Study of the use of microwave radiation for heating process fluids in a vehicle

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Abstract. The predominance of a cold climate in the territory of the Russian Federation causes the prevalence of low-temperature conditions during the operation of vehicles, which cause a decrease in the reliability of the engine start-up and an increase in its warm-up time. At the present time, changing the operating modes of the engine fuel system, the introduction of additives to improve the quality of fuel, as well as the use of various types of heaters, one of which is the heating of process fluids with microwave radiation are ways to solve these problems. The use of microwave radiation for heating liquids is considered in the field of railway and pipeline transport, but is not well understood in road transport. Earlier studies have allowed to establish the change in physic and chemical properties in the processing of fuel microwave radiation. The purpose of this article is to study the effect of the use of microwave-treated fuels on the quality of engine start-up and warm-up under low temperature conditions.

1. Introduction
Features of the Russian Federation location, which is to prevalence the cold climate in its territory, leads to the need to study the adaptation of vehicles to low temperature conditions. One of the scientific and practical tasks in this area is to increase the reliability of engine start-up, which is already difficult at temperatures of -10°C and lower [1-3]. This indicator is estimated by starting the engine, which should occur within three attempts with a duration of no more than 15–20 s., when regular fuel is supplied to the engine and energy from batteries charged at 75% is used. At the same time, the interval between attempts, which should be from 1 to 1.15 minutes, is also set. The criteria for the reliability of the engine start-up are the minimum starting temperature, the minimum starting frequency and the conditional average friction pressure. The minimum safe start temperature is the lowest ambient temperature at which the engine can be reliably started. Moreover, the temperature of the components and parts of the engine, coolant and engine oil should not differ from the ambient temperature by more than 1°C.

When the vehicle is operated in a climatic region with low temperatures, the difficulty in starting the engine is due to the poor quality of the air-fuel mixture and an increase in the heat loss of the air-fuel charge. A low ambient temperature causes a decrease in the temperature of the incoming stream and an increase in the intensity of heat removal from the fuel-air charge to the cylinder walls. As a result, a decrease in the temperature and pressure of the working fluid at the end of the compression cycle is observed. At the same time, the deterioration in the quality of the air-fuel mixture, associated with an increase in the viscosity of the fuel (diesel) and an increase in the surface tension, changes the ignition delay period at the end of the compression stroke, reduces the fineness of atomization of the
Currently, to improve the reliability of engine start-up in low-temperature operating conditions, they change engine-operating conditions, introduce various additives into fuel, or use various types of heaters: pre-start, tape, heat-electric heaters, and consider treating process fluids with ultra-high frequency as a modern method (microwave). However, the latter method of heating process fluids used in road transport is not well understood, which determines the purpose of this work that is to study the effect of the use of microwave-treated fuels on the quality of engine start-up and warm-up under low temperature conditions.

2. Methodology

The adaptability of vehicles for operation in low-temperature conditions is one of the most important scientific and practical tasks, both previously performed work and ongoing work. In this area, Reznik L.G., Petrov A.I., Karnaukhov V.N., Manyashin A.V., Chaynikov D.A., Abakumov G.V., Gavaev A.S., Corberan JM, Gonzalez-Gil A., Bjurling F., Palancin R., Torregrosa-Jaime B. were engaged in research [4-9]. Currently, ways to change the operating modes of the fuel supply system, the introduction of additives to improve the quality of fuel used, the introduction of heaters various types have been proposed to improve the reliability of engine start-up in low-temperature operating conditions.

The change in the operating modes of the fuel supply system is performed to ensure the required nature of the flow of the fuel supply, mixing and combustion processes. For this, the fuel cycle is increased 1.5-2.5 times, and the injection advance angle is reduced by 5-10°. As a result, this mode provides an increase in the temperature of the air charge in the cylinder during the injection period. However, it can cause contradictions between the parameters in comparison with the operating mode that is a disadvantage of this method.

The reliability of the engine start-up also depends on the quality of the fuel used, which does not always meet European quality standards. In this case, additives, which in some cases require adding them in large quantities and can only have a narrowly targeted effect, are introduced into the fuel to improve engine start. Evaluation of the quantitative use of additives is one of the research topics that were performed; the development of additives that affect the properties of the fuel when they are added in small quantities (micro, nano) is currently only being carried out [10-13].

According to previous studies, the change in the physicochemical properties of fuels, which can contribute to improving the reliability of engine start-up in low-temperature operating conditions, can be achieved by applying microwave radiation when the fuel is heated, which reduces the density, viscosity and surface tension of the fuel molecules. Reducing the density of the fuel improves the quality of its spraying, but in some cases, it increases the range of the jet to the state of contact with the cold walls of the cylinder, which causes the transition of volumetric mixture formation to volume-film mixing. Reducing the viscosity of the fuel also affects the formation of the fuel torch and leads to a decrease in the diameter of the fuel molecules, reduces the range of the jet and provides a uniform formation of the fuel-air mixture, which is also achieved by reducing the surface tension of the molecules. At the same time, a change in the physicochemical properties of fuels during the processing of microwave radiation can also influence the change in fuel consumption, in particular, if the viscosity of the fuel decreases, then the fuel efficiency increases to 15%. This impact will be traced in assessing the environmental performance of the engine. The scientific works of Bukharkin A.K., Kalina E.V., Kutova A.I. and Makarova O.K. describe that when the fuel is processed by microwave radiation. It is possible to achieve a change in the chemical composition, which will lead to an increase in the energy produced by the combustion of molecules and a decrease in the amount of harmful substances released into the atmosphere with exhaust gases from vehicles [14-19]. Thus, the goal of this work is to study the effect of the use of microwave-treated fuels on the quality of the engine start-up and warm-up in low-temperature conditions.
2.1. Experimental research methodology

The experiment included two main stages: the study of the effect of the microwave-treated fuel use on the engine start-up parameters and the study of the effect of the use of microwave-treated fuel on the engine warm-up parameters. At the first stage of the study, the following actions were performed successively. The diesel engine generator was kept at a specific temperature in accordance with the experiment plan for 10 hours, while the battery of the diesel generator engine was simultaneously under these conditions. Then the upgraded fuel was injected, which was processed by microwave radiation for 180 s. for sample number 2, for 300 s. for sample number 3 and for 480 s. for sample number 4 and kept for 24 hours in a closed container in the open air, after that an attempt was made to start the engine. In this case, according to the works Oberemok V.Z. and Patrahaltseva N.N. an assumption was made about the dependence of the duration of the launch on the upgraded fuel on the ambient air temperature, which would be similar to the change on ordinary fuel.

After the engine was started, the second stage of the experiment was carried out, which included warming up the engine of the diesel generator at idle mode with the enriched working mixture to a temperature of + 40 °C, while during the warm-up period the time for performing this operation was recorded. In this case, the dependence of the engine warm-up time on the upgraded fuel from the ambient air temperature will have a linear appearance, which is similar to the change observed when using conventional fuel. This assumption was made according to the work of Ertman S.A.

The experiment was conducted using a diesel generator SDMO DIESEL 15000TE. The engine temperature was measured using the Checktemp 1 electronic thermometer, which is equipped with a remote sensor and is designed to carry out expert measurements of air temperature, gases, solutions, semi-solids and surfaces, both in laboratory and in field conditions. During the experiment, the thermometer was installed in the gas pipeline at a distance of 15 cm from the intake manifold of the engine.

3. Discussion of the experiment results

In the experiment, along with samples of the upgraded fuel number 2 (microwave processing time is 180s.), number 3 (microwave processing time is 300s.), number 4 (microwave processing time is 480s.) control sample number 1 was also used, which was not subjected to microwave radiation. When the effect of using microwave-treated fuel on the engine start parameters was investigated, the total time required to start the engine was recorded as an output parameter, and the input parameter was the ambient air temperature. The results of the first stage of the experiment were presented graphically in the form of the dependence of the change in the duration of the engine start-up on the ambient temperature, when the control sample number 1 and the upgraded fuel samples 2, 3, 4 are used that is shown in Figure 1.

![Figure 1](image_url)

**Figure 1.** The dependence of the change in the duration of the engine start-up on the ambient temperature, when the control sample number 1 and the upgraded fuel samples of numbers 2, 3, 4 are used.
Reducing the viscosity and density of the fuel as a result of its treatment with microwave radiation leads to a decrease in the time taken to start-up the engine at a temperature of -34°C by 22% or 4s. for sample number 4 of fuel, and, therefore, we can conclude the positive effect of microwave heating on the reliability of engine start-up.

The dependences obtained can be described mathematically, which is represented as formulas (1) for the control sample number 1 and formulas (2, 3, 4), respectively, for samples processed by microwave radiation numbered 2, 3, 4.

\[
T_{start-up1} = 2.72 - 0.51t \\
T_{start-up2} = 2.70 - 0.49t \\
T_{start-up3} = 2.53 - 0.49t \\
T_{start-up4} = 2.34 - 0.48t
\]

where \(T_{start-up}\) is engine start time, s; \(t\) is ambient temperature, °C.

At the second stage of experimental studies, the warm-up time of a diesel generator engine was recorded as an output parameter, while the input parameter, just like at the first stage and was the ambient air temperature. The results of the experiment were presented graphically in the form of the dependence of the change in the duration of a diesel engine generator warming up on the ambient temperature, when the control sample number 1 and the upgraded fuel samples numbered 2,3,4 were used, which is shown in Figure 2.

![Figure 2. The dependence of the change in the duration of the engine warm-up of a diesel generator on the ambient temperature, when the control sample number 1 and the upgraded fuel samples under numbers 2,3,4 are used.](image)

The dependences obtained can be represented mathematically in the form of formulas (5) for the control sample number 1 and formulas (6-8) for samples of fuel treated with microwave radiation numbered 2, 3, 4.

\[
T_{warm-up1} = 2.47t - 0.25 \\
T_{warm-up2} = 2.11t + 0.20 \\
T_{warm-up3} = 2.00t + 0.55 \\
T_{start-up4} = 2.14t - 0.10
\]

where \(T_{warm-up}\) is engine warm-up time, min.; \(t\) is ambient temperature, °C.
4. Conclusion

The adaptability of vehicles for operation in low-temperature conditions is an actual scientific and practical task at the present time, since these conditions lead to a decrease in the reliability of engine start-up and an increase in the time it takes to warm-up. The article presents an analysis of ways to improve the reliability of engine start-up in low-temperature conditions, one of which is heating the fuel with microwave radiation.

In the course of experimental studies, the dependences of changes in the quality indicators of the start-up and engine warming up from the ambient air temperature when using a control sample of conventional fuel and samples of fuel treated with microwave radiation were established. As a result, the efficiency of application of the last samples was revealed, since they allow to reduce the engine start-up time by 22% and the warm-up time by 12%.

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