Heat and mass transfer in different multiphase environments

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Abstract. Annotation text: the paper presents a method for studying the process of heat and mass transfer, dividing it into three elementary types: thermal conductivity, convection and thermal radiation, as well as examples of these types occurring in reality in multiphase media.

1. Theoretical basis of technical physics and energy.

One of the most important disciplines that form the theoretical basis of technical physics and energy, is thermodynamics and heat transfer.

Thermodynamics is the science of the laws governing the transformation of energy from one type to another, the most general macroscopic properties of matter. She studies various both physical and chemical phenomena caused by energy transformations. The use of laws of thermodynamics allows us to analyze the properties of substances, to predict their behavior in various conditions. Thermodynamics makes it possible to explore various processes from simple in homogeneous media to complex with physical and chemical transformations, biological, etc.

Thermodynamics is based on two experimentally established laws (principles).

The first law (the beginning) is essentially the law of transformation and conservation of energy in relation to the processes studied in thermodynamics; «The process of the emergence or disappearance of energy is impossible».

The second law (the beginning) – determines the direction of the flow of real (non-equilibrium) processes; «The process is impossible, which has the only result of the transformation of heat into work».

Heat transfer (heat and mass transfer) is the study of spontaneous irreversible processes of heat distribution (transfer) in space with a non-uniform temperature field.

Heat is transferred by the three simplest fundamentally different ways:
- thermal conductivity
- convection
- thermal radiation.

These methods correspond to such methods of heat transfer, such as:
- molecular
- convective
- radiation.
The fundamentals of the theory of heat were laid by Academician M.V. Lomonosov; he created the mechanical theory of heat and first established the laws of conservation of matter and energy. Studies have shown that heat transfer is a complex process. Therefore, when studying, this process is conditionally divided into simple phenomena. There are three of the above types of heat transfer (thermal conductivity, convection and thermal radiation) [1].

The phenomenon of heat conduction is that energy is exchanged by direct contact between body particles, by elastic waves, by diffusion of atoms or molecules, and by diffusion of free electrons.

The phenomenon of convection occurs only in liquids and gases. It consists in the fact that energy transfer is carried out by moving particles. At the same time, the state and nature of fluid movement are very important. The phenomenon of convection is always accompanied by the phenomenon of heat conduction [2].

The phenomenon of thermal radiation is the process of energy propagation in the form of electromagnetic waves. By nature, this phenomenon is different from heat conduction and convection and is accompanied by a double transformation of energy – thermal energy into radiant energy and, conversely, radiant energy into thermal energy.

In reality, these above listed elementary types of heat exchange are not isolated and are rarely found in their pure form. In most cases, one type of heat transfer is accompanied by another [3].

For example, in a steam boiler, in the process of heat transfer from the flue gases to the external surface of the heating tubes, all three types of heat exchange are simultaneously involved - heat conduction, convection and heat radiation. And from the external surface of the heating pipes to the internal through a layer of soot, a metal wall and a layer of scale, heat is transferred only by heat conduction. And finally, heat is transferred from the inner surface of the heating pipes to water only by convection [4].

Consequently, in some parts of the path of heat transmission, elementary types of heat exchange are in the most diverse combination and it is very difficult to separate them.

In practical calculations, such complex processes are sometimes advisable to consider as one. So, for example, the transfer of heat from a hot liquid to a cold one through a wall separating them is called a heat transfer process.

The combination of all three types of heat transfer is called complex heat transfer. However, the study of the laws of complex heat transfer is a rather difficult task. Therefore, each of the three types of heat exchange is studied separately, after which it becomes possible to carry out calculations related to complex heat transfer:
- temperature gradient \( \text{grad } t = \frac{dt}{dn} \);
- thermal conductivity \( \lambda \);
- the amount of heat \( Q \), etc.

Temperature measurement is performed using mercury thermometers, thermocouples and bolometers (resistance thermometers). The use of one or another method of measurement is determined by the conditions of the experiment; in most cases, thermocouples are used, of which the most popular are copper-constantan, iron-constantan and nickel-nichrome with a wire diameter of 0.1 to 0.5 mm. It is best to make thermocouples and calibrate them yourself; the skill necessary for this is acquired very quickly.

Wire for thermocouples should be of superior quality, preferably in double insulation [6].

2. Determination of thermal conductivity coefficients \( \lambda \).

Most methods for determining the coefficients of thermal conductivity of materials based on the stationary mode are:
- plate method;
- pipe method;
- ball method.

For our case, the plate method is more suitable. This method is based on the law of thermal conductivity of a flat wall of unlimited size.
If the amount of released heat is equal to $Q$ and the temperatures $t_1$ and $t_2$ are known, then the coefficient of thermal conductivity is determined from the following relationship:

$$\lambda = \frac{Q \delta}{F(t_1 - t_2)} = \frac{0.86 \cdot I \cdot \Delta E \delta}{F(t_1 - t_2)},$$

where $F$ is the surface of the central heater, m$^2$; $\delta$ is the sample thickness, m.

### 3. Determination of heat transfer coefficient ($\alpha$).

The methods for determining and studying the heat transfer coefficient are very diverse. In each case, these methods are determined by the task and the specific setting of the experience.

$$\alpha_0 = \frac{Q}{F(t_w - t_f)},$$

where $Q$ is the power consumption; $t_w$ is the wall surface temperature, $t_f$ is the wall surface temperature.

$$\alpha_0 = \alpha_c + \alpha_j$$

$\alpha_0$ is the total heat transfer coefficient.

### Finding

Thus, the phase transformations of a substance (condensation, boiling, evaporation) are accompanied by a significant change in the heat exchange conditions near the surface. The transition of the coolant from one aggregative state to another affects the mechanism and intensity of heat transfer [2].

1. With condensation.
   In cases of contact of steam with a wall, the temperature of which is below the saturation temperature, condensation occurs. Most often in technical devices film condensation occurs. Drip condensation is observed only in cases where the liquid does not wet the surface.

2. When boiling in large amounts.
   In these cases, the process of heat exchange between the liquid and the heating surface is accompanied by the transformation of the liquid into steam.

3. When boiling in conditions of fluid flow through the pipes.
   Heat and mass transfer during the boiling of a fluid moving through pipes and channels has a number of features that are caused by the temperature change of the wall and the liquid along the pipe. The saturation temperature along the length of the pipe decreases due to a decrease in pressure due to hydraulic resistance. According to the terms of heat exchange, the pipe can be divided into a number of sections. In the inlet section, the temperature of the pipe wall is less than the saturation temperature. In the second section of the pipe, the wall temperature exceeds the saturation temperature, but the core of the flow has not yet reached this temperature. Therefore, vapor bubbles that separate from the heating surface are partially or completely condensed in the central part of the stream. This phenomenon is called boiling underheated liquid. By the beginning of the third section, the central part of the flow reaches the saturation temperature. Developed bubble boiling occurs at this site. Here the steam content can reach a large value, and essentially a two-phase flow moves through the pipe.

4. When evaporated.
   The mechanism of heat transfers when steam enters the boundary layer of hot gas is the same as when a coolant is supplied to the surface of the gas, but the phase transition on the heat exchange surface leads to some peculiarities. In a stationary process of heat exchange, part of the heat supplied to the surface of the film compensates for the heat of evaporation of the liquid, and part of it is spent...
on heating the film and transferred to the wall. If the heat supplied to the surface of the film is equal to
the heat expended to evaporate the liquid, then the film will have a constant temperature throughout
the thickness and heat will not be transferred to the wall. This process of evaporation is called
adiabatic. Similarly, the process of evaporation of a solid proceeds.

If the surface temperature is less than the temperature at the triple point of the phase diagram, then
the substance passes from a solid to a vapor state, bypassing the liquid phase. This process of
evaporation is called sublimation.

Consequently, the calculation of heat transfer during evaporation and sublimation cannot be
performed without an estimate of mass transfer, i.e. without calculating the mass flow rate of steam.

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