SHOCK-TO-DETONATION TRANSITION IN A TWO-PHASE MIXTURE OF LIQUID TRIETHYLALUMINUM WITH SUPERHEATED STEAM

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Abstract: The article presents an experimental proof of the possibility of shock-to-detonation transition in a two-phase mixture of liquid triethylaluminum (TEA, $Al(C_2H_5)_3$) — a pyrophoric material reacting with water — and superheated steam in a shock tube. It is shown that fine synchronization of TEA injection into the superheated steam flow with the arrival of a decaying shock wave leads to its amplification with subsequent propagation at an almost constant velocity of 1500–1700 (at a relatively low TEA injection dose) and 2000–2300 m/s (at a relatively high TEA injection dose) in the tube during a certain time interval. These velocity levels are consistent with thermodynamic calculations of the detonation velocity in fuel-lean and near-stoichiometric TEA – superheated steam mixtures, respectively. When a large dose of TEA is introduced, the pressure profiles in the pressure wave resemble the pressure profiles in the detonation waves propagating in gaseous and two-phase fuel–air mixtures.

Keywords: shock wave; superheated steam; liquid triethylaluminum; chemical energy release; shock wave amplification; shock-to-detonation transition

DOI: 10.30826/CE25180107 **EDN:** IKKDXR

Figure Captions

Figure 1 Schematic (*a*) and photograph (*b*) of the shock tube: P1–P8 — pressure sensors; and F3–F5 — optical sensors. Dimensions are in millimeters

Figure 2 Photographs of n-dodecane sprays in open air in one experiment ($V_f = 2.5$ ml) at different times after the start of injection: (*a*) 4.8 ms; (*b*) 7; and (*c*) 10 ms

Figure 3 Photographs of kerosene sprays in open air in one experiment ($V_f = 10$ ml) at different times after the start of injection: (*a*) 10 ms; (*b*) 20; and (*c*) 30 ms

Figure 4 States of superheated steam behind shock waves in experiments at $T_{\mathrm{LPC}} = 415 \pm 5$ K and $P_{\mathrm{LPC}} = 0.1$ MPa

Figure 5 Measured dependences of the shock wave velocity on the traveled distance in experiments with similar initial conditions. The working gas 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 dose of the working fluid is $V_f = 2.5$ ml. The delay in shock wave arrival is $4 \leq \tau_S \leq 5$ ms. The vertical dash-dotted line corresponds to the position of the working fluid atomizer in the low-pressure chamber (LPC)

Figure 6 Examples of records by pressure sensors P3–P5 (solid curves) and optical sensors F3–F5 (dotted curves) in an experiment with TEA injection. The working gas 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 fluid is TEA. The dose of the working fluid is $V_f = 2.5$ ml. The delay in shock wave arrival is $4 \leq \tau_S \leq 5$ ms

Figure 7 Measured dependences of the shock wave velocity on the traveled distance in experiments with similar initial conditions. The working gas 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 fluid is TEA. The working fluid dose is $V_f = 10$ ml. The shock wave arrival delays are $\tau_S = 25.6$ and 30.8 ms. The vertical dash-dotted line corresponds to the position of the working fluid atomizer in the LPC

Figure 8 Examples of records by pressure sensors P1–P8 (black curves) and optical sensors F3–F5 (grey curves) in an experiment with TEA injection. The working gas is superheated steam ($T_{\rm LPC} = 415 \pm 5$ K, $P_{\rm LPC} = 0.1$ MPa, and $P_{\rm HPC} = 0.34$ MPa). The working fluid is TEA. The working fluid dose is $V_f = 10$ ml. The delay in the shock wave arrival is $\tau_S = 30.8$ ms

Figure 9 Calculated (curves [7]) and measured (gray stripes) values of the detonation velocity in mixtures of TEA with superheated steam at $P_0 = 0.1$ MPa, $T_0 = 400$ K, and TEA doses of $V_f = 2.5$ (*a*) and 10 ml (*b*): signs — estimated values of the fuel-to-oxidizer equivalence ratio Φ under the experimental conditions

Acknowledgments

The work was carried out with the financial support of the Ministry of Science and Higher Education of the Russian Federation (agreement No. 075-15-2024-543 dated April 24, 2024).

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Received November 14, 2024
After revision January 22, 2025
Accepted January 27, 2025

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