A STUDY OF CONVECTIVE HEAT FLUXES FOR MATERIALS INTERACTED WITH DUST-LOADED FLOWS BY INVERSE PROBLEMS METHOD

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Studies of heat and mass transfer in heterogeneous media (in partial in dust-loaded flows) are intensely developing at present time. This is related to important practical applications of results of these studies in aerospace industry, nuclear energetic, chemical technology, and a number of other fields. One of the significant cases of materials interaction with the environment proves the availability of solid particles in the incoming flow (heterogeneous two-phase flow). In this case we observe a heat flux gain delivered to the surface

$$q_0 = -\left(\frac{\alpha}{C_P}\right)_0 \left(I_l - I_w\right) - \Delta q_0 , \qquad (1)$$

where Δq_0 characterizes the additional of fine-dispersed phase on the surface. In the general case:

$$\Delta q_0 = \sum_{\alpha} \Delta q_0^{\alpha} . \qquad (2)$$

Each component (2) is connected with some separate factor of thermal interaction (solid particles energy transfer to the body at the expense of incomplete elasticity of collisions, surface roughness enhancement, additional flow turbulization by driven out particles etc.). The commonly accepted is the form of writing of only that component which is related with energy transfer:

$$\Delta q_0^1 = f_0 \frac{G_p V_p^2}{2} , \qquad (3)$$

where G_p is mass rate of solid particles; V_p is velocity of solid particles; f_0 is accommodation coefficient ($0 \le f_0 \le 1$).

An algorithm and results of numerical-experimental study of heat transfer of a specimen streamlined by a high-enthalpy dust-loaded flow are presented. The unknown parameters of heat balance equations on the external surface of specimen and corresponded heat fluxes are determined by inverse problems of heat transfer solving by iterative regularization method. Also the algorithm is proposed and results are analyzed of optimal experiment design (search of optimal points of thermosensors installation) for determining of heat fluxes in the case of moving external boundary of specimen

The present paper outlines a method of processing and analyzing experimental data based on the methodology of the solution of inverse heat transfer problems. It permits the investigation of heat transfer in surface erosion and the creation of an approximate mathematical model taking into account the influence of various factors of dust-loaded flows. The solution of the problems is constructed as follows. First, some family of approximate mathematical models is considered; each model takes account of a different number of factors determining the heat transfer with dust-loaded flows and includes the corresponding unknown parameters. Then, using the results of measuring the parameters of the incoming flows and the temperature in some internal points of specimen, the inverse problem on the determining of unknown parameters is solved for each mathematical model of the interaction of materials with dust-loaded flows. As a result, the mathematical model, which gives the minimal, least-square deviation of the theoretical from the experimental measured temperatures is chosen.

The use of inverse problems method calls for thorough analysis of the computational properties of algorithm (stability, uniqueness, convergence, etc.). All these are critically affected by the so-called "scheme of temperature measurement" or point of the thermosensors installation. The result of computational simulations indicates that the accuracy of solution of inverse problem may be improved considerably by the proper choice of the optimal scheme of location of temperature sensors. The problem of optimal design of corresponded experiments in case of moving external boundaries of specimen is considered.

The transient experiments are conducted on gas-dynamic stand specially designed for modeling dust-loaded flows. Solid powder particles of diameter .01 mm are injected in the gas flow through an atomizer. The uniformity of the particle distribution over the flow cross-section and the rate of the particles are ensured by a special supply system and maintained experimentally. A supersonic two-phase flow is formed in a nozzle, the shape of which ensures the most effective acceleration of the particles. The structure of the specimen models permits the use of a one-dimensional mathematical model of thermal conduction. The heat transfer in the calorimeter is covered by a following equations

$$C(T)\frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda(T)\frac{\partial T}{\partial x}\right), \quad x \in (X_0, X_1), \quad \tau \in (\tau_{\min}, \tau_{\max}] \tag{4}$$

$$T(x, \tau_{\min}) = T_0(x), \quad x \in [X_0, X_1], \tag{5}$$

$$-\beta_1 \lambda(T)\frac{\partial T(X_0,\tau)}{\partial x} + \alpha_1 T(X_0,\tau) = q_1(\tau), \quad \tau \in (\tau_{\min}, \tau_{\max}] \tag{6}$$

$$-\beta_2 \lambda(T)\frac{\partial T(X_1,\tau)}{\partial x} + \alpha_2 T(X_1,\tau) = -\left(\frac{\alpha}{C_P}\right)_0 (I_l - I_w) - \Delta q_0, \quad \tau \in (\tau_{\min}, \tau_{\max}] \tag{7}$$

The results of temperature measurements inside the specimen are assigned as necessary additional information to solve an inverse problem

$$T^{\exp}(x_m,\tau)=f_m(\tau),\quad \mathrm{m}=\overline{1,\mathrm{M}} \tag{8}$$

Writing down a least-square error of the design and experimental temperature values in points of thermocouples positioning

$$J(u)=\sum_{m=1}^{M}\int_{\tau_{\min}}^{\tau_{\max}}\left(T\ \left(x_m,\tau\right)-f_m(\tau)\right)^2 d\tau \tag{9}$$

where $T(x,\tau)$ is determined from a solution of the boundary-value problem (4)-(7). It is assumed here that the conditions of uniqueness of the inverse problem solving are satisfied.

Proceeding from the principle of iterative regularization, the estimated parameters can be determined through minimization of functional (9) by gradient methods of the first order prior to a fulfillment of the condition

$$J(\bar{p})\le\delta_f$$

(9)

where $\delta_f=\sum_{m=1}^{M}\int_{\tau_{\min}}^{\tau_{\max}}\sigma_m(\tau)\,d\tau$ is integral error of temperature measurements $f_m(\tau)$, m=1,M, and σ_m - measurement variance.

To construct an iterative algorithm of the inverse problem solving a conjugate gradient method of minimization was used.