CALCULATION OF THE PERIODIC COOLING OF A FLUIDIZED BED

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On the basis of an analytical solution equations are recommended that make it possible to determine the temperature of the medium at the bed outlet and the temperature of the particles and the equipment walls at any point during the cooling (heating) of a fluidized bed.

In fluidized-bed heat-exchange equipment periodically loaded with fine-grained material the processes of heat transfer between the particles and the medium proceed under nonstationary conditions. Heat transfer between the walls of the equipment and the fluidized bed may have a significant effect on this process.

In this note we present an analytical solution, similar to that proposed in [1], to the problem of determining the law of variation of the temperatures of the medium at the outlet from the bed, the particles and the reactor walls at any moment during the cooling (heating) of the bed. In deriving the basic equations it was assumed that the thermal resistance of the particles themselves is small, that owing to the intense mixing the temperature of the particles is constant throughout the bed, that the thermophysical characteristics of the medium, the particle material, and the walls are constant, and that no heat is lost to the surrounding medium.

The mean integral temperature of the medium over the thickness of the bed, assuming ideal displacement, is given by [2]

$$t_h^{m}(\tau) = t_1 - [t_2(\tau) - t_1]\, q. \tag{1}$$

Using the heat balance and heat transfer equations, we obtain integral expressions for determining the corresponding temperatures:

$$t_p(\tau) = \exp[-a\tau]\left\{\int_0^\tau a\,[t_1 + (t_2(\tau) - t_1)\,q]\times \exp[a\tau]\,d\tau + t_p(0)\right\}, \tag{2}$$

$$t_w(\tau) = \exp[-a_1\tau]\left\{\int_0^\tau a_1\,[t_1 + (t_2(\tau) - t_1)\,q]\times \exp[a_1\tau]\,d\tau + t_w(0)\right\}, \tag{3}$$

$$aq\,\exp[-a\tau]\int_0^\tau t_2(\tau)\exp[a\tau]\,d\tau + a_1 b_1 q\exp[-a_1\tau]\int_0^\tau t_2(\tau)\exp[-a_1\tau]\,d\tau + \exp[-a\tau]\,[t_p(0) - A] + \exp[-a_1\tau]\,[b_1 t_w(0) - B] + A + B + G - Ct_2(\tau) = 0. \tag{4}$$

Solving the last equation we obtain a relation for the temperature of the medium at the outlet from the fluidized bed at any moment of time with allowance for the heat accumulated in the reactor walls:

$$t_2(\tau) = -\frac{L}{N} + 2\exp\left[-\frac{M}{2}\tau\right]\times\left[\frac{\frac{D}{2}\sqrt{M^2+4N} + \frac{LM}{2N}}{\sqrt{M^2+4N}}\times \mathrm{ch}\left(\frac{\tau}{2}\sqrt{M^2+4N}\right) + \frac{\frac{L}{2N}\sqrt{M^2+4N} + K - \frac{DM}{2}}{\sqrt{M^2+4N}}\times \mathrm{sh}\left(\frac{\tau}{2}\sqrt{M^2+4N}\right)\right]. \tag{5}$$

Then substituting for $t_2(\tau)$ in Eqs. (2) and (3), after transformations we have

$$t_p(\tau) = t_p(0) + t_1(1 - \exp[-a\tau]) + \frac{2aq}{a^2 - Ma - N}\left\{\exp\left[-\frac{M}{2}\tau\right]\times\left\{\left[aK - KM/2 - aDM/2 - DN + L(aM - M^2 - 2N)/2N\right]\times\left[\sqrt{M^2+4N}\right]^{-1}\times \mathrm{sh}\left(\frac{\tau}{2}\sqrt{M^2+4N}\right) + \frac{1}{2}\left[aD - K + \frac{L(a-M)}{N}\right]\times \mathrm{ch}\left(\frac{\tau}{2}\sqrt{M^2+4N}\right)\right\} - \left[aD - K + \frac{L(a-M)}{N}\right]\exp[-a_1\tau]\right\}, \tag{6}$$

$$t_w(\tau) = t_w(0) + t_1(1 - \exp[-a_1\tau]) + \frac{2a_1 q}{a_1^2 - Ma_1 - N}\left\{\exp\left[-\frac{M}{2}\tau\right]\times\left\{\left[a_1K - \frac{KM}{2} - \frac{a_1DM}{2} - \right.\right.\right. \tag{7}$$

$$-DN+\frac{L(a_1M-M^2-2N)}{2N}\Bigg]\times\left[\sqrt{M^2+4N}\right]^{-1}\times$$

$$\times\,\mathrm{sh}\left(\frac{\tau}{2}\sqrt{M^2+4N}\right)+$$

$$+\frac{1}{2}\left[a_1D-K+\frac{L(a_1-M)}{N}\right]\times$$

$$\times\,\mathrm{ch}\left(\frac{\tau}{2}\sqrt{M^2+4N}\right)\Bigg\}-$$

$$-\left[a_1D-K+\frac{L(a_1-M)}{N}\right]\exp[-a_1\tau]\Bigg\}. \quad (7)\ \text{(cont'd)}$$

If in expressions (6), (7) we assume that $1/c_1 > 3$, $a_1 \ll a$, $b_1 \to 0$ (in this case $t_p(0) \approx t_2(0)$, $q \approx 1 - c_1$), they simplify to

$$t_2(\tau)=t_1+\exp\left[-a_1\left(c_1+\frac{a_1}{a}\right)\tau\right]\times$$

$$\times\Bigg\{\left[t_p(0)-t_1\frac{c_1+a_1}{c_1-a_1}\right]\times\mathrm{ch}\left[\frac{\tau}{2}(c_1a-a_1)\right]+$$

$$+\left[\frac{t_p(0)(1-2c_1)+3t_1b_1-4t_1c_1}{c_1(1-a_1)}-t_1\right]\times$$

$$\times\,\mathrm{sh}\left[\frac{\tau}{2}(c_1a-a_1)\right]\Bigg\}, \quad (8)$$

$$t_p(\tau)=t_p(0)+t_1(1-3\exp[-a\tau])+$$

$$+\frac{2}{a}\exp\left[-\frac{\tau}{2}(c_1a+a_1)\right]\times$$

$$\times\Bigg\{(a-a_1)t_1\,\mathrm{ch}\left[(c_1a-a_1+b_1a)\frac{\tau}{2}\right]+$$

$$+\frac{2a(a-a_1)t_p(0)+t_1[(c_1a-a_1)^2-c_1a_1a]}{(c_1a-a_1)/a}\times$$

$$\times\,\mathrm{sh}\left[\frac{\tau}{2}(c_1a-a_1+b_1a)\right]\Bigg\}, \quad (9)$$

$$t_w(\tau)=t_w(0)+t_1(1-\exp[-a_1\tau])-$$

$$-\frac{2(1-c_1)}{b_1a}\Bigg\{\exp\left[-\frac{\tau}{2}(c_1a+a_1)\right]\times$$

$$\times\Bigg\{\left[\frac{t_p(0)(a-a_1)+t_1(c_1a-a_1)b_1}{2}\right]\times$$

$$\times\,\mathrm{ch}\left[\frac{\tau}{2}(c_1a-a_1+ab_1)\right]+$$

$$+\left[(a_1-a)t_p(0)+\frac{(c_1a-a_1)^2-3ab_1(c_1a+a_1)}{c_1a-a_1+ab_1}\right]\times$$

$$\times\,\mathrm{sh}\left[\frac{\tau}{2}(c_1a-a_1+ab_1)\right]\Bigg\}-[(a-a_1)t_p(0)+$$

$$+t_1(c_1a-a_1)b_1]\exp[-a_1\tau]\Bigg\}. \quad (10)$$

The relations obtained can be recommended for determining the duration of the periodic process or the temperatures of the particles, walls, and medium at any moment during the cooling (heating) of a fluidized bed.

NOTATION

G_m, G_p, G_w are the mass flow rates of the fluidizing medium, mass of the particle charge, and the reactor walls in the region of the fluidized bed; c_m, c_p, c_w are the mass specific heats of the fluidizing medium, particle material, and the reactor walls; F_p, F_w are the surface areas of the particles and the reactor walls; α_p, α_w are the coefficients of heat transfer from the particles to the fluidizing medium and from the fluidized bed to the reactor walls; t_1 is the temperature of the fluidizing medium at the inlet to the bed; $t_2(0)$, $t_p(0)$, $t_w(0)$ are the temperatures of the fluidizing medium, the particles and the reactor walls at $\tau = 0$; $t_2(\tau)$, $t_p(\tau)$, $t_w(\tau)$—temperatures of fluidizing medium, particles and reactor walls at time τ; $D = [G + t_p(0) + b_1t_w(0)]/C$; $K = [Aa + Ba_1 + G(a + a_1) + a_1t_p(0) + ab_1t_w(0)]/C$; $L = (A + B + G)aa_1/C$; $G = t_1(q - 1 - b_1 + b_1q + c_1)$; $M = [c_1(a + a_1) - aq - a_1b_1q]/C$; $N = aa_1(q + b_1q - C)/C$; $A = t_1(1 - q)$; $B = b_1t_1(1 - q)$; $C = q + b_1q + c_1$; $a = \alpha_p F_p/G_p c_p$; $a_1 = \alpha_w F_w/G_w c_w$; $c_1 = G_m c_m c_m/\alpha_p F_p$; $b_1 = \alpha_w F_w/\alpha_p F_p$; $q = 1/(1 - \exp[-1/c]) - c_1$.

REFERENCES

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