Design adaptation of the automobile and tractor diesel engine for work on mixed vegetable-mineral fuel

Alexei Khokhlov1, Anton Khokhlov1, Dmitry Maryin1, Denis Molochnikov1,*, and Ilnar Gayaziev2

1Ulyanovsk State Agrarian University named after P.A. Stolypin, 432017 Ulyanovsk, Russia
2Kazan State Agrarian University, 420015 Kazan, Republic of Tatarstan, Russia

Abstract. The article is devoted to the solution of the problem associated with the partial substitution of marketable mineral diesel fuel (DF) with mixed vegetable-mineral (MDF) engine fuel. The bio-component of MDF is vegetable oil, for example, Camelina seed oil. A design option of a dual-fuel feeding system has been proposed, the main component of which is a mixing and metering unit for vegetable oil and mineral diesel fuel which allows electric metering units controlled by an electronic control unit (ECU) to respond to signals from diesel load-speed sensors (crankshaft speed, injector rack position (fuel injection pump)) and temperature gauge of camelina oil, to ensure the feed of mixed diesel fuel with components of different content. The use of mixed diesel fuel based on vegetable oil, containing for example 50% of mineral commercial fuel and 50% of camelina oil, makes it possible with a slight decrease in the effective power (not more than 6%) and some increase in the specific effective consumption of mixed fuel (up to 14%) to save 50% of fuel of petroleum origin, as well as to reduce the smoke opacity of exhaust gases by 17–20% and reduce the content of carbon oxide by 35–40% compared with the work of a diesel engine on commercial mineral diesel fuel.

1 Introduction

The energy efficiency improvement of the world economy and development of renewable energy sources is one of the main objectives of the present time. A promising direction to solve this problem is the partial substitution of diesel fuel with mixed vegetable-mineral fuel [1]. Rapeseed oil has become the most common in the Russian Federation and the EU as a biological component of MDF, which is widely used in the food industry. The cultivation of rapeseed requires fertile land, warm temperatures, moisture and careful adherence to the technology of cultivation. All this confines the cultivation of rape seed only to countries with favorable climatic conditions [2, 3]. Therefore, one of the promising biocomponents of MDF is camelina oil (camoil), which is obtained from the seeds of camelina. Camelina seeds can be cultivated both as an annual, and a winter crop. Camelina belongs to frost and drought resistant crops, with low requirements for sunshine, moisture and fertilizers and can be cultivated in various climatic zones [4–6].

2 Materials and methods

Operational studies were conducted on the farm “Vozrozhdenie” (Revival) of the Ulyanovsk region. Two tractors of the MTZ-82 model were used in the study. One tractor was used as a control one – it ran on commercial mineral diesel fuel (100% diesel fuel), another experimental one – ran on mixed camelina oil-mineral fuel 50% camelina oil + 50% diesel fuel (this composition of mixed diesel fuel was selected on the basis of tribological studies of mixed camelina oil-mineral fuel and accelerated testing of pump units of the fuel injection pump for wear of plunger pairs).

The tractors of the same year of manufacturing were under observation, with approximately the same operating time and carrying out the same amount of work at the cattle-breeding farm of an enterprise.

The following items were taken as the assessment indicators of plunger pair wear rates in pump units of the fuel injection pump: geometric dimensions of parts of plunger pairs (ovality and taper of the plunger, diameters of the plunger and sleeve, annular gap between the plunger and sleeve); the weight of parts of plunger pairs (plunger, bushing); volumetric cyclic fuel feeding, hydraulic density of plunger pairs.

Prior to operation studies for the fuel injection pumps, new plunger pairs U16c15 (4UTNM 1111410-01) from one manufactured batch of the Altai fuel equipment plant were selected for the injection pumps to be installed on the tractors under study. Before installation, the parts of each plunger pair were marked, weighed, and their original geometrical dimensions were measured, and plunger pairs were tested for hydraulic density.

Each fuel injection pump with control plunger pairs was adjusted on the bench for adjusting and testing high-pressure fuel pumps in accordance with the running parameters of the diesel engine D-243 (4Ch 11 / 12,5). A
dual-fuel system for running on a mixed camelina oil-mineral fuel was installed on the experimental tractor.

Monitoring the operation of the tractors under study was carried out on the basis of operation time $T_{op}$, running hours (according to the standard counters of running hours), and the fuel consumed $G_{min}$, kg (according to registration-intake fuel consumption cards).

3 The results of the study

A dual-fuel feeding system for diesel engines was developed and manufactured for the design adaptation of an automobile and tractor diesel engine to work on two types of fuel RF patent for invention No. 2582535 [7, 8]. The proposed dual-fuel feeding system ensures the preparation of MDF, depending on the load-speed mode of a diesel engine, directly during tractor operation (Fig. 1).

![Fig. 1. The scheme of the dual fuel feeding system of a diesel engine (name of positions in the text).](https://doi.org/10.1051/bioconf/20201700077)

According to the patent obtained: “The dual-fuel feeding system contains (Fig. 1) a tank of mineral fuel 1, a tank of vegetable oil 2, coarse filters for mineral fuel 3 and vegetable oil 4, a filter for fine cleaning of fuel 5, a primary fuel pump 6, an electric pump for feeding vegetable oil 7 with a check valve 8, a high-pressure fuel pump complete with the centrifugal speed governor 9, nozzles 10, fuel lines 11 and a vegetable oil and mineral diesel fuel metering unit 12, having two inlet ducts 13, 14 and one outlet 15.

In the inlet ducts 13, 14 electric metering units 16, 17 are installed, electrically connected through an electronic control unit 18 with a temperature gauge of vegetable oil 19 and the sensor of the load-speed mode 20, and sent through the electronic control unit 18 into the electrical circuit of the electric metering units 16, 17. The electric metering unit of vegetable oil 17 is opened to the appropriate size, and the electric metering unit of mineral fuel 16 is closed to the same size changing the percentage ratio of mineral fuel and vegetable oil in the mixed fuel.

The electric metering units 16, 17, prevent one type of component from flowing into the other tank. The bypass valves 21, 22, due to the discharge of a part of the mineral fuel and vegetable oil in the suction cavity of the electric pumps 25, 7, maintain a constant pressure in the inlet ducts 13, 14 of the vegetable oil and mineral diesel fuel metering unit 12 ahead of the electric metering units. This increases the accuracy of the percentage of mineral and vegetable components in the mixed fuel, regardless of the difference in their properties.

When one of the electric pumps 25, 7 stops working, the injection valves 23, 24 exclude the rapid pressure drop of the fuel and oil ahead of the electric metering units 16, 17. In addition, with low consumption of mixed fuel and different levels of mineral fuel and vegetable oil in their tanks, the injection valves 23, 24, along with maintaining a constant pressure in the inlet ducts 13, 14 of the mixing and metering unit of vegetable oil and mineral diesel fuel 12, with open electric metering units 16, 17, prevent one type of component from flowing into the other tank.

The check valves 8, 26 are standard units of electric pumps 7 and 25 and are designed to prevent the drainage of vegetable oil and mineral fuel and the formation of air pockets when electric pumps 7 and 25 are turned off. Before stopping the engine in response to a signal from the ECU, the electric metering unit of mineral fuel 16
opens fully and the electric metering unit of vegetable oil 17 is fully closed. After burning up mixed fuel from the mixing unit and filling it with mineral diesel fuel, the engine stops. To ensure high-quality mixing and the required percentage of components of MDF when a diesel engine is running on mixed camelina oil-mineral fuel, a patented design of a vegetable oil and mineral diesel fuel metering unit is proposed (RF patent for invention No. 2582700 [8, 9]).

According to the patent, the mixing and metering unit contains (fig. 2) a cover 1, plugs 2, an electric diesel fuel meter 3, an electric metering unit of vegetable oil 4, a special bolt 5, a pipe union 6, a damper screen 7, metal packing 8, a diesel fuel inlet duct 9, a vegetable oil inlet duct 10, working cavity 11, mixing cavity 12 and outlet duct of mixed diesel fuel 13.

Components to be mixed (mineral fuel and vegetable oil) through the inlet ducts for components 9 and 10, as well as electric metering units 3 and 4, placed on the cover 1, go to the working cavity 11 of the mixing unit. From the working cavity 11 through the duct in a special bolt 5, the components enter the mixing cavity 12.

The mixed components pass through the labyrinths of metal packing 8 constantly changing speed and direction of motion, due to which they are intensively mixed. The prepared mixed fuel from the cavity 12, after passing through the damper screen 7, leaves the mixing unit through the outlet duct of the mixed fuel 13 and enters the U-shaped duct of the fuel injection pump and then to the nozzles of an engine”.

The general view of the mixing and metering unit of vegetable oil and mineral diesel fuel is presented in fig. 3.

The mixing and metering unit of vegetable oil and mineral diesel fuel provides high-quality mixing and exact dispensing of MDF components owing to the application of electric metering units controlled by the electronic control unit (ECU) depending on the loading and high-speed mode of the diesel and temperature of vegetable oil. The small volume of the mixing cavity makes it possible to quickly feed the required composition of MDF when changing the mode of operation of the engine, as well as to reduce the engine operation time before it stops.

The STM 32 microcontroller was taken as the basis when developing the ECU. A program for the ECU microcontroller has been developed, which provides the feed of mixed diesel fuel in accordance with the operation mode of a diesel engine [10, 11]. On the basis of the developed block diagrams, an ECU program of work was made to ensure the operation of electric metering devices that set the required ratio of MDF components depending on the diesel load-speed mode and the temperature of vegetable oil determined by the temperature gauge, which is a thermocouple (Fig. 5).

The mixing unit was calibrated by means of mixing mineral diesel fuel and vegetable (camelina oil) to produce mixed diesel fuel with a different ratio of components. The composition of mixed camelina oil-mineral fuel is set by electric metering units of a mixing unit in response to the ECU signals. The required percentage of camelina oil and mineral diesel fuel in MDF is set by pressing the “fuel composition” buttons of the control of electric metering units (Fig. 4).

Before starting a tractor, the electric power is supplied to the ECU (1 – the button of power on / off). The button 2 – 0 of the fuel composition is turned on while the mixing and metering units ensure the feed of
only mineral diesel fuel (0 is displayed on the digital electronic display 8). By switching on the corresponding fuel composition buttons 3, 4, 5, 6, the mixing and electric metering units provide the feeding of MDF with the following percentage ratio of components: 10 % camelina oil + 90 % DF (1 – fuel composition, 10 is displayed on the digital electronic display) 25 % camelina oil + 75 % DF (2 – fuel composition, 25 is displayed on the digital electronic display) 50 % camelina oil + 50 % DF (3 – fuel composition, 50 is displayed on the digital electronic display) and 75 % camelina oil + 25 % DF (4 – fuel composition 75 is displayed on the digital electronic display). Each fuel composition type, except for zero, has an automatic adjustment of the MDF feed (within the specified fuel composition) by the signals of the diesel load-speed mode sensor (Fig. 5), consisting of an end position sensor for the injector rack and a magnetic induction sensor of the engine crankshaft speed.

Fig. 5. Sensor installation locations: 1 – crankshaft speed sensor; 2 – temperature gauge; 3 – injector rack position.

There is a button in the ECU for fixing the fuel composition (7), when turned on, the maximum amount of camelina oil corresponding to the included fuel composition is fed (the symbol “F – 9” and the number of the corresponding fuel composition type “10” are displayed on the electronic display in Fig. 4). Operational studies were carried out on the third fuel composition type (50 % of camelina oil and 50 % of DF) with the fuel composition fixation button on.

4 Conclusion

The advantages of the developed dual-fuel system and the mixing and metering unit are the versatility of use in various types of automotive diesel engines, multi-fuel, free availability of components and parts, the ability to manufacture in small enterprises, competitiveness, small capital investments and short payback period. The use of diesel fuel based on vegetable oil, containing for example 50 % of mineral commercial fuel and 50 % of camelina oil, makes it possible with a slight decrease in the effective power (not more than 6 %) and some increase in the specific effective consumption of mixed fuel (up to 14 %) to save 50 % of fuel of petroleum origin, as well as to reduce the smoke opacity of exhaust gases by 17–20 % and reduce the content of carbon monoxide by 35–40 % compared with the work of a diesel engine on commercial mineral diesel fuel.

References

2. A.P. Ukhkanov, D.A. Ukhkanov, L.I. Sidorov, The use of radish oil as a biocomponent of mixed diesel fuel (Penza State Agrarian University, Penza, 2018)
3. D.A. Ukhkanov, A.P. Ukhkanov, Diesel fuel supply when working on rapeseed-mineral fuel (Penza State Agrarian University, Penza, 2018)