International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 3 (2018) pp. 1703-1709

The Study of the Process of Combustion of the Alcohol-Fuel Emulsions and Natural Gas in a Diesel Engine

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Abstract

The paper presents the results of research of indicators of the combustion process of a diesel engine 4F 11.0/12.5 in its environmental energy: methanol - and ethanol-fuel emulsions and natural gas with exhaust gas recirculation (EGR). Thus the necessity to use environmental energy sources for diesel engines. With the aim of developing, determining and optimizing the composition of ecological energy for diesel conducted its tests when working on diesel fuel, methanol - and ethanol-fuel emulsions, natural gas with EGR. Experimental studies have established that to use ecological energy for diesel 4F 11.0/12.5 when operating on natural gas with EGR is necessary to apply a ratio of gas 80% of the ignition portion of diesel fuel – 20%; when operating on mixtures with alcohols were used emulsion of the following composition: alcohol (methanol or ethanol) is 25%, detergent-dispersant additive succinimide C-5A – 0.5%, water - 7%, diesel fuel – 67.5%. A complete range of experimental studies of diesel 4F 11.0/12.5 when you work on the specified energy for various adjustment, load and speed modes of operation.

The conclusion to prove the possibility of using diesel of environmental energy, such as natural gas, ethyl and methyl alcohols. Moreover, experimental research of working process of diesel engine 4F 11.0/12.5 determined by the values of averaged maximum temperature of the cycle is T_{max}, the maximum pressure p_z, the degree of pressure increase λ, the rigidity of the combustion process $dp/d\varphi$ and the angle corresponding to the ignition delay period φ_i.

Keywords: diesel, combustion, methanol-fuel emulsion, ethanol-fuel emulsion, natural gas, exhaust gas recirculation.

FORMULATION OF INVESTIGATED PROBLEM

Turning to alternative energy sources as one of the foundations of future global energy was a logical result of the historical development and awareness of the need to diversify the used primary energy sources with the aim of improving energy and environmental security of countries, regions and specific energy users [1-5]. In addition, according to forecasts by 2020 the annual consumption of energy will amount to 18-20 billion tons in oil equivalent [6-9].

In the world as propulsion energy used by millions of heat engines, which generate more than 85% energy, but consume huge amount of oxygen a year (more than 1 billion tons) and throw hundreds of millions of tons of harmful substances into the atmosphere [10-12]. Since diesel engines have lower toxicity equivalent (in 1,5-2,0 times relative to gasoline engines), ie have a definite ecological advantage, and high fuel efficiency (25-30%), they can be considered prospects relative to other types of heat engines in many spheres of human activities. But, unfortunately, due to large-scale use of diesel engines, their emissions are increasing every year, more and more contaminating the surrounding environment [13-16]. So, despite the inevitable increase in oil prices and deteriorating environmental conditions associated primarily with the increase in the number of power plants running on liquid fuel oil, an intensive search for alternative energy sources [17-20].

EXPERIMENTAL STUDIES

In the Vyatka state agricultural Academy at the Department of heat engines, automobiles and tractors of the conducted research, methanol - and ethanol-fuel emulsions and natural gas as the environmental energy for the diesel 4F 11.0/12.5 [21].

When testing the diesel emulsions were investigated emulsions with different quantitative content of alcohol and additives. The alcohol concentration ranged from 10 to 50% by weight in 10% increments, and the concentration of the additive is from 0.5 to 2% in 0.5% increments.

In research originally, the criterion of stability was made the time before the appearance of visually observed changes (sediment or sludge) sample of an emulsion to the time before the start of sedimentation. From the graphs presented in figure 1, it is seen that the stability of emulsions depends not only on the alcohol concentration and the concentration of additive (K_{ad}) and the introduction in its composition of distilled water.

Thus, when the concentration of methanol 25% (see figure 1, a) the stability of the emulsion increases from 17.9 hours when K_{ad} = 0.5% to 34.6 hours when K_{ad} = 2.0%, i.e. 93.3%. And the stability of the ethanol-fuel emulsion (figure 2, b) with an ethanol content of 50% increases from 16.3 hours, with additive concentration 0.5% to 18.9 hours with increasing content of the additive up to 2.0%.

Thus, the prepared alcohol-environmental energy have a "margin of safety" over the time flow of the process of sedimentation as it still does not characterize the separation of the emulsion into two phases. During this time, a sample of the alcohol of the emulsion can take the initial composition due to light shaking (or vibration motor). After completion of sedimentation in the sample of an alcohol of the emulsion begins the process of flocculation - the formation of drops of the constituent ingredients. Further increasing of the volume of droplets and their adhesion leads to the completion of the process of coalescence, i.e. complete separation of the dispersion medium alcohol and a hydrocarbon phase. For the study, methanol- and ethanol-fuel emulsion stability to coalescence was 4 to 6 days. According to the research results, it was concluded that the use of water in the emulsion is really greatly increases the stability of alcoholic emulsions.

Succinimide C-5A is an effective emulsifier for emulsions of reverse type. The addition of water, in combination with this additive leads to an even more significant increase in the stability of emulsions (from 1-6 minutes to 1.5-100 hours). The received results allow to speak about possibility of application of succinimide, in conjunction with H_2O, as an emulsifier for the preparation of environmental alcohol of the emulsion out of the fuel system of a diesel engine.

By results of researches of stability of alcoholic emulsions was determined that emulsions with a concentration of alcohol of 50% is optimal from the point of view of resistance to the processes of destruction. In our opinion, this is due to the marginal increase in the concentration of alcohol in the emulsion, which in this case goes from "reverse" to "straight", but it makes impossible ignition of such fuel in the combustion chamber of a diesel engine, which was confirmed during initial tests on the engine. And, despite the high results of stability studies of alcohol mixtures, the use of emulsions with a high content of alcohol it is impossible due to the increased "stiffness" and the misfire of the diesel.

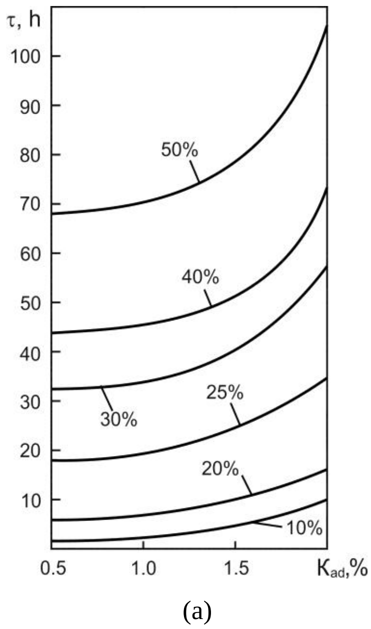
As a result of studies of physico-chemical properties of emulsions, stability and initial tests as the optimal for diesel 4F 11.0/12.5 were taken of the emulsion of the following composition: alcohol (methanol or ethanol) is 25%, detergent-dispersant additive succinimide C-5A – 0.5%, water - 7%, diesel fuel – 67.5%. All further testing of the diesel engine were carried out on the emulsions of this composition. Also experimental studies it was found that for obtaining ecological energy resource for diesel 4F 11.0/12.5 when operating on natural gas with EGR of the fulfilled gases it is necessary to apply the following correlation: gas – 80%, the ignition portion of diesel fuel – 20% [21].

Figure 2, a shows the parameters of the combustion process of a diesel engine 4F 11.0/12.5, depending on the angle of installation of an advancing of injection of fuel Θ_{inj}, when the engine speed n=2200 min^{-1}.

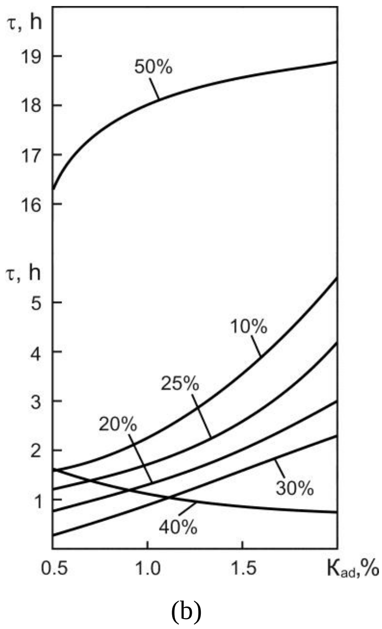
Analyzing the graphical dependences of the characteristics of combustion should be pointed out that with increase Θ_{inj} increase of the maximum average gas temperature in cylinder T_{max}, the maximum pressure of the combustion p_z, the degree of pressure increase λ, the rigidity of the combustion process $(dp/d\varphi)_{max}$ and the value of the angle φ_i corresponding to the ignition delay for the diesel process.

When working on natural gas, natural gas with different degrees of EGR, methanol - and ethanol-fuel emulsion, there is a decrease of the ignition delay period. This is due to features of mixing. The fact that natural gas and alcohols used have smaller values of cetane number compared to diesel fuel, which naturally reduces the tendency to spontaneous ignition. And with the increase in Θ_{inj} is given more time on the mixing, which is beneficial in the Autoignition process and reduces the angle corresponding to the ignition delay period.

Looking at the schedules of the gas-diesel process EGR it is possible to notice a decrease in p_z and $(dp/d\varphi)_{max}$ relative gas diesel process without EGR. When Θ_{inj}=23^o the maximum pressure in the cylinder of a diesel engine when operating on natural gas is equal to 8.5 MPa, working on natural gas with EGR 10% – 8.1 MPa, which corresponds to the diesel process. The value of $(dp/d\varphi)_{max}$ at Θ_{inj}= 23^o when operating on natural gas with EGR 10% is characterized 0.60 MPa/deg, which corresponds to a decrease of 13.0% relative to the gas-diesel process without EGR.

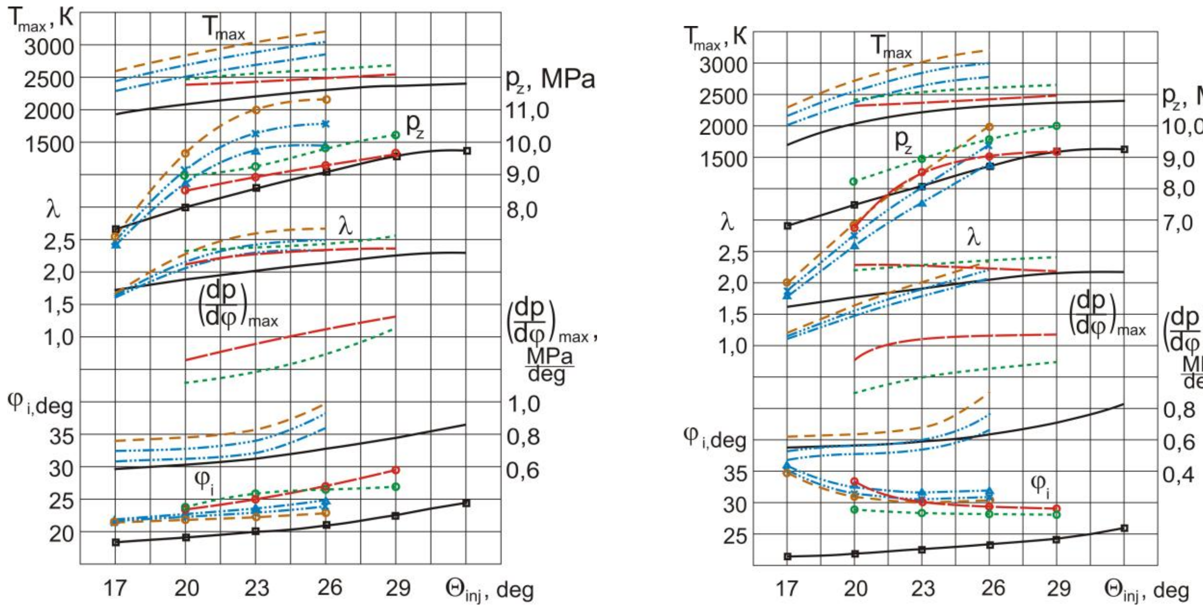


(a)



(b)

Figure 1. The results of experimental studies of environmental stability of the mixture of alcohol with succinimide additive C-5A: K_{ad} - succinimide the concentration of the additive C-5A; 10, 20, 30, 40, 50% - concentration of alcohol; a - methanol with 7 wt % water content; b – ethanol with 7 wt % water content



(a) (b)

Figure 2. The impact of applying the alcohol-fuel emulsions and natural gas on the performance of the combustion process of a diesel engine 4F 11.0/12.5, depending on changes Θ_{inj}: a – n=2200 min^{-1}; b – n = 1700 min^{-1}; ——— – diesel fuel; – – – - gas-diesel fuel; ···–··· - gas-diesel fuel with EGR 10%; ··–··– - gas-diesel fuel with EGR 20%; - - - - - ethanol-fuel emulsion; —— – - methanol-fuel emulsion

The fall of the parameters of the combustion process at the investigated angles of an advancing of injection of fuel Θ_{inj} of a diesel engine operating on natural gas with EGR is characterized by a decrease of the excess air ratio, which causes some increase of the angle corresponding to the ignition delay period.

Considering the differences of operation of the diesel engine on alcohol-fuel emulsions from the diesel process, it is necessary to highlight that the values of parameters of process of combustion in an alcohol-fuel emulsions increased. So, when Θ_{inj}=23º in the transition from diesel-methanol-fuel emulsion has been increasing Tmax to 11.0%, p_z 4.9%, $(dp/d\varphi)_{max}$ 2.1 times the degree of pressure increase λ by 19.0%, the angle φ_i corresponding to the ignition delay period, 33.3%. And the transition process with the diesel on ethanol-fuel emulsion at the same angle Θ_{inj}=23º are observed increase in Tmax by 14.6% overall, at 9.9%, $(dp/d\varphi)_{max}$ is 71.2%, the degree of pressure increase λ by 19.5%, the angle φ_i corresponding to the ignition delay period, by 24.4%.

On the basis of the conducted research the use of alcohol-fuel emulsions and natural gas with recirculation leads to the values of the parameters of the combustion process of a diesel engine 4F 11.0/12.5, shown in table 1.

Table 1. The results of studies of indicators of the combustion process of a diesel engine 4F 11.0/12.5 when Θ_{inj}=23º and nominal mode (n=2200 min^{-1}, p_{ef}=0.64 MPa)

Fuel	Index				
	T_{max}, K	p_z, MPa	λ	$(dp/d\varphi)_{max}$, MPa/ deg	φ_i, deg
Diesel	2190	8.1	1.90	0.59	22.5
Natural gas	3010 (increase by 37.4%)	8.5 (increase by 4.9%)	2.0 (increase by 5.3%)	0.69 (increase by 17.0%)	30.0 (increase by 33.3%)
Natural gas with EGR 10%	2790 (increase by 27.4%)	8,1 (corresponds to diesel fuel)	1,90 (corresponds to diesel fuel)	0,60 (increase by 1.7%)	31,0 (increase by 37.8%)
Natural gas with EGR 20%	2680 (increase by 22.4%)	7,5 (decrease by 7.4%)	1,80 (decrease by 5.3%)	0,54 (decrease by 8.5%)	32,0 (increase by 6.7%)
Methanol-fuel emulsion	2430 (increase by 11.0%)	8,5 (increase by 4.9%)	2,26 (increase by 19.0%)	1,25 (increase by 2.1 times)	30,0 (increase by 33.3%)
Ethanol-fuel emulsion	2510 (increase by 14.6%)	8,9 (increase by 9.9%)	2,27 (increase by 19.5%)	1,01 (increase by 71.2%)	28,0 (increase by 24.4%)

The results of studies of the characteristics of the combustion process of a diesel engine 4F 11.0/12.5, depending on Θ_{inj}, when the rotational speed of a crankshaft of the diesel engine corresponding to the maximum torque of $n=1700$ min^{-1}, shown in figure 2, b. Exploring the curves of parameters of the combustion process at $n=1700$ min^{-1} clearly shows that their dependencies mainly correspond to the nominal mode with different numerical values (table 2).

Figure 3, a shows the performance of the combustion process of a diesel engine 4F 11.0/12.5 a speed of 2200 min^{-1} and an installation angle of an advancing of injection of fuel $\Theta_{inj}=23°$ in different load modes.

Considering the diesel engine works on natural gas, can be clearly seen that with increasing load there is a "classic" rise of the maximum average gas temperature in the cylinder, maximum pressure, pressure ratio, stiffness of the combustion process and reduction of the angle corresponding to the ignition delay period. Thus, the range of load changes from 0.13 to 0.71 MPa, the values of T_{max} increase from 1400 to 3560 K, or by 2.5 times; $p_{z\ max}$ from 5.2 to 10.4 MPa, or exactly 2 times and λ from 1.2 to 2.5, or 2.1 times; $(dp/d\varphi)_{max}$ from of 0.46 to 0.76 MPa/deg, or 65.2%, and the decrease in φ_i from 30.5 to 29.5° of crankshaft rotation, or 1° of crankshaft rotation.

When a diesel engine works on natural gas with recirculating nature of the flow curve coincides with the gas-diesel process, and the values of the graphs "lie" below the curves of the gas-diesel process (except φ_i) in the whole range of loads and decrease with the increasing degree of EGR. So, when working on natural gas with 40% EGR at $\Theta_{inj}=23°$ in the range of loads from 0.13 to 0.51 MPa is reduced compared to the gas-diesel process, the maximum temperature averaged 100-400 K, the maximum pressure 7.9-19.2% of the stiffness of combustion 40.4-34.5%.

When working on natural gas with 10% EGR at full load is reduced compared to the gas-diesel process, the maximum averaged temperature 150 K, the maximum pressure is 3.5% and the stiffness of the combustion process by 15.5%; when working with 20% EGR, the maximum averaged temperature 300 K, the maximum pressure is 9.4% and the stiffness of the combustion process by 18.8%. The angle corresponding to the ignition delay when running on natural gas with EGR is higher than when gas diesel at all loading modes and it increases with the increase in the degree of EGR.

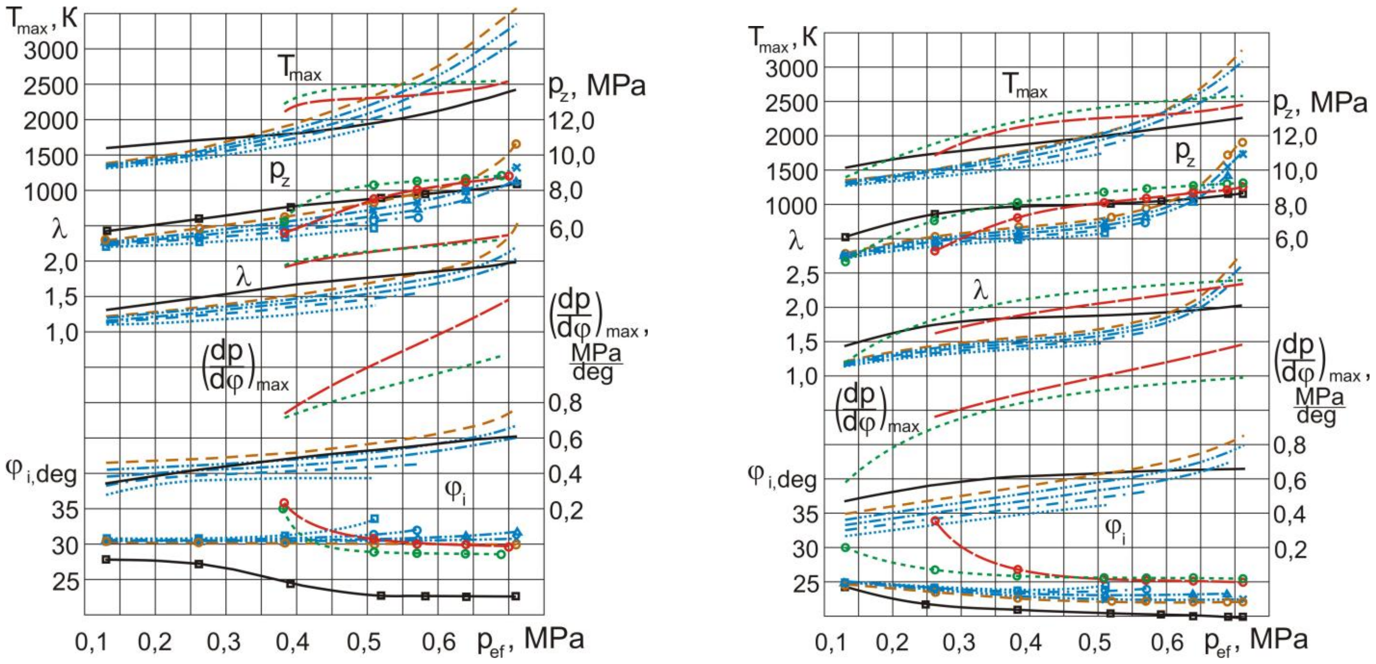
Analysis of the curves corresponding to the diesel engine works on an alcohol-fuel emulsions at a nominal frequency of rotation shows that the nature of the change curves are similar to the settings while the diesel process in the whole range of load changes, re (from 0.38 to 0.70 MPa). The lack of values of indicators of the combustion process at the $p_{ef} < 0,38$ MPa is connected with the combustion instability and misfire.

Figure 3, b shows the performance of the combustion process of a diesel engine 4F 11,0/12,5 at speed 1700 min^{-1}, corresponding to the maximum torque, and an installation angle of an advancing of injection of fuel $\Theta_{inj}=23°$ in different load modes.

Analysis of the curves at the speed of maximum torque, shows their similarity to nominal speed at different numerical values of the absolute indicators of combustion: T_{max}, p_z, λ, $(dp/d\varphi)_{max}$, φ_i.

Table 2. The results of studies of indicators of the combustion process of a diesel engine 4F 11.0/12.5 when $\Theta_{inj}=23°$ and the rotation speed corresponding to the maximum torque ($n=1700$ min^{-1}, $p_{ef}=0.69$ MPa)

Fuel	Показатели				
	T_{max}, K	p_z, MPa	λ	$(dp/d\varphi)_{max}$, MPa/ deg	φ_i, deg
Diesel	2210	8,6	2,0	0,64	20,0
Natural gas	3050 (increase by 38.0%)	11,0 (increase by 27.9%)	2,60 (increase by 30.0%)	0,83 (increase by 29.7%)	22,0 (increase by 10.0%)
Natural gas with EGR 10%	2880 (increase by 30.0%)	10,2 (increase by 18.6%)	2,40 (increase by 20.0%)	0,76 (increase by 18.8%)	24,0 (increase by 20.0%)
Natural gas with EGR 20%	2710 (increase by 22.6%)	9,2 (increase by 7.0%)	2,32 (increase by 16.0%)	0,66 (increase by 3.1%)	23,0 (increase by 15.0%)
Methanol-fuel emulsion	2460 (increase by 11.3%)	8,9 (increase by 3.5%)	2,30 (increase by 15.0%)	1,36 (increase by 2.1 times)	25,0 (increase by 25.0%)
Ethanol-fuel emulsion	2540 (increase by 14.9%)	9,2 (increase by 7.0%)	2,36 (increase by 18.0%)	1,19 (increase by 85.9%)	25,5 (increase by 27.5%)



(a) (b)

Figure 3. The impact of applying the alcohol-fuel emulsions and natural gas on the performance of the combustion process of a diesel engine 4CH 11,0/12,5 depending on the load change at Θ_{inj}=23º: a – n = 2200 min^{-1}; b – n = 1700 min^{-1}; ——— – diesel fuel; – – – - gas-diesel fuel; ···—··· - gas-diesel fuel with EGR 10%; -··-··- - gas-diesel fuel with EGR 20%; · — · — - gas-diesel fuel with EGR 30%; ·········· - gas-diesel fuel with EGR 40%; - - - - - - ethanol-fuel emulsion; ——-— - methanol-fuel emulsion

Figure 4 shows the parameters of the combustion process of a diesel engine 4F 11,0/12,5 at an installation angle of an advancing of injection of fuel Θ_{inj}=23º depending on the speed variation.

Considering the diesel engine works on natural gas it is clearly seen that with increase in speed there is a decrease in the maximum average gas temperature in the cylinder, maximum pressure, pressure ratio, stiffness of the combustion process and increasing the angle corresponding to the ignition delay period. Thus, in the speed range from 1200 to 2400 min^{-1} there is a decrease in T_{max} from 3100 to 3000 K, or 3.2%; $p_{z\,max}$ from 10.9 to 8.1 MPa, or by 25.7%; λ from 2.56 to 1.94, or 24.2%; $(dp/d\varphi)_{max}$ 0.98 to 0.61 MPa/deg, or 37.8%, increase in φ_i from 19.0 to 33.5º of crankshaft rotation, or 14.5º of crankshaft rotation. When diesel engine works on natural gas with EGR the nature of the flow curve coincides with the gas-diesel process, and the values of the graphs "lie" below the curves of gas diesel process without EGR (except φ_i) throughout the speed range and decrease with increasing degree of EGR. So, when working on gas-diesel process with 10% EGR in the range from 1200 to 2400 min^{-1} is reduced in comparison with the gas-diesel process, the maximum averaged temperature at 200 K, the maximum pressure of 7.3 to 4.9%, the degree of pressure increase λ by 6.3 and 5.3%, the rigidity of the combustion process 8.2-18.4% and the increase in the angle φ_i from 0 to 0.5º of crankshaft rotation. The use of EGR 20% in the range from 1200 to 2400 min^{-1} leads to a decrease relative to gas-diesel process without recirculation maximum gas temperature of 350-400 K, maximum pressure 11.0 and 13.6%, the degree of pressure increase λ by 10.2% to 12.4%, the rigidity of the combustion process by 11.5-33.7% the increase in the angle φ_i from 0.5º to 2.5º.

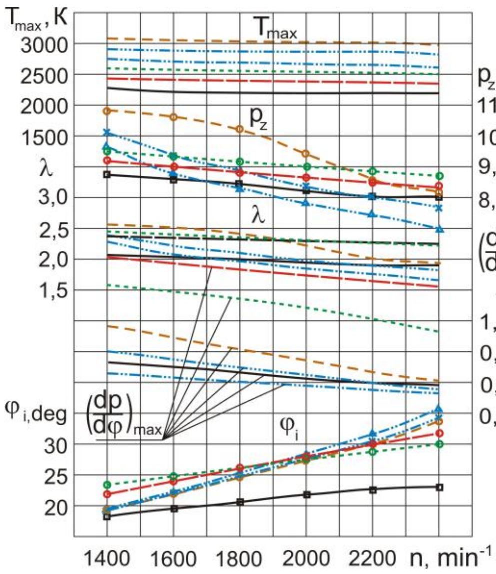


Figure 4. The impact of applying the alcohol-fuel emulsions and natural gas on the performance of the combustion process of a diesel engine 4F 11,0/12,5 depending on the speed variation when Θ_{inj}=23º; ——— – diesel fuel; – – – - gas-diesel fuel; ···—··· - gas-diesel fuel with EGR 10%; -··-··- - gas-diesel fuel with EGR 20%; - - - - - - ethanol-fuel emulsion; ——-— - methanol-fuel emulsion

When comparing the values of indicators of the combustion process in the cylinder of a diesel engine 4F 11,0/12,5 depending on the speed variation when Θ_{inj}=23º when operating on diesel fuel and alcohol fuel emulsions can be noted that all values of indicators of the combustion process in the transition of the diesel engine to work on alcohol-fuel ekklesia rise throughout the speed range.

ACKNOWLEDGEMENT

Presented results were obtained during performance of research work in accordance with topic No. 31 (section 31.03) plan the research work of the Federal state educational institution of higher professional education Vyatka state agricultural Academy of the Ministry of agriculture of the Russian Federation for 2016-2020.

CONCLUSION

This solution is the improvement of the combustion process of a diesel engine 4F 11,0/12,5 and presents the results of experimental studies demonstrate the promise of use as ecological energy sources for diesel engines of mixtures of methyl and ethyl alcohols and natural gas.

The results of experimental studies on the use of natural gas in a diesel engine 4F 11,0/12,5 was chosen the following relation: gas 80%, the ignition portion of diesel fuel - 20%. The results of studies of physico-chemical properties of the alcohol-fuel emulsions of different composition as optimal for the specified diesel was taken of emulsion of the following composition: alcohol (methyl, ethyl) - 25%, succinimide C-5A - 0,5%, water - 7%, diesel fuel - 67,5%. All bench tests of a diesel engine were conducted on the above fuel compositions.

Experimental research of working process of diesel engine 4F 11,0/12,5 determined values of indicators of the combustion process. When Θ_{inj}=23º and the nominal mode (n=2200 min^{-1}, p_{ef}=0,64 MPa) obtained the following results: Diesel fuel - T_{max}=2190 K; p_z=8,1 MPa; λ=1,90; $(dp/d\varphi)_{max}$=0.59 MPa/deg; φ_i=22,5º; Natural gas - T_{max}=3010 K (increase by 37.4%); p_z=8,5 MPa (increase by 4.9%); λ=2,0 (increase by 5.3%); $(dp/d\varphi)_{max}$=0.69 MPa/deg (increase by 17.0%); φ_i=30,0º (increase by 33.3%); Natural gas with EGR 10% - T_{max}=2790 K (increase by 27.4%); p_z=8,1 MPa (corresponds to diesel fuel); λ=1,9 (corresponds to diesel fuel); $(dp/d\varphi)_{max}$=0,60 MPa/deg (increase by 1.7%); φ_i=31,0º (increase by 37.8%); Natural gas with EGR 10% - T_{max}=2680 K (increase by 22.4%); p_z=7.5 MPa (decrease by 7.4%); λ=1,8 (decrease by 5.3%); $(dp/d\varphi)_{max}$=0,54 MPa/deg (decrease by 8.5%); φ_i=32,0º (increase by 6.7%); Methanol-fuel emulsion - T_{max}=2430 K (increase by 11.0%); p_z=8,5 MPa (increase by 4.9%); λ=2.26 (increase by 19.0%); $(dp/d\varphi)_{max}$=1.25 MPa/deg (increase by 2.1 times); φ_i=30,0º (increase by 33.3%); Ethanol-fuel emulsion - T_{max}=2510 K (increase by 14.6%); p_z=8,9 MPa (increase by 9,9%); λ=2,27 (increase by 19.5%); $(dp/d\varphi)_{max}$=1,01 MPa/deg (increase by 71.2%); φ_i=28,0º (increase by 24.4%).

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