SPHERICAL DIFFUSION FLAMES: SOOT FORMATION

S. M. Frolov, V. S. Ivanov, F. S. Frolov, and P. A. Vlasov

N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation

Abstract: The joint American–Russian space experiment (SE) Flame Design (Adamant) was carried out on the International Space Station (ISS) in the period from 2019 to 2022. The objective of the joint SE was to study the mechanisms of control of soot formation in a spherical diffusion flame (SDF) formed around a porous sphere (PS) and radiative extinction of the SDF under microgravity conditions. The objects of the study were "normal" and "inverse" SDFs of gaseous ethylene in an oxygen atmosphere with nitrogen addition at room temperature and pressures ranging from 0.5 to 2 atm. A normal flame is a flame formed in an oxidizing atmosphere when fuel is supplied through the PS. An inverse flame is a flame formed in a fuel atmosphere when an oxidizer is introduced through the PS. Presented in the paper are the results of calculations of soot formation in normal and inverse SDFs. The calculations are based on a one-dimensional nonstationary model of diffusion combustion of gases with detailed kinetics of ethylene oxidation supplemented with a macrokinetic mechanism of soot formation. It is shown that soot formation in normal and inverse SDFs is concentrated in the region where the local C/O atomic ratio and local temperature satisfy the conditions $0.32 < \mathrm{C/O} < 0.44$ and $T > 1300{-}1500$ K.

Keywords: space experiment; microgravity; spherical diffusion flame; ethylene; numerical simulation; soot formation; radiative flame extin

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Figure Captions

Figure 1 Photograph of the PS mounted on a gas supply tube (*a*) and the schematic of the computational domain (*b*)

Figure 2 Photographs of the SDFs of ethylene in the Flame Design (Adamant) SE under microgravity conditions on the ISS: (*a*) sooty normal flame; and (*b*) sooty inverse flame [26, 27]

Figure 3 Examples of the time histories of the flame radius: (*a*) normal flame (19142J3); (*b*) inverse flame (22018G2); signs — experiment; and curves — calculation

Figure 4 Examples of the time histories of the flame temperature: (*a*) normal flame (19142J3); (*b*) inverse flame (22018G2); signs — experiment; and curves — calculation

Figure 5 Examples of time histories of the size (*a*) and temperature (*b*) of a quasi-stationary inverse flame (21328D1): signs — experiment; and curves — calculation

Figure 6 Calculated time histories of the temperature of normal (*1*) and inverse (*2*) flames undergoing radiative extinction

Figure 7 Typical calculated structures of normal (19171D4) (*a*) and inverse (220181G2) (*b*) diffusion flames in 20 s after ignition: *1* — $Y_{\mathrm{C_2H_4}}$; *2* — $Y_{\mathrm{O_2}}$; *3* — $Y_{\mathrm{N_2}}$; *4* — $Y_{\mathrm{CO_2}}$; *5* — $Y_{\mathrm{H_2O}}$; *6* — Y_{CO}; *7* — Y_{OH}; and *8* — $Y_{\mathrm{soot}} \cdot 10^4$ (*a*) and $Y_{\mathrm{soot}} \cdot 10^6$ (*b*)

Figure 8 Dynamics of change in the calculated total soot mass $m_{\mathrm{soot},\Sigma}$ vs. time for normal (*1*) and inverse (*2*) flames with different values of Z_{st}: (*a*) $t = 1$ s; (*b*) 5; (*c*) 10; (*d*) 15; (*e*) 20; (*f*) 25; (*g*) 30; (*h*) 35; (*i*) 40; (*j*) 45; (*k*) 50; (*l*) $t = 1$ s

Figure 9 The normalized cumulative rate of soot formation $\dot{m}_{\mathrm{soot},\Sigma}(t)$ in normal (*1*) and inverse (*2*) flames listed in Tables 2 and 3 as a function of the instantaneous local gas temperature at the point of maximum soot mass fraction in the flame structure

Figure 10 Calculated dependences of the cumulative rate of soot formation $\dot{m}_{\mathrm{soot},\Sigma}(t)$ on the C/O atomic ratio and temperature at the point of maximum soot concentration in the flame structure at different times after ignition: (*a*) 2 s; (*b*) 5; (*c*) 10 s; *1* — $\dot{m}_{\mathrm{soot},\Sigma}(t) > 0$; *2* — $\dot{m}_{\mathrm{soot},\Sigma}(t) < 0$

Figure 11 Calculated dependences of temperature on the local C/O atomic ratio (*a*) and temperature $T_{0.53}$ and atomic ratio $(\mathrm{C/O})_{1305}$ on the stoichiometric mixture fraction Z_{st} (*b*) in normal (*1*) and inverse (*2*) flames in 2 s after ignition [20]

Figure 12 Calculated dependences of temperature on the local C/O atomic ratio in normal (black curves) and inverse (grey curves) flames in 2 (*a*), 10 (*b*), 20 (*c*), and 30 s (*d*) after ignition. The regions colored with semitransparent grey fill correspond to the parametric domains of soot formation

Table Captions

Table 1 Macrokinetic mechanism of soot formation

Table 2 Conditions for normal flames

Table 3 Conditions for inverse flames

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Contributors

Frolov Sergey M. (b. 1959) — Doctor of Science in physics and mathematics, head of department, head of laboratory, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; professor, National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), 31 Kashirskoe Sh., Moscow 115409, Russian Federation; smfrol@chph.ras.ru

Ivanov Vladislav S. (b. 1986) — Doctor of Science in physics and mathematics, leading research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; research scientist, Federal Research Center Scientific Research Institute of System Development, Russian Academy of Sciences, 36-1 Nakhimovskii Prosp., Moscow 117218, Russian Federation; ivanov.vls@gmail.com

Frolov Fedor S. (b. 1981) — Candidate of Science in physics and mathematics, senior research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; f.frolov@chph.ru

Vlasov Pavel A. (b. 1955) — Doctor of Science in physics and mathematics, leading research scientist, N. N. Semenov Federal Research Center for Chemical Physics of the Russian Academy of Sciences, 4 Kosygin Str., Moscow 119991, Russian Federation; assistant professor, National Research Nuclear University MEPhI, 31 Kashirskoe Sh., Moscow 115409, Russian Federation; iz@chph.ras.ru