THERMAL EFFICIENCY OF CROSSCURRENT DESIGN IN MULTIZONE FLUIDIZED-BED FURNACES

V. M. Dement'ev, T. I. Kolesnik,
A. N. Vanzha, and L. S. Bolikhova

UDC 66.046.4:536.244

It is shown that crosscurrent design is an efficient way of organizing heat exchange in the preheating and cooling zones of multizone fluidized-bed furnaces.

We shall consider a multizone furnace with fluidized bed and evaluate the possibilities for utilization of the heat of gases and finished product; we assume that after traversing a zone, the gas and the material are at the same temperature, i.e., each furnace zone acts as a mixing heat exchanger [1-6].

Then following the n-th zone, the temperature of the material is

$$t_{\mathrm{n\ mat}} = t_{n+1}\frac{1}{1+W} + t_{n-1}\left[1 - \frac{1}{1+W}\right]. \tag{1}$$

We now assume that we use a baffle to separate the given zone into two sections.

Following the first temperature, the material is at the temperature

$$t'_{\mathrm{n\ mat}} = t_{n+1}\frac{1}{1+\frac{W}{2}} + t_{n-1}\left[1 - \frac{1}{1+\frac{W}{2}}\right], \tag{2}$$

while following the second section (i.e., following the zone that has been divided into two sections) when $t_{n+1} = t'_{\mathrm{n\ mat}}$,

$$t''_{\mathrm{n\ mat}} = t_{n+1}\frac{1}{\left(1+\frac{W}{2}\right)^2} + t_{n-1}\left[1 - \frac{1}{\left(1+\frac{W}{2}\right)^2}\right]. \tag{3}$$

Similarly, for division into three sections,

$$t'''_{\mathrm{n\ mat}} = t_{n+1}\frac{1}{\left(1+\frac{W}{3}\right)^3} + t_{n-1}\left[1 - \frac{1}{\left(1+\frac{W}{3}\right)^3}\right], \tag{4}$$

while for i sections we have

$$t^{i}_{\mathrm{n\ mat}} = t_{n+1}\frac{1}{\left(1+\frac{W}{i}\right)^i} + t_{n-1}\left[1 - \frac{1}{\left(1-\frac{W}{i}\right)^i}\right]. \tag{5}$$

In the limit, when i → ∞,

$$t^{i\to\infty}_{\mathrm{n\ mat}} = t_{n+1}e^{-W} + t_{n-1}(1 - e^{-W}). \tag{6}$$

The exponential relationship (6) resembles that obtained earlier for determination of temperatures in a pneumatic conveyer, which is close to ideal-displacement equipment [7, 8] and crossflow fluidized-bed equipment in the absence of particle mixing [7], i.e., when the number of sections goes to infinity we approach an ideal-displacement device, as we might expect.

Institute of Ferrous Metallurgy, Donetsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 17, No. 2, pp. 280-284, August, 1969. Original article submitted November 9, 1968.

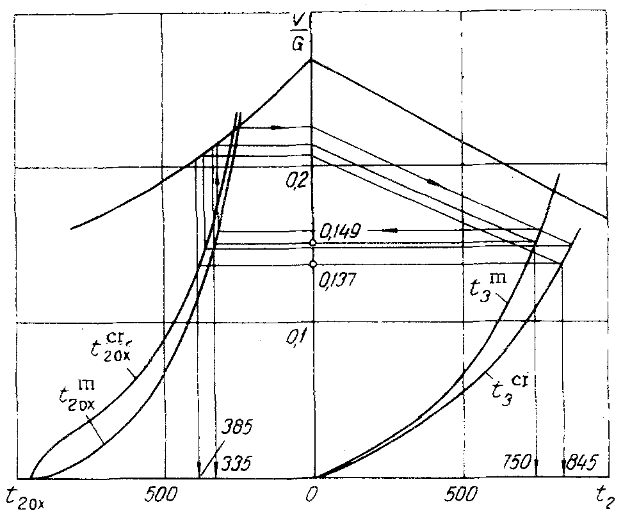

Fig. 1. Auxiliary nomogram for four-zone furnace with direct-contact and crossflow–counterflow heat-exchange systems.

From (6), we can determine the temperature of the material following the fluidized-bed zone for ideal displacement of the material; from the thermal viewpoint, this corresponds to crossflow heat exchange.

Comparing (1) and (6), we see that a crossflow heat exchanger is more effective than a direct-contact design. The efficiency is higher the larger the ratio of the water equivalents of the gas and the material.

Thus, for example, when material at $t_{n+1} = 1000$°C is cooled by cold air at $t_1 = 20$°C, with $W = 1$ and 2, when the zone is acted in direct-contact mode, we obtain 510°C and 347°C, respectively; when the zone is switched to crossflow operation, the final temperature of the material is 390°C and 152°C.

It should be noted that the so-called counterflow multizone fluidized-bed heat exchangers described previously [1-5] are essentially direct-contact–counterflow devices, since a single element in such a system, which is of the counterflow type as a whole, operates as a direct-contact heat exchanger.

Below we shall consider a crossflow–counterflow heat exchanger, i.e., we shall look at the case in which a single element operates as a crossflow device within an overall counterflow system.

We consider a multizone furnace; the preheating and cooling zones are separated into i sections by baffles. There are no baffles in the fuel firing zone.

We employ the methods of [6] for the calculations. We recall that on the right-hand quadrant of the design nomogram we construct the relationship

$$\left(\frac{V}{G}\right)_{\mathrm{m}} = \frac{c_1}{Kc_{\mathrm{g}}\eta_{am}}\frac{1}{X_n}, \tag{7}$$

where

$$\frac{1}{X_n} = \frac{t_n - t_{n-1}}{t_{n-1} - t_n}. \tag{8}$$

We write (5) in a similar form:

$$\frac{t_n - t_{n+1}}{t_{n-1} - t_n} = \left(1 + \frac{W}{i}\right)^i - 1 \tag{9}$$

since $W = VKc_g\eta_{am}/Gc'$, we can solve (9) for V/G,

$$\left(\frac{V}{G}\right)_{\mathrm{cr}} = \frac{c'}{Kc_{\mathrm{g}}\eta_{am}}\, i\left[\left(\frac{1}{X_n} + 1\right)^{\frac{1}{i}} - 1\right]. \tag{10}$$

We can reduce (10) to the form (7),

$$\left(\frac{V}{G}\right)_{\mathrm{cr}} = \frac{c'}{Kc_{\mathrm{g}}\eta_{am}}\frac{A}{X_n}, \tag{11}$$

TABLE 1. Comparison of Characteristics for Four- and Six-Zone Limestone Furnaces with Fluidized Bed

Number of zones	Heat-exchange system	V/G, m^3/t	Temperature, °C	
			exit gases	material removed
Four	Direct-contact– counterflow	149	453	335
Four	Crossflow—counterflow	137	341	282
Six	Direct-contact – counterflow	136	362	180

where

$$A=\frac{i\left[\left(\frac{1}{X_n}+1\right)^{\frac{1}{i}}-1\right]}{\frac{1}{X_n}}, \tag{12}$$

or, in the limit, when i → ∞,

$$A=\frac{\ln\left(\frac{1}{X_n}+1\right)}{\frac{1}{X_n}}. \tag{13}$$

Similarly, we can show that for the cooling zone the specific gas flow rate under crosscurrent conditions can be represented as

$$\left(\frac{V}{G}\right)_{\text{cr}}=\frac{c_1\eta_{am}}{Lc_a}X_m\frac{1}{A}, \tag{14}$$

where A is the same correction factor, found from (12) or (13). In the given case, the correction factor A is shifted to the denominator, since the direction of heat exchange is reversed, and the gas and material temperature are interchanged.

In this manner, we can design a multizone furnace with sectionalized fluidized beds in the preheating and cooling zones [6] with a correction for sectionalization in the form of the coefficient A.

As an illustration, let us look at calculations for a four-zone limestone roasting furnace using a sectionalized fluidized bed with two preheating zones and one cooling zone.

The initial data are

$$i=4;\ \xi=1{,}7;\ t_{n-1}=950\,^\circ\text{C};\ t_{n+1}=10\,^\circ\text{C};\ t_{\text{o air}}=50\,^\circ\text{C};$$

$$L_{\alpha=1,1}=10{,}5\ \text{Nm}^3/\text{Nm}^3;\ K_{\alpha=1,1}=11.5\ \text{Nm}^3/\text{Nm}^3;$$

$$c_1=0.96\ \text{kJ/kg}\cdot\text{deg C};\ \ c_\text{r}=1.46\ \text{kJ/kg}\cdot\text{deg C};\ \ c_\text{B}=\ \text{kJ/kg}\cdot\text{deg C};$$

$$q=1670\ \text{kJ/kg};\qquad Q_\text{p}^l=35500\ \text{kJ/Nm}^3.$$

We use the results to construct an auxiliary nomogram (see Fig. 1). In the right-hand quadrant, the temperature of the material is plotted along the axis of abscissas, while the air preheating temperature is plotted in the left-hand quadrant.

As we see, sectionalization of the preheating and cooling zones is provided for in the graph by shifting the curves in accordance with A.

Table 1 shows the results obtained from this nomogram for a four-zone furnace in direct-contact –counterflow operation (with no sectionalization of the preheating and cooling zones) and for crossflow –counterflow operation (with sectionalization). For comparison, we have also shown calculated results for a six-zone furnace (three preheating zones and two cooling zones), with direct-contact–counterflow operation.

As Table 1 shows, the use of crosscurrent heat exchange in the preheating and cooling zones makes it possible either to improve the furnace thermal characteristics or, while preserving the previous characteristics, to reduce the total number of furnace zones (from six to four in our case).

NOTATION

W	is the ratio of the water equivalents of gas and material;
V, G	are the per-hour flow rates of gas (fuel) and finished product, Nm^3/h, kg/h;
K, L	are the output of combustion products and the air consumption per Nm^3 of gas (fuel), Nm^3/Nm^3;
c_a, c_g, c', c_1	are the heat capacities of the air, gas, raw material, and finished product, $kJ/Nm^3 \cdot deg$, $kJ/kg \cdot deg$;
q	is the fuel flow rate for the thermal process per kilogram of finished product, kJ/kg;
n_{am}	is the coefficient for the heat lost to the ambient;
Q_p^l	is the calorific value of the gas (fuel), kJ/Nm^3;
t_{n+1}	is the initial temperature of the material supplied to the n-th zone of the fluidized bed, deg;
t_{n-1}	is the same, for gas;
t_n	is the temperature in the n-th zone, deg;
$t_{0\,air}$	is the initial temperature of the air, deg;
ξ	is the material flow-rate coefficient;
i	is the number of sections.

LITERATURE CITED

1. V. M. Dement'ev, Inzh.-Fiz. Zh., 2, No. 12 (1959).
2. R. Rose and L. Winterstein, Chemische Techn., 13, No. 11 (1961).
3. A. P. Baskakov, Inzh.-Fiz. Zh., 6, No. 1 (1963).
4. A. I. Tamarin, Inzh.-Fiz. Zh., 6, No. 4 (1963).
5. I. G. El'perin and V. A. Minkov, Inzh.-Fiz. Zh., 6, No. 11 (1963).
6. V. M. Dement'ev, Inzh.-Fiz. Zh., 11, No. 6 (1966).
7. N. I. Gel'perin and V. G. Ainshtein, Khimicheskaya Promyshlennost, No. 10 (1962).
8. N. I. Gel'perin, V. G. Ainshtein, and V. B. Kvasha, Fundamentals of Fluidized-Bed Engineering [in Russian], Khimiya (1965).
9. A. I. Tamarin, Inzh.-Fiz. Zh., 7, No. 5 (1964).