E3S Web of Conferences **548**, 08003 (2024) https://doi.org/10.1051/e3sconf/202454808003
AGRITECH-X 2024

Study of the possibility of reducing diesel exhaust gas smoke engine bio additives into fuel

Akbarjon Normurodov[1*], *Vladimir* Markov[2], *Zayniddin* Oripov[1], and *Bobirjon* Tukhtaev[1]

[1]Navoi State University of Mining and Technologies, Navoi, 210100, Uzbekistan
[2]Bauman Moscow State Technical University, Moscow, 105005, Russia

Abstract. One of the modern ways to reduce the technogenic impact of the transport sector on the environment is the expansion of the use of biofuels. The article discusses computational studies of the flow of these fuels in a sprayer using the Ansys Fluent software package. The stationary flow of the specified fuels into the sprayer of a diesel nozzle of the FDM-22 type Plant was simulated which was manufactured by the Noginsk Fuel Equipment Plant with a sprayer of the Altai Precision Products Plant was simulated. The sprayer had five spraying holes with a diameter of 0.35 mm. At the same time, the pressure at the entrance to the design area was 51.5 MPa, and the back pressures were 0.1 and 8.9 MPa. While comparing the flow of rapeseed oil, to the flow of the emulsion of rapeseed oil and ethanol has a higher injection rate. However, compared with the flow of petroleum diesel fuel, it has a lower injection rate.

1 Introduction

The deepening energy crisis and the need to reduce the emission of harmful substances into the atmosphere with exhaust gases (EG) of internal combustion engines necessitate a wider use of alternative fuels [1, 2]. According to a number of their properties, these biofuels differ from the properties of petroleum diesel fuel (DF), so it is advisable to use them in mixtures with diesel fuel or other alternative fuels. These mixtures also include emulsified fuels [3, 4]. At the same time, the problem of determining the parameters of the flow of such fuels in atomizers of diesel injectors remains insufficiently studied. These parameters have a significant impact on the quality of the processes of fuel supply, fuel atomization and mixture formation. The objectives of the study were to simulate the fuel supply of a diesel engine when it is fed with diesel fuel and biofuels, as well as a comparative analysis of the parameters of the flow of mixed and emulsified fuels in atomizers of diesel injectors.

2 Properties of fuels and the object of study

The flow parameters at the outlet of the spray holes differ significantly for mixed biofuels (mixtures of vegetable oils with petroleum diesel fuel) and for emulsified biofuels (mixtures of vegetable oils with alternative fuels that do not mix with vegetable oils, in particular with

---

* Corresponding author: a_nor7@mail.ru

ethyl alcohol). During the calculations, oil diesel fuel of brand L according to GOST 305-2013, rapeseed oil (RM) and an emulsion of 70% by weight of RM and 30% ethyl alcohol (EA) were studied. In table. Table 1 shows data on some properties of the studied fuels [5].

In the simulation, an FDM-22 type injector manufactured by the Noginsk Fuel Equipment Plant with an atomizer type 171 of the Altai Plant of Precision Products (APPP) was studied. This atomizer had five spray holes with a diameter of 0.35 mm and a length of 1.1 mm. The maximum stroke of the atomizer needle was 0.32 mm.

Table 1. Properties of diesel fuel, rapeseed oil and ethyl alcohol at a temperature of 40°C.

Fuel	**Fuel properties**			
	Density, kg/m^3	**Kinematic viscosity, mm^2/s**	**Surface tension coefficient, mN/m**	**Saturated steam pressure, kPa**
DF	822.7	2.4	26.4	4.8
RO	914.6	36.0	32.3	0
EA	782.2	1.1	20.6	18.0
70% RO and 30% EA	883.2	45.0	28.8	5.4

3 Modeling

When carrying out computational studies of the parameters of the flow of various fuels, the symmetrical geometry of the element of the flow part of the atomizer with one spraying hole was considered (Fig. 1).

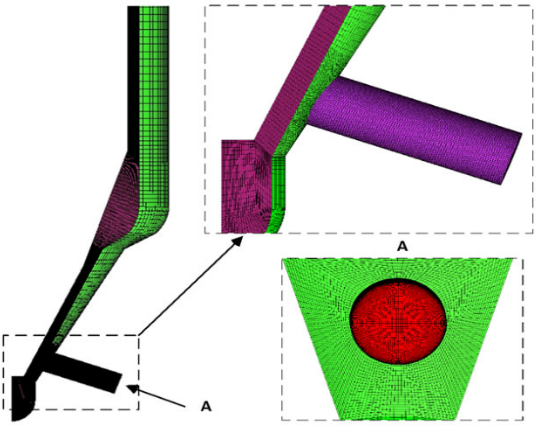

Fig. 1. Model of the computational grid of the studied nozzle sprayer.

The stationary flow of the oil DF, RO and emulsions 70% RO and 30% EA n the flow part of the atomizer at the maximum lift of the nozzle needle. Emulsion considered EA in RO with an ethanol droplet diameter of 50 mcm. The fuel was considered incompressible.

Computational studies of the flow of fuels in the flow part of the atomizer were carried out in the software package Ansys Fluent [6]. The flow in the atomizer was modeled using a multiphase equilibrium model (mixed fuel model).

Taking into account the difference in the density of the components in the emulsion, a multiphase model was used. The momentum equations are used for the mixed phase in the form:

$$\frac{\partial}{\partial t}(\rho_m\vec{u}_m) + \nabla(\rho_m\vec{u}_m \otimes \vec{u}_m) = -\nabla(p) + \nabla[(\mu_m + \mu_\tau)(\nabla\vec{u}_m + \nabla^T\vec{u}_m] - \quad (1)$$

$$-\nabla\left(\textstyle\sum_{q=1}^{N} a_q\rho_q\, \vec{u}_{dr,q}\vec{u}_{dr,q}\right), \quad (2)$$

where ρm, $\vec{u}_m$, μm – density, velocity and viscosity of the mixed phase; μτ – turbulent viscosity; N – number of phases; αq, ρq, $\vec{u}_{dr,q}$– volume fraction, density and drift rate q respectively. The properties and velocity of the mixed phase were determined as:

$$\rho_m = \textstyle\sum_{q=1}^{N} a_q\rho_q;\ \mu_m = \sum_{q=1}^{N} a_q\rho_q\mu_q;\ \vec{u}_m = \sum_{q=1}^{N} a_q\rho_q\,\vec{u}_q) \quad (3)$$

where μq and $\vec{u}_q$ – molecular viscosity and phase velocity q. The mass conservation equations for the mixed and vapor phases are expressed as follows:

$$\frac{\partial\rho_m}{\partial t} + \nabla(\rho_m\vec{u}_m) = 0;\quad \frac{\partial\rho}{\partial t}(\alpha_v\rho_v) + \nabla(\alpha_v\rho_v\vec{u}_v) = R_v. \quad (4)$$

The rate of mass transfer due to cavitation Rv was modeled using the Schnerr-Sauer cavitation model, obtained from the Rayleigh-Plesset equation:

$$R_v = \frac{\rho_v\rho_l}{\rho_m}\left(\frac{4\pi}{3}n_b\alpha_v\right)^{1/3}(1-\alpha_v)^{4/3}\left(\frac{2}{3}\left|\frac{p_v-p}{p_l}\right|\right)^{1/2}, \qquad \text{for pv} \le \text{p}; \quad (5)$$

$$R_v = -C_{cond}\frac{\rho_v\rho_l}{\rho_m}\left(\frac{4\pi}{3}n_b\alpha_v\right)^{1/3}(1-\alpha_v)^{4/3}\left(\frac{2}{3}\left|\frac{p_v-p}{p_l}\right|\right)^{1/2}, \quad \text{for pv} > \text{p}, \quad (6)$$

where nb – density number of cavitation bubbles; Ccond – bubble condensation constant; ρl – is the density of the liquid (DF and emulsions RO and EA). The mass conservation equations are closed using the condition $\sum_{\mathrm{q}=1}^{\mathrm{N}} \mathrm{a_q}\rho_{\mathrm{q}} = 1$. Wander rate q – $\vec{u}_{dr,q}$ calculated taking into account the relative velocity of the secondary phases q, k to primary phase p – $\vec{u}_{qp}$, $\vec{\mathrm{u}}_{\mathrm{kp}}$ and is expressed by the formula:

$$\vec{u}_{dr,q} = \vec{u}_{qp} - \textstyle\sum_{k=1}^{N}\alpha_k\,\rho_k\vec{u}_{kp}/\rho_m. \quad (7)$$

Relative velocity of the secondary phase q in relation to the primary phase p calculated by the following formula:

$$\vec{u}_{dp} = \frac{\rho_q d_q^2}{18\mu_q f_e}\left(1 - \frac{\rho_m}{\rho_q}\right)\vec{\alpha}, \quad (8)$$

where dq – phase particle size q (ethanol droplet diameter or cavitation bubble diameter); fe – resistance function. Model resistance function used Schiller-Naumann [8]

$$f_e = 1 + 0{,}15\ \mathrm{Re}^{0{,}687} \qquad \text{for Re} \le 1000$$

$$\text{and } \mathrm{f_e} = 0{,}0183\mathrm{Re} \qquad \text{for Re} > 1000. \quad (9)$$

where Re – Reynolds number calculated taking into account phase particles. They were modeled using the turbulent model RANS, implementing k-ε turbulence model [7, 8].

4 Results

Flow simulation DF, RO and the indicated emulsion was performed at the pressure at the inlet to the computational domain 51.5 MPa and two different back pressures – 0.1 and 8.9 MPa. Back pressure equal to 0.1 MPa, corresponds to atmospheric, and the back pressure equal to 8.9 MPa, corresponds to the pressure in the combustion chamber of a diesel engine at the moment of injection. The fuel temperature is taken constant and equal to 40°C

To analyze the characteristics of the flow of these fuels through the spray hole, a uniaxial reporting system was used, the starting point of which coincides with the center of the inlet section of the hole, and the coordinate axis is directed along the axis of the hole. The distance from the specified point to the current cross section of the hole is denoted as lp. Meaning lp = 0 mm corresponds to the inlet, and the value lp = 1.1 mm – outlet. The calculated values of the mass flow rate and the flow rate coefficient for the flow of fuels are given in the Table 2. These data show that compared to RO use of emulsion RO and EA reduces mass fuel consumption mainly due to a decrease in emulsion density. At the same time, due to the high saturation vapor pressure of ethanol, cavitation inside the spray hole increases, which reduces the flow coefficient. Compared to oil DF emulsion flow RO and EA characterized by higher fuel consumption and a lower consumption coefficient. This is mainly due to the relatively high density and viscosity of the emulsion. At back pressures 8.9 and 0.1 MPa and transition from DF on the emulsion, the consumption coefficient decreases, respectively, by 8.8% and 7.3%.

Table 2. Calculated values of fuel flow parameters.

Back pressure, MPa	Type of fuel	Consumption, g/s	Flow rate
0.1	DF	14.42	0.52
	RO	16.58	0.56
	Emulsion RO and EA	14.58	0.51
8.9	DF	14.39	0.57
	RO	14.96	0.56
	Emulsion RO and EA	14.56	0.55

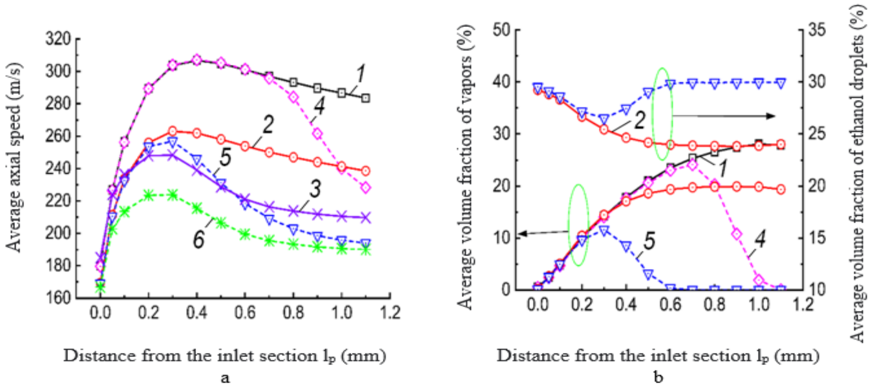

Fig. 2. The values of the axial flow velocity (a) and the volume fraction of vapors (b) averaged over the cross section of the hole for the studied fuels at various counter-pressures [MPa]: *1* – DF; 0.1; *2* – emulsion; 0.1; *3* – RO; 0.1; *4* – DF; 8.9; *2* – emulsion; 8.9; *3* – RO; 8.9.

Presented in Fig. 2(a). The calculated characteristics show that the fuel flow rate increases significantly when entering the atomizer orifice, which is explained by the formation of a low pressure area as a result of a sharp change in the flow direction (Figure 3) and the occurrence of cavitation.

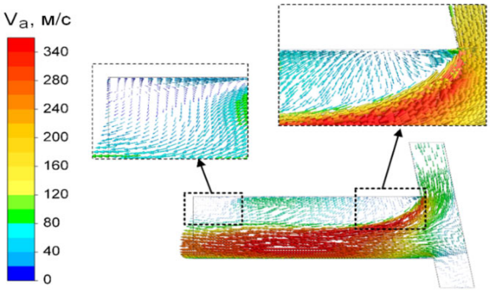

Fig. 3. Velocity vector distribution V_a flow in the longitudinal section of the spray hole at back pressure 8.9 MPa.

Its appearance is confirmed by data on the volume fraction of fuel vapors in the cross section of the atomizer hole (Fig. 2b) and the distribution of these vapors in the longitudinal section of the hole (Fig. 4). From Fig. 2, and it is also seen that in each cross section of the hole DF has the highest average axial velocity under all conditions studied. In this case, the emulsion flow rate is always greater than that of RO, and has the highest flow velocity DF.

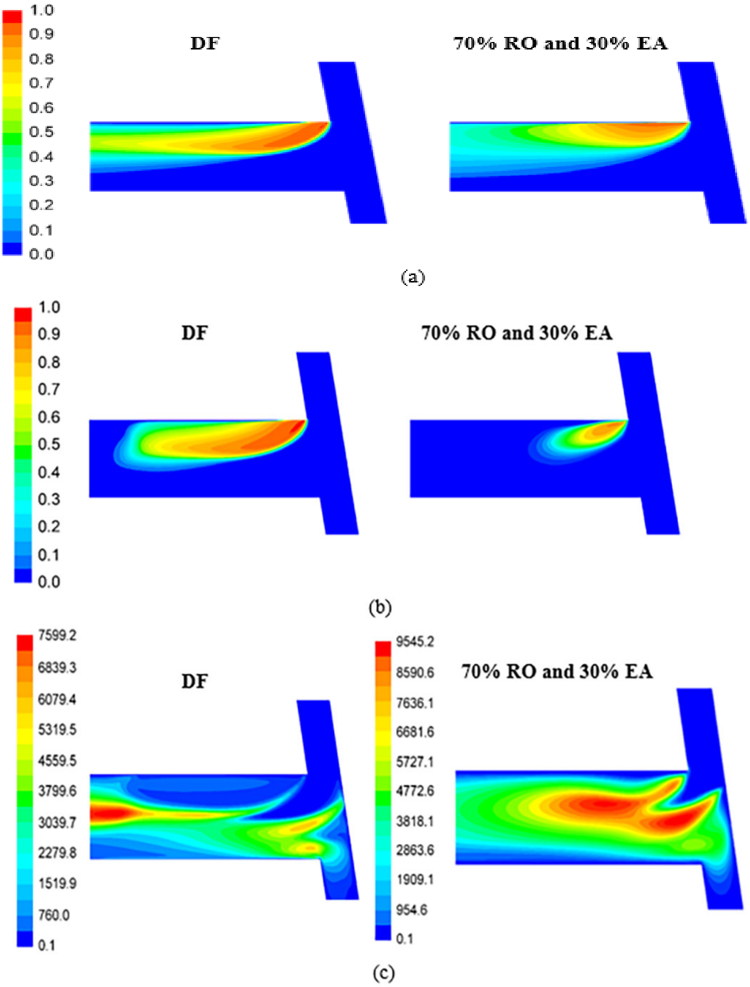

Fig. 4. Distribution of the volume fraction of fuel vapors in the longitudinal section of the nozzle opening at back pressures 0.1 MPa (*a*) and 8.9 MPa (*b*), turbulence kinetic energy distribution (m^2/s^2) at back pressure 8.9 MPa (*c*).

The high turbulence of the fuel flow at the outlet of the spray hole accelerates the disintegration of the jet and improves the quality of mixture formation. With back pressure 8.9 MPa the entry of fuel into the hole is characterized by a sharp increase in the kinetic energy of turbulence (Fig. 5) due to a change in the direction of the flow, a sharp narrowing of the flow area, the appearance of vortices and the generation of cavitation bubbles. Then, as the fuel flows through the spray hole, this energy is gradually dissipated. With the flow DF and backpressure (8.9 MPa) close to exit (lp = 0.8…1.1) due to the condensation of vapors in cavitation bubbles, vortices are formed that increase the kinetic energy of turbulence (Fig. 2 (b), 4 (b), 4 (c)). As the emulsion flows through the hole, this energy is dissipated [1, 9, 10]. In the presence of backpressure, the highest value of the kinetic energy of turbulence at the exit from the hole is typical for DF, but the magnitude of this energy is commensurate with the analogous energy of the emulsion. With counterpressure, the value of this energy is commensurate with the similar energy of the emulsion. With back pressure 0.1 MPa the maximum kinetic energy of turbulence at the outlet of the hole is noted for RO, and the minimum for DF (Fig. 5).

In general, during the flow of the emulsion RO and EA the fuel flow rate in the spray holes decreases compared to the flow DF (Fig. 2.a). But the lower flow rate of the emulsion is partially compensated by additional turbulence. In the combustion chamber of a diesel engine, there is a sharp evaporation of ethanol droplets, and better spraying of biofuels [10, 11].

The results of computational studies of the flow of the considered fuels in the nozzle sprayer suggest the processes of fuel decomposition, mixing and combustion. These biofuels will also have an impact on the fuel efficiency and toxicity of the exhaust gas running on the studied fuels.

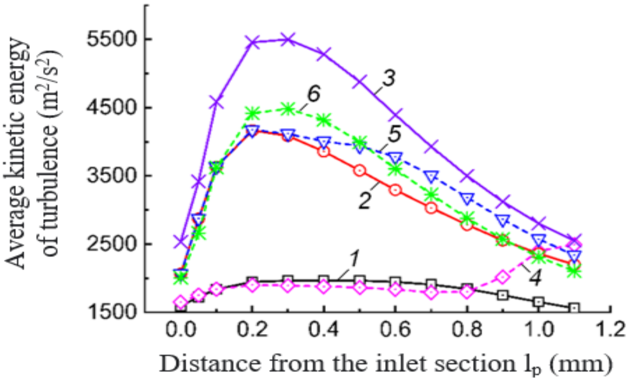

Fig. 5. The values of the kinetic energy of turbulence averaged over the cross section of the hole for the studied biofuels at different pressures [MPa]: *1* – DF; 0.1; *2* – emulsion; 0.1; *3* – RO; 0.1; *4* – DF; 8.9; *2* – emulsion; 8.9; *3* – RO; 8.9.

5 Conclusion

The obtained result of computational studies

- Computational studies of the flow parameters of the investigated fuels like - petroleum diesel fuel (DF), rapeseed oil (RO), emulsions 70% RO and 30% ethyl alcohol (EA) confirmed the influence of the properties of these fuels on the parameters of the fuel flow in the nozzle atomizer.
- Emulsification RO ethanol significantly affects the flow parameters in the nebulizer. Compared with RO the emulsion has a higher flow rate but a lower fuel mass flow rate. Compared to oil DF the emulsion has a higher mass fuel consumption, but a lower flow rate.
- With back pressure 0.1 MPa the kinetic energy of turbulence at the outlet of the emulsion hole is higher than that of DF. With back pressure 8.9 MPa the largest value of the kinetic energy of turbulence at the outlet of the hole has DF, but the magnitude of this energy is commensurate with the analogous energy of the emulsion.
- The lower flow rate of the emulsion is partially compensated by additional turbulence, while a sharp evaporation of ethanol droplets is observed in the

combustion chamber of the diesel engine, which contributes to a more qualitative mixing.

References

1. G.V. Melnik, Engine Engineering **3**, 47-51 (2007)
2. G.V. Melnik, Materials of the CIMAC-2016 Congress Engine Building **4**, 38-57 (2019)
3. I.V. Piskunov, O.F. Glagoleva, I.A. Golubeva, Natural gas motor fuel. Alternative fuel transport **4**, 68-77 (2021)
4. S.C. Mat, M.Y. Idroas, M.F. Hamid, Z.A. Zainal, Renewable and Sustainable Energy Reviews **82**, 808-823 (2018). https://doi.org/10.1016/j.rser.2017.09.080
5. Sa. Bowen, V.A. Markov, S.N. Devyanin, V.A. Neverov, F.S. Karpets, Automobile. Road. Infrastructure **1(35)**, 11 (2023)
6. S.A. Plotnikov, P.Y. Kantor M.V. Motovilova, Engine Engineering **2**, 19-23 (2020)
7. Sa. Bowen, *Improving the Operational and Technical Performance of Diesel Engine by Improving the Fuel Supply Process and Fuel Properties*: dissertation candidate of technical sciences (M., MSTU named after N.E. Bauman, 2021), p 139
8. G.H. Schnerr, J. Sauer, Physical and Numerical Modeling of Unsteady Cavitation Dynamics, *Conference*: *ICMF*-2001, 4th International Conference on Multiphase Flow, New Orleans, pp. 1-12. (2001)
9. D. Mukhitdinov, Y. Kadirov, A. Abrorov, M. Tukhtamishova, E3S Web of Conferences **486**, 03021 (2024)
10. U. Goldberg, O. Peroomian, S.A. Chakravarthy, Fluids Engineering **3**, 457-462, (1998)
11. R.O. Muminov, A.N. Ruzibaev, N.N. Juraev, J.R. Ravshanov, D.A. Kuziev, Coal Journal **1**, 94-99 (2024). http://dx.doi.org/10.18796/0041-5790-2024-1-94-99