EFFECT OF SECONDARY MIXING ON FUEL IGNITION AND COMBUSTION IN A DIESEL ENGINE

A. A. Buzukov and B. P. Timoshenko

The possibility of improving air-fuel mixture ignition by optimal contouring of the wall on which the jet is incident is confirmed. It is also shown that a decrease in the limiting temperature and in the ignition delay leads, in turn, to an increase in fuel-combustion efficiency, which ensures faster stabilization of engine operation after starting. Under diesel-engine nominal rating conditions, secondary mixing no longer has a profound effect on ignition and combustion processes.

Baev et al. [1] showed that a correct choice of the shape of the combustion-chamber wall made it possible to improve air-fuel mixture ignition under diesel-engine starting conditions. This phenomenon is based on the "secondary-mixing effect" [2] which, as shown in experiments, is most favorable when the primary contact between the jet and the wall is glancing and the secondary mixture discharge is accomplished by a sharp turn of the flow in a specially contoured cavity. Thus, for example, Baev et al. showed [1] that placement of a plate shaped according to the above conditions on the path of an air-fuel jet caused a decrease in the limiting self-ignition temperature $T_e$ from 630 to 600 K (diesel fuel DL) and a 30% decrease in the ignition delay $\tau_i$.

The present paper describes the results of an experimental verification of the recommendations of [1, 2] on improving mixture ignition and burning when a fuel is injected into a cavity whose geometry is consistent with the shape of the combustion chamber of an actual diesel engine. In addition, we consider the effect of secondary mixing on the heat-release dynamics with injection into a medium with an elevated temperature that corresponds to the engine nominal rating conditions when self-ignition is already ensured.

The experiments were performed on an unpowered model facility using the procedure described by Baev et al. [1]. In the first test series (variant A), to obtain reference data, we injected the fuel into the ambient space 2 (see Fig. 1) of a dosed cylindrical test section with a diameter of 150 mm and a distance of 65 mm between the end faces ($V_1 = 1470 \text{ cm}^3$). To study the secondary-mixing effect on ignition and combustion processes, a thin-walled box-like construction 5 was mounted in volume 2. It was opened from outside and simulated a sector of a plane combustion chamber in the diesel piston in its radial cross-section coinciding with the axis of one of the injection orifices. In the second test series (variant B), the jet of an air-fuel mixture (6 is its axis) was incident on the flat portion of surface 7 of the "piston bottom." In the third case (variant C), plate 7 was curved in such a way that cavity 9 was formed on its surface. The jet reaches the cavity from which the mixture was partially thrown back into the unconfined space of the "combustion chamber." The cavity shape and size (which are clear from Fig. 1) were chosen such that it overlapped the cross section of the jet which has an initial expansion angle of $\sim 15^\circ$ under the examined conditions [3]. Figure 1 shows a sketch of the combustion chamber of an actual diesel engine (variant D).

Diesel fuel DL was used in the experiments, with a single injection portion of $90 \pm 3 \text{ mg}$. The time dependence of the pressure $p_f$ in the fuel system is shown in Fig. 2a, where $\tau_f$ is the injection duration. All experiments were performed at initial static pressure in the volume $p_V = 0.9 \text{ MPa}$ and in the initial...
temperature range $T_V = 550-900$ K. Note that under the indicated conditions, the air-to-fuel ratio $\alpha$ determined for the entire test volume varied from 3.5 to 6.5, depending on the temperature $T_V$. It is the high value of $\alpha$ that allows one to use the previously tested procedure of calculating the mixture-combustion pressure (see below). However, for the insert volume ($V_2 = 75$ cm$^3$), $\alpha = 0.2-0.35$. These values of $\alpha$ are close to those observed at diesel-engine starting.

Figure 2b shows oscillograms of the bulk-pressure increment $\Delta p_V$ for fuel combustion under different experimental conditions. These oscillograms were used in the experiments to determine the ignition delay $\tau_i$, the time of active heat release $\tau_h$, and the bulk-pressure increment $\Delta p_V$.

The initial bulk pressure was maintained with an accuracy of 3% and the temperature was maintained with an accuracy of 1%. The error in determining the time intervals was estimated at 5%. The main scatter of the results in determining $\tau_i$ is caused by the instability of thermochemical processes occurring in this time range, and it reaches 15% at moderate and high temperatures of the medium and 25% at low temperatures. Therefore, to increase the reliability of the results, the ignition delay $\tau_i$ was measured in 5 K intervals (the potentiometer scale factor), and it was measured at least twice with a temperature variation from above and from below at a constant pressure of the medium. Then, the values of $\tau_i$ were averaged over the range $T = (T_V - 15) \ldots (T_V + 15)$ K. Estimates show that owing to this procedure, the relative error of $\tau_i$ at moderate and high temperatures decreased to 7%, but it was still as high as 12% with approach to the limiting low temperatures at the self-ignition limit. Note that the time interval between fuel injections was not smaller than 40 sec, and this ensured volume purging and guaranteed the equality of the bulk-air temperature and the insert-body temperature.

Figure 3 shows curves of $\tilde{\tau}_i$ versus the temperature of the medium obtained for the above-mentioned three variants of interaction of the air-fuel mixture jet with the combustion-chamber wall. In constructing the curves, we used a commonly used coordinate system [4-6]. It is logarithmic for $\tilde{\tau}_i$ and proportional as $1/T_V$ for temperature. Unlike the generally accepted dimensional value of $\tilde{\tau}_i$, its nondimensional value is defined