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Computational simulation characteristics desorption in TPS aggregates

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Abstract. The article describes the modified model of desorption in a continuously operating apparatus in fluidized bed, which allows for a refined timing warm adsorbent particles of spherical shape at a flow of hot air to equalize the temperature along the radius of granules and assess relevant energy costs.

Recovery absorbance adsorbent needed in cases of realization of technological cycles with continuous flow of a large amount of air [1], or a freestanding conditions (aircraft, space stations, submarines [2]). Gas flow pattern of interaction with the adsorbent depends on the design of desorption installation [2].

On the complexity and energy consumption of this stage can be judged according to the literature. In the dehumidification plants silicagel adsorbent during regeneration is heated up to 100...110 °C. To prepare the gel for subsequent absorption, it is cooled by blowing cold air or other gas [1, 2]. Application temperature above or decreases below the optimum adsorption capacity of the sorbent. Conducting desorption unnecessarily high temperatures also increase energy consumption of the process [2, 3]. Adsorbent used for drying hot gas having a temperature of silica gel 573 . . . 653 K.

In the thesis [2] gives the maximum temperature regeneration gas equal to 673 K, the temperature of the end of the heating – 473 K.

We describe a modified model of desorption, which allows to carry out a refined calculation time of heating the adsorbent particles to align the radial temperature granules and assess relevant energy costs.

The adsorbent in the form of spherical particles with a diameter d is washed with hot air having a temperature t_b, in a continuously operating machine with a weighted layer, characterized fluidization number k_p [3]. The adsorbent is supplied to the apparatus from an initial temperature t_0. Thermophysical properties of its $(\rho, c, \lambda.)$ are known.

Required to determine the time required to heat the grains of the adsorbent to temperatures t_k, close to the ambient temperature ($\Delta t = t_b - t_k = 5 \ldots 10\,^\circ$C.), and compute the amount of heat used for heating the spent adsorbent mass Q.

The process of warming adsorbent granules considering the assumptions made following described boundary value problem [4].

$$\frac{\partial T}{\partial \tau} = a\left(\frac{\partial^2 T}{\partial r^2} + \frac{2}{r}\frac{\partial T}{\partial r}\right); \qquad (1)$$

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$$\text{at}\tau = 0 \;\; T = T_0; \;\; \text{at } r = 0 \;\; \frac{\partial T}{\partial r} = 0; \;\; \text{at } r = d_c/2 \;\; \lambda_c \frac{\partial T}{\partial r} = \alpha_b \left(T_b - T\right). \tag{2}$$

There α_b – coefficient of heat transfer from the heated air to the adsorbent grains.

The manual [3] to calculate the time of heating pellets used as a nomograms, of the relative temperature at the center of the number of pellets Bio different Fourier numbers.

For more accurate analysis and facilitate parametric analysis on the PC used the exact analytical solution of this problem, which has the form [4]

$$T\left(r, \tau\right) = T_b - \left(T_b - T_0\right) \sum_{n=1}^{\infty} A_n B_n \exp\left(-\mu_n^2 Fo\right), \tag{3}$$

there μ_n– roots of the characteristic equation

$$\mu_n \operatorname{ctg}\left(\mu_n\right) = 1 - Bi. \tag{4}$$

Coefficients and parameters in (3) and (4) were calculated as follows:

$$\mathrm{Bi} = \frac{\alpha_b d_c}{2\lambda_c}; \;\; \mathrm{Fo} = \frac{4a_c\tau}{d_c^2}; \;\; A_n = (-1)^{n+1} \frac{2\mathrm{Bi}\sqrt{\mu_n^2 + (\mathrm{Bi}-1)^2}}{\mu_n^2 + \mathrm{Bi}\left(\mathrm{Bi}-1\right)}; \;\; B_n = \frac{d_c \sin\left(\mu_n \frac{2r}{d_c}\right)}{2r\mu_n}. \tag{5}$$

In [4], the values of the first six roots for different values of the Bio number (Bi). In applied problems using two-three roots.

When calculating on PC tabular representation roots inconvenient and using different interpolation formulas. The manual [5] provides such approximation:

$$\mu_1 = \sqrt{7,5\left[\sqrt{1 + \mathrm{Bi}\left(0,8 + 0,04\mathrm{Bi}^2\right)}\right] - 1} \quad \text{when } \; \mathrm{Bi}{\le}1; \tag{6,a}$$

$$\mu_1 = \frac{\pi}{2}\left\{1 + \frac{1,5}{2+\mathrm{Bi}}\left[\sqrt{1 + \frac{16\left(\mathrm{Bi}-1\right)\left(\mathrm{Bi}+2\right)}{3\pi^2}} - 1\right]\right\} \quad \text{when } \; \mathrm{Bi}{>}1. \tag{6,b}$$

For the second and third roots used Lagrange interpolation polynomial to the second power [6].

In order to clarify the calculation of the coefficient of heat transfer from the air to the surface of the sorbent granules in fluidized bed, carried out in the manual [3] using the nomograms brought below the corresponding theoretical and experimental curves for thermal mass transfer in such an environment.

Criterion value is calculated according to the formula of Archimedes

$$Ar_b = \frac{g\rho_b\rho_a d_a^3}{\mu_b^2}, \tag{7}$$

the density (ρ_b) and the dynamic viscosity of air (μ_b) are taken at t_b. Used in their calculation approximation dependences of the handbook [7]. In contrast to the benefits [3], where the critical number was Lyaschenko of nomograms in the improved method is evaluated by Reynolds for speed-fall

$$\mathrm{Ly}_k = \mathrm{Re}_v^3/\mathrm{Ar}_b, \tag{8,a}$$

determined by solving the quadratic equation [8]

$$0,351\mathrm{Re}_v^2 + 18\mathrm{Re}_v - \mathrm{Ar}\varepsilon^{4,75} = 0. \tag{8,b}$$

Then there was the critical fluidization velocity

$$w_k = \left(g\rho_c\mu_b \mathrm{Ly}_k/\rho_b^2\right)^{1/3}. \tag{9}$$

Table 1. Characteristics of the fluidized bed defined by "manual" and refined techniques.

Options	Ly_k	w_k, M/c	Ly	Re	α, $\mathrm{B_T/(M^2K)}$	t_a, c
findings [6]	2.75	1.09	174	773	290	16
improved technique	4.20	1.27	268.8	1520	436.3	11.2

The air speed, referred to the cross section of the machine is

$$w_b = k_p w_k.$$

For this rate is calculated criterion Lyaschenko

$$\mathrm{Ly} = \rho_b w_b^3 / (g \rho_c \nu_b). \quad (10)$$

From the values of properties and Re_b Ar_b, determined porosity fluidized bed [8]

$$\varepsilon_p = [\mathrm{Re}_v (\mathrm{Re}_v/\mathrm{Ar}_b)(18 + 0,36\,\mathrm{Re}_v)]^{0,21}. \quad (11)$$

The manual [3], this value was using nomograms.

Reynolds airflow

$$\mathrm{Re}_b = w_b d_c / \left(\varepsilon_p \nu_b\right). \quad (12)$$

Nusselt number for the given mode of heat transfer

$$\mathrm{Nu}_b = 0,\ 4\mathrm{Re}_b^{0,67} \mathrm{Pr}_b^{0,33}, \quad (13)$$

The coefficient of heat transfer from air to the surface of the granule

$$\alpha_b = \lambda_b \mathrm{Nu}_b / d_c. \quad (14)$$

Appearing in (13) and (14) Prandtl and coefficient of thermal conductivity, determined at t_b.

It then computes the Bio criterion for the first expression of (5), the first three values are the roots of the transcendental equation (4) are computed coefficients A_n, B_n and the coefficients are set equal to 1 and the formula (3) are the temperatures for different times (Fourier numbers).

The amount of heat required to heat the mass of the adsorbent to temperatures t_k, calculated in the usual manner

$$Q_c = c_c M_c (t_k - t_0). \quad (15)$$

The described algorithm has been implemented in Turbo Pascal. To test the compiled and debugged the program dealt with the problem of benefits [3] solved using two nomograms. As implied adsorbent zeolite NaX, having a density $\rho_c = 1100\,\mathrm{kg/m^3}$, the specific heat capacity of mass $c_c = 870\,\mathrm{J/(kg \cdot K)}$, the thermal conductivity $\lambda_c = 0.24\,\mathrm{W/(m \cdot K)}$ temperature $t_b = 190\,^\circ\mathrm{C}$, the initial temperature of the pellets $t_c = 20\,^\circ\mathrm{C}$, the final temperature $-t_k = 185\,^\circ\mathrm{C}$, fluidization by $k_p = 4$.

Comparison of the results showed that the presence of nomograms of the critical number Lyaschenko, porosity layer and weighted criterion Fo. error gave 34%, 66% and 43, respectively. And this has led to large values of the Reynolds number and the heat transfer coefficient from the air to the granule adsorbent and less time warming her. The amount of heat it takes to perform the desorption sample of 1 kg of zeolite NaX, equals 143.6 kJ.

The manual [3], the thermal properties of silica gel at 293 K: $c_c = 920\,\mathrm{J/(kg \cdot K)}$, $\lambda_c = 0.2\,\mathrm{W/(m \cdot K)}$, $\rho_c = 1100\,\mathrm{kg/m^3}$, with calculation of these data showed that ta increase to 14.2 s, and Q_c – to 153.1 kJ.

Varying the temperature from 200 to 400 °C during the desorption of silica granules diameter 2.85 mm showed that the warm-up time increases from 8.2 s to 10.3 s and Q_c from 161.3 to 345.6 kJ. In the case of granules with a diameter of 5.8 mm t_a increases from 25.5 to 29.8 s and Q_c – between 162 and 345.7 kJ.

To ensure these indicators needs electric heater 35 kW.

The results should be regarded as minimum as drainage granules assumed by their uniform flow. In the case of the regime inside dimensional fluidized bed aggregates TPS work area will cover a small area and there will be a need to ensure the directional movement of moist air on the area of finding a weighted layer.

In the present embodiment of dehumidification in TES silica aggregates will be located in different places in the tank as a scavenger cartridges [9]. Rate 1 kg silica technical averaged 50 ₽ and 140 ₽ zeolite. Consequently, the cost of its acquisition and use are small.

If you need to drain a fixed amount of air and adsorbent has a low price, produced on an industrial scale, in the opinion of the applicant, it is permissible to implement disposable adsorbing cartridges, kitted out with silica gel or zeolite. If necessary, repeating this procedure several times.

Therefore, this scheme can be waived from the adsorbent regeneration step, which greatly simplifies and reduces the cost of air drying procedure.

Thus, implemented model desorption of moisture absorber on PC, which allows more accurate in comparison with the existing method, which uses a nomogram to calculate the temperature field inside the adsorbent pellets and determine its drying time and the cost of heat for this procedure.

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