ON SOME FEATURES OF GAS FLOWS THROUGH POROUS OBJECTS WITH HEAT SOURCES

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Summary For the investigation of 1D and 2D (plane and axisymmetric) unsteady regimes of the gas flow through the porous objects with heat sources the mathematical model and the original numerical method have been developed, which is based on a combination of explicit and implicit finite-difference schemes. Two-dimensional unsteady processes in the smoothly converging and stepwise converging objects and the porous objects with the nonuniform distribution of heat sources have been considered.

INTRODUCTION

A lot of catastrophes results in appearance of heat sources. Some heat sources often arise in porous media, as the obstructions of the ruinous buildings, geological material, etc. Taking into account the high danger of such objects it is necessary to be able to liquidate such heat sources. The example of the exploded unit of the Chernobyl nuclear power plant showed that the gas (air) cooling of such heat sources may be the only available counteraction method of the disaster [1]. This work is devoted to the mathematical modelling of gas flow through the porous objects with heat sources when pressure difference at the inlet and the outlet from the object is known. Developed mathematical model and numerical method can be also used for investigating the processes in different technological objects such as perspective cooling devices for electronics, perspective pebble bed modular nuclear reactors and so on.

MATHEMATICAL MODEL AND NUMERICAL METHOD

The porous heat-evolutional object is supposed to be homogeneous and motionless; it is bounded of impermeable non-heat-conducting side walls and is opened at the top and at the bottom. The heat-evolutional process in solid phase results from the process of “chemical” reaction. The cold gas is conveyed under pressure into the inlet of the porous object (at the bottom); the gas flows up through porous medium, is heated as a result of the heat exchange, and flows out into a free space with given pressure (at the top). For example, such physical model describes a destroyed unit of a nuclear power plant [1]. Mathematical model is constructed on the model of two interactive interpenetrative continua [2] and includes the continuity equations, the momentum conservation equations, the energy equations and the equations of state for each phase (solid and gas). The intensity of the interphase heat exchange is assumed to be proportional to the difference of the phase temperatures at the considered point of the medium; the heat evolution is directly proportional to the concentrations of the reagent whose rate of decay is directly proportional to the concentration itself. In the energy equations for gas and solid phases not only interphase heat exchange, thermal conductivity and heat evolution in solid phase but also the power of internal forces in gas are taken into account. For description of gas dynamics, the equation of momentum conservation for porous media is used, which is more correct than the classical Darcy’s equation and can be used in a greater range of Reynolds numbers. The temperature dependence of gas viscosity is taken into account because it was shown in [3] that temperature dependence of gas viscosity changes the solution essentially not only quantitatively, but qualitatively also. Assuming the volume and weight of the condensed phase changes insignificantly, these changes can be neglected. According to this, as the solid medium is immovable and homogeneous, the equations of continuity and motion for it degenerate. The closure equations of the model are the continuity equation for gas and the perfect gas equation of state.

The inlet gas temperature, inlet gas pressure and outlet gas pressure are supposed to be known. Also the heat exchange conditions are known at the inlet and at the outlet of the porous object and at the bounding impermeable walls. The distinctive feature of the concerned model is that the flow rate and the gas velocity at the porous object inlet and outlet are unknown and must be calculated by solving.

The boundary conditions in the problems of given class differ substantially from the conditions in classical problems of the mechanics of multi-component media, and this fact impedes here the application of widely known finite-difference schemes. Therefore, an original numerical method have been developed, which is based on a combination of explicit and implicit finite-difference schemes, for the investigation of 1D and 2D (plane and axisymmetric) unsteady regimes of the porous object cooling [4, 5]. The energy equations and momentum conservation equations are transformed into the explicit finite difference equations. The gas temperature, the solid phase temperature and the gas filtration velocities are determined from these equations. The continuity equation is transformed into the implicit finite difference equation. From this equation taking into account the perfect gas equation of state the gas pressure is determined using Thomas algorithm [6]. The gas density is determined from the perfect gas equation of state. Damping fourth-order terms [6] must be added in the finite difference equations of continuity and momentum conservation. The advantage of the proposed numerical method is freedom from the need to solve difficult systems of algebraic equations, so that, using geometrical decomposition, the algorithm can be easily and efficiently parallelized.

GAS FLOWS THROUGH SOME POROUS HEAT-EVOLUTIONAL OBJECTS

The phenomenon of the unlimited heating of the object on the undercritical boundary conditions, on which the stable steady-state regime exists, is revealed. This phenomenon may arise from the fast drop and subsequent increase of the gas pressure at the inlet of the porous heat-evolutional object. It is shown that when the fast drop of the gas pressure at the inlet of the object to the value below the critical point and subsequent increase of the gas pressure at the inlet of the object to the value above the critical point take place, as the new steady-state regime of cooling may be established, as the unlimited heating of the object may takes place. So it is revealed that the unlimited heating of the porous heat-evolutional object may appear when the boundary conditions are undercritical. It will result in the overheating and melting of the porous object under the conditions, satisfied the steady-state criterion.
Two-dimensional (plane and axisymmetric) unsteady problems of the cooling of the smoothly converging and stepwise converging objects have been considered. To this end, 2D unsteady problem of initiating the forced filtration at the moment of the start of heat-evolution in the solid phase is solved for porous objects of a smoothly converging and stepwise converging shape. The new steady-state regimes of cooling or the unlimited heating of the heat-evolutional objects, which leads to melting of the solid phase, are shown to be established in these cases depending on the initial and boundary conditions and the problem parameters. The cooling process is shown to be affected strongly by the shape of the porous heat-evolutional object. Narrowing of the porous object in its upper part makes worse total cooling of the object. Zones with the slow gas flows result in intensive local heating. It may disturb stability even if the heat evolution in the solid phase is a little. The comparison of the axisymmetric and plane gas flows has been made [5] and it is revealed that the essential distinction in the cooling process of the axisymmetric and plane objects is possible – only the modification of the object configuration from plane to axisymmetric may lead to breaking the steady-state cooling regime, to overheating and destruction of the object.
The plane and axisymmetric gas flows through the porous objects with the nonuniform distribution of heat sources have been considered. To this end, 2D unsteady problem of initiating the forced filtration at the moment of the start of heat-evolution in the solid phase is solved for objects with different parameters of the heat-evolutional zone. It is shown that the porous object heating is affected not only by the height of the heat-evolutional zone and the heat-evolution intensity therein but also by the distance of the heat-evolutional zone from the object inlet as well as by the width of the heat-evolutional zone. The phenomenon of a reduction of the porous object heating with increasing distance of the heat-evolutional zone from the porous object inlet is revealed both in plane case as in axisymmetric case. An ambiguous dependence of the porous object heating on the width of the heat-evolutional zone is identified: at a growth of the heat-evolutional zone width, the heating of the object may both increase and decrease depending on the distance of the heat-evolutional zone from the object inlet.

CONCLUSIONS

For the investigation of two-dimensional (plane and axisymmetric) unsteady regimes of the gas flow through the porous objects with heat sources the original numerical method have been developed, which is based on a combination of explicit and implicit finite-difference schemes. Two-dimensional unsteady problems of the cooling of the smoothly converging and stepwise converging objects have been considered; the influence of the heat-evolutional object geometry on the cooling process has been analyzed. Also the gas flow through the porous objects with the nonuniform distribution of heat sources has been considered; the influence of different parameters of the heat-evolutional zone on the cooling process has been analyzed.

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