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Numerical Simulation of Filtration Gas Combustion: Front Propagation Velocity

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Abstract : The phenomenon of filtration gas combustion (FGC) had been discovered experimentally at the beginning of 80's of the previous century. It has a number of important applications in such areas as chemical technologies, fire-explosion safety, energy-saving technologies, oil production. From the physical point of view, FGC may be defined as the propagation of region of gaseous exothermic reaction in chemically inert porous medium, as the gaseous reactants seep into the region of chemical transformation. The movement of the combustion front has different modes, and this investigation is focused on the low-velocity regime. The main characteristic of the process is the velocity of the combustion front propagation. Computation of this characteristic encounters substantial difficulties because of the strong heterogeneity of the process. The mathematical model of FGC is formed by the energy conservation laws for the temperature of the porous medium and the temperature of gas and the mass conservation law for the relative concentration of the reacting component of the gas mixture. In this case the homogenization of the model is performed with the use of the two-temperature approach when at each point of the continuous medium we specify the solid and gas phases with a Newtonian heat exchange between them. The construction of a computational scheme is based on the principles of mixed finite element method with the usage of a regular mesh. The approximation in time is performed by an explicit–implicit difference scheme. Special attention was given to determination of the combustion front propagation velocity. Straight computation of the velocity as grid derivative leads to extremely unstable algorithm. It is worth to note that the term 'front propagation velocity' makes sense for settled motion when some analytical formulae linking velocity and equilibrium temperature are correct. The numerical implementation of one of such formulae leading to the stable computation of instantaneous front velocity has been proposed. The algorithm obtained has been applied in subsequent numerical investigation of the FGC process. This way the dependence of the main characteristics of the process on various physical parameters has been studied. In particular, the influence of the combustible gas mixture consumption on the front propagation velocity has been investigated. It also has been reaffirmed numerically that there is an interval of critical values of the interfacial heat transfer coefficient at which a sort of a breakdown occurs from a slow combustion front propagation to a rapid one. Approximate boundaries of such an interval have been calculated for some specific parameters. All the results obtained are in full agreement with both experimental and theoretical data, confirming the adequacy of the model and the algorithm constructed. The presence of stable techniques to calculate the instantaneous velocity of the combustion wave allows considering the semi-Lagrangian approach to the solution of the problem.

Keywords : filtration gas combustion, low-velocity regime, mixed finite element method, numerical simulation
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