Flame Propagation in Closed Vessels with Inert Porous Medium Wetted with Fuel.

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The scientific interest in the problem of combustion in porous media (PM), which surface is wetted with a liquid film of fuel, and free volume of the pores is filled with gaseous oxidizer and vapors of this fuel, is due to opportunity of realization of various subsonic steady-state combustion regimes. When the concentration of fuel vapors at initial conditions is in the flammability limits in free space without PM the high velocity regime (HVR) [1] is possible (flame speed from 10 to 0.1 m/s). The combustion in PM in an evaporative - diffusion regime (EDR) can occur when the concentration of fuel vapors are below the lean limit. During combustion the fuel evaporates from the surface of PM in this case. Flame propagation velocity in this regime is varied from 3 to 10 cm/c [2].

The purpose of this contribution is experimental examination of the specific features of flame propagation in the PM wetted with fuel in the HVR and EDR regimes in the closed vessel.

Experiment. The experiments were carried out in closed thermostatic vertical tube with square cross section $48 \times 48\,mm$ and length of $1{,}2 \div 2\,m$, filled with PM wetted with n-octane. As the PM were used: two kind of porous material made of aluminum foil (FPM) with thickness of 51 or 77 μ of identical structure, but different apparent density, σ=25.4 and $37.8\,kg/м^3$; open porosity polyurethane foam (PF) with an apparent density 22 $kg/м^3$; a filling from steel polished balls (SB) of 8 mm diameter with apparent density 4700 $kg/м^3$.

Before experiment the thermostatic tube was filled with n-octane. After that, the liquid was discharged and the tube was charged with air up to particular pressure and was sealed. Flame propagation then was initiated by pulsewise heated nichrome wire wetted with n-octane, in 48x48x48 mm cavity located in the top section of the tube. The wetting of the spiral is necessary to initiate the process in the PM under conditions when the fuel vapor concentration is less than the lean concentration limit. In experiments for each PM varied initial temperature of system T_0 (from 18 to 39°C) and initial pressure of the mixture, p_0, (from 0.07 to 0.7 MPa), thus allowed us to change an equilibrium fuel vapor concentration in enough wide limits.

Results and discussion. At a thermodynamic equilibrium to each value of p_0 there corresponds a particular composition of gas phase adequate to partial pressure of fuel vapor at given temperature. The mixture composition was calculated and expressed via the equivalence ratio, ϕ.

Flame propagation in PM wetted with fuel takes place between upper and lower limits on pressure. Their position relative to the limits in free space (without PM) depends on PM heat capacity and initial temperature.

In tested range of p_0 and T_0 change in SB ($2.2 \cdot 10^6 J/(m^3$K) heat capacity) there is only one regime, HVR. In this case both limits on pressure are inside flammability limits in free space.

In high porosity media ($3.4 \cdot 10^4 J/(m^3K)$ heat capacity) the situation is different. Both HVR and EDR can be implemented in the system. For example, for FPM with $\sigma = 37.8$ $kg/м^3$ at $T_0 = 27$°C the HVR exists at $0.08 < p_0 < 0.17$ MPa ($0.76 < \phi < 1.64$) and EDR at $0.17 < p_0 < 0.5$ MPa ($0.25 < \phi < 0.76$). In HVR the dependence of flame velocity on the mixture composition $S(\phi)$ has typical dome- shaped form with characteristic shift of S_{max} toward rich mixtures [1]. The EDR is implemented not only outside HVR limit ($\phi < 0.76$), but also outside lean flammability limit in free space ($\phi < 0.6$). The transition from one regime to another with variation of p_0 occurs continuously in this instance. In this case one limit on pressure is at rich side (inside flammability limits in free space) and restricts HVR but another is at lean side (outside flammability limit in free space) and restricts EDR.

Under certain conditions in high porosity medium there can be only EDR. For example, in the FPM with $\sigma = 25.4\ kg/м^3$ at T_0=20 °C there is only EDR with velocities from 3 to 5 cm/s. Both pressure limits are in lean mixtures outside flammability limits in free space.

At decreasing of initial temperature T_0 the pressure range of flame propagation is narrowed down and there is T^* such, that at $T_0 < T^*$ it is impossible to initiate flame propagation both in HVR and in EDR.

It was examined the influence of PM heat capacity (for two kind of FPM mentioned above) on flammability limits. It turned out that inappreciable change of summary heat capacity of the system ($\sim$ 10%) was enough to fix change of flammability limit in EDR. The flammability limits area diminishes with magnification of a heat capacity. If to magnify heat capacity per unit volume by two order of value (SB), the EDR area disappears.

As far as value of pressure rise in closed system with PM is concerned, it is known [3] that in the general case the maximal pressure depends on the relation between the vessel size, L, and combustion zone size, δ. However in large vessels when $\delta \ll L$ the maximal pressure close to end pressure determining by equilibrium conditions in the gas- PM system.

We have experimentally measured the combustion zone size and equilibrium temperature after [3]. It turns out that the zone size in EDR is the same order of value (3 cm) as in the dry PM. Therefore the pressure rise in the experiments is determined by equilibrium temperature of the system. These temperatures turned out lower than in dry system because of increase in heat capacity of the system due to liquid phase.

During combustion only some part of fuel burns another stays on PM surface and some part are in combustion products as vapor. The equilibrium temperature is determined by heat balance with taking into account evaporation of a part of liquid fuel during combustion. This evaporation, on the one hand, takes heat that promotes decrease of pressure and temperature. On the other hand, evaporation of liquid increases number of moles in a gas phase, which gives in pressure rise. Analysis has shown, that for our experimental conditions the value of pressure rise due to increase in moles number at evaporation of liquid, on the order of value exceeds pressure drop owing to smaller heating of the system. Our experiments show that the end pressure in fuel wetted PM is higher than in the same PM but without liquid phase.

In concluding we remark three main results. Firstly, in wetted with fuel PM there are two different combustion regimes HVR and EDR. Secondly, flammability limits of EDR are high sensitive to PM heat capacity variation. Thirdly, the pressure rise in wetted PM is higher than in dry PM.

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