APPLICABILITY OF MONODISPERSED TECHNOLOGY IN CRYOGENIC TECHNOLOGY

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Possible specific fields of application of hollow microgranules in cryogenic technology are examined. It is pointed out how a high degree of monodispersity of granules helps to improve the performance of different cryogenic systems.

A technology for producing spherical monodispersed microgranules (or drops), whose diameters in one series of experiments differed by not more than 1%, has now been developed in the Department of Cryogenics of the Moscow Power Engineering Institute. The granules (drops) were obtained from different substances – liquid nitrogen, water, glycerine, vacuum oil, gallium, tin, and lead. For each material the most important dimension of the granule, namely, the average statistical diameter, varied from series to series within prescribed limits. The sizes of microgranules for all series of experiments and substances falls into the range 30-800 μm. In addition, the technology developed makes it possible to produce monodispersed microgranules from substances with significantly different values of the coefficients of dynamic and kinematic viscosity and temperature of the starting flow of liquid. In the experiments the extreme values of these quantities ranged from 1.48 to $1.6 \cdot 10^{-4}$ Pa·sec for the dynamic viscosity, from $1.2 \cdot 10^{-3}$ to $0.2 \cdot 10^{-2}$ m^2/sec for the kinematic viscosity, and from 75 to 603 K for the temperature of the liquid.

These achievements show that it may be possible to develop in the near future a technology for obtaining hollow microgranules with the same degree of dispersity with respect to diameter and thickness of the granule wall. Figure 1 shows a hollow spherical granule together with its main parameters.

The greatest prospects for using hollow microgranules in cryogenic technology are in systems for storing cryogenic agents and in heat regenerators. In storage systems they can also be used for storing gas and for improving the characteristics of vessels for storing liquid cryogenic agents. It is well known that the strength of materials depends on a scale factor, i.e., as the volume of a bulk mass decreases the probability of the appearance of microcracks in it decreases. For this reason, a thin-wall microvessel in the form of a spherical microgranule can withstand internal pressures of several hundreds of megapascals [1]. In Fig. 2 the mass-size characteristics of a system for storing gas in microvessels are plotted and compared with those of a standard vessel.

If a system for storing hydrogen in a standard vessel at a pressure of 15 MPa (this mass of the gas is 0.67 kg) is compared with a system consisting of microgranules with a diameter of 600 μm and wall thickness 15 μm (for storing the same mass of hydrogen), then the computed values of $(P_{max})_M$ and $(P_{max})_V$ are 4.3 and 26 MPa, respectively. Therefore providing for the conditions chosen a pressure for storing in microgranules exceeding 26 MPa sharply reduces the mass-size characteristics of the system as compared with the traditional method. At the same time, comparing the energy required to service such a system shows that the traditional system will be more advantageous. For this reason, the use of the proposed system for storing gas in microvessels is justified only when the system itself is a part of a transportation system which uses as fuel, for example, the gas stored in the cavity of the microgranules. In this case, the overall energy advantages of the transportation system are realized by increasing the stored fuel or by conserving fuel. The loading and extraction of gas can be performed by means of diffusion of gas through the wall of a microvessel. Estimates show that if the loading time is limited by the duration of the work shift (8-10 h) and the gas storage is limited to a month and more, then the difference in the temperatures in the system at these stages should be several hundreds of degrees.

Hollow microgranules can also be used as thermal insulation for tanks for storing liquid cryogenic agents [2]. Efficient thermal insulation properties of a hollow microgranule are

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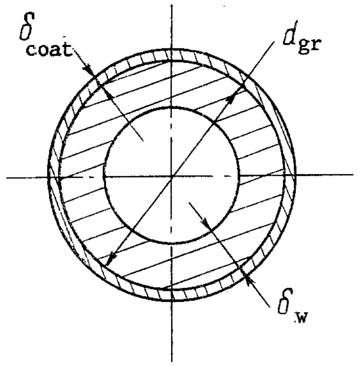

Fig. 1

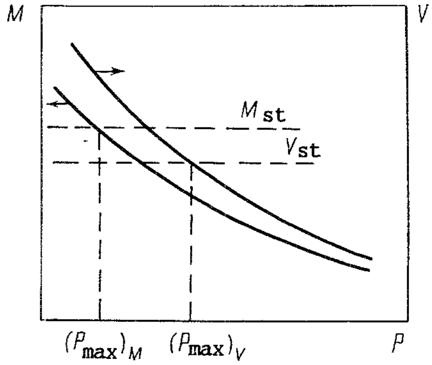

Fig. 2

Fig. 1. Basic dimensions of a hollow microgranule.

Fig. 2. Mass-size characteristics of a system for storage of gas in hollow microgranules versus the gas pressure. M_{st} and V_{st} are the mass-size parameters of a standard vessel; $(P_{max})_M$ and $(P_{max})_V$ are the maximum pressure in comparing systems with respect to mass and volume.

achieved by reducing to a minimum the thickness of the wall, coating the outer surface of the granule with metal, and evacuating the cavity of the granule.

The most difficult question in the process of preparing a hollow microgranule is achieving a prescribed thickness of the wall of the granule. Figure 3 shows the dependence of the ratio of the heat fluxes transmitted by means of heat conduction through continuous and hollow microgranules prepared from the same material on the ratio of the thickness of the granule wall to the radius.

Analysis of the results shows that the ratio $\delta_w/R_{gr} \leqslant 0.02$ is best. For a granule with radius R_{gr} = 300 μm this gives a wall thickness of not greater than 6 μm. It can be shown that for such microgranules the contact thermal resistance can be neglected compared with the thermal resistance of the "framework" itself of the granule.

In addition to the method examined above for transmitting heat in a layer consisting of a collection of microgranules, heat is also trasnmitted by radiation within the cavity of a microgranule as well as between separate particles.

A vacuum can be produced in the cavity of a microgranule at the time the granule is produced, when the cavity is formed by passing a small amount of easily condensing gas inside a liquid jet of the material forming the wall of the microgranule [3]. When the thermal insulation is used at low temperatures the gas condenses and the pressure in the cavity drops.

Coating the outer surface of the microgranule with metal significantly reduces heat transfer by radiation in the fill layer. The monodispersity of the granules, as expected, will improve the characteristics of the process itself and the quality of the coating. But a given coating, which improves the reflective properties of the particles, on the one hand, also increases the heat inflow by heat conduction along the "framework" of the granule. This effect is especially significant, if the thermal conductivity of the material of the wall is significantly different from that of the coating. This makes it necessary to estimate the possible thickness of the coating, which can be done based on the relation $\delta_{coat} \ll (\delta_w \lambda_w)/\lambda_{coat}$, where λ_w and λ_{coat} are the thermal conductivity of the material of the wall and coating, respectively. Therefore hollow microgranules with a thin wall, coated on the outside by a thin layer of metal, improve the thermal insulation properties of fill consisting of such granules, since all components of the heat flux transferred through the fill layer decrease.

Improving the thermal insulation of vessels used for storing liquid cryogenic agents reduces evaporation as well as the cost of recondensation of the gas and it increases the storage time of the liquid and the workability of the system as a whole. The mass-size characteristics of storage systems are also indirectly improved.

The applications, studied above, of hollow microgranules are very closely related with the possibility of using microgranules as fill in heat regenerators. One of the main indicators of existing exchangers is the thermal diffusivity of the fill, whose value affects the

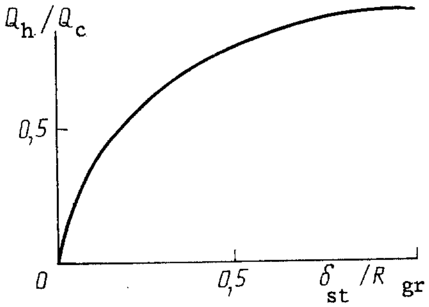

Fig. 3

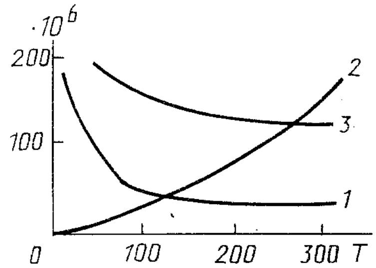

Fig. 4

Fig. 3. Ratio of the heat fluxes along the "framework" of hollow and continuous granules as a function of the thickness of the granule. Q_h and Q_c are the heat fluxes transmitted by heat conduction along the "framework" for hollow and continuous granules.

Fig. 4. Thermal diffusivity of the material as a function of the temperature: 1) lead, 2) helium, 3) tin. T, K; a, m^2/sec.

capability of the fill rapidly to accumulate and give up heat. Figure 4 shows the temperature dependence of the thermal diffusivity of the helium, tin, and lead. It shows that these substances have roughly the same thermal diffusivity, and they are competitive for use as the material for the filler granules in heat regenerators. It is obvious that in this case a hollow microgranule for holding helium should have a quite thin wall and the helium pressure should not differ much from atmospheric pressure. The cavity can be filled with helium when the hollow microgranule itself is fabricated.

The use of monodispersed microgranules as fill in heat regenerators is especially effective in microcryogenics. The hollow microgranules will apparently be relatively expensive to produce, so that the use of such granules as fill is justified only for heat exchangers with a small volume. The monodispersity of the particles in this case is very important from two viewpoints. First, it makes it possible to calculate quite simply the hydrodynamic characteristics of the fill and therefore also the process of pumping the working body through the fill. Second, from the theory of heat transfer it is known that a sphere is the most effective shape for organizing a cooling or heating process, i.e., the heating and cooling time is shortest for a sphere under otherwise identical conditions. These advantages suggest that hollow microgranules may find wide application in heat regenerators in microcryogenics.

NOTATION

d_{gr} and R_{gr}, outer diameter and the radius of a granule; δ_w, thickness of the wall of a granule; δ_{coat}, thickness of the coating on the wall of a granule; λ_w, thermal conductivity of the wall of a granule; λ_{coat}, thermal conductivity of the coating; a, thermal diffusivity; T, temperature; P, pressure within the granule cavity; $(P_{max})_M$ and $(P_{max})_V$, maximum pressure when comparing systems by mass and size; M and V, mass and size of the system; and Q, heat flux.

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