Introduction. The process of heat transfer of a liquid during ice formation presents a rather complex problem, since freezing means not only the transition of a substance from one state to another with different thermophysical properties, but also the liberation of the latent heat of melting. Problems of this type fall into a wide class of problems known as the Stephan problem [1]. In its original statement, i.e., on the assumption that there is no convection in a liquid and that the thermophysical properties are constant, one finds the law of phase interface motion in time by solving heat conduction equations with nonlinear boundary conditions. The basic methods of solving such problems have been classified and are most fully presented in [2].

Allowance for such factors, very frequently occurring in real situations, as multidimensionality, boundedness in space, liquid supercooling below crystallization temperature, and certain aspects of convective heat transfer at the phase interface greatly complicates the statement of the corresponding problems, the solution of which requires special mathematical techniques [3-7], approximate numerical methods and supercomputers [8], or similarity theory methods with a large number of definitive criteria [9]. The insuperable mathematical difficulties that sometimes arise compel investigators to resort to a traditional technique, i.e., to use the methods of classical heat conduction theory and to take into account the above-mentioned factors in boundary conditions determined experimentally.

All of the above-enumerated features of the process require a special detailed examination; however, the amount of research carried out by the present time makes it possible to analyze only some of them.

The aim of the present review is to summarize research efforts over the past years devoted to the determination of the laws governing convective heat transfer at the "liquid-solid body" phase interface.

Effect of the Formed Solid Phase Shape on Heat Transfer of the Surface Immersed in an Infinite Flow (Exterior Problem). The first attempts to analyze the process of heat transfer in the period of transition from the liquid to the solid state under forced convection conditions were undertaken in [10-12], where the authors limited their discussion primarily to a qualitative description of the process.

A detailed investigation of the coupling between the phase interface surface shape and heat transfer in the case of flow past a frosted plate was reported in [13, 14]. The theoretical analysis is restricted to problems of laminar flow with a relatively simple geometry of the phase interface surface. The one-dimensional heat transfer model developed is based on the assumption of the presence of a thin ice layer; therefore when constructing the solution the heat transfer coefficient is assumed to be independent of the shape of the ice and is defined in the same way as for a plate with no ice ("clean" plate). Analysis of the process with the aid of a two-dimensional model shows that a parabolic ice layer is formed on the plate, with the parabola tip being displaced forward from the leading edge of the plate to a certain nominal distance. In this case, the heat transfer coefficient is calculated with the use of the laminar boundary layer theory relations. Comparison of the predicted results with experimental data shows that application of a simple one-dimensional approximation is more expedient in the majority of practical cases [13].

The transition from a laminar to turbulent flow regime on the ice surface differs substantially from the process of transition on a clean plate [14]. Figure 1 schematically shows the regimes of flow and the shape acquired by the surface of ice in each regime.
In turns out that depending on the behavior of the ice thickness there exist two different forms of ice surface in the transient flow regime: the “step-like” and “smooth.” In the case of the “smooth” form, the ice thickness gradually decays in the entire transient regime, whereas in the case of the “step-like” form it undergoes transformation in a sudden jump at a certain point where an ice thickness maximum is observed. In the course of time this point can be displaced toward the leading edge of the plate, accounted for by the local melting of ice. A dimensionless parameter has been found which uniquely determines the shape of the surface in the transient regime: when $Re_0^{0.13}H/x_{H} > 0.15$ the “step-like” form of the ice surface develops, and when $Re_0^{0.13}H/x_{H} < 0.15$ the “smooth” surface is formed. The critical $Re_0$ number at which the flow regime alters lies within $7 \cdot 10^4 - 1 \cdot 10^5$ for a “smooth” transition as against $1 \cdot 10^5$ for a “clean” plate. Experimental investigation of heat transfer has shown that with the “step-like” form of the ice surface the transition to a turbulent mode is accompanied by a substantial (by a factor of 1.5-2.5) rise in the heat transfer rate at the ice-water interface as compared with a “clean” plate (Fig. 1b). This trend of investigation was further developed in [15], where the transition from the laminar to turbulent mode of flow was investigated in the presence of a rather thick layer of ice. It is shown that on compliance with certain regime conditions on the ice-water surface, one can observe an instability in the existence of the plane phase interface. Wavy ice appears which represents a system of periodic crests and troughs. The authors defined the region for the existence of such a form of the ice surface by the following inequality: $\Theta_c > 12$.

The thickening of ice leads to stable growth in the heat transfer rate. Thus, as compared with a clean surface the heat transfer flux from wavy ice is higher by 30-60%. The reason for this is an additional agitation of the flow by each wave formed on the ice surface.

In [16] heat transfer with the formation of ice on the outer surface of a cylinder in a cross flow is studied. Within the scope of the experiments carried out it was found that the thickness of the nonfrozen layer increases monotonically from $\varphi = 0$ to $\varphi \sim 120^\circ$ and that it is virtually constant within the range $120^\circ \leq \varphi \leq 180^\circ$. These results allowed one to represent the nonfrozen layer profile as: the form of the ice from the forward stagnation point to $\varphi \sim$