Analysis of thermophysical properties of cooling elements

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Abstract. The essence of the study is to analyse thermophysical properties of cooling elements of electronic equipment. For optimal selection of structural materials and effective cooling of working surfaces, authors carried out numerical studies of the elements based on cadmium selenide, gallium arsenide, indium phosphide, etc.

1. Introduction
Studying heat dissipated by elements of devices (e.g., automatic units), which should be defined for more accurate design of local air conditioning and ventilation systems, is impossible without deep understanding of mechanisms of thermal phenomena in sealed devices, when, along with energy sources, heated zone has drains.

2. The main provisions
Due to correct thermophysical calculation, it is possible to obtain dependencies that allow selection for electronic equipment of materials with the same thermophysical characteristics taking into account the possibility of effective cooling.

Figure 1. Conventional image of single-block sealed electronic devices with chassis cooled by the flow-through fluid: a-horizontal chassis; b-vertical chassis.
Considering the basic laws of the heat transfer theory, let us describe general case of the thermal regime of a sealed device, when, along with energy sources, heated zone has drains. The energy drain is provided with liquid flowing through a tube soldered on the chassis or through a special channel available in the chassis. When defining average surface temperature in the heated zone, it is assumed that the energy sources and flows are distributed evenly over the heated zone.

Assuming that total power of all energy sources is known, ambient temperature in the area of the devices and temperature of the liquid flowing into it are also specified, all geometric parameters of the devices are known, on the basis of the law of energy conservation, a system of heat balance equations is built, which allows establishing analytical relationship between temperatures in the heated zone and casing with the specified parameters.

This equation can be written, firstly, under the assumption that there is a good thermal contact between tubes and chassis, and average temperature of the tube walls is equal to average temperature of the heated zone. Secondly, it is supposed that temperature of the liquid varies linearly along the tube length.

Creation of the thermal conductivities connection scheme usually begins with identifying of conditionally isothermal areas in the devices under study and the system of bodies taking part in heat exchange process. These areas are called conditionally isothermal since their temperature field can be uneven in real devices.

Within each area, a point is selected which is designated by the symbol of average temperature in the corresponding area. The points of the areas involved in direct heat exchange are connected through thermal conductivity. The thermal scheme thus obtained consists of nodal points whose potentials correspond to temperatures of conditionally isothermal regions and thermal conductivities. If the nodal point is an energy source, it is marked with an arrow directed to this point, with the power symbol designating the energy source; if the nodal point is an energy drain an arrow with the symbol of the drain power is directed from the point.

We distinguish four isothermal areas in accordance with the created scheme of the thermal process: heated zone, casing, water flowing through the tube and air surrounding the devices. Heat energy dissipated by the heated zone is divided into two heat streams. The first stream is dissipated in the environment, overcoming in sequence thermal resistances "heated zone - casing" and "housing – environment". The second stream is carried away by the coolant, overcoming thermal resistance between the tube and the liquid.

The pattern of convective flows inside the electronic device depends on the size and orientation of the chassis, density of the mounting parts, their size and relative position, size of the air gaps between the heated zone and casing, as well as temperature of the surfaces of the parts, chassis and casing. The heat transfer process in such difficult conditions cannot be described by known equations, so, to define thermal conductivity, we will present actual design of the devices in the form of their physical models.

In the parallelepiped physical model of the device, actual heated zone is replaced by parallelepiped, equal in volume, with dimensions of the base equal to dimensions of the chassis.

Therefore, when calculating thermal conductivity, a device with a cylindrical casing should be modeled by a device with casing and heated area equal in volume to the actual ones but of parallelepiped shape.

It follows from the above analysis results that thermal characteristics of the device, i.e. dependence of the heated zone and casing temperature on power of the energy sources can be defined using a method of successive approximations, and the calculation starts with defining temperature of the casing that unambiguously defines the power and temperature in the heated zone.

Let us calculate heat dissipated by electrical elements of automatic equipment used in power engineering.

Basic data for the calculation are as follows: shape and size of the casing, orientation and dimensions of the chassis, number of parts and components and their size, emissivity factor of all internal and external surfaces of the device. If a tube through which the coolant flows is soldered on the chassis, it is necessary to know size of the tube, fluid flow rate and its physical parameters.
To draw the device thermal characteristics, it is enough to calculate two points of this characteristic; the third point is the coordinate origin. Thermal characteristics are monotonic power functions, so three points are enough.

Let us consider conditions for calculation of operation of automatic control devices and industrial power plants. In these devices, as a rule, there are no cooling and thermal control systems, so heat generation occurs in the regime of natural convection.

We assume that heated area of the device consists of a chassis with parts located on it. For different heat transfer conditions in the heated zone, convective heat flow from its surface is expressed either by heat exchange coefficient or by heat transfer coefficient.

In the case of natural convection inside the sealed casing, it is convenient to use heat transfer coefficient between the heated zone and the casing, in the case of forced convection - heat exchange coefficient for area between the heated zone and air inside the devices.

Let us calculate values of heat flow, heat exchange and heat transfer coefficients for electronic devices with casing made in the form of parallelepiped with the following sizes: \(L_1=380\text{mm}, \ L_2=585\text{mm}, \ L_3=380\text{mm}\). Sizes of the chassis \(l_1\) and \(l_2\) are approximately equal to corresponding sizes of the casing. The chassis is oriented horizontally. Outer parts of the chassis and housing are surrounded by air with temperature of \(t_1=300\text{C}\) or \(t_2=400\text{C}\).

Calculations were made for the following cooling elements: antimonide aluminum (AlSb), cadmium selenide (CdSe), cadmium telluride (CdTe), gallium arsenide (GaAs), gallium antimonide (GaSb), gallium phosphide (GaP), indium selenide (InSe), indium arsenide (InAs), indium phosphide (InP), mercury telluride (HgTe), mercury selenide (HgSe), zinc selenide (ZnSe), zinc telluride (ZnTe); the calculation results are given in table 1.

Table 1. Calculations for the cooling elements.

| Item No. | Element  | \(C, \text{kJ/m}^3\text{K}\) | \(K, \text{W/m}^2\text{K at } \Delta t=10^0\text{C}\) | \(K, \text{W/m}^2\text{K at } \Delta t=20^0\text{C}\) | \(\lambda=f(T)\) |
|-----------|----------|----------------|----------------|----------------|----------------|
| 1         | AlSb     | 59.68         | 1.62           | 2.11           | 9491.1·\text{T}^{-0.8903} |
| 2         | CdSe     | 4.34          | 1.40           | 1.73           | 5·10^\text{8}·\text{T}^{-3.26} |
| 3         | CdTe     | 7.13          | 1.47           | 1.87           | 32548·\text{T}^{-1.48} |
| 4         | GaAs     | 47.66         | 1.62           | 2.09           | 139156·\text{T}^{-1.4014} |
| 5         | GaSb     | 36.63         | 1.63           | 2.08           | 428306·\text{T}^{-1.649} |
| 6         | GaP      | 107.07        | 1.65           | 2.12           | 39040·\text{T}^{-1.0385} |
| 7         | InSe     | 50.44         | 1.61           | 2.11           | 2760.2·\text{T}^{-0.7046} |
| 8         | InAs     | 134.16        | 1.64           | 2.13           | 56318·\text{T}^{-1.0633} |
| 9         | HgTe     | 2.75          | 1.28           | 1.56           | 983.04·\text{T}^{-1.035} |
| 10        | HgSe     | 2.78          | 1.27           | 1.51           | 2992.9·\text{T}^{-1.25} |
| 11        | ZnSe     | 5.59          | 1.44           | 1.81           | 1232.2·\text{T}^{-0.95} |
| 12        | ZnTe     | 9.09          | 1.51           | 1.92           | 2518.9·\text{T}^{-0.99} |

Using the obtained numerical data, it was possible to define correlation between thermal conductivity and heat transfer coefficients as \(K=B·\lambda\gamma\), that is given in column 6 of table 1.
3. Conclusions
It follows from the analysis of the data given in table. 1 that the elements of automation and electronic devices made of materials whose thermal conductivity is in the range from 40 to 740 W/m·K do not reach such heat transfer values in the case of heat exchange by natural convection. On the contrary, these elements have thermal conductivity values ranging from 1 to 10 W/m·K, and there is a significant increase in heat transfer coefficients with an increase in thermal conductivity.

These results allow selection for electronic equipment of materials with the same thermophysical characteristics taking into account possibility of effective cooling.

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