INFLUENCE OF SOLID ADSORBENT STRUCTURE ON THE CONTACT MASS TRANSFER PROCESS IN THE ABSORPTION OF BINDER FROM THERMOPLASTIC SYSTEMS

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An examination is made of the influence of the structural characteristics of porous adsorbents on the process of removal of paraffin binder from thermoplastic systems.

The study of contact mass transfer between ceramic intermediate products (steatite, etc.), and adsorbent substrates, involves the investigation of the actual structure of the porous adsorbents and its role in the process in question.

At present, our information on this point is meager, and indicates, in one case, that the maximum value of the binder fraction escaping into the adsorbent may be 23% of the initial amount in the casting [1]. Elsewhere it is suggested that this fraction may be 5–10% [2, 3]. We note, also, that in [1] a definite connection is postulated between the rate of the process and the amount of binder absorbed, on the one hand, and the sorption properties of the substrate material, on the other. However, it is proposed to relate the absorbing power of the adsorbent to the integrated pore volume.

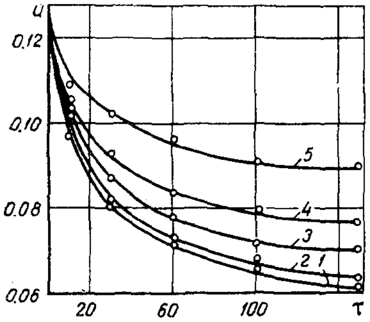

Fig. 1. Curves of removal of industrial binder at constant medium temperature of 373° K on ceramic substrates: 1) alumina with W = 40%; 2, 3, and 4) faience with W of 17, 14 and 11%, respectively; 5) chamotte with W = 17%. Specific mass content u in kg/kg, time τ in min.

The ceramic slabs (faience, chamotte, alumina, zirconium, etc.) used as adsorbent substrates are capillary-porous bodies. From analogy with known ideas about the forms of the moisture band during passage of liquid binder from a casting to an adsorbent, we may assume the presence in the latter of adsorption and capillary bond forces between liquid and adsorbent. A certain amount of binder is retained by the material like wetting moisture [4, 13, 14]. According to the ideas developed in [4, 10], the macropores of the body are assigned mainly the role of paths along which the substance being adsorbed is transported from the ouside medium to the micropore surfaces. Of course, according to the case examined, the division into micro- and macropores should be correspondingly different.

We set up experiments whose aim was, first, to explain the influence of the integrated porosity of the substrate on the intensity of the process, and, second, to determine the dependence of the process of absorption of an industrial binder on the adsorbent structure.

The first series of tests was conducted in a thermostatic chamber at T = 373° K with substrates of the following porosity: alumina—40%, faience—11, 14, and 17%, chamotte—17%. On each substrate we made five castings of SK-1 slip. To determine the kinetics of binder removal from the castings, the latter were removed successively from the substrates and a determination was made of the mass content of paraffin binder in the parts. If the amount of binder removed by the alumina substrate is assumed to be 100%, then the amounts removed on the other substrates are as follows: faience 76, 86, 95; chamotte 56% (Fig. 1). The results of the tests show that the amount of binder removed by the alumina substrate considerably exceeds that for the faience substrates, in spite of the large difference (several times) in integrated porosity. Again, at the same porosity of faience and chamotte slabs (W = 17%), the amount of binder removed by the former is greater by a factor of 1.7. Thus, the tests have not established a quantitative relation between the total porosity of the adsorbent and the amount of binder absorbed.

The study of the porous structure of bodies usually reduces to obtaining the differential curve of pore volume distribution in terms of radius [5]. For ceramic materials the method of mercury porometry is quite reliable, and allows one to obtain the desired characteristic of the bodies over a wide range of variation of pore size—from tenths to tens of microns [6, 7, 12]. Tests were conducted on the substrates under investigation with the aid of a mercury porometer using a technique analogous to that described in [8–10]. The result was curves of volume porosity V on applied pressure p. The differential curves of pore volume distribution in terms of effective radius are given in Fig. 2a. The total volume or pores in any section from r_1 to r_2 was determined as

$$V_i = \int_{r_1}^{r_2} D(r)\,dr. \qquad (1)$$

It may be seen from Fig. 2a that for faience slabs the curves exhibit a maximum corresponding to pore size of $r_{ef} = 0.2\ \mu$; for an alumina substrate $D_{max}(r)$ corresponds to $r_{ef} = 0.3\ \mu$, and, finally, for chamotte $r_{ef} = 0.14\ \mu$. We note that for chamotte and alumina substrates, as is seen from Fig. 2a, the presence of a second maximum may be assumed in the region $r_{ef} \leq 0.06\ \mu$. The results of processing the curves are presented in the table.

For convenience of comparison of the porosity values obtained by exposing the specimens in water (according to the method of [11]) with those determined by the above method, the former were scaled to the value

$$V' = W(\gamma_0/\gamma_w). \qquad (2)$$

It may be seen from the comparison that for faience specimens the porosity values obtained by the two methods agree with sufficient accuracy ($V_f \simeq V'_f$). For the alumina specimen, $V_a = 0.64\ V'_a$, and for the chamotte $V_c = 1.24\ V_c$. These facts permit us to predicate the presence, for alumina specimens, of a considerable volume of pores with $r < 0.06\ \mu$, and the presence at the same time of closed pores for the chamotte specimens. Evidently the latter proved to be impermeable to ordinary penetration of liquid (during absorption of water), but mercury penetrates into these pores at a pressure up to $p \approx 1275 \cdot 10^4\ N/m^2$.

Returning to Fig. 1, we shall analyze the contact mass transfer process with allowance for the structure of the adsorbent substrates. It follows from the table that in the section $r = 0.1$–$0.6\ \mu$ the largest pore volume is characteristic of the alumina specimen ($V_{a(i)} = 0.240\ cm^3/cm^3$), followed by the faience specimens, ($V_{f(i)} = 0.238$–$0.170\ cm^3/cm^3$), and finally the chamotte, ($V_{c(i)} = 0.088\ cm^3/cm^3$). At the section $r = 0.1$–$0.4\ \mu$, in which $D_{max}(r)$ is located, the chamotte specimen has minimum pore volume (Fig. 2a and the table). On the other hand, the ability of the slabs to absorb paraffin binder decreases in the same order (as follows from Fig. 1) and in comparable amounts.

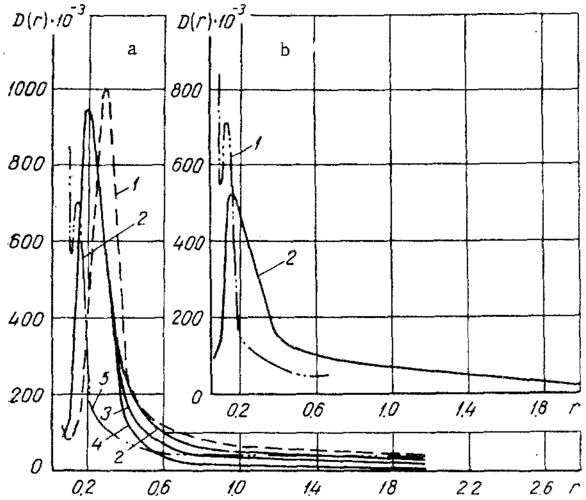

Fig. 2. Differential curves of volume distribution of pores D(r) ((cm^3/cm^3)/μ) in terms of their effective radius r (μ): a) for alumina specimens with W = 40% (1) and faience specimens with W = 17.6, 14.2, and 11.2% (2, 3, and 4), respectively; b) for prepared substrates and previously tested specimens: 1) chamotte with W = 17.3%; 2) experimental chamotte with W = 14.2%.

In the range of finer pores ($r = 0.1$–$0.06\ \mu$), the chamotte substrate has the largest pore volume ($V_{c(i)} = 0.079\ cm^3/cm^3$), in comparison with the other specimens. Since this specimen proved to be worst from the viewpoint of the possibility and rate of mass absorption of paraffin, one must recognize that the influence of the fine pores in question on the binder absorption effect is inconsiderable. The decrease of absorption ability of specimens with a relatively large pore volume ($r_{ef} < 0.1\ \mu$) may be evidently attributed to their "inaccessibility" for comparatively large molecules like those of technical paraffin.

The experiments have shown that the pore volumes with $r_{ef} > 1.0\ \mu$ for chamotte and alumina specimens are 0.135 and $0.225\ cm^3/cm^3$, respectively, in contrast to faience, for which they are substantially less, ($V_{f(i)} = 0.035$–$0.094\ cm^3/cm^3$). Comparison of these data with results of tests with contact mass transfer (Fig. 1) permits us to conclude that the role

Radial Distribution of Pore Volume

Capillary-porous substance	Moisture absorption according to Soviet standard to GOST 7025-54		$V' = \Sigma V_{(i)}$, cm^3/cm^3	Pore volume $V_{(i)}$, cm^3/cm^3 at r, μ				
	W, g/g	V', cm^3/cm^3		0.06–0.1	0.1–0.4	0.4–0.6	0.6–1.0	>1.0
alumina	0.400	0.780	0.500	0.005	0.195	0.045	0.030	0.225
faience	0.176	0.330	0.358	0.004	0.212	0.026	0.022	0.094
faience	0.142	0.258	0.258	0.004	0.170	0.019	0.013	0.052
faience	0.112	0.214	0.215	0.004	0.155	0.015	0.006	0.035
chamotte	0.173	0.240	0.323	0.079	0.075	0.013	0.021	0.135

of the above pores in the process in question is weak. This may be understood if one takes account of the relatively small specific area of the volume of pores with $r_{ef} > 1.0\ \mu$ in comparison with the remaining area of the adsorbents.

Thus, we may conclude that adsorbents having in their structure mainly pore volumes with $r_{ef} = 0.1$–$0.6\ \mu$ are the most intense absorbers of paraffin binder.

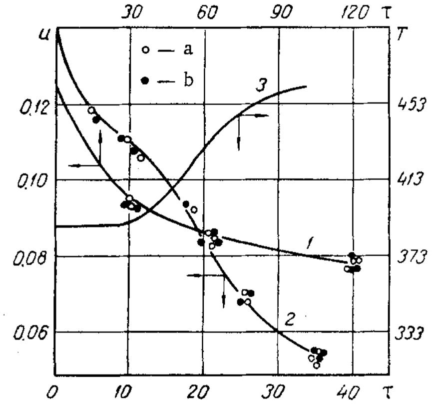

Fig. 3. Dependence of specific mass content u (kg/kg) of castings on process time τ (min) for castings with $r_{ef} = 0.1$–$0.6\ \mu$: 1) at constant medium temperature of 373° K; 2) at variable temperature determined by curve 3; a) on faience: b) on chamotte substrate.

It was necessary to investigate the kinetics of contact mass transfer in the case of variation of the structure of the adsorbent chamotte in such a way that the volume of pores with $r_{ef} = 0.1$–$0.6\ \mu$ increased.

As has already been remarked, the chamotte slabs possess the lowest adsorption properties. They were made of refractory Chasov-Yar clay (60%) and Chasov-Yar chamotte (40%). The granulometric mass composition was 70% of particles of size 1.0–2.0 mm and 30% of particles less than 1 mm. The maximum firing temperature of the slabs was 1253° K.

For tests with chamotte slabs of modified structure we used the above material, but the granulometric composition of the prepared mixture was close in particle distribution to that used in the preparation of the faience slabs, this being: greater than 1 mm–5%; 0.5–1.0 mm–20%; 0.25–0.50 mm–30%; and less than 0.25 mm–45%. Firing was done at a temperature of 1313° K. The slabs obtained had a moisture absorption W = 14.2%. Figure 2b shows the differential curves of radial pore volume distribution for the prepared substrates and those tested earlier. It was established that $V = V' = 0.263$ cm³/cm³. Integration over the sections gave the following pore volume distribution:

r, μ	0.06–0.1	0.1–0.6	0.6–1.0	>1.0
$V_{(i)}$, cm³/cm³	0.004	0.130	0.032	0.097

As follows from the data presented, we were able to obtain roughly 50% greater volume of pores with $r = 0.1$–$0.6\ \mu$, as well as to reduce appreciably the volume of pores for $r = 0.06$–$0.1\ \mu$ and $r > 1.0\ \mu$, in comparison with the previous specimens. The test results for the contact mass transfer kinetics of castings on the new chamotte and faience substrates with identical W = 14.2% are shown in Fig. 3. Comparison experiments were conducted under identical conditions with two regimes of heat treatment. The thermograms of the process represent the variation of the temperature of the exposed surface of the substrate at a point 20 mm from the slab edge. The tests showed that the prepared substrates possess the same absorption capacity as faience. Thus the investigation demonstrates the simple possibility of intensifying the contact mass transfer process in the removal of industrial binders on the porous adsorbent substrates by means of appropriate choice of adsorbent structure.

Notation

W—maximum moisture absorption, %; u—specific mass content, kg/kg; p—pressure, N/m²; V—volume porosity, cm³/cm³; D(r)—radial pore volume distribution function, (cm³/cm³)/μ; r—pore radius, μ; τ—time, min; T—temperature, °K; γ_0—specimen density, kg/m³; γ_W—density of water, kg/m³.

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