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AN INFLUENCE OF INJECTION PUMP WEAR OF A TRACTOR ENGINE ON EXHAUST GAS TOXICITY

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Summary. The following scientific work presents experimental research results of toxic compounds of exhaust gasses emission level in function with effective engine's S-4003 power by farm tractor Ursus C-360 and theoretical correlation evaluated throughout curvilinear regression method analysis, in respect of representative precise pairs research sets wear of injection pumps. The research was carried out in an engine's brake hall with two rotational speeds of engine in full load range. The level of toxic compounds emission in exhaust gases is determined with spectrometric method. Wear level of precise pairs of the injection pumps was defined with hydraulic method.

Key words: injection pump, precise pairs, wear, exhaust gas toxicity, tractor engine.

INTRODUCTION

Complex usage conditions of farm tractors and inconsistent engine's usage functions have a particularly adverse impact on the correct operation of injection apparatus. The fact of usage practice is that inefficient fuel systems determine over 50% reasons of compression-ignition engine's failures [Falkowski and Krępeć 1979, Krasowski 1990].

Injection apparatus has a precise construction, complex operational system and must bear considerable mechanical and thermal loads. In injection systems particularly effective for usage are precise pairs. Injection pump press section wear and injectors pulverize nozzle depend on the construction, exploitation but also on the accomplishment technology and applied construction materials. Research results released by [Kałdoński 1984, Kałdoński 1989] allow to ascertain that production level of precise pairs bring many exceptions, both in thermal and mechanical treatment. The course of precise units wear process is complex and depends on factors causing wear and its intensity results in the following forms: abrasion, erosion, cavitations, corrosion. Generally, the reason of precision pairs wear is abrasive impact of fuel pollution i.e. quartz, corundum, ferric oxide (non-organic materials), resins, hard asphalt (organic materials) and fine metal particles remaining after mechanical treatment [Krasowski and Pielecki 1982, Lejda 1989, Zabłocki and Siuta 1979].

Press elements, pump's press valves (shut-off) and pulverizers' wear cause: loss of hydraulic integrity of the particular fitted elements, worse press parameters and fuel injection, irregular process of mixture composition and its consumption in the engine, worse efficiency of the engine and an increase of environmental pollution with toxic exhaust gas components. Furthermore, due to injection apparatus wear a relevant influence on an engine's parameters is exerted by regulation parameters, particularly angle of injection allowance [Bocheński 1990, Derkacz and Krasowski 1986, Falkowski and other 1989, Krasowski and other 1994, Oyudo 1990, Wasilewski 1997, Wasilewski 2004, Wasilewski 2005].

The present work contains research results of CO and HC emission levels in the exhaust gases of tractor's engine S-4003 depending on injection pump's precise pairs wear level.

DESCRIPTION OF RESEARCH STAND AND METHOD

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.

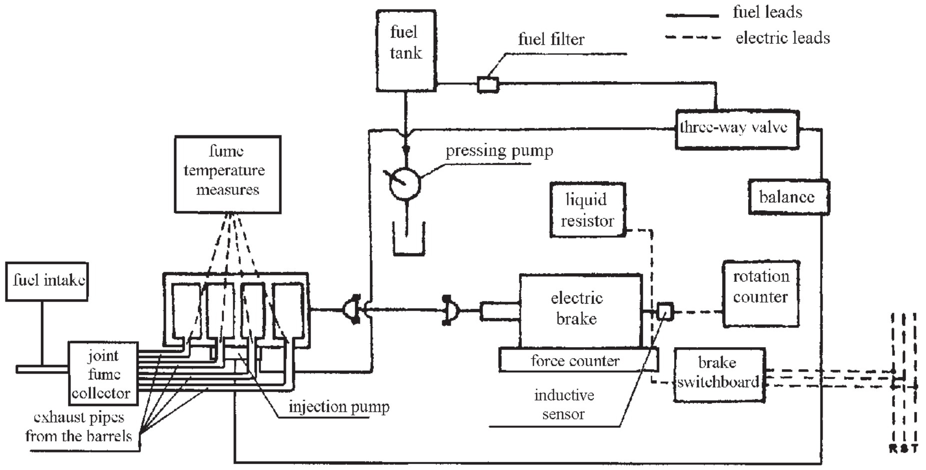


Fig. 1. The diagram of the test stand

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 rotational speed of the engine was measured by means of an inductive sensor cooperating with a digital counter of the type N05.

Injection pump's P24T8-3a precise pairs wear level was defined with special equipment with hydraulic method, taking measurements of time of fuel pressure decrease (diesel oil of relative viscosity E_{20} = 1,25 şE and density γ_{20} = 0,828 kg/dm^3 by temperature of 20şC), caused by leakage through untight units. On the basis of the taken measurements of precise pairs wear level there were obtained tree units of pressure elements type FPE8-3a and two sets of shut-off valves type DV73, which were used during station research.

Research sets of pressure elements:

– set I (new): pressure elements selected from brand-new units, with the highest tightness, for which the time of pressure decrease from 25 to 20 MPa (average fuel pressure in the high-pressure system) was on average 13,6 s – assumed wear level equal to 0%,

– set II: pressing elements selected from units phased out of operation, for which the time of pressure decrease from 25 to 20 MPa (near to average of analyzed dozen units) was on average 1,2 s – assumed wear level equal to 100%,

– set III: pressing elements, for which the time of pressure decrease from 25 to 20 MPa was on average 7,1 s – assumed wear level equal to 50%.

Research units of shut-off valves:

– set I (new): pressing valves selected from brand-new units, with the highest tightness, for which the time of pressure decrease from 25 to 20 MPa was on average 301 s – assumed wear level equal to 0%,

– set II: pressing valves, for which the time of pressure decrease from 25 to 20 MPa was on average 56 s, in accordance with scientific literature [Hebda and other 1980] with the time of pressure decrease below 60 s valves are not suitable for longer operation – assumed wear level being equal to 100%. Furthermore, basing on the found characteristics of injection dozing pump equipped with the same set of valves it is possible to state that, compared to new valves, higher dozing of fuel by stable position of pump's toothed bar, thus in part of unload valve wear was dominant.

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.

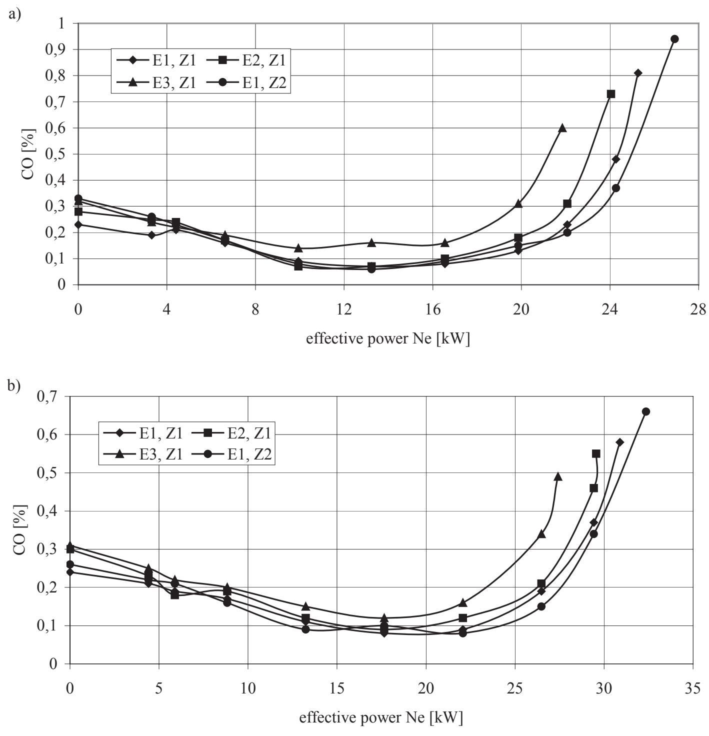
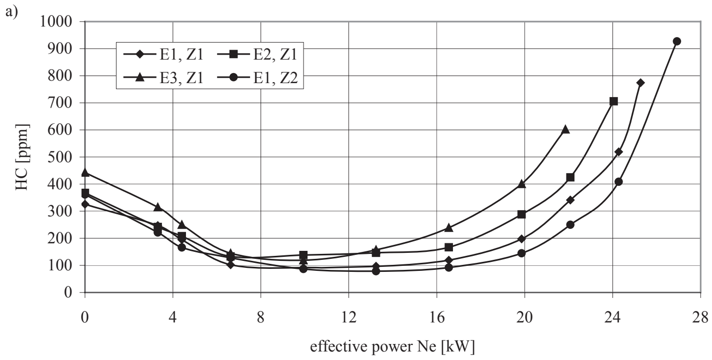


Fig. 2. Variation of CO emission level in exhaust gases in function of effective power (N_e) of tractor's engine S-4003 depending on injection pump's precise pairs wear level: a) 1500 rpm, b) 2000 rpm; E1 – pressing elements 0% of wear, E2 – pressing elements 50% of wear, E3 – pressing elements 100% of wear, Z1 – shut-off valves 0% of wear, Z2 – shut-off valves 100% of wear



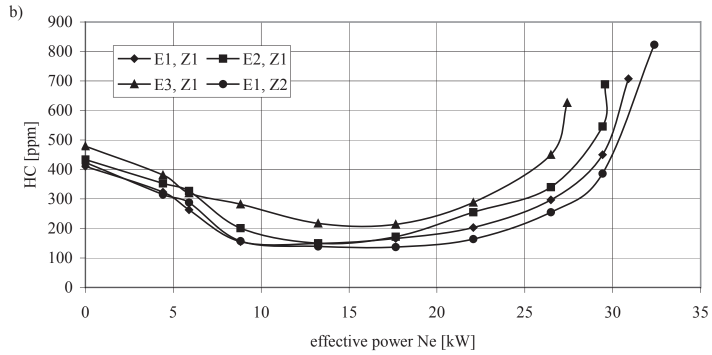
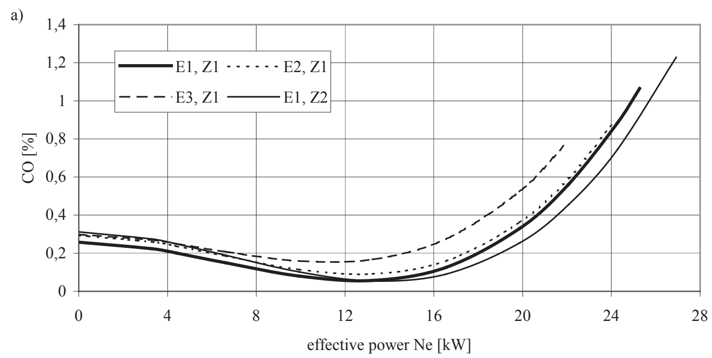


Fig. 3. Variation of HC emission level in exhaust gases in function of effective power (N_e) of tractor's engine S-4003 depending on injection pump's precise pairs wear level: a) 1500 rpm, b) 2000 rpm; E1 – pressing elements 0% of wear, E2 – pressing elements 50% of wear, E3 – pressing elements 100% of wear, Z1 – shut-off valves 0% of wear, Z2 – shut-off valves 100% of wear



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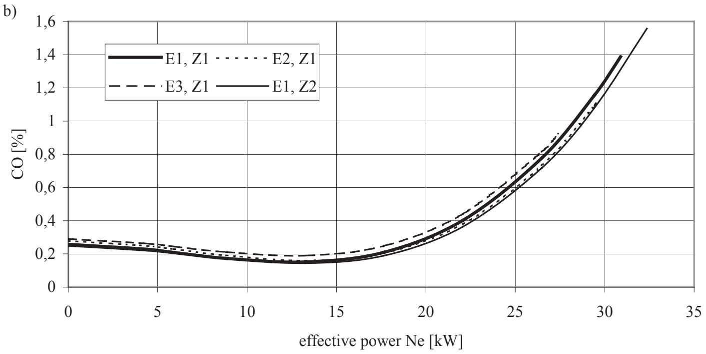
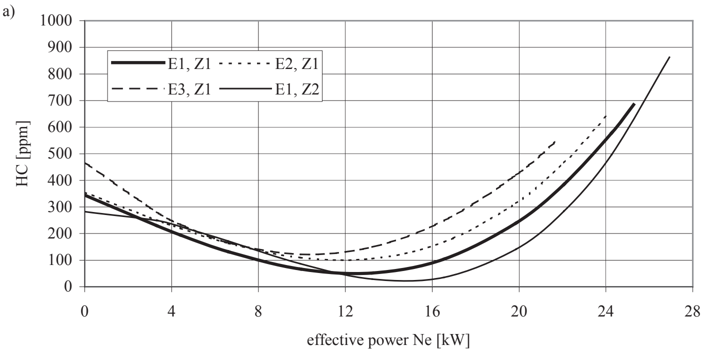


Fig. 4. Variation of CO emission level in exhaust gases in function of effective power (N_e) of tractor's engine S-4003 depending on injection pump's precise pairs wear level (regression analysis): a) 1500 rpm, b) 2000 rpm; E1 – pressing elements 0% of wear, E2 – pressing elements 50% of wear, E3 – pressing elements 100% of wear, Z1 – shut-off valves 0% of wear, Z2 – shut-off valves 100% of wear

a)



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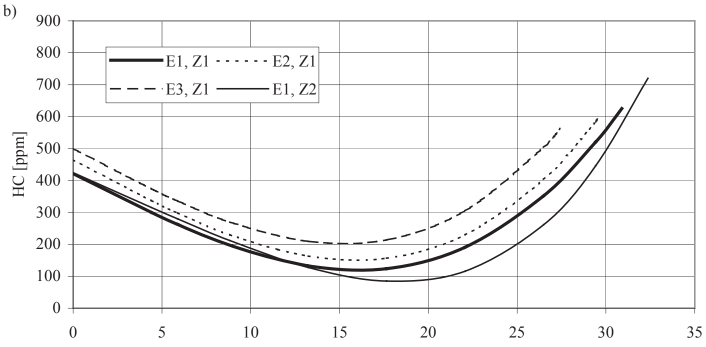

Fig. 5. Variation of HC emission level in exhaust gases in function of effective power (N_e) of tractor's engine S-4003 depending on injection pump's precise pairs wear level (regression analysis): a) 1500 rpm, b) 2000 rpm; E1 – pressing elements 0% of wear, E2 – pressing elements 50% of wear, E3 – pressing elements 100% of wear, Z1 – shut-off valves 0% of wear, Z2 – shut-off valves 100% of wear

Table 1. Regression analysis

Precise pairs research sets	Rotational speed	Compound of exhaust gases	Regression equation	Coefficient of determination R^2
E1, Z1	1500 rpm	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 rpm	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
E2, Z1	1500 rpm	CO	$y = 0,2936 – 0,0038 \cdot Ne^2 + 0,0002 \cdot Ne^3$	0,9393
		HC	$y = 354,9227 – 32,2596 \cdot Ne + 0,0766 \cdot Ne^3$	0,9659
	2000 rpm	CO	$y = 0,278 – 0,002 \cdot Ne^2 + 0,0001 \cdot Ne^3$	0,9423
		HC	$y = 464,296 – 29,575 \cdot Ne + 0,0389 \cdot Ne^3$	0,9213
E3, Z1	1500 rpm	CO	$y = 0,2988 – 0,0034 \cdot Ne^2 + 0,0002 \cdot Ne^3$	0,9438
		HC	$y = 467,4216 – 67,2511 \cdot Ne + 3,2664 \cdot Ne^2$	0,9783
	2000 rpm	CO	$y = 0,2904 – 0,0019 \cdot Ne^2 + 0,0001 \cdot Ne^3$	0,9625
		HC	$y = 499,2844 – 29,2732 \cdot Ne + 0,042 \cdot Ne^3$	0,9415
E1, Z2	1500 rpm	CO	$y = 0,3119 – 0,0041 \cdot Ne^2 + 0,0002 \cdot Ne^3$	0,9340
		HC	$y = 282,5268 – 3,6197 \cdot Ne^2 + 0,1642 \cdot Ne^3$	0,9353
	2000 rpm	CO	$y = 0,2627 – 0,002 \cdot Ne^2 + 0,0001 \cdot Ne^3$	0,9454
		HC	$y = 424,1786 – 24,7321 \cdot Ne + 0,001 \cdot Ne^4$	0,9288

RESEARCH RESULTS AND ANALYSIS

Variations of CO and HC content in the exhaust gases to effective power (N_e) of tractor engine S-4003 were received based on experimental research results, depending on injection pump's precise pairs wear level, were presented on load characteristics: for rotational speed of engine 1500 rpm – adequately in Fig. 2a and 3a, for speed 2000 rpm – adequately in Fig. 2b and 3b. In Fig. 4 and 5 were presented adequately to the above-mentioned course of research theoretical dependences, assigned on the basis of curvilinear regression analysis method. Selection of proper regression equation (Table 1) 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).

An analyses of the above-presented dependencies proved that:

1. An increase of CO and HC content in exhaust gases for worn pressing elements, compared to brand-new sets, in the whole range of loads and with two rotational speeds of the engine. For pressing elements with assumed level of wear of 100%, an average increase of CO and HC in whole range of loads was adequately 74,7% and 66,2% by n=1500 rpm and 54,4% and 44,3% by n=2000 rpm in relation to new sets. For pressing elements with assumed wear level of 50%, by n=1500 rpm – CO increase at 20,2%, HC at 22,6%, while by n=2000 rpm – adequately at 15,3% and 16,9%, over the results received for new elements.
2. An increase of accumulation of CO and HC in the exhaust gases (idling and low engine's load) and decrease of emission level of those components (higher load of the engine) for worn shut-off valves compared to the new valves, from few to about 20%. Lower toxicity of exhaust gases for worn valves in relation to new, noticeable especially by higher engine loads is the result of above mentioned characteristic of their wear, which caused that obtained proper rotational speed by the engine with the same load cause lower fuel dozing.

3. An engine's power increase initially decreases CO and HC content by exhaust gases (higher temperature by cylinders cause higher intensity of exhaust reheat) and afterwards a sudden increase of these compounds emission (decrease of air excess coefficient).

4. Good correlation of theoretical curves to effective function dependents of CO and HC contents in the exhaust gases of the tested engine in respect of high determination factors R^2, which for research precision pairs sets and accomplished measurement conditions are enclosed in 0,9039 to 0,9783.

CONCLUSIONS

The research showed that injection pump's precision pairs wear has a relevant influence on carbon monoxide's and hydrocarbon's emission. A more negative influence for toxic components in exhausted gases were received for worn pressing elements, compared to worn shut-off valves. In case of the analyzed valves, where wear by unload part was dominant, an increase of fuel doze in consequence of reduced unloading capacity to some extent compensated the decline caused by untightness. Furthermore, the highest toxicity of exhaust gases relating to worn precise pairs of injection apparatus is noticeable for injectors pulverize nozzles, which were confirmed by many research results, therein published by the author.

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WPŁYW ZUŻYCIA POMPY WTRYSKOWEJ SILNIKA TRAKTORA NA TOKSYCZNOŚĆ SPALIN

Streszczenie. Praca przedstawia wyniki badań eksperymentalnych poziomu emisji toksycznych składników spalin w funkcji mocy efektywnej silnika S-4003 ciągnika rolniczego Ursus C-360 oraz zależności teoretyczne wyznaczone w oparciu o metodę analizy regresji krzywoliniowej, dla reprezentatywnych pod względem zużycia zestawów badawczych par precyzyjnych pompy wtryskowej. Badania przeprowadzono w hamowni silnikowej przy dwóch prędkościach obrotowych silnika w pełnym zakresie obciążenia. Poziom emisji związków toksycznych w spalinach określono metodą spektrometryczną. Stopień zużycia par precyzyjnych pompy wtryskowej określono metodą hydrauliczną.

Słowa kluczowe: pompa wtryskowa, pary precyzyjne, zużycie, toksyczność spalin, silnik ciągnikowy.