PRESUMPTIONS OF EFFECTIVE OPERATION OF DIESEL ENGINES RUNNING ON RME BIODIESEL. RESEARCH ON KINETICS OF COMBUSTION OF RME BIODIESEL

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Abstract. The results of experimental research on kinetics of fuel combustion of diesel engine A41are presented in the publication. The change of characteristics of indicated work (in-cylinder pressure and temperature, period of induction, heat release and heat release rate) and fuel injection (fuel injection pressure, fuel injection phases) was determined in diesel engine running on RME biodiesel being compared to diesel fuel. The results of researches were used to explain experimentally determined changes of operational and ecological characteristics of diesel engine running on RME biodiesel. In addition, the reliability of diesel engine A41 running on RME biodiesel was evaluated. The presumptions of effective operation of diesel engines running on RME biodiesel were formulated.

Keywords: kinetics of combustion, heat release, fuel injection, reliability of diesel engine, biodiesel.

1. Introduction

Publication continues the presentation of results of common researches of Lithuanian Agricultural University and Klaipėda University into production and adaptation of biodiesel in fleets of diesel engines of Lithuania. Researches are conducted under the auspices of Council of science and studies of Lithuania and performed under the framework of international project "EUREKA. BIOWASTEFUEL.E!3234". The results of researches on chemical, physical and motor properties of various biodiesels, as well as on the change of operational and ecological characteristics of diesel engine running on biodiesel were presented in previous publications. The results of research on kinetics of combustion and fuel injection of diesel engine A41 are presented in this publication. The presumptions of effective operation of diesel engines running on RME biodiesel are formulated on the basis of the obtained results of researches. Experimental researches were performed together with Altaj State Technical University (Russian Federation).

Nowadays the researches on biodiesel fuel are directed to reduction of cost price [1] and improvement of low temperature characteristics. The usage of waste vegetable oils and animal fats for the production of biodiesel is one of the promising ways to reduce the cost price of biodiesel. The improvement of low temperature characteristics is solved by applying fuel additives. As a result, the multicomponental biodiesel fuels are created. The base of new types of biodiesels consists of traditional types of biodiesel: rapeseed methyl ester – RME, soybean methyl ester – SME, palm-oil ester – PME. The new biocomponents change properties of biodiesel and influence differently the work process of diesel engine which forms the main technical-economical and ecological parameters. The comparative research on characteristics of indicated work of diesel engine forms the base to choose the proportions of biocomponents of new biodiesels, which practically realises the engineering of fuel. It also allows to evaluate the optimum and critical values of parameters of biodiesel and to take compromise decisions regarding optimisation of regulation parameters of diesel engine.

The goal of the performed research was to evaluate the change of parameters of fuel injection and kinetics of fuel combustion of diesel engine A41 running on RME biodiesel. The results of research will be used to prove the observed changes of operational and ecological parameters, to evaluate the change of reliability of diesel engine and formulate the presumptions of effective operation of diesel engines running on RME biodiesel.

2. Materials and methods

The object of the research is chosen in respect of the structure of diesel engines park of Agricultural machines of Lithuania (see Fig 1) and technical characteristics of mostly spread models of diesel engines.

Such choice enssures the possibility of practical application of obtained results of the research. The object of the research is the section of one cylinder of tractor purpose diesel engine A41 (producer JSC "Altaiskij motornij zavod", Russian Federation).

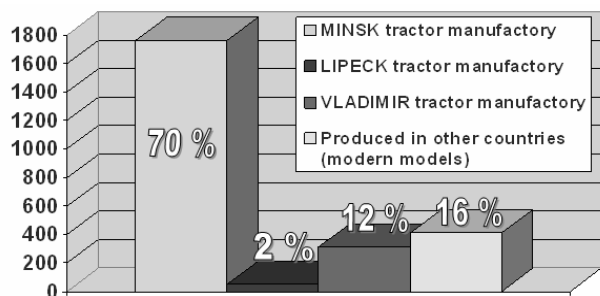Diesel engine A41 is characterised by similar technical and constructive parameters, presented in Table 1.

Fig 1. Statistical data of registered new tractors with diesel engines in Lithuania per year 2003

Table 1. Parameters of researched diesel engine

No	Parameter	1A41
1	Cylinder diameter D, m	0,13
2	Piston stroke length S, m	0,14
3	Engine displacement V_h, dm³	1,86
4	Compression ratio ε	16
5	Rated output P_e, kW	14
6	Rated break mean effective pressure p_{me}, MPa	0,85
7	Rated speed n, rpm	1750
8	Parameters of fuel injector	4×0,25×150°
9	Fuel injection	direct
10	Type of combustion chamber	open

Tested types of fuel: summer diesel fuel according to standard GOST 305, biodiesel RME, certified according to standard LST EN 14214, produced in JSC "Rapsoila" (Mažeikiai, Lithuania), RME blends with mineral diesel fuel by volummetric proportions 90/10 (B10), 85/15 (B15) and 70/30 (B30).

The main physical-chemical and motor parameters of tested fuels are presented in Table 2.

Table 2. Main physical-chemical parameters of tested fuels

No	Characteristic	Fuel				
		Diesel fuel	RME	B10	B15	B30
1	Density at 20 °C, g/cm³	0,840	0,887	0,845	0,847	0,854
2	Viscosity at 40 °C, stc	2,6	4,83	3,0	3,2	3,8
3	Cetan number	46	51,6	51,04	50,76	49,92
4	Heating value H_u, kJ/kg	42470	37417	41965	41707	40954
5	Stoichiometric ratio L_0	0,495	0,433	0,489	0,485	0,476
6	Chemical composition					
	C, %	87,0	77,0	86,0	85,5	84,0
	H, %	12,6	12,1	12,55	12,52	12,45
	O, %	0,4	10,9	1,45	1,98	3,55

NOTE: cetan number of biodiesels B10, B15 and B30 is calculated depending on values of cetan numbers that compose the biodiesel.

The parameters of high pressure fuel injection system and indicated process were measured by piezo sensors. The in-cyliner pressure P_g, fuel injection pressure P_f, the start of fuel injection phase φ_{f1} and the end φ_{f2} were measured. The error of measurement of pressures P_g and P_f is ± 0,5 %. The error of measurement of fuel injection phases (φ_{f1} and φ_{f2}) and characteristic angles of cranckshaft is ± 0,5 ºCA. The signals of sensors were transferred by 20 channels into registration station of high-speed processes H-2000. The received signals were treated and collected by program complex "AC-Test". The mathematical modelling of temperature of gases and characteristics of heat release were performed by applying the program complex "Cycle". The main aspects of research on indicated process and fuel injection process are shown in Fig 2.
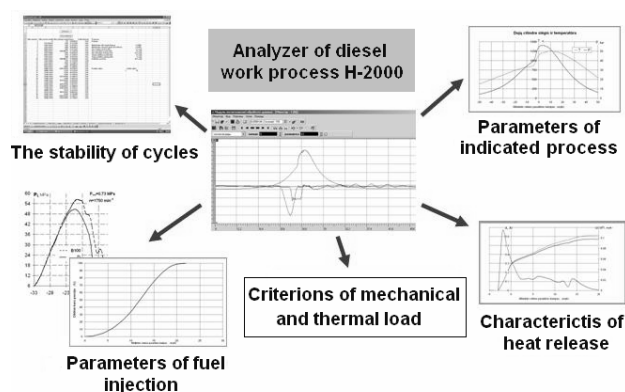

Fig 2. The aspects of research on work process and characteristics of fuel injection of diesel engine A41

The properties of heat release have influence on power, fuel consumption, reliability, the level of sound, vibration and harmful emission of exhaust gases of diesel engine. The process of formation of fuel – air mixture has primary influence on heat release. This process depends on dynamic state of air charge and fuel injection properties. Because of that the research on kinetics of combustion is related with research on characteristics of fuel injection.

XK and XA types of thermocouple are used for measurement of the temperature of cooling liquid, lubricating oil and exhaust gases of diesel engine. The relative error of measurement of temperature is ± 1 %. Fuel consumption is measured with automated device АБР-50. The relative error of measurement of fuel consumption is ± 0,5 %.

The algorithm for calculation of characteristics of heat release $X = f(\varphi)$ and $dX/d\varphi = f(\varphi)$ is based on differencial equation of first law of thermodynamics:

$$(c_v'G' + c_v''G'')\frac{dT}{d\varphi} = [H_u - 0,7T + 182] \times$$

$$q_{cikl}\frac{dX}{d\varphi} + \frac{dQ_w}{d\varphi} - K_4 P_B, \qquad (1)$$

where p and T – in-cylinder pressure and temperature; G' and G'' – masses of air and products of complete combustion; c_v' ir c_v'' – isochoric specific heat capacity

of air and products of complete combustion; q_{cycle} – the portion of fuel injected during one cycle; Q_w – heat losses through cylinder liner into cooling system, which can be alternatively calculated by methodics of G. Woschni [2] or Central Institute of Diesel Reseach (St. Peterburg, Russian Federation) [3]; X – coefficient of heat release; K_4 – constant; P_B – trigonometric function.

The possibility to enter the chemical composition of a wide range of fuels is realised by the mathematical model. The following chemical elements can be entered: coal – C, hydrogen – H_2, oxygen – O_2, water – H_2O, sulphur – S. The chemical composition of fuel oxidator (air) is entered by the following components: O_2, nitrogen – N_2, carbon dioxide – CO_2, H_2O and argon A_r. The values of internal energy and specific heat capacity of air and products of complete combustion are calculated by empyrical extrapolational polynomial equation of the third degree [4]:

$$U', U'', c', c'' = A_0 + A_1 T + A_2 T^2 + A_3 T,^3 \qquad (2)$$

where A_0, A_1, A_2, A_3 – coefficients, which are calculated by third degree polynomial equations depending on temperature and mass values of air and products of complete combustion (N_2, CO_2, H_2O, SO_2 and A_r).

Stoichiometric ratio L_0 of the ammount of air which is theoretically required for complete combustion of fuel, is calculated depending on chemical composition of fuel by formula:

$$L_0 = \frac{1}{0,21}\left(\frac{C^M}{12} + \frac{H^M}{4} - \frac{S^M + O^M}{32}\right), \qquad (3)$$

where C^M, H^M, O^M, S^M – mass portions of fuel elements, kg/kg fuel.

The heating value H_U is determined by formula of Mendelejev widely used in practice:

$$H_U = [81 C^M + 246 H^M - 30(0^M - S^M) - 6(W^M + 9 H^M)] / 4.19, \qquad (4)$$

where C^M, H^M, O^M, S^M, W^M – mass portions of fuel elements, kg/kg fuel.

The thermal and mechanical load of parts of cylinder – liner group can be evaluated by widely used in practice indirect criterions, which is allowable in comparative research. The following indirect criterions were used:

- maximum in-cylinder pressure p_{max}: for evaluation of mechanical load;
- maximum in-cylinder temperature T_{max} and medium temperature of compression – power stroke T_{cycle}: for evaluation of thermal load;
- criterions of prof. A. Kostin q_p ir q_y: for evaluation of the thermal load.

3. The results of experimental researches

3.1. Parameters of indicated work

The air ratio α is one of the main parameters which influences the work process of diesel engines especially without air turbocharging. The air ratio α is calculated

by formula: $\alpha = G_{air} /(G_f \times L_0)$, where G_{air} – air consumption per hour, kg/h, G_f – fuel consumption per hour, kg/h.

The air ratio of biodiesel increases depending on lower value of stoichiometric ratio: 0,476 and 0,433 – values of biodiesels B30 and B100 compared to value of mineral diesel fuel – 0,495. The consumption of air G_{air} is consistent under equal environmental conditions and equal work regimes. In this case the air ratio depends only on fuel consumption G_f and stoichiometric ratio L_0. The fuel consumption can be expressed by formula: $G_f = b_e P_e$, where b_e – brake specific fuel consumption, g/kWh, P_e – diesel engine brake power, kW.

The air ratio becomes the function of two arguments: b_e and L_0 at the identical diesel brake power (P_e = const). The biggest change of brake specific fuel consumption is determined at low loads of diesel engine running on biodiesel (see Fig 3). The higher value of air ratio of biodiesel is predetermined by different values of stoichiometric value L_0 being compared with mineral diesel fuel at low loads. This difference compensates the growth of break specific fuel consumption b_e by increasing workload. The increase in air ratio α is the following for the biodiesels being compared with mineral diesel fuel: B30 ~ 0,5 ÷ 0,15 and B100 ~ 0,75 ÷ 0,3, $\alpha \approx$ idem at nominal loads.

The effectiveness of convertation of the heat of fuel combustion into indicated work is evaluated by overall efficiency factor η_i. It can be determined as a function of the following parameters: air ratio α, compression ratio ε and ratio p_{max}/p_a (p_a – pressure of working fluid at the beginning of compression stroke) [5].
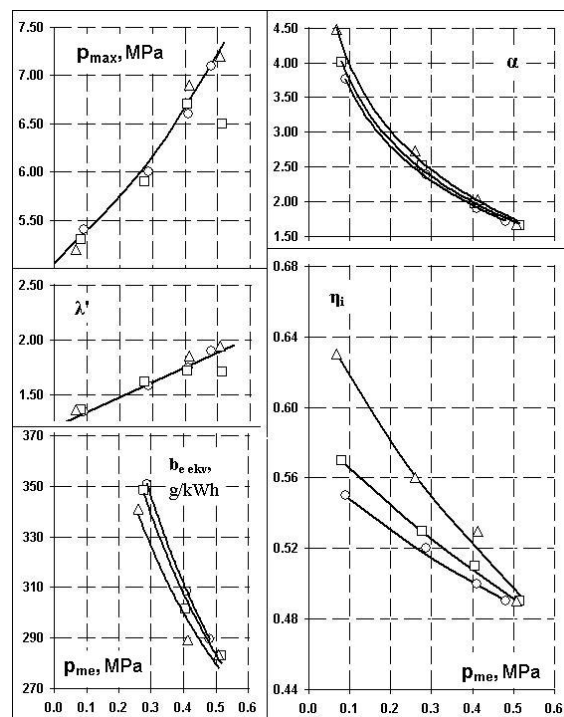

Fig 3. Parameters of work process of diesel engine A41 while running on biodiesel: $\bigcirc$ – diesel fuel, $\square$ – RME biodiesel B30, $\triangle$ – RME biodiesel B100

The indicated efficiency factor is the function of three arguments: α, ε and λ (where λ – pressure ratio) regarding the dependence on theory of internal combustion engines $p_{\max} = p_a \varepsilon^{n_1} \lambda$. The number of arguments decreases down to two $\eta_i = f(\alpha, \lambda)$ at the constant constructive parameters of combustion chamber ($\varepsilon = \text{const}$).

The pressure ratio λ depends mainly on cycle quantity of fuel q_{cycle} or fuel consumption per hour G_f by constant regulation of fuel supply systems for diesels without turbocharging. The linear dependence, viz. pressure ratio λ change can be seen depending on load of diesel engine (see Fig 3). The value of pressure ratio λ differs only by $2 \div 3$ % for the different tested fuels at constant rated output P_e ($\lambda' = p_{\max} / p_c$', where p_c – pressure of working fluid at the start of combustion, (see Fig 3). In case of made notes the indicated efficiency factor depends exceptionally on air ratio α.

Functions $\eta_i = f(\alpha)$ are presented in Fig 4. Obviously, air ratio α is not the universal argument for evaluation of the change of indicated efficiency factor when replacing mineral diesel fuel by biodiesel. The coefficients a and b of function $\eta_i = a + b\alpha$ are different for different types of fuel.
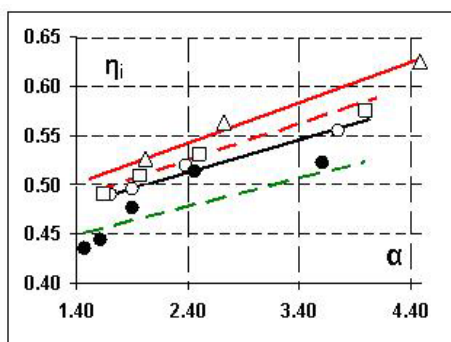

Fig, 4. Dependence of the indicated efficiency factor of function η_i on air ratio α of diesel engine A41: $\bigcirc$ – diesel fuel, $\square$ – RME biodiesel B30, $\triangle$ – RME biodiesel B100

The indicated efficiency factor can be additionally influenced by different characteristics of fuel injection and combustion depending on physical – chemical properties of fuel [6].

The multiparameter characteristics $\eta_i, p_{mi} = f(\alpha, \lambda, p_k, n)$ and mathematical models based on it should be corrected to be used in practice for biodiesel [5].

The equivalent fuel consumption $b_{e\ ekv}$ beside the indicated efficiency factor is used for the evaluation of fuel economy parameters: $b_{e\ ekv}^B = b_e^B \dfrac{H_u^B}{H_u^D}$ (see Fig 3) [7]. The equivalent fuel consumption experimental determination is less complicated in practice. The observed relative change of equivalent fuel consumption is similar to relative change of indicated efficiency factor when replacing mineral diesel fuel by biodiesel.

3.2. The mechanical and thermal load of diesel engine

The temperature of exhaust gases T_r is a less sensitive parameter than indicated efficiency factor in case of replacing the sort of fuel. Almost identical level of the temperature of exhaust gases T_g was determined for the following sorts of fuel: mineral diesel fuel, B30 and B100 at P_e = idem (see Table 3).

Table 3. Temperature of exhaust gases of tested fuels

No	Fuel	p_{me}, MPa			
		0,07÷0,09	0,26÷0,29	0,41	0,48÷0,52
1	Diesel fuel	260 ℃	365 ℃	450 ℃	490 ℃
2	B30	250 ℃	350 ℃	430 ℃	510 ℃
3	B100	245 ℃	340 ℃	430 ℃	510 ℃

The temperature of exhaust gases T_g is widely used in practice as indirect criterion for evaluation of thermal load of parts of cylinder-liner group of diesel engine. The temperature of exhaust gases non-completely reflects thermal load of diesel engine because of changes of spontaneous fuel injection phases at running of diesel engine on different sorts of fuel. The following parameters are used additionally for evaluation of the change of thermal load: maximum in-cylinder temperature T_{max}, medium temperature of compression – power stroke T_{cycle} and criterions of prof. A. Kostin q_p and q_y (see Fig 5).

Obtained results show that the replacement of mineral diesel fuel with biodiesel up to concentration of B100 does not increase mechanical load of parts of cylinder-liner group of diesel engine. The identical value of maximum pressure p_{max} is obtained independently on the sort of fuel at constant rated output P_e = idem. Experimental data curve of maximum pressure divergence from generalized curves is about $\pm 1 \div 1,5$ bar (see Fig 3). Criterions q_p and q_y are proportional to relative flow of heat near the bottom of piston and cooling system of diesel engine:

$$q_p = 2,34 c_m \left(\frac{D}{\eta_v p_K}\right)^{0,38} (p_{me} \times b_e \frac{T_K}{T_0})^{0,88} \quad (5)$$

$$q_y = 462,5 c_m^{0,565} \times \frac{p_{me} b_e T_K}{D^{0,5}(\eta_v p_K)^{0,38}}. \quad (6)$$

where D – diameter of cylinder, η_v – air ratio of filling the cylinder, c_m – medium speed of piston, p_k – turbocharging pressure, T_k – temperature of turbocharging air, T_0 – environmental temperature.

After non-complicated simplifying for the diesel without turbocharging the functions of criterions q_p and q_y can be expressed as follows: $q_p = K_1 \beta^{0,88}$, $q_y = K_2 \beta^{0,5}$, where $\beta = 1/\alpha$ – ratio of usage of air fluid, reverse to air ratio α, K_1 and K_2 – constants.
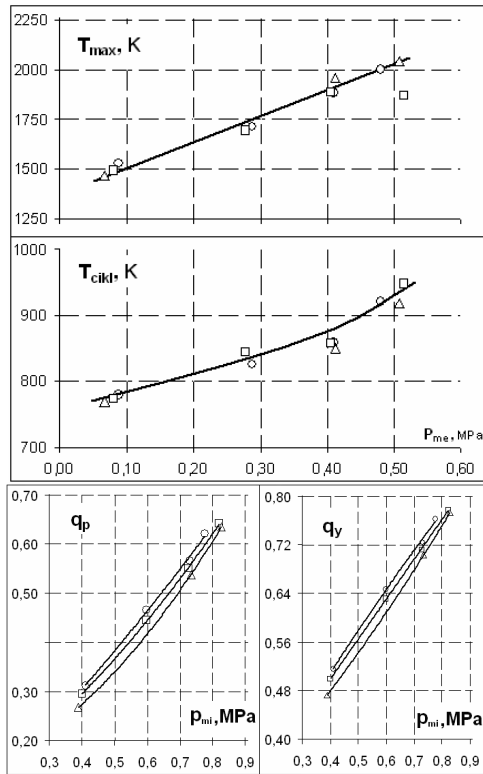
Fig 5. Criterions of thermal load of diesel engine A41 while running on biodiesel: : ◯ − diesel fuel, ☐ − RME biodiesel B30, △ − RME biodiesel B100

The determined change of criterions q_p and q_y of different sorts of fuel depending on load (see Fig 5) confirms that replacement of mineral diesel fuel by biodiesel does not increase thermal load and heat transferring into cooling system at the same level of rated output.

3.3. The characteristics of fuel injection

The replacement of mineral diesel fuel by biodiesel practically does not change the phases of fuel injection (φ_{f1} − start of injection and φ_{f2} − end of injection) and duration of injection at the same fuel injection timing and rated output.

The charcateristic phases of biodiesel injection remain the same being compared with mineral diesel fuel (see Fig 6).

The analogous results of researches are obtained and for rapeseed oil while viscosity of it is ~ 15 % higher being compared to mineral diesel fuel. The viscosity of biodiesel B100 is ~ 85 % and density is ~ 5 % higher being compared to mineral diesel fuel.

The replacement of mineral diesel fuel with biodiesel ensuring the same level of rated output of diesel engine is related to the increase of cycle quantity of fuel q_{cycle} because of lower heat value H_u of biodiesel. The constancy of duration of fuel injection $\varphi_{f\,inj}$ confirms

that the intensiveness of injection or pressure of injection (speed of volume and mass injection) increases by using biodiesels. The increase of fuel pressure before

fuel injector P_f is determined within the whole researched range of loads (see Fig 7).

The higher pressure before fuel injection P_f of biodiesels stabilizes characteristic of fuel injection. The real timing of lifting of injector needle is earlier for $1 \div 1,5\,°$ CA up to dead top center (see Fig 8).
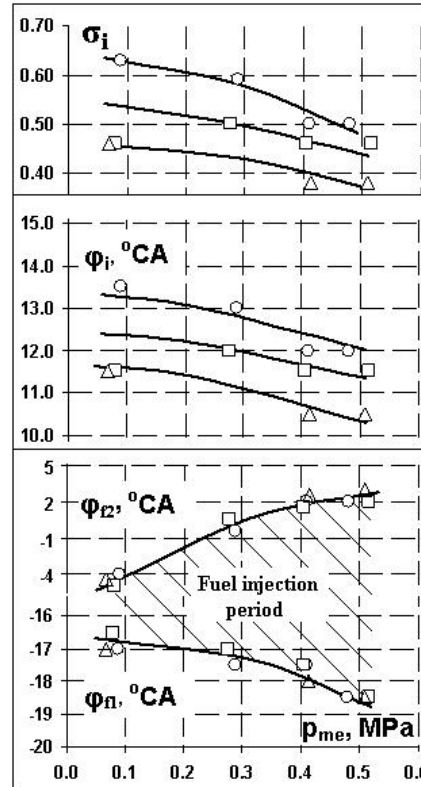

Fig 6. Phases of fuel injection of A41 while running on biodiesel: : ◯ − diesel fuel, ☐ − RME biodiesel B30, △ − RME biodiesel B100
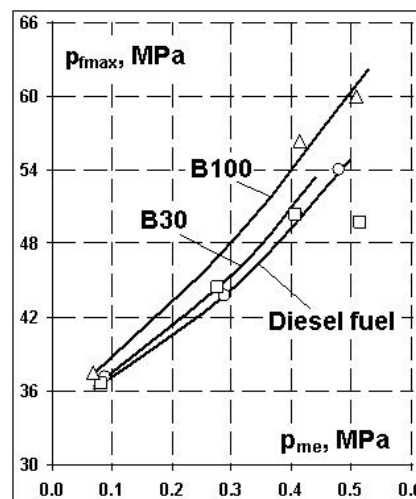

Fig 7. The change of maximum pressure before fuel injection P_f of diesel engine A41 while running on biodiesel: ◯ − diesel fuel, ☐ − RME biodiesel B30, △ − RME biodiesel B100
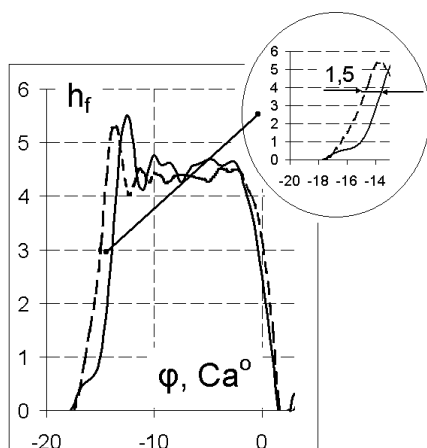
Fig 8. The characteristic of lifting of injector needle h_f of diesel engine A41: ⎯⎯⎯ – diesel fuel, ‒ ‒ ‒ – RME biodiesel B100

The front of characteristic of fuel pressure before fuel injection remains unchanged (see Fig 9). Is it known that the increase of profile and maximum value of P_f together with density of fuel significantly influence the quality of fuel injection: the size of fuel droplets, the dispersity and, as a result, period of induction φ_i and kinetic phase of combustion.
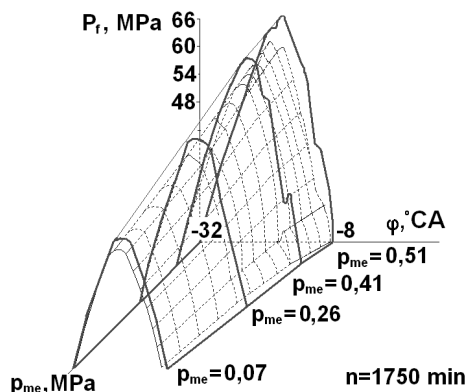

Fig 9. The characteristic of fuel injection P_f of diesel engine A41: ⎯⎯⎯ – RME biodiesel B100, ‒ ‒ ‒ . – diesel fuel

The law of fuel injection in differential and integral $\overline{g} = f(x)$ forms can be reasonably estimated depending on experimentally determined characteristic $P_f = f(\varphi)$:

$$\frac{dg}{d\varphi} = \mu_p f_p \sqrt{2\rho} \, \frac{P_f - P_{cil}}{\sqrt{|P_f - P_{cil}|}} \times \frac{1}{Gn_s} \,, \qquad (7)$$

where P_{cil} – in-cylinder pressure, G – cycle portion of fuel, n_s – revolutions of fuel pump crankshaft, μ_p, f_p – effective square of holes of injector.

Experimentally obtained and manually treated characteristics $\overline{g} = f(\varphi)$ at corresponding values of indicated pressure p_{mi} shows that the law of fuel injection remains the same when replacing the mineral diesel fuel by

biodiesel. The above data made available to state that the critical deviations of macro factors of fuel injection are not determined for the replacement of mineral diesel fuel by biodiesel up to pure biodiesel B100, and extra regulation of fuel supply system is not required.

The torch of biodiesel is characterised by worse micro factors of injection – dispersity of injection because of higher values of density ρ, viscosity υ and forces of surface tension σ of biodiesel [8]. The ratio of sizes of biodiesel and mineral diesel fuel droplets evalting by Zauter diameter [9] is determined by formula:

$$\frac{D_{32}^{Bio}}{D_{32}^{D}} = \left(\frac{\rho^{Bio}}{\rho^{D}}\right)^{0,0733} \times \left(\frac{\upsilon^{Bio}}{\upsilon^{D}}\right)^{0,1465} \times \left(\frac{\sigma^{Bio}}{\sigma^{D}}\right)^{0,193} . \quad (8)$$

The influence of parameters ρ, υ and σ on diameter D_{32} of droplets of torch is estimated by index of degree. It is obvious, D_{32} is mostly influenced by viscosity υ and forces of surface tension σ. The force of surface tension σ^{Bio} of biodiesel is higher approximately by 10 %, the value of viscosity of biodiesel is two times higher and thus predetermine the biggest influence on D_{32}. The waited overall increase of D_{32} is 17 % for biodiesel B100.

3.4. The characteristics of heat release

The characteristics of evaporation of biodiesel is as worse as dispersity: temperature at the start of evaporation of RME – 299 ºC, when the same of mineral diesel fuel – 178 ºC and higher value of specific enthalpy of evaporation. The influence of working fluid of biodiesel on work process is evaluated by characteristics of heat release X, $dX/d\varphi = f(\varphi)$ (see Figs 10, 11). The analysis of characteristics of heat release is accented on the first – kinetic $(dX_I/d\varphi)_{max}$ and the second – diffusion $(dX_{II}/d\varphi)_{max}$ maximums of speed of heat release.

$(dX_I/d\varphi)_{max}$ forms the dynamic parameters of work process: ratio of pressure speed $(dp/d\varphi)_{max}$, pressure ratio λ, maximum pressure of cycle p_{max} and emission of nitric oxides NO_x. The character of fuel combustion in the second – diffusion phase influences parameters of fuel economy and emission of products of non-complete combustion: (carbon monoxide CO, hydrocarbons CH and smoke).

The reduction of induction period φ_i for the biodiesel B30 and B100 is determined by 1º CA and 2º CA (see Fig 6). The values of cetane number of biodiesels B30 and B100 are 50 and 57 being compared to the same of mineral diesel fuel – 46. The quantity of fuel injected per cycle reduces together with the reduction of induction period φ_i, because the start of injection and the law of injection remain constant. The observed reduction of $(dX_I/d\varphi)_{max}$ (see Fig 10) is related to lower quantity of injected and prepared for combustion fuel (because of worse characteristics of evaporation) at the time of induction period. The significant reduction of $(dX_I/d\varphi)_{max}$ is observed at regime of nominal load: $(dX_I/d\varphi)_{max}$ reduces approximately by 30 % from 0,09 ºCA^{-1} down to 0,06 º CA^{-1} medium indicated pressure $p_{mi} = 0,4 \div 0,5$ MPa.
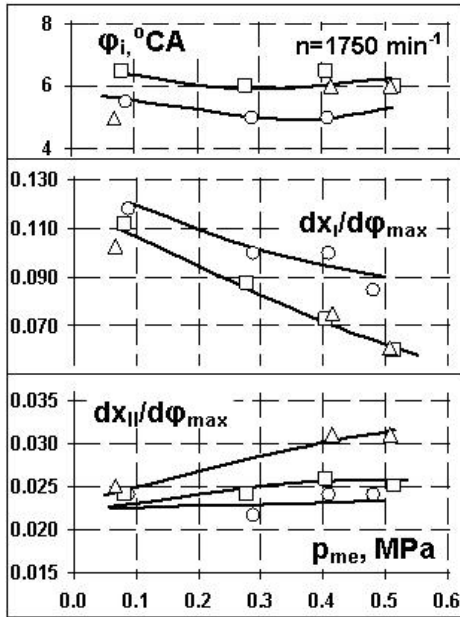
Fig 10. The parameters of heat release of diesel engine A41 while running on biodiesel: ○ − diesel fuel, □ − RME biodiesel B30, △ − RME biodiesel B100
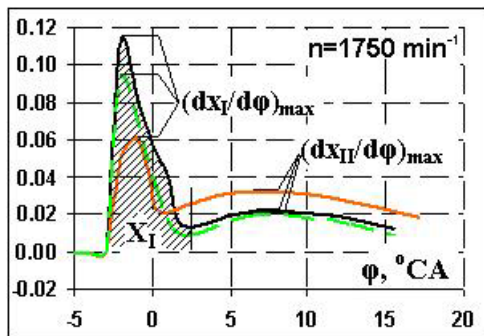

Fig 11. The change of characteristics of heat release $(dX_I/d\varphi)_{max}$ and $(dX_{II}/d\varphi)_{max}$ of diesel engine A41 while running on biodiesel: ──── − diesel fuel, − − − − − RME biodiesel B30, ──── − RME biodiesel B100

As a result, the dynamic parameters of load reduce: ratio of pressure speed $(dp/d\varphi)_{max}$ reduces from 0,9 MPa/° CA down to 0,85 MPa/° CA for biodiesle B30 and down to 0,7 MPa/° CA for biodiesle B100 at the regime of load $p_{mi} = 0,73 \div 0,83$ MPa.

The criterions of mechanical load of parts of cylinder-liner group p_{max} and pressure ratio λ depend mainly on heat quantity Q_{Pmax} released until the moment the maximum cycle pressure is reached at the identical conditions. The identical level of $Q_{Pmax} \approx$ idem is determined for all tested sorts of fuels. The said above confirms the constancy of experimentally determined parmeters p_{max}, $\lambda \approx$ idem. The mentioned fact is related to the increase of speed of heat release in the second - diffusion phase of combustion when running on biodiesel.

The heat release in the second phase of combustion increases by increasing the load p_{me} (p_{mi}) when running on biodiesel. The increase of quantity of biocomponent

in RME biodiesel approximatelly equally increases $(dX_{II}/d\varphi)_{max}$ (see Fig 11). The dependence of parameter $(dX_{II}/d\varphi)_{max}$ on load is significant being compared to the same of mineral diesel fuel: $(dX_{II}/d\varphi)_{max}$ increases from 0,023 CA^{-1} at low load up to 0,026 CA^{-1} at load regime $p_{me} = 0,5$ MPa. The replacement of mineral diesel fuel by biodiesel B100 increases $(dX_{II}/d\varphi)_{max}$ up to 0,031 CA^{-1} that is by ~ 35 % higher being compared to the same of mineral diesel fuel.

The increase of $(dX_{II}/d\varphi)_{max}$ predetermines increase of indicated efficiency factor η_i at running of diesel engine on biodiesel. The intensification of diffusion phase of combustion also reduces the emission of non-complete combustion (CO, CH and smoke), which is a characteristic feature of biodiesel. The mostly believable reason for intensification of diffusion phase of combustion is the higher concentration of oxygen in the biodiesel: 10 % being compared to the same of diesel engine ~ 1 %. The oxygen presented in the composition of biodiesel takes part in combustion increasing at the same time overall and local air ratios and thus becomes the reason for intensification of combustion.

The results of experimental researches confirm the positive influence of biodiesel on all main described above work parameters of diesel engine: the increase of indicated efficiency factor η_i, the constancy of mechanical and thermal load of parts of cylinder-liner group, the reduction of emission of products of non–complete combustion (CO, CH and smoke).

4. Conclusions

The new data on dynamics of biodiesel combustion was obtained by complex researches into characteristics of fuel injection and indicated work of diesel engine 1A41. The results of researches had allowed to substantiate the conformity with the law of change of main operational parameters of diesel engine while running on biodiesel fuel. The following principal propositions for replacement of mineral diesel fuel by biodiesel in operating fleets of diesel engines of Lithuania were formulated:

1. The law and phases of fuel injection of RME biodiesel and biodiesel B100 as well remain constant being compared to mineral diesel fuel. The increase of maximum injection pressure by 5 % for biodiesel B30 and by 10 % for B100 stabilises characteristics of injection.

2. The reduction of induction period by ~ 15 % while running on biodiesel (B30 and B100 respectively by 1 and 2 °CA) influences the reduction of heat release in kinetic phase $(dX/d\varphi)^I_{max}$ by ~ 30 %. It also reduces the mechanical load of parts of cylinder-liner group: ratio of pressure speed $(dp/d\varphi)_{max}$ reduces from 0,9 MPa/° CA down to 0,85 MPa/ ° CA for biodiesel B30 and down to 0,7 MPa/° CA for biodiesel B100 at the regime of load $p_{mi} = 0,73 \div 0,83$ MPa.

3. The increase of heat release at diffusion phase of combustion $(dX/d\varphi)^{II}_{max}$ by ~ 55 % (from 0,023 CA^{-1} at low load up to 0,026 CA^{-1} at load regime $p_{me} = 0,5$ MPa for biodiesel B30 and up to 0,031 °CA for B100) positi-

vely influences the increase of indicated efficiency factor η_i by ~ 2 % and partly compensates the increase of fuel consumption because of lower heat value of biodiesel being compared to mineral diesel fuel.

4. The reduction of intensiveness of heat release $(dX/d\varphi)^{I}_{max}$ in kinetic phase of combustion and the increase of intensiveness of heat release $(dX/d\varphi)^{II}_{max}$ in diffusion phase of combustion at the same time predetermines the constancy of heat quantity Q_{Pmax} released untill the moment the maximum cycle pressure is reached. As a result, the running of diesel engine on biodiesel does not increase maximum in-cylinder pressure p_{max} and characteristic temperatures of gases which forms mechanical and thermal load of parts of cylinder-liner group.

5. The determined interrelations of parameters of indicated work allow to state the following directions of modification of mathematical modelling programs for adapting them for the research of biodiesel:

- the correction of criterional and multifunctional dependences such as $\eta_i = f(\alpha, \lambda, p_k, \varepsilon, T_k)$ by entering simplexes for discovering properties of biodiesels;
- the formation of analytic formulas of characteristics of heat release X, $dX/d\varphi = f(\varphi)$ for biodiesels and of dependence on main parameters of work process and work regime as well.

6. The achieved constant temperature of exhaust gases T_g while running of diesel engine on biodiesel at the constant rated load P_e = idem for all sorts of tested fuels allows to forecast qualitative similar change of main operational parameters of turbocharged diesel engines as well.

Presumptions of effective operation of diesel engines running on RME biodiesel:

1. Concentration of biodiesel fuel up to and equal to 30 % in mixture with mineral diesel fuel is optimal to be used practically in respect of fuel saving change and effect of the improvement of ecological parameters. Specific fuel consumption deterioration and thrust characteristics decrease were as follows: for B30 biodiesel fuel – 2÷3 % at the constant load. Ecological parameters were changed as follows: CO – 30÷37 %, CH ~ 20÷50 %, smoke emission ~ 50÷55 % while increase of nitric oxides NO_x emission was appropriately ~ 10÷12 %.

2. The running of diesel engine on biodiesel and biodiesel B100 as well does not require extra regulation of fuel supply system: neither maximum portion of the cycle nor the static fuel injection timing.

3. Allowable by technical regulations of maintenance the reduction of fuel injection timing by 2° of crank angle makes available to obtain complex reduction of all harmful emission parameters including nitric oxides (NO_x) while running on biodiesel fuel, i.e. rapeseed methyl esters.

4. The running of diesel engine on biodiesel and biodiesel B100 as well does not increase thermal and mechanical load of parts of cylinder-liner group and does not deteriorate the parameters of reliability.

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