AMPLIFICATION OF THE SHOCK WAVE IN A TWO-PHASE MIXTURE OF SUPERHEATED STEAM AND LIQUID TRIETHYLALUMINUM

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Abstract: The possibility of shock wave amplification in a two-phase mixture of superheated steam and liquid triethylaluminum (TEA, $Al(C_2H_5)_3$) is demonstrated experimentally for the first time. Fine synchronization of the moment of TEA injection in the flow of superheated steam with the arrival of an attenuating shock wave is shown to ensure shock wave propagation with a nearly constant speed of 1500–1700 m/s in a tube during a certain time interval. This speed level is consistent with the thermodynamic calculation for the detonation speed in the fuel-lean superheated steam – TEA mixture. Since the pressure profiles recorded in the experiments do not generally correspond to the pressure profiles relevant to detonation waves, it is still premature to assert that the shock-to-detonation transition is obtained.

Keywords: shock wave; superheated steam; liquid triethylaluminum; chemical energy release; shock wave amplification

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Figure Captions

Figure 1 Calculated dependence of the detonation speed D_{CJ} on the fuel-to-steam equivalence ratio Φ for the superheated steam – TEA mixture at $P_0 = 0.1$ MPa and $T_0 = 400$ (*1*) and 500 K (*2*) [7]

Figure 2 Schematic of the experimental setup (*a*) and its main element, the shock tube (*b*). Dimensions are in millimeters

Figure 3 Schematic (*a*) and photograph (*b*) of the fluid atomizer

Figure 4 Photographs of water (*a*) and TS-1 kerosene (*b*) sprays at 3 (*a*) and 4.4 ms (*b*) after the synchronizing signal, respectively

Figure 5 Example of records of pressure sensors P1–P8 (solid curves) and optical sensors F3–F5 (dotted curves) in an experiment without injection of working fluid. The working medium is superheated steam (steam temperature in the low pressure chamber (LPC) is $T_{\mathrm{LPC}} = 445 \pm 5$ K, steam pressure $P_{\mathrm{LPC}} = 0.1$ MPa, and initial pressure in the high pressure chamber (HPC) is $P_{\mathrm{HPC}} = 0.24$ MPa). The countdown of time is from methane–oxygen mixture ignition in the HPC

Figure 6 Measured dependences of the shock wave velocity on the traveled distance in five experiments with the same initial conditions. Working medium is superheated steam ($T_{\mathrm{LPC}} = 415 \pm 5$ K, $P_{\mathrm{LPC}} = 0.1$ MPa, and $P_{\mathrm{HPC}} = 0.34$ MPa)

Figure 7 Measured dependences of the shock wave velocity on the traveled distance in experiments with the same initial conditions. The working medium is superheated steam ($T_{\mathrm{LPC}} = 415 \pm 5$ K, $P_{\mathrm{LPC}} = 0.1$ MPa, and $P_{\mathrm{HPC}} = 0.34$ MPa). The working fluids are TEA, n-dodecane, and water. The time delay of shock wave arrival is $4 \le \tau_S \le 5$ ms. The vertical dashdotted line corresponds to the position of the fluid atomizer in the LPC

Figure 8 Examples of records of pressure sensors P3–P5 (solid curves) and optical sensors F3–F5 (dashed curves) in two experiments with TEA injection under the same initial conditions. The working medium is superheated steam ($T_{\mathrm{LPC}} = 415 \pm 5$ K, $P_{\mathrm{LPC}} = 0.1$ MPa, and $P_{\mathrm{HPC}} = 0.34$ MPa). The time delay of shock wave arrival is $4 \le \tau_S \le 5$ ms

Figure 9 Measured dependences of the shock wave velocity on the traveled distance in experiments with the same initial conditions. The working medium is superheated steam ($T_{\mathrm{LPC}} = 415 \pm 5$ K, $P_{\mathrm{LPC}} = 0.1$ MPa, and $P_{\mathrm{HPC}} = 0.34$ MPa). The working fluids are TEA, TS-1 kerosene, and n-dodecane. The time delay of shock wave arrival is $7 \le \tau_S \le 9$ ms. The vertical dashdotted line corresponds to the position of the fluid atomizer in the LPC

Figure 10 Measured dependences of the shock wave velocity on the traveled distance in experiments with the same initial conditions. The working medium is superheated steam ($T_{\mathrm{LPC}} = 415 \pm 5$ K, $P_{\mathrm{LPC}} = 0.1$ MPa, and $P_{\mathrm{HPC}} = 0.34$ MPa). In four experiments, the working fluid is TEA (filled symbols). The delay time of shock wave arrival is $\tau_S = 10$ ms. In seven experiments (open symbols), a shock wave propagates through superheated steam without injection of working fluid. Plotted for the sake of comparison is a curve for n-dodecane injection at a time delay of shock wave arrival $\tau_S = 9$ ms. The vertical dashdotted line corresponds to the position of the fluid atomizer in the LPC

Figure 11 Measured dependences of the shock wave velocity on the traveled distance in experiments with the same initial conditions. The working medium is superheated steam ($T_{\mathrm{LPC}} = 415 \pm 5$ K, $P_{\mathrm{LPC}} = 0.1$ MPa, and $P_{\mathrm{HPC}} = 0.34$ MPa). The working fluids are TEA or H_2O. The delay times of shock wave arrival are $\tau_S = 22$ and 48 ms. The vertical dashdotted line corresponds to the position of the fluid atomizer in the LPC

Table Caption

Properties of working fluids

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