

# THE NUMERICAL MODELING OF THE THERMAL CONDITION OF DEVICES WITH COMPLEX STRUCTURE.

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There are some difficulties at calculations of thermal condition of devices and the equipment with complex structure. The complex structure signifies, that devices and the equipment consist of a structure parts with the various physical properties, the closed and open-ended cavities where occurs convection and, also, internal and external sources of thermal emissions.

The basic complexities at calculations of thermal condition of similar devices consist in multidimensionality of thermal streams and presence of heat transfer between solid bodies and mobile environments. The value of the last is defined, also, and intensity of air convection in points, adjoining to a surface. It is impossible to define intensity of convection in usual thermal models, for example mass-averaged. Therefore the theoretical calculations, made on the basis of these models have approximate character. And the basic method of a designing at creation of similar devices is the carrying out of experiment and the subsequent operational development of a design.

The carrying out of experiments, as a rule, is expensive and is labor-consuming. Increase of accuracy of theoretical calculations would allow to lower volume of experimental work. That would reduce expenses of time and means for creation of similar devices with complex structure.

To take into account multidimensionality of thermal streams and the convection component of heat transfer and by that to raise accuracy of theoretical calculations it is possible within the framework of mathematical model on the basis of system of the partial differential equations, including equations Navier-Stokes and the equation of energy, and also the thermal equation of a condition.

## Mathematical model.

The basic equations for convective heat transfer in Bussinesk approximation can be written down in the following kind:  
equations Navier-Stokes

$$\nabla \mathbf{V} = 0$$

$$\frac{\partial \mathbf{V}}{\partial t} + \nabla(\mathbf{V} \otimes \mathbf{V}) = \frac{1}{\rho} \nabla(\mu \nabla \mathbf{V}) - \frac{\nabla P}{\rho} + \mathbf{G}, \quad (1)$$

the equation of energy

$$\frac{\partial h}{\partial t} + \nabla(\mathbf{V}h) = \frac{1}{\rho} \nabla \left( \frac{\lambda}{C_p} \nabla h \right) + S, \quad (2)$$

the equations of concentration of reacting substances

$$\frac{\partial C_i}{\partial t} + \nabla(\mathbf{V}C_i) = \nabla(D_i \nabla C_i) + M_i, \quad (3)$$

and also the thermal equation of a condition

$$\rho = \frac{P_0}{RT},$$

where,  $\mathbf{V}$  – a vector of speed;

$h$  – enthalpy;

$\rho$  – density;

$P$  – pressure;

$\mathbf{G}$  – gravities;

$S$  – sources of thermal emissions;

$\mu$  – dynamic viscosity;

$C_p$  – a specific thermal capacity;

$\lambda$  – coefficient of heat conductivity;

$C_i$  – a mass fraction of quantity  $i$ ;

$D_i$  – diffusion coefficient for quantity  $i$ ;

$M_i$  – sources of mass emissions of quantity  $i$ ;

$P_0$  – static pressure, characteristic for the given problem.

For definition of intensity of radiant heat exchange the following model of radiation has been accepted. Internal and external surfaces of the device are radiating surfaces. Their temperature is supposed a constant by the current moment time, equal an averaged temperature. Absorption of radiation in associates of surface environments does not occur.

For the system consisting from  $n$  of surfaces of radiation, the density of a stream of resulting radiation is defined by dependence

$$q_{rezi} = \sum_{k=1}^n (E_{effi} - E_{effk}) \cdot \varphi_{ik} \quad (4)$$

Where,  $\varphi_{ik}$  – angular coefficient of radiation  $i$  surface on  $k$  surface.

The density of a stream of effective radiation develops of own radiation of a surface and the reflected radiation of other surfaces

$$E_{effi} = E_i + (1 - \varepsilon_i) \sum_{k=1}^n E_{effk} \varphi_{ik} \quad (5)$$

Where,  $E_i = 5,67 \cdot \varepsilon_i \left( \frac{T_i}{100} \right)^4$  – own radiation  $i$

surface;

$\varepsilon_i$  – a degree of blackness  $i$  surface.

Having written down the equation (5) for all surfaces we shall receive system from  $n$  the algebraic equations for definition  $n$  effective streams of radiation. On their values, on the equation (4), find density of a stream of resulting radiation for all surfaces.

### Method of the solution.

The problem is solved by numerical methods in the computational area, which include areas, occupied with a solid bodies and a fluid.

The flow domain is broken into control volumes. For each of which discrete analogues of the initial differential equations (1-3) are made.

In whole flow domain the problem is solved as a problem convection heat exchange. However owing to equality to zero of speeds in the area, occupied with a solid body, here the pure problem of heat conductivity will be solved. As a result of the solution of such problem we shall receive distribution of speed in a fluid and distributions of temperature in a solid body and a fluid which will be automatically coordinated on border of the unit of a solid body from a fluid.

Calculation of non-stationary process is realized as follows: for the initial moment of time values of sizes of all determined parameters - components of speed and temperature are set. Making speeds are accepted equal to zero, and temperature for all central points to equal reference temperature. Further for each step on time the hydrodynamic problem originally is solved. The received values of speeds are used for the decision of the equations of conservation of energy and a finding of values of temperature.

Physical properties of materials which values depend on temperature can will be specified on each step on time according to change of temperature for all control volumes.

### Application.

As example of the device with complex structure is thermostat (fig. 1).

The thermostats task is to maintain the certain temperature in the measuring hole, located in the leveling block 2 (fig. 1). The heater 3 is switched on and switched off depending on indications of the gauge of temperature 4. The temperature of the external case 11, 12, 13 should not be high. Therefore heating 1 and leveling blocks are surrounded with isolation 5,6, including protective 7 and radiating 8 screens. Screens and the external case are cooled also due to natural convection of air. Thermostat is designed for work in two modes 300°C and 600°C.

Calculations were carried out under the scheme, submitted on (fig. 2). Besides thermostat in flow domain are included the basis, on which is located thermostat, and a surrounding air. On flow domain the uniform grid 440x110 units is put. The step between central points makes 1mm on both axes. Dimensions of thermostat itself make 370x150 mm. The problem is solved as axis-symmetric.

By the beginning of calculation making speeds are accepted equal to zero, and temperature for all central points to equal reference temperature 20°C. Process heating of thermostat occurs as follows. Heating and leveling blocks fast get warm. In the top part the leveling block directly adjoins to air. Air is heated up and in the top part of the central block the whirlwind is formed. This whirlwind increases in sizes in process of continuation of heating. All thermostats central part in due course gets warm. There begins convection of air. Outside thermostat air goes from below upwards, being heated up from an external wall.

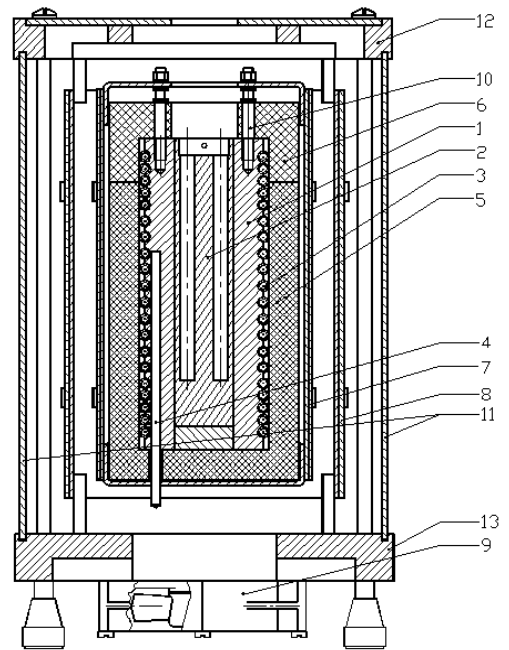


Fig. 1. Thermostat. A general view.

1 - the heating block; 2 - the leveling block; 3 - a heater; 4 - the gauge; 5 - isolation; 6 - isolation; 7 - the protective screen; 8 - the radiating screen; 9 - the fan; 10 - fixture; 11 - lateral walls; 12 - the top wall; 13 - the bottom wall.

Distribution of values of temperature and stream function at achievement of thermostat an operating condition 300°C and 600°C are submitted on fig. 3, 4.

Parameter of quality of thermostats work is distribution of temperature lengthways the measuring hole. On fig.5,6 are resulted the calculated and experimental values of temperature lengthways the measuring hole of thermostat, on fig.5 for an operating condition 300°C, on fig.6, for an operating condition 600°C.

### The conclusion.

The submitted technique allows to take into account multidimensionality of thermal streams and the influence natural and compelled convection on a thermal mode of devices and the equipment with complex structure, and also to study laws of process of heating. The calculated values of temperature correspond to the data of experiments.

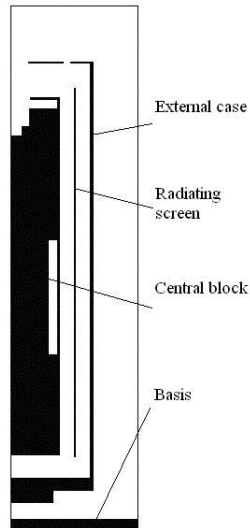


Fig. 2. Flow domain.

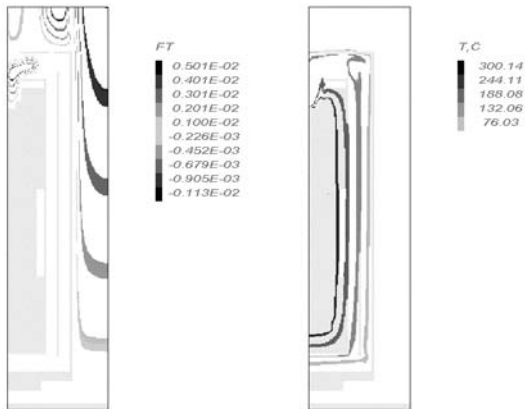


Fig. 3. Distribution of values of temperature and stream function at an operating condition 300°C.

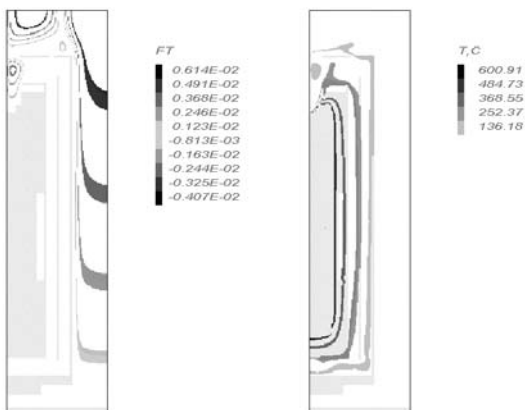


Fig. 4. Distribution of values of temperature and stream function at an operating condition 600°C.

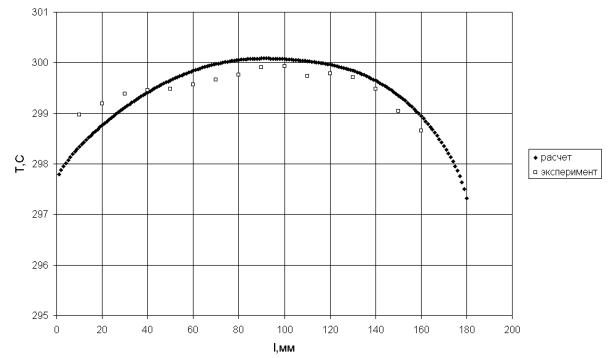


Fig. 5. Distribution of values of temperature in the measuring hole at an operating condition 300°C.

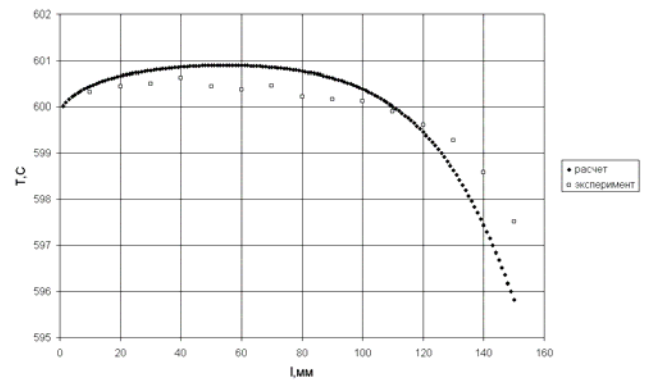


Fig. 6. Distribution of values of temperature in the measuring hole at an operating condition 600°C.