ULTRASOUND-INDUCED DECREASE IN THE VISCOSITY OF FROZEN DIESEL FUEL

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The possibility of using ultrasound energy to reduce the viscosity of frozen diesel fuel in long 3D-curved channels of small diameter was demonstrated experimentally. The effectiveness of the proposed method is due to the thermal effect of ultrasound and intensification of mixing of the liquid fuel with solid wax particles on the phase boundary under the effect of elastic vibrations. The ultrasound effect does not alter the properties of diesel fuel regulated by GOST 305–82. For this reason, the proposed method can be used in automotive and tractor engineering.

At low temperatures, movement of diesel fuel in the fuel line is impeded and the pressure loss of coarse and fine filters increases as a result of thickening of diesel fuel with precipitation of wax crystals.

Heating the automobile's fuel system is an effective method of restoring fuel feed [1]. However, the electric heaters used for this purpose are installed in isolated sections of the fuel system due to design features and high power consumption: usually in the fuel intake from the fuel tank, coarse and fine filters, fuel-priming pump [2].

With this arrangement of the heating elements, frozen fuel in the 3D-curved fuel line cannot be heated over its entire length, from tank to engine. We have proposed a method for heating the diesel fuel in a long fuel line using acoustic energy [3].

![Graph](image)

Fig. 1. Waveguide temperature \( t \) vs. sonication time \( \tau \) at vibration amplitude \( \xi = 15 \mu m \) (a) and ultrasound vibration amplitude \( \xi \) for sonication time \( \tau = 30 \text{ sec} \) (b) at a distance from the transformer of: 1) \( \lambda/2 \); 2) \( 5\lambda/2 \); 3) \( 9\lambda/2 \).
Fig. 2. Diesel fuel viscosity $v$ vs. ultrasound intensity $I$.

The decrease in the viscosity of petroleum products induced by ultrasound has long been known. In 1959, experiments were described on use of acoustic vibrations for controlling wax sediments in pipelines\cite{4,5}. It was found in\cite{6} that solid wax particles are heated as a result of strong absorption of ultrasound vibrations by crude oil so that the viscosity of the crude decreases.

The viscosity of crude with a high wax and gum content decreases most sharply. However, the imperfection of ultrasound equipment and low efficiency of ultrasound transformers did not allow efficiently using acoustic energy for controlling crude waxing at low temperatures.

Diesel fuel has physical and chemical properties similar to those of crude oil\cite{7}. As a consequence, the problem of thickening of diesel fuel at low temperatures in fuel lines of small diameter can probably be solved with ultrasound. As indicated in\cite{8,9}, high thermal energy is released in propagation of ultrasound in metallic materials as a result of dissipation of energy and internal friction of the metal.

In order to utilize this effect for heating diesel fuel, we installed a flexible, corrosion-resistant steel waveguide 0.6 mm in diameter inside the 3D.curved fuel line. The waveguide was firmly fastened through a holder to a longitudinal-vibration ultrasound piezotransformer connected to a generator for studying the effect of ultrasound on distribution of thermal energy along its length.

The acoustic system was adjusted to a resonant frequency of $26\pm 0.2$ kHz. The ultrasound intensity was established with the amplitude value of the current in the transformer feed circuit. The waveguide temperature was measured with TXK-1199 thermocouples welded by contact welding at points at distance $\lambda/2$ (where $\lambda$ is the wavelength) from the site of attachment of the wave guide to the end of the ultrasound transformer concentrator. The amplitude of the vibrations was measured at the inlet of the waveguide system using an induction transformer placed in the vibration loop at the site of attachment of the waveguide.

According to Fig. 1a, the temperature increased uniformly at the control points with an increase in the sonication time, attaining the maximum values in 15-20 sec. In further sonication, the temperature remained constant, attaining $-60^{\circ}$C on average along the length of the waveguide, and the temperature gradient was $55-85^{\circ}$C. The temperature increased more intensively at points distant from the ultrasound transformer.

The increase in the temperature along the length of the waveguide can be attributed to the fact that low-frequency (in comparison to longitudinal) torsional and flexural vibrations whose amplitude also increases over the length of the waveguide arise in propagation of ultrasound waves in a long flexible waveguide, in addition to longitudinal vibrations, and their amplitude also increases along the length of the waveguide. This results in additional friction of the thermocouple and waveguide and consequently an increase in the emf in the working junction of the thermocouple. This event must be taken into consideration in developing methods of controlling the temperature of long flexible waveguides.

The temperature rose smoothly up to an amplitude of 15 $\mu$m with an increase in the amplitude of the vibrations (see Fig. 1b); at values greater than 20 $\mu$m, the temperature increased sharply, which caused the waveguide to fail.

Since a temperature within the limits of 40-60$^{\circ}$C is required for heating diesel fuel, we can conclude based on the curves obtained that an ultrasound system for heating with amplitude fluctuations of up