XV International Scientific Conference "Chemistry and Chemical Engineering in XXI century" dedicated to Professor L.P. Kulyov

Thermophysical properties of granules of instant drinks in the process of structuring

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Abstract

In this article the research of the thermophysical properties of the material depending on its moisture content been represented. The interrelation of various physical properties with the content of moisture in the mass were detected. In addition, their dependence on the quantitative ratio and the properties of structural carcass and pore spaces were proved. The need to consider the volume phase composition of the mixture was justified. A formula to calculate the thermal conductivity coefficient of the product molded from disperse materials was obtained on the basis of Lykov criterion defining the property of drying material and volume phase concentrations. It is proved that the use of volume phase characteristics of disperse systems opens new possibilities for improving the methodologies for determining the those thermophysical properties of dry and wet dispersion materials, allows increasing the reliability results of these definitions, revealing the mechanism of anomalous heat conductivity of wet material.

Keywords: thermal conductivity, drying, Lykov criterion, heat capacity, solid, liquid, gas phase, structuring, thermophysical properties;

1. Introduction

When forming disperse systems their structural and phase characteristics are closely interlinked, moreover structural and mechanical, rheological and molding properties of these systems are in close interrelation with the content of moisture in the mass and depend on the quantitative ratio and properties of structural carcass and pore

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spaces. Toughness of condensation-crystallization structure formed in the process of hardening predetermines initial moisture content in the systems. Regardless of the nature of the disperse system solid phase, there is a linear relation between the volume concentration of the solid phase K_s and the moisture content of the material W, as in the preparation of the molding composition, and during drying[1].

Formation of a structural chassis molded product is due to coarser particles, which cannot bind significant amounts of moisture[2]. Consequently, the bulk of the moisture bound substance filling the pore space[1], which are represented mainly by fine particles, forming pore suspension with liquid[2,3,4]. On this basis the water-holding capacity of disperse systems and the character of their interactions with liquid predetermined physicochemical properties of powder particles[1,5]. Thus the properties and character of the pore suspensions formed in the structural carcass of the molded product depend on the kind of the disperse mixture and the colloid-chemical properties, such as dispersibility, hydrophilicity, sorption activity, ion exchange capacity and swellability. Uneven distribution of temperature fields and moisture content on the cross sections depends on the geometric dimensions of the product and drying modes. Energy costs for liquid evaporation depend on its properties.

2. Materials and Methods

Drying material properties affected for the operating parameters of drying and almost completely reflected by the Lykov criterion - Lu. The capillary impregnation coefficient K_{ci} is known to depend on the dispersity of the solid phase, porosity in the test zone and also the liquid surface tension, the viscosity quantity and the liquid wettability of the solid phase[1,2,4]. Considering that the moisture conductivity coefficient is an analogue capillary impregnation coefficient, we conclude that any quantity of the sample moisture content corresponds to a full-defined quantity of the solid phase volume concentration. It follows that the value of moisture conductivity coefficient in Lykov criterion characterizes interrelation between the density change of particle packing of solid phase and its moisture absorption.

Properties of the dried material depend on the thermal diffusivity coefficient, which characterizes thermal inertial properties of the body and is the diffusion coefficient of heat in physical meaning[4]. Then, considering the Fourier thermal conductivity equation, the molecular heat transfer q is represented as:

$$q = -a_P \cdot \rho_W \Delta H = -(\lambda_W / C_{PW} \cdot \rho_W) \cdot \rho_W \Delta H \tag{1}$$

when a_P – the diffusion enthalpy coefficient; ρ_W – the density of wet material, kg/m; ΔH – the enthalpy gradient of a body; λ_W – the thermal conductivity of the wet material; C_{PW} – the heat capacity of wet material, $\frac{kj}{kg \cdot K}$.

The multiplication $C_{PW} \cdot \rho_W$ characterizes the ability of the product per unit volume of material to store heat. Consequently, the thermal capacity of the material is defined as an additive value of the volume fractions of all phases of the wet disperse medium, but not mass fractions:

$$C_W = c_S K_S + c_l K_l + c_g K_g \tag{2}$$

when c_S, c_l, c_g - the heat capacity of solid, liquid and gas phases of the system; K_S, K_l, K_g - the content of solid, liquid and gas phases in the disperse system, expressed as the ratio of their volumes.

Considering the physical meaning and dimension of the thermal conductivity coefficient it is evidently that its value does not depend on the mass of the substance and we can also calculate thermal conductivity using the rule of additivity as suggested in[4].

Various authors[1,4,7,8] propose the dependences to calculate the thermal conductivity coefficient of wet disperse materials which are empirical without taking into account the volume phase composition of the mixture. An exception is[6], in which the author takes into account the volume concentration of the solid and liquid phases in the material, but ignores the presence of the gas phase.

Because the presence of all the phases (solid, liquid and gas) predetermines the density of these materials, the

value of thermal conductivity coefficient of disperse materials should be calculated taking into account their volume content. The gas phase due to its low density has a very low mass, but there is no reason to ignore it. Since it will take up more volume and it has low thermal conductivity, it will provide a greater thermal resistance to heat transfer process. Therefore it can be argued that the total thermal conductivity of polydisperse materials is predetermined by the bulk concentration and the thermal resistance of all phases and substances included in the molded object. Based on this in mind, the dependence for calculating the thermal conductivity coefficient of the product molded from disperse materials λ_w can be written as:

$$\lambda_w = \frac{(K_s + K_l)/(1 - K_s)}{\dfrac{K_s \alpha_1}{\lambda_{S1}} + \dfrac{K_s \alpha_2}{\lambda_{S2}} + \dfrac{K_s \alpha_3}{\lambda_{S3}} + \dfrac{K_l}{\lambda_l} + \dfrac{K_g}{\lambda_g}} \tag{3}$$

when correspondingly $\lambda_w, \lambda_{Si}, \lambda_l, \lambda_g$, the coefficients of heat conductivity of solid (i=1,2,3), liquid and gas phases;

$\alpha_1, \alpha_2, \alpha_3$ - the bulk concentration coefficients which are the components of a solid phase (where it is represented by three components), their amount is equal to unity.

Testing the possibility of this dependence was carried out on the example of different material mixtures. First we determined the thermal conductivity coefficient for dry samples with the dimensions of 40•40•90 mm, pressed by the method of semi-ductile molding of mass at a pressure of 50 MPa, according to[1] with a constant heat source. Then they were dried at 60° C and cooled to 20° C. The experimental value of the thermal conductivity coefficient of mixture in the dense condition on the average is - 0.696 W/m•K.

3. Discussion

Relations thermophysical properties of the material and its moisture content is shown in Fig. 1.
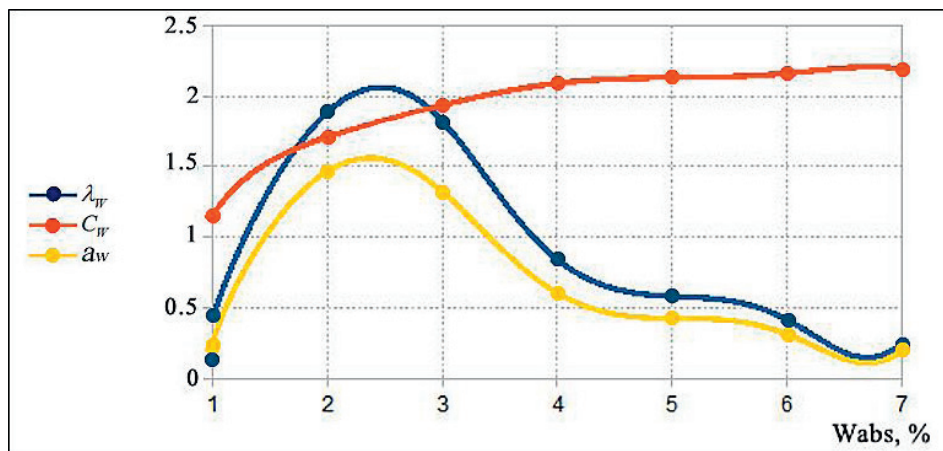

Fig. 1. The change of the material thermophysical properties depending on the moisture content.

Apparently from drawing, the thermal capacity almost linearly increases to value of forming humidity of W = 2.4 % then, despite change of phase composition of material, its change it is insignificant. The latter occurs because of the fact that increasing of the moisture content of material entails the volume concentration redistribution of liquid and volume concentration of a solid phase, which have different densities. In process of formation of hydration shells in a disperse medium, water with the highest heat capacity leads to an increase of the material heat

capacity. When the thickness of the liquid layer between the particles will reach the size of 1.5 microns, the liquid membranes are distributed throughout the volume of material, and the subsequent increase in their thickness does not significantly affect the material properties accumulating the heat.

Decrease of material thermal conductivity at low moisture occurs due to high thermal resistance of a gas phase. When moisture is W = 1.0 – 1.2 % to W = 1.6 % the material thermal conductivity sharply increases to its maximum. At the maximum point the value of the thermal conductivity coefficient exceeds the thermal conductivity of all phases composing this material. This phenomenon of anomalous thermal conductivity of wet materials can be explained by Krisher hypothesis[6], which suggests that under the action of a force field of the solid phase, water molecules rigidly is oriented forming a layer of strongly bound water in the form of ice-like crystalline carcass[1]. Herewith we do not exclude that subsequent molecular layers of water are located in a straight order and also have a small thermal resistance as the Brownian motion is absent therein. This is especially noticeable when a monomolecular layer of strongly bound water acquires the property of continuity throughout the volume of the molded product. In this case the smallest capillary moisture is provided the material gets the maximum thermal conductivity.

4. Conclusions

Using the volume phase characteristics of disperse systems allows improving the method for thermophysical properties determination properties of dry and wet disperse materials, increases the reliability of the results of these definitions and reveals the mechanism of anomalous thermal conductivity of wet materials. Their use allows predicting not only the change of thermophysical properties, but also the behavior of materials at drying in a wide range of moisture content by means of Lykov criterion.

Acknowledgements

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