust gases analysis of researched tractor's engine was defined using mass spectrometer. Samples of exhaust gases were taken from behind common collector of exhaust gases (Fig. 1), at every load characteristic measurement point.

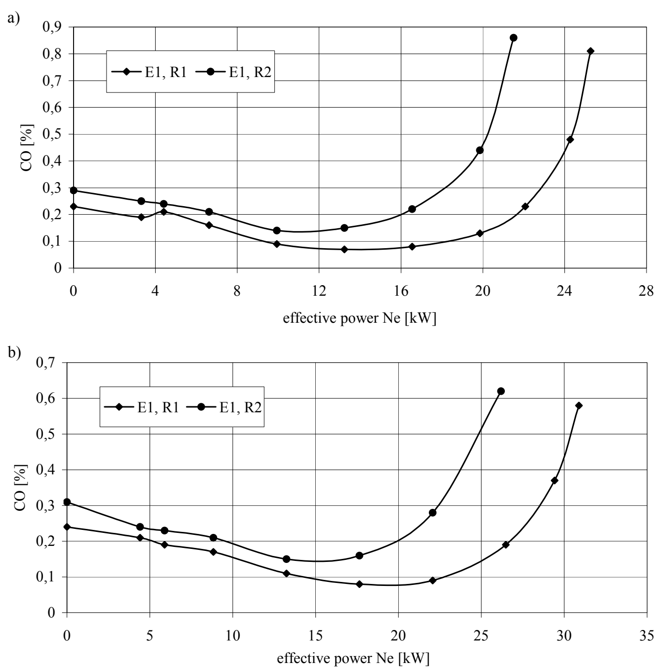
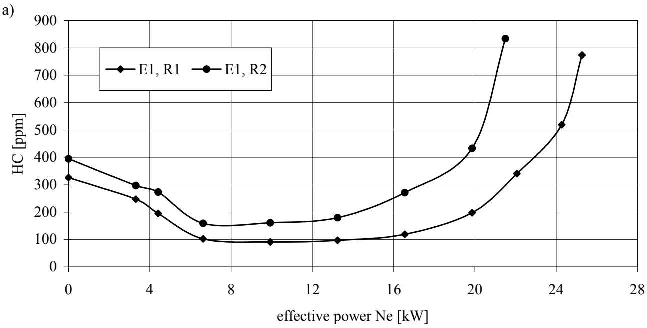


Fig. 2. Variation of CO emission level in exhaust gases in function of effective power (N_e) of tractor's engine S-4003 depending on injector's spray nozzle tips wear level: a) 1500 rpm, b) 2000 rpm; E1 – pressing sections 0% of wear, R1 – spray nozzles 0% of wear, R2 – spray nozzles 100% of wear

a)



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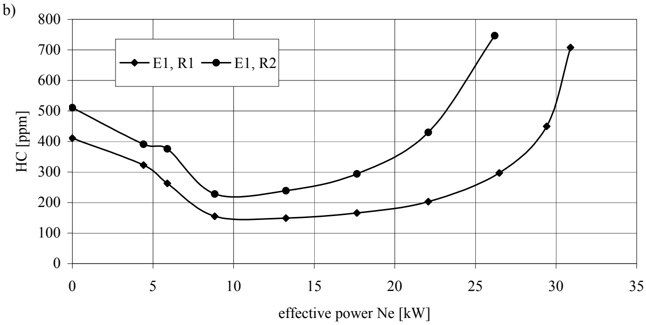
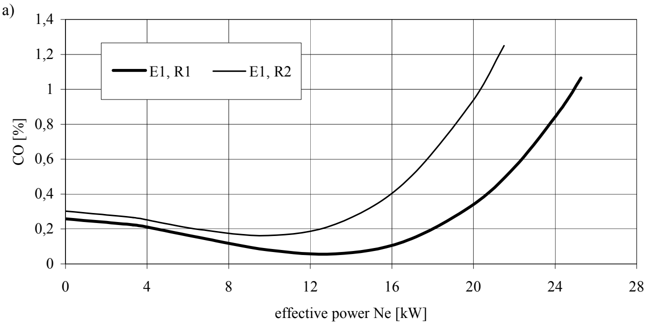


Fig. 3. Variation of HC emission level in exhaust gases in function of effective power (N_e) of tractor's engine S-4003 depending on injector's spray nozzle tips wear level: a) 1500 rpm, b) 2000 rpm; E1 – pressing sections 0% of wear, R1 – spray nozzles 0% of wear, R2 – spray nozzles 100% of wear

a)



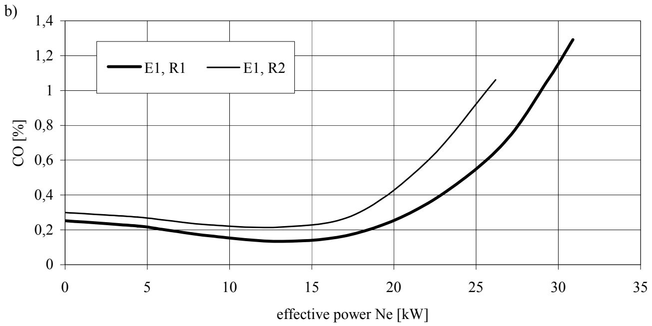


Fig. 4. Variation of CO emission level in exhaust gases in function of effective power (N_e) of tractor's engine S-4003 depending on injector's spray nozzle tips wear level (regression analysis): a) 1500 rpm, b) 2000 rpm; E1 – pressing sections 0% of wear, R1 – spray nozzles 0% of wear, R2 – spray nozzles 100% of wear

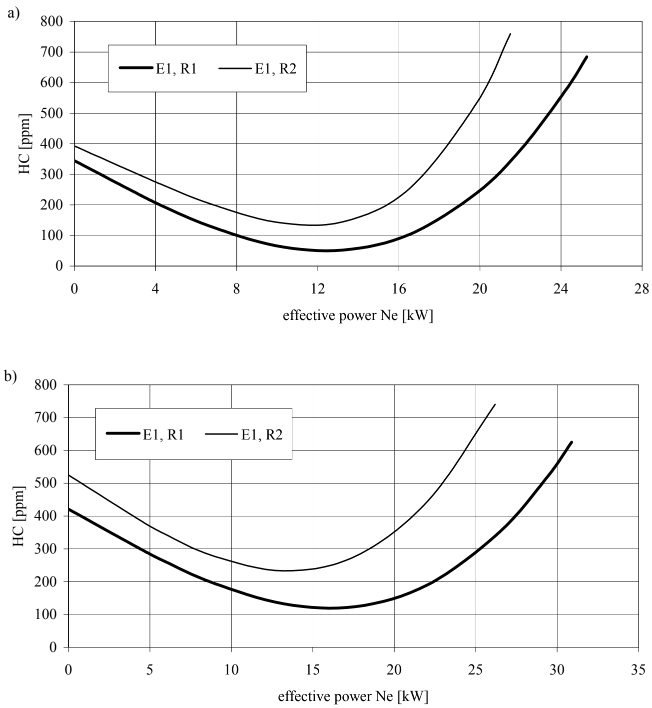


Fig. 5. Variation of HC emission level in exhaust gases in function of effective power (N_e) of tractor's engine S-4003 depending on injector's spray nozzle tips wear level (regression analysis): a) 1500 rpm, b) 2000 rpm; E1 – pressing sections 0% of wear, R1 – spray nozzles 0% of wear, R2 – spray nozzles 100% of wear

RESEARCH RESULTS AND THEIR ANALYSIS

Figures 2 and 3 show the results of the research into CO and HC emission levels in exhaust gas from S-4003 tractor engine depending on wear of injector spray nozzle tips. Figures 4 and 5 show theoretical correlation between the above experimental processes, which was found with curvilinear regression analysis method. Selection of proper regression equation (Table 2) was made based on coefficient of determination value R^2, test function value F-Snedecora for testing model adequacy and on significance levels of particular elements of regression function (tests t-Student).

The analysis of the above correlation points to:

1. A considerable increase in CO concentration in exhaust gas when worn out spray nozzle tips were used, in stark contrast to new sets. This was the case within full engine load range and at the two rotational speeds of the engine. For 100% worn-out spray nozzles an average increase in CO concentration, within full engine load range, amounted to 97% at 1500 r.p.m. and 80,6% at 2000 r.p.m., in comparison to standard sets.
2. A considerable increase in HC concentration in exhaust gas when worn out spray nozzles were used in comparison to new sets – by 80,4% at 1500 r.p.m. and by 67,6% at 2000 r.p.m. (average figures within full engine load range).
3. A sharp Ne power decrease (visible in engine performance at maximum engine load) when worn out spray nozzles were used – by 4,85 kW (15,7%) at 2000 r.p.m and by 3,87 kW (15,3%) at 1500 r.p.m. in comparison to standard sets.
4. There is a remarkable consistency between theoretical curves and real CO and HC concentration functions in the exhaust gas of the tested engine. This is due to high R^2 coefficients of determination, which fluctuate from 0,9039 to 0,9813 for the research sets of spray nozzles and the testing conditions.

CONCLUSIONS

It was found that the wear of injector spray nozzle tips results in a sharp rise in carbon monoxide and hydrocarbons emission in exhaust gas. Apart from increased toxicity, worn out spray nozzles cause poor performance of diesel engines, as evidenced by numerous research results, also by those published by the author. In tractor engines spray nozzles wear out faster than in car engines because tractors are used for different types of work, usually in harsh conditions, e.g. dusty air. Harmful compounds emitted by tractor engines severely affect the environment.

Table 2. Regression analysis

Research sets of spray nozzles	Rotational speed	Compound of exhaust gases	Regression equation	Coefficient of determination R^2
E1, R1	1500 obr/min	CO	$y = 0,2577 - 0,0038 \cdot Ne^2 + 0,0002 \cdot Ne^3$	0,9039
		HC	$y = 344,4416 – 35,5275 \cdot Ne + 0,0767 \cdot Ne^3$	0,9454
	2000 obr/min	CO	$y = 0,2525 – 0,0019 \cdot Ne^2 + 0,0001 \cdot Ne^3$	0,9448
		HC	$y = 421,2003 – 28,2214 \cdot Ne + 0,0365 \cdot Ne^3$	0,9085

E1, R2	1500 obr/min	CO	$y = 0{,}3025 - 0{,}0044 \cdot Ne^2 + 0{,}0003 \cdot Ne^3$	0,9384
		HC	$y = 392{,}1946 - 29{,}6155 \cdot Ne + 0{,}0047 \cdot Ne^4$	0,9352
	2000 obr/min	CO	$y = 0{,}2998 - 0{,}0018 \cdot Ne^2 + 0{,}0001 \cdot Ne^3$	0,9813
		HC	$y = 524{,}8333 - 32{,}4471 \cdot Ne + 0{,}0593 \cdot Ne^3$	0,9585

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WPŁYW ZUŻYCIA KOŃCÓWEK ROZPYLAJĄCYCH NA TOKSYCZNOŚĆ SPALIN SILNIKA WYSOKOPRĘŻNEGO

Streszczenie. Praca przedstawia wyniki badań eksperymentalnych koncentracji toksycznych związków w spalinach silnika ciągnikowego S-4003 oraz zależności teoretyczne (równania regresji), dla reprezentatywnych pod względem zużycia zestawów badawczych końcówek rozpylających wtryskiwaczy. Badania przeprowadzono w hamowni silnikowej w pełnym zakresie obciążenia przy dwóch prędkościach obrotowych silnika. Do określenia zawartości składników toksycznych w spalinach wykorzystano spektrometr masowy. Stopień zużycia rozpylaczy określono metodą hydrauliczną.

Słowa kluczowe: końcówki rozpylające, zużycie, toksyczność spalin, silnik ciągnikowy.