CHEMICAL STRUCTURES OF FILTRATION COMBUSTION WAVES IN A POROUS MEDIA: LEAN AND RICH LIMITS FOR METHANE-AIR MIXTURES

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During the last decade the theory of filtration combustion has been developed for combustion of gaseous mixtures in inert porous media. Although, this consideration was based on single-step global kinetic mechanism for combustion, it explains the general properties of the filtration combustion waves, including direction and velocity of propagation, thermal structure, etc [1] Particular attention was given to so-called superadiabatic effect allowing self-sustained combustion of gaseous mixtures with very low adiabatic combustion temperature [2]

In lean and ultra-lean combustion, the use of detailed chemical kinetics is essential to refine properties of the waves, e.g. to characterize completeness of combustion and pollution formation. Detailed kinetic consideration is of primary importance for understanding the chemical mechanism of superadiabatic waves in the ultra-rich region [3], where the degree of partial oxidation and final-product composition is completely defined by interaction of complex combustion kinetics with heat transfer in the porous body.

In the present work, chemical structures of superadiabatic combustion waves are studied experimentally and numerically for methane/air mixtures with equivalence ratios from 0 2 to 3. The filtration combustion of premixed methane/air mixtures was initiated in the quartz tube (internal diameter 36 mm) filled with the uniform packed bed of alumina pellets. To prevent heat losses and achieve quasi-uniform temperature profiles the tube was covered with high-temperature insulation. Temperature distribution along the axis of the tube was measured with the set of S-type thermocouples Chemical composition of combustion products was monitored by gas chromatograph and in-line CO and NO_x, analyzers.

Numerical calculations are based on consideration of a full set of elementary reactions for methane-air combustion using one-dimensional flame code PREMIX [4]. The first approach includes obtaining spatial distributions for elementary species by integration over given experimental temperature profiles The second one is a steady-state solution for self-sustained combustion waves propagating in porous media. These treatments are based on the assumption of local temperature equilibrium between the gas and porous medium. Product reactant composition, combustion wave velocity and maximum temperature in the wave are compared with experimental data and chemical diagnostics results

The focus of experimental and numerical efforts in the lean region, characterized by complete combustion, was on pollution formation chemistry and influence of the multistep kinetic on the integral parameters of the combustion wave, including velocity and temperature profile The concentration of carbon monoxide is rapidly reducing with a decrease of equivalence ratio. For an equivalence ratio equal to 0 5 the CO concentration is close to 500 ppm and for equivalence ratio equal to 0.2 the measured values are below 10 ppm. Corresponding values for NO_x concentrations are 5 and 1 ppm respectively. Thus, this combustion process could be applied for ultra-low emission burners, direct air heaters, etc It is shown that formation of NO_x, and CO in the combustion wave could be

well describe within one-temperature approximation using the GRI Mechanism 2.11

Starting from equivalence ratios above 1.0 complete combustion could not be achieved due to the low oxygen content in the mixture. As a result partial oxidation products such as H_2, CO and C_2, hydrocarbons appear in the significant concentrations in the exhaust gases. These products became dominant for superadiabatic combustion waves with equivalence ratios above 2, where up to 70% of methane is converted to CO and H_2. Kinetic simulation revealed the complex chemical structure of the superadiabatic combustion waves in the ultra-rich region. It is shown that the combustion wave is composed of an exothermic wave followed by an endothermic one. In the exothermic wave, partial oxidation of methane takes place with formation of hydrogen, carbon monoxide and water. Then the reaction of "steam reforming" occurs in the endothermic region where unburned methane is reformed by water with production of additional hydrogen and carbon monoxide.

References

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