Journal of Engineering Physics and Thermophysics, Vol. 69, No. 2, 1996

EFFECTIVE THERMAL CONDUCTIVITY AND THERMAL DIFFUSIVITY OF CATALYSTS AND THEIR SUPPORTS AS FUNCTIONS OF TEMPERATURE IN VARIOUS GASEOUS MEDIA AND IN VACUUM. III. RADIATIVE COMPONENT OF THE THERMAL CONDUCTIVITY, CONTACT THERMAL CONDUCTIVITY, AND CONTRIBUTION OF A GASEOUS MEDIUM TO THE EFFECTIVE THERMAL CONDUCTIVITY OF GRANULATED POROUS CATALYSTS AND THEIR SUPPORTS

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UDC 536.21

It is established on the basis of experimental data that heat transfer in loads of granulated porous catalysts and their supports proceeds via intergranule contacts and the gaseous medium that fills pores and intergranule space, and by means of radiative heat transfer between granule surfaces. An equation is obtained that makes it possible to calculate the effective thermal conductivity of catalysts and their supports not investigated experimentally as functions of temperature, granule dimensions, load density, concentration, and type of introduced metallic particles in various gaseous media.

Investigations of the thermal conductivity and thermal diffusivity of supports and deposited catalysts have shown that the thermal conductivity λ and thermal diffusivity a of both supports and catalysts increase linearly with temperature in vacuum and in various gaseous media.

Four main processes contribute to the mechanism of heat transfer in loads of the supports and catalysts under investigation: 1) heat transfer via the granule contact; 2) heat transfer via a gaseous medium that fills pores and space between protruding roughnesses of surfaces in contact; 3) radiative heat transfer between granule surfaces; 4) heat transfer by means of convection of the gas in pores and between granules.

For the samples under investigation the pore dimensions (~ 100 Å) and the gaps at granule contacts are insignificant, which inhibits initiation of convective gas flows under the action of the temperature gradient.

Conditions for initiation of convection in porous materials are determined from the critical values of the filtration Rayleigh number [1-8]

$$\mathrm{Ra}^{*}_{\mathrm{cr}} = \mathrm{Gr}\,\mathrm{Pr}\,\mathrm{Da}\ ,$$

where Gr, Pr, and Da are the Grashof, Prandtl, and Darcy numbers, respectively.

According to [1-4], convective heat transfer is initiated at $\mathrm{Ra}^{*}_{\mathrm{cr}} \approx 40$. In our experiments $\mathrm{Ra}^{*}_{\mathrm{cr}} = 4 \cdot 10^{-4}$, which bears witness to the absence of convective heat transfer.

The increase in the thermal conductivity and thermal diffusivity of the samples with temperature observed in our experiments results from an increase in the thermal conductivity of the gas that fills pores and gaps between granules of the supports and catalysts, a small increase in the intergranule contact area, and an increase in the radiative heat transfer.

Indeed, heat transfer at intergranule junctions proceeds not only via contacts but also via pores, an appreciable number of which are situated at the contact. This leads to a decrease in the thermal resistance of the contact and, consequently, to an increase in heat transfer via these contacts.

Dushanbe Pedagogical University, Dushanbe, Tadjikistan. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 69, No. 2, pp. 291-300, March-April, 1996. Original article submitted October 7, 1993; revision submitted October 25, 1994.

 1062-0125/96/6902-0234$15.00

According to experimental data, λ and a of the supports and catalysts under investigation are insignificant in vacuum compared to the thermal conductivity and thermal diffusivity in gaseous media, which is indicative of insignificant heat transfer via intergranule contacts of the samples.

Thus, the absence of gas in pores leads to a sharp increase in thermal resistance and correspondingly to a decrease in thermal conductivity and thermal diffusivity.

The increase in the thermal conductivity and thermal diffusivity of the supports and catalysts under investigation in vacuum with temperature observed in our experiments can be explained by an insignificant increase in the area of the contact spot between granules and an increase in the fraction of the radiative heat transfer.

Investigations showed that for the same content of metallic additives the maximum values of thermal conductivity and thermal diffusivity were observed for copper-containing catalysts, whereas the minimum values were observed for cobalt-containing ones.

The thermal conductivity of a deposited copper catalyst containing 28.8% metallic additives with granule dimensions of 0.8–1.25 mm on an N-1 support is 14.5% higher than that of a deposited cobalt catalyst containing 30% metallic additives with granule dimensions of 0.8–1.25 mm on an N-1 support in nitrogen at 293 K, when, according to [5, 6], the thermal conductivity of copper is 4.5 times greater than λ for cobalt. This demonstrates the insignificant contribution of metallic crystals of various materials to the increase in the thermal conductivity and thermal diffusivity of the catalysts under investigation.

According to our experimental data, metallic additives with higher values of thermal conductivity and thermal diffusivity contribute more subtantially to the increase in λ and a of a catalyst load compared to metallic additives with lower values of thermal conductivity and thermal diffusivity.

Thus, with an increase in the concentration of metallic additives the increase in thermal conductivity and thermal diffusivity depends on both the change in their volume and the thermophysical properties of the metallic additives, especially their thermal conductivity and thermal diffusivity.

We made a quantitative estimate of the radiative component of the thermal conductivity of the objects under investigation at various temperatures and found its correlation with the effective thermal conductivity.

Transfer of radiation energy in solid bodies is characterized by the cofficient of radiative thermal conductivity λ_r, which in the case of a "gray" medium (the absorption coefficient is independent of the emission frequency) is calculated by the Rosseland formula [7]:

$$\lambda_r = \frac{16}{3} \frac{n^2}{\beta} \sigma T^3 , \tag{1}$$

where n is the refractive index; σ is the Stefan-Boltzmann constant; β is the spectral attenuation coefficient.

For real media in the region of partial transparency β depends on the temperature and the radiation spectrum.

Polts [8] used formula (1) to calculate the radiative component of the thermal conductivity for a gray medium bounded by diffuse surfaces, and proposed the formula

$$\lambda_r = \frac{16}{3} \frac{n\sigma}{\beta} T^3 V(\varepsilon_w, \delta) , \tag{2}$$

where $V(\varepsilon_w, \delta)$ is a function that accounts for the optical thickness of the sample δ and the degree of backness ε_w of the bounding surfaces (walls).

Men' and Sergeev [9] note that the Polts formula yields an error not higher than 10% for a thin layer about 5 mm thick at a fluence density up to $7.5 \cdot 10^3$ W/(m·K), and the error reaches 20% with increase in the optical thickness of the layer.

Luikov has shown [10] that if the pore walls are not transparent for thermal radiation, then the radiative component of the thermal conductivity can be represented as follows:

$$\lambda_r = 4 f \sigma \delta T^3 , \tag{3}$$

where δ is the size of the particle; f is a coefficient related to the opticogeometric characteristics of the pore model and the calculation scheme. According to data of various authors, f takes various values: $f = 1/3$ (Bosworth); $f = \varepsilon_m/(a - \varepsilon_m)$ (Argo and Smith); $f = \varepsilon_m$ (Schotte); $f = (\delta\varepsilon_m^2)/ad$ (Chudnovskii); $f = 0.865[3\Pi\varepsilon_m + (1-\Pi)\varepsilon_m]/[1 + (1 - \Pi)(1 - \varepsilon_m)]$ (Nikitin); $f = (1 + 5\cdot 10^{-5}/r)0.16/(1 - \Pi)^{-1.15}$ (Shorin, Zarudnyi, and Serebryanyi); $f = \varepsilon_m\Gamma$ (Leob), where ε_m is the degree of blackness of the material; Π is the porosity; Γ is a geometric factor.

Luikov notes that none of the models can be favored.

Calculations showed that for one and the same load of the objects under investigation the scatter in the parameter f calculated using different equations is as large as 70%.

Application of the above formulas in practical calculations of the radiative component of the thermal conductivity seems to be impossible since each of the formulas contains a set of quantities that should be determined experimentally.

Therefore, in order to determine the radiative component of the thermal conductivity of the objects under investigation we proceeded from the assumption that the thermal conductivity in vacuum λ_{ef}^{v} can be represented as the sum of the thermal conductivity via granule contacts λ_c and the thermal conductivity due to radiation λ_r:

$$\lambda_{ef}^{v} = \lambda_c + \lambda_r . \tag{4}$$

The above formulas that determine λ_r contain the factor $F\sigma T^3$, which determines the increase in the thermal conductivity with temperature. Therefore Eq. (4) can be represented in the form

$$\lambda_{ef}^{v} = \lambda_c + F\sigma T^3 , \tag{5}$$

where $\lambda_r = F\sigma T^3$ is the thermal conductivity due to radiation (here $F = 4f\delta$); λ_c is the contact thermal conductivity, which in a first approximation is temperature-independent, since the area of the contact spot of a granule varies insignificantly with temperature.

Let us write Eq. (5) for the temperature T_1 and the current temperature value T:

$$\lambda_{ef1}^{v} = \lambda_c + F\sigma T_1^3 , \quad \lambda_{ef2}^{v} = \lambda_c + F\sigma T^3 . \tag{6}$$

whence we have for the coefficient F:

$$F = \frac{\lambda_{ef1}^{v} - \lambda_{ef2}^{v}}{\sigma (T^3 - T_1^3)} . \tag{7}$$

Then we obtain the following expression for λ_r:

$$\lambda_r = \frac{\lambda_{ef2}^{v}(T) - \lambda_{ef1}^{v}(T_1)}{T^3 - T_1^3} T^3 . \tag{8}$$

By substituting the value (7) into the first equation of (6) we find

$$\lambda_c = \lambda_{ef1}^{v} - \frac{\lambda_{ef2}^{v}(T) - \lambda_{ef1}^{v}(T_1)}{T^3 - T_1^3} T_1^3 . \tag{9}$$

Knowing λ_c, one can calculate the radiative component of the effective value of the thermal conductivity of the catalysts and supports under investigation at any temperature using formula (4).

Calculations with formula (4) showed that for the samples under investigation the value of the radiative component of the thermal conductivity at a temperature of 293 K equals 5% of the effective thermal conductivity with high accuracy, i.e., $\lambda_c \approx 0.05\lambda_{ef}^{293}$. Therefore, for the contact thermal conductivity we have

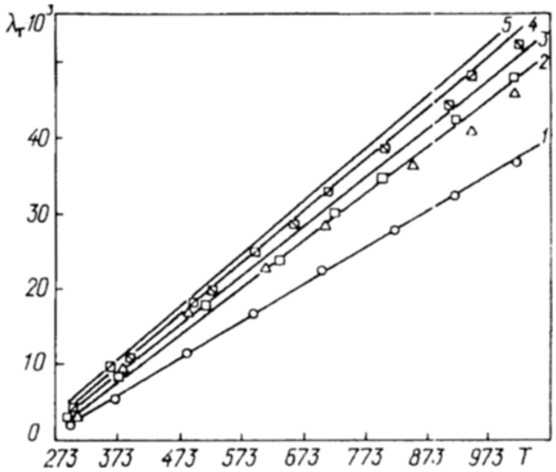

Fig. 1. Radiation component of the thermal conductivity of copper catalysts deposited on an N-1 support with granule dimensions of 0.8–1.25 mm as a function of temperature: 1) N-1; 2) N-1 + 4.5% met.; 3) N-1 + 12% met.; 4) N-1 + 23.4% met.; 5) N-1 + 28.8% met.

$$\lambda_c = \lambda_{ef}^{293} - 0.05\,\lambda_{ef}^{293} = 0.95\lambda_{ef}^{293}\,. \tag{10}$$

Thus, assuming that λ_c is virtually temperature-independent, one can estimate from the formula (4) the fraction of the radiative component at any temperature using the value of λ_{ef}.

Calculations showed that for the objects under investigation the value of λ_r increases in vacuum with temperature, and at a temperature of 1016.8 K the value of the radiative component for a catalyst containing 31.6 wt.% iridium on an N-1 support equals 38% of the effective thermal conductivity.

From Eqs. (4) and (10) we obtain

$$\lambda_r = \lambda_{ef}^{v} - 0.95\lambda_{ef}^{293}\,. \tag{11}$$

Calculations with Eq. (11) showed that λ_r for the catalysts and supports under investigation depends on temperature, thermophysical properties of the catalysts and supports, load density, concentration, and individual properties of introduced metallic particles in the catalysts.

The radiative component of the thermal conductivity of the objects under investigation increases linearly with temperature (Fig. 1).

Indeed, if we take into account in (8) the linear dependence of the effective thermal conductivity on T and set $\lambda_{ef} = CT_1$, $\lambda_{ef} = CT$, we obtain

$$\lambda_r = \frac{C\,(T - T_1)}{T^3 - T_1^3}\,T^3\,,$$

whence it follows that $\lambda_r \sim T$. We should emphasize that this results from the decrease in the degree of blackness and the increase in the attenuation coefficient (see (1)) with increase in temperature [11, 12].

It is evident from Fig. 1 that the radiative component of the thermal conductivity of the catalysts increases with the weight concentration of the metallic particles. The maximum increase in the radiative component of the thermal conductivity with temperature is observed for catalysts containing metallic particles with a high value of thermal conductivity. Indeed, the greatest increase in the radiative component of the thermal conductivity with temperature is observed for copper-containing catalysts.

In order to establish the dependence of the radiative component of the thermal conductivity of the objects under investigation on temperature, granule dimensions, load density, concentration, and individual properties of the introduced metallic particles we processed the data in the form of the dependence

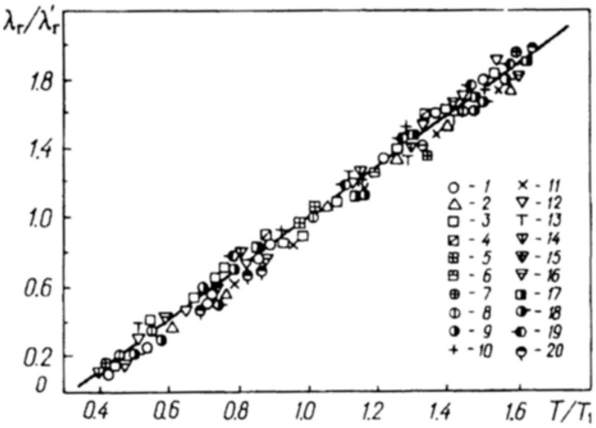

Fig. 2. Dependence $\lambda_r/\lambda_r' = f(T/T_1)$ for the catalysts under investigation and their supports: 1) N-1 (0.8–1.25); 2) N-1 (2–3); 3) N-1 (3–4); 4) N-2 (0.8–1.25); 5) N-2 (2–3); 6) N-2 (3–4); 7) N-1 + 31.7% Ir (0.8–1.25); 8) N-1 + 31.2% Ir (2–3); 9) N-1 + 30% Ir; 10) N-3 (1–2); 11) N-3 (2–3); 12) N-3 (3–4); 13) N-1 + 20% Ir (2–3); 14) N-1 + 6.5% Co (0.8–1.25); 15) N-1 + 15% Co (0.8–1.25); 16) N-1 + 25% Co (0.8–1.25); 17) N-1 + 10% Ru (0.8–1.25); 18) N-3 + 20% Ir (1– 2); 19) N-1 + 30% Ir (1–2); 20) N-3 + 10% Ir (1–2) mm.

$$\frac{\lambda_r}{\lambda_r'} = f\left(\frac{T}{T_1}\right), \tag{12}$$

where λ_r and λ_r' are the radiative components of the thermal conductivity at temperatures T and $T_1 = 673$ K, respectively.

Feasibility of the dependence (12) for the objects under investigation is shown in Fig. 2, according to which all experimental points fit a common straight line well. This straight line is described by the equation

$$\lambda_r = (1.5T/T_1 - 0.5)\,\lambda_r' . \tag{13}$$

An analysis of λ_r' for the objects under investigation showed that it increases linearly with the granule dimensions.

In processing experimental data for the dependence of λ_r' on the granule dimensions we obtained an equation of the form

$$\lambda_r' = (0.055d/d_1 + 0.945)\,\lambda_r'' , \tag{14}$$

where λ_r'' is the radiative component of the thermal conductivity of the objects under investigation for mean granule dimensions $d_1 = 1$ mm at a temperature $T_1 = 673$ K.

An analysis of λ_r'' for the supports under investigation showed that it is a function of the load density ρ:

$$\lambda_r'' = (83.9 \cdot 10^{-3} - 61.3 \cdot 10^{-6}\rho), \quad \mathrm{W/(m \cdot K)} . \tag{15}$$

From Eqs. (13)-(15), for calculation of the radiative component of the thermal conductivity of the investigated supports with various granule dimensions as a function of temperature T and load density ρ we obtain

$$\lambda_r = (1.5T/T_1 - 0.5)\,(0.055d/d_1 + 0.945)\,(83.9 \cdot 10^{-3} - 61.3 \cdot 10^{-6}\rho), \quad \mathrm{W/(m \cdot K)} . \tag{16}$$

For the catalysts under investigation λ_r'' increases linearly with the load density ρ and it also increases with the thermal conductivity of the metallic fillers.

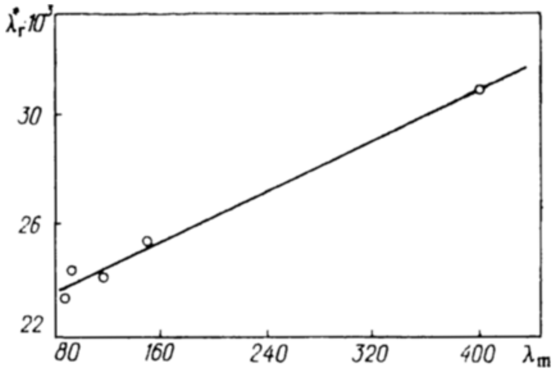

Fig. 3. Dependence of λ_r^* on the thermal conductivity of introduced metallic catalysts.

In processing experimental data for the dependence of λ_r'' on the load density of the investigated catalysts we obtained the equation

$$\lambda_r'' = (0.71\rho/\rho_1 + 0.29)\,\lambda_r^*\,, \tag{17}$$

where λ_r^* is the value of λ_r'' for a value of the catalyst load density $\rho_1 = 1300\ \text{kg/m}^3$.

An analysis of λ_r^* for the catalysts under investigation showed that it is a function of the thermal conductivity of the introduced metallic particles (Fig. 3).

The straight line in Fig. 3 is described by the equation

$$\lambda_r^* = 2.17\cdot 10^{-5}\lambda_m + 22.53\cdot 10^{-3}\,,\ \ \text{W/(m}\cdot\text{K)}\,. \tag{18}$$

From Eqs. (17) and (18) we obtain

$$\lambda_r'' = (0.71\rho/\rho_1 + 0.29)\,(2.17\cdot 10^{-5}\lambda_m + 22.53\cdot 10^{-3})\,,\ \ \text{W/(m}\cdot\text{K)}\,. \tag{19}$$

Substituting Eq. (19) into (14); we obtain the following expression for calculation of λ_r'':

$$\lambda_r' = (0.055d/d_1 + 0.945)\,(0.71\rho/\rho_1 + 0.29)\,(2.17\cdot 10^{-5}\lambda_m + 22.53\cdot 10^{-3})\,,\ \ \text{W/(m}\cdot\text{K)}\,. \tag{20}$$

From Eqs. (13) and (20), for calculation of the radiative component of the thermal conductivity of the catalysts under investigation we obtain

$$\lambda_r = (1.5T/T_1 - 0.5)\,(0.055d/d_1 + 0.945)\,\times$$

$$\times\,(0.71\rho/\rho_1 + 0.29)\,(2.17\cdot 10^{-5}\lambda_m + 22.53\cdot 10^{-3})\,,\ \ \text{W/(m}\cdot\text{K)}\,. \tag{21}$$

Equation (21) establishes the dependence of the radiative component of the thermal conductivity of the catalysts under investigation on temperature T, granule dimensions d, load density ρ, and thermal conductivity of the introduced metallic particles λ_m.

Calculations of the radiative component of the thermal conductivity of the objects under investigation with relationships (16) and (21) showed that they describe the experimental data with an accuracy up to 8%.

With Eqs. (16) and (21) one can calculate the radiative component of the thermal conductivity for catalysts not studied experimentally that contain various metals with various weight concentrations and for their supports with granule various dimensions and shapes within the temperature interval 293–1073 K.

An analysis of the experimental data showed that the contact thermal conductivity λ_c of the objects under investigation depends on granule dimensions, concentration, and individual properties of the introduced metallic particles.

In processing and generalization of the experimental data we obtained the following equations for calculation of the contact thermal conductivity of the supports and catalysts under investigation:

for the supports

$$\lambda_c = (0.055\, d/d_1 + 0.945)\,(0.19 - 14\cdot 10^{-5}\rho)\,, \quad W/(m\cdot K)\,, \tag{22}$$

for the catalysts

$$\lambda_c = (0.055\, d/d_1 + 0.945)\,(1.25\rho/\rho_1 - 0.245)\,(6.15\cdot 10^{-5}\lambda_m + 5.25\cdot 10^{-2})\,, \quad W/(m\cdot K)\,. \tag{22'}$$

Equations (22) and (22') establish the dependence of the contact thermal conductivity of loads of the catalysts and their supports on granule dimensions d, load density ρ, and thermal conductivity of the introduced metallic particles λ_m.

A check of Eqs. (22) and (22') showed that they describe the contact thermal conductivity of the catalysts under investigation and their supports with the accuracy of 5%.

With Eqs. (22) and (22') one can calculate the contact thermal conductivity of catalysts and supports not studied experimentally with various values of porosity as a function of granule dimensions, load density, and thermal conductivity of the introduced metallic particles.

The effective thermal conductivity λ_{ef} of loads of catalysts and supports in gaseous media can be represented as follows:

$$\lambda_{ef} = \lambda_c + \lambda_r + \lambda_g\,, \tag{23}$$

where λ_c is thermal conductivity via granule contacts; λ_r is the radiative thermal conductivity; λ_g is the thermal conductivity by means of the gaseous medium.

Expression (23) with account for $\lambda_{ef}^{v} = \lambda_c + \lambda_r$ can be written in the following form:

$$\lambda_{ef} = \lambda_{ef}^{v} + \lambda_g\,. \tag{24}$$

From Eq. (24) we obtain an expression for the component of the thermal conductivity by means of the gaseous medium at various temperatures:

$$\lambda_g = \lambda_{ef} - \lambda_{ef}^{v}\,. \tag{25}$$

Calculations with Eq. (25) showed that the contribution of the gaseous medium to the effective thermal conductivity of the objects under investigation depends on temperature, properties of the filling gas, and individual properties of the catalysts and their supports.

According to the results obtained, λ_g increases linearly with temperature, and with increase in the thermal conductivity of the filling gas its contribution to the effective thermal conductivity of loads of the catalysts and supports increases. Hydrogen has the highest value of thermal conductivity, and therefore it makes the greatest contribution to the effective thermal conductivity of the catalysts and supports.

The contribution of the gaseous medium to the effective thermal conductivity of loads of the objects under investigation also depends on the type of supports and catalysts. The greatest contribution of the gaseous medium to the effective thermal conductivity is observed for the N-3-type support, whereas the smallest one is observed for the N-1 support. The greater the thermal conductivity of the introduced metallic particles, the greater the contribution made by the gaseous medium to the effective thermal conductivity of the catalyst. Indeed, the greatest contribution of the gaseous medium to the effective thermal conductivity is observed for catalysts containing copper particles.

To establish the dependence of λ_g on the temperature T and the thermal conductivity of the filling gas the data were processed in the form of the following functional dependence:

$$\frac{\lambda_g}{\lambda_g'} = f\left(\frac{T}{T_1}\right), \quad (26)$$

where λ_g' is the contribution of the thermal conductivity of the filling gas to the effective thermal conductivity at a temperature $T_1 = 673$ K. The dependence (26) for the catalysts and supports under investigation, as shown by our investigations, is represented well by a common straight line that is described by the equation

$$\lambda_g = (0.58 + 0.42T/T_1)\,\lambda_g' . \quad (27)$$

Using relationship (27), one can calculate λ_g as a function of temperature, provided λ_g' is known.

In processing the experimental data we obtained the following equation for calculation of λ_g':

$$\lambda_g' = (31.5 \cdot 10^{-4} \lambda_{GT_1} + 0.37)\,(0.68 - 34 \cdot 10^{-5} \rho), \ \ \mathrm{W/(m \cdot K)} . \quad (28)$$

From Eqs. (27) and (28) we obtain the following expression for calculation of λ_g of the supports under investigation:

$$\lambda_g = (0.58 + 0.42T/T_1)\,(31.5 \cdot 10^{-4} \lambda_{GT_1}/\lambda_{GT_1}' + 0.37) \times (0.68 - 34 \cdot 10^{-5} \rho), \ \ \mathrm{W/(m \cdot K)} . \quad (29)$$

Equation (29) determines the dependence of λ_g of the supports under investigation on temperature T, thermal conductivity of the filling gas λ_{GT_1}, and load density ρ.

In processing theexperimental data we obtained the following equations for calculation of the contribution of thethermal conductivity of the filling gas to the effective thermal conductivity of the catalysts under investigation

$$\lambda_g = (0.58 + 0.42T/T_1)\,(0.63\lambda_{GT_1}/\lambda_{GT_1}' + 0.37) \times$$

$$\times\, (0.68\rho/\rho_1 + 0.32)\,(1.74 \cdot 10^{-4} \lambda_m + 0.35), \ \ \mathrm{W/(m \cdot K)} , \quad (30)$$

$$\lambda_g = \lambda_G\,[0.55\,(T/T_1)^2 - 1.62T/T_1 + 0.26] \times$$

$$\times\, (0.76\rho/\rho_1 + 0.24)\,(8.4 \cdot 10^{-2} \sqrt{\lambda_m} + 2.715), \ \ \mathrm{W/(m \cdot K)} . \quad (31)$$

Equations (30) and (31) determine the dependence of the contribution of thethermal conductivity of the filling gas to the effective thermal conductivity of the catalysts under investigation λ_g on temperature T, thermal conductivity of the filling gas λ_G, load density ρ, and thermal conductivity of the metallic particles introduced into the catalysts λ_m.

A check of Eqs. (29), (30), and (31) for the supports and catalysts under investigation showed that they approximate the experimental data with an error up to 8%.

With Eqs. (29), (30), and (31) one can calculate the contribution of the thermal conductivity of the filling gas to the effective thermal conductivity of supports and catalysts not studied previously that contain various weight concentrations of theintroduced metallic particles and have various porosities within the temperature interval 293–1073 K.

From relationship (23), in view of Eqs. (16), (21), (22), (23), (29)-(31) we obtain the following equations for calculation of the effective thermal conductivity of loads of catalysts and supports:

for catalysts

$$\lambda_{ef} = (0.055\, d/d_1 + 0.945)\,[1.25\rho/\rho_1 - 0.245)\,(6.15 \cdot 10^{-5} \lambda_m +$$

$$+\, 5.26 \cdot 10^{-2}) + (1.55T/T_1 - 0.5)\,(0.71\rho/\rho_1 + 0.29)\,(2.17 \cdot 10^{-5} \lambda_m +$$

$$+\, 22.53 \cdot 10^{-3})] + (0.58 + 0.42T/T_1)\,(0.63\lambda_{GT_1}/\lambda_{GT_1}' + 0.37)\,(0.68\rho/\rho_1 +$$

$$+ 0.32)(1.74\cdot 10^{-4}\lambda_m + 0.35), \quad W/(m\cdot K), \tag{32}$$

$$\lambda_{ef} = (0.055\, d/d_1 + 0.945)\,[(\rho/\rho_1 - 0.245)(6.15\cdot 10^{-5}\lambda_m +$$

$$+ 5.26\cdot 10^{-2}) + (1.55T/T_1 - 0.5)(0.71\rho/\rho_1 + 0.29)(2.17\cdot 10^{-5}\lambda_m +$$

$$+ 22.53\cdot 10^{-3})] + \lambda_G\,[0.55\,(T/T_1)^2 - 1.62T/T_1 + 0.26]\times$$

$$\times (0.76\rho/\rho_1 + 0.24)(8.4\cdot 10^{-2}\sqrt{\lambda_m} + 2.715), \quad W/(m\cdot K); \tag{33}$$

for supports

$$\lambda_{ef} = (0.055\, d/d_1 + 0.945)\,[(0.189 - 14\cdot 10^{-5}\rho) +$$

$$+ (1.5T/T_1 - 0.5)(83.9\cdot 10^{-3} - 61.3\cdot 10^{-6}\rho)] + (0.58 + 0.42T/T_1)\times$$

$$\times (0.63\lambda_{GT_1}/\lambda'_{GT_1} + 0.37)(0.68 - 34\cdot 10^{-5}\rho), \quad W/(m\cdot K). \tag{34}$$

Equations (32)-(34) determine the dependence of the effective thermal conductivity of the load of catalysts and supports on temperature T, granule dimensions d, load density ρ, thermal conductivity of the introduced metallic particles λ_m, and thermal conductivity of the filling gas λ_G.

A check of Eqs. (32)-(34) showed that they describe the effective thermal conductivity of loads of catalysts and supports with an error up to 8%.

With Eqs. (32)-(34) one can calculate the effective thermal conductivity of catalysts and supports not studied experimentally as a function of temperature, granule dimensions, load density ρ, and concentration and type of introduced metallic particles in various gaseous media.

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