SECTIONING OF FLUIDIZED BEDS BEING MOISTENED

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The effect of sectioning of a fluidized bed, which is being moistened with the release of heat of hydration, on the temperature of the material at the outlet from the apparatus is studied using a mathematical model.

Heat exchange and mass exchange in sectioned fluidized beds were studied in [1]. However, a fluidized bed being moistened with the release of heat of hydration has certain special features which are manifested, in particular, when it is sectioned. The authors [2] have obtained a system of equations relating the output parameters of a moistened fluidized bed, both with respect to the gas and to the solid material, with the input parameters. It was also shown that this mathematical model reflects the integral results of the complex heat- and mass-exchange processes occurring in a fluidized bed which is being moistened. A study of a sectioned fluidized bed which is being moistened is carried out in the present report using a mathematical model of the process. Three schemes have been considered: sectioning of the fluidized bed into two parts by height with opposite movement of the gas and the material, arbitrarily called "countercurrent," and with movement of the gas and the material in the same direction, henceforth called "concurrent," as well as sectioning of the fluidized bed along the length of the apparatus – "crosscurrent."

A detailed explanation of the notation adopted for the parameters of the process is given in the "Notation" section. The calculations were conducted in application to the process of moistening of sodium sulfate before briquetting in fluidized bed apparatus constructed at the Ural Scientific-Research Chemical Institute [3]. However, the results of the calculations are of interest primarily in the analysis of processes taking place in a fluidized bed being moistened with the release of reaction heat.

Parameters of the apparatus above which are close to those for summer operating conditions are adopted in the calculations, namely: air temperature at inlet to apparatus $\theta_0 = 25°C$, moisture content of air at inlet $Z_0 = 8$ g/kg, temperature of material at inlet $T_0 = 20°C$; the specific output K, kg/kg, expressed in the form of the ratio of the material output of the apparatus to the amount of air supplied to the apparatus, is taken as 0.8 kg/kg. The material was moistened to 9% in the apparatus and in the process 75 kcal of heat was released per kilogram of water going into the moistening.

The total height H of the fluidized bed in both sections for the "concurrent" cases was taken as constant and equal to 0.47 m.

The relative height h_1 of the fluidized bed in the first section along the path of the gas and the degree of moistening of the material over the cross sections were varied in the calculations.

The results of these calculations for the "countercurrent" scheme are presented in Fig. 1.

As is seen, with an increase in the moistening of the material in the second section the temperature of the material at the outlet from the apparatus is reduced when h_1 is constant. The lowest temperature is observed with complete (to 9%) moistening of the material in the second section. That amount of moisture which can be completely evaporated from the surface of the material without increasing its moisture is supplied to the first section in this case; thus, the first section operates as a refrigerator in this case.

It also follows from Fig. 1 that to obtain the lowest temperature of the material at the outlet from the apparatus the relative bed height h_1 of the first section should lie in the range of 0.4-0.6.

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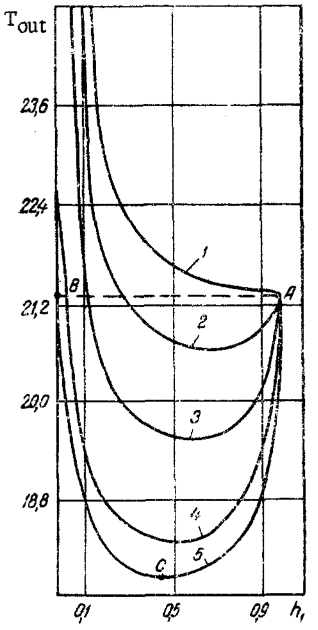

Fig. 1

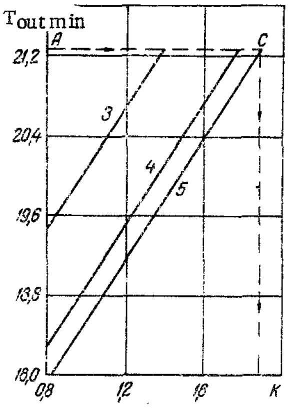

Fig. 2

Fig. 1. Dependence of temperature of material at outlet (T_{out}) from a two-stage apparatus operating on the "countercurrent" scheme with variation in the relative height h_1 of the fluidized bed in the first section and in the degree of moistening of the material in the second section: 1) material not moistened; 2) moistening by 30%; 3) by 60%; 4) by 90%; 5) complete moistening of material (by 100%). T_{out}, °C.

Fig. 2. Dependence of lowest temperature (°C) of material discharging from a two-section countercurrent apparatus on the specific load K, kg/kg. The numbers of the curves correspond to the numbers of the curves in Fig. 1; point A is the temperature of the material discharging from a one-section apparatus; point C is the temperature of the material at the outlet from a two-section countercurrent apparatus.

It is interesting to note that in all the modes under consideration one can attain a temperature of the material discharging from the apparatus which is considerably lower than the temperature θ_0 = 25°C of the air supplied to the apparatus.

When the relative height of the fluidized bed in the first section equals unity the two-section apparatus degenerates into a one-section apparatus.

The point A characterizes the temperature of the material at the outlet from a one-section apparatus. Earlier [2] we determined the temperature of the material at the outlet from a one-section apparatus with the same parameters of the process. This temperature coincides with the temperature of point A.

The considerable reduction in the temperature of the material at the outlet from the apparatus when it is sectioned by the "countercurrent" scheme can be explained by the fact that with an increased specific supply of water to the second section the temperature of the material in it is considerably increased. The temperature difference between the material and the gas increases in this section and the amount of removable heat increases. With an increase in the temperature level in the second section the air temperature at the outlet from the apparatus also increases, the amount of moisture evaporated in the second section increases accordingly, and the amount of heat removed from the material through the evaporation of part of the moisture supplied to the apparatus increases.

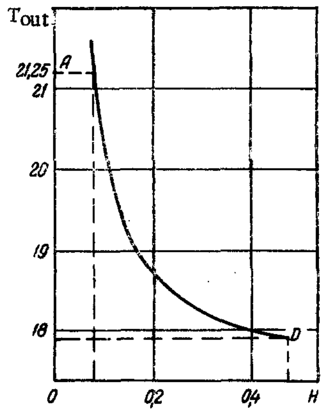

Fig. 3

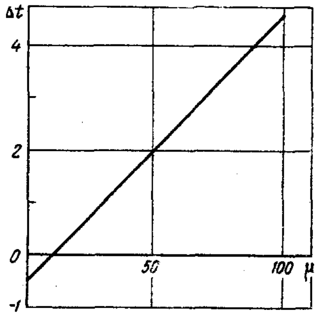

Fig. 4

Fig. 3. Dependence of the temperature of the material discharging from a two-section countercurrent apparatus on the total bed height in the two sections (H). The point A corresponds to the temperature of material discharging from a one-section apparatus at a bed height H = 0.47 m; point D corresponds to the temperature under the conditions of plotting of curve 5 in Fig. 1 and to point C lying on this curve. T_{out}, °C; H, m.

Fig. 4. Greatest reduction in temperature (°C) of material at the outlet from a two-stage countercurrent apparatus as a function of the specific heat of hydration μ, kcal/kg.

During this time the first section operates as a refrigerator, producing a further reduction in the temperature of the material before its discharge from the apparatus. When all the moisture is supplied to the second section, with the relative height of the bed in this section equal to unity, the temperature of the material discharging from the apparatus is determined by point B on curve 5 (Fig. 1). In this case the second section becomes a one-section apparatus. Naturally, the temperatures of the material at points A and B are the same. The left branches of the curves (starting with the fourth) are raised considerably above the point B. In this case there is a large amount of water supplied to the first section of the apparatus with a small bed height in it, which leads to considerable release of heat in this section and an increase in the temperature of the material discharging from the apparatus. At the same time, because of the small bed height of the first section the amount of heat removed with the gas is slight.

Curve 1 is somewhat different in nature. This curve does not give a reduction below point A in the temperature of the material discharging from the apparatus when the bed is sectioned by height. This is easily explained. Actually, curve 1 is plotted for the case of the absence of moistening of the material in the second section. This means that all the moistening of the material occurs in the first section, the bed height in which gradually decreases with a decrease in h_1, which causes an increase in the temperature of the material in this section and thus an increase in the temperature of the material at the outlet from the apparatus. The fact that the material which is in the second section is heated up because of the increased temperature of the gas coming from the first section also has an effect.

Curves characterizing the variation in the lowest temperature of the discharging material in a two-section countercurrent apparatus (point C) as a function of the specific load of the apparatus are presented in Fig. 2. As would be expected, with an increase in the specific load the temperature of the material discharging from the apparatus increases, other conditions being equal. In Fig. 2 one can trace the increase in the specific output of the apparatus with its two-stage operation by the "countercurrent" scheme in comparison with a one-section apparatus. The temperature of the material discharging from a one-section apparatus (point A) equals 21.25°C with a specific load K = 0.8 kg/kg for the parameters which we adopted for the process. The same temperature of the discharging material can be obtained with an increase in the specific output K to 1.86 kg/kg with full moistening of the material in the second section of the apparatus during its two-stage operation by the "countercurrent" scheme (curve 5).

Thus, the sectioning of the apparatus by height in the case of complex heat- and mass-exchange processes should lead to an increase in its output at a given temperature of the material at the outlet from the apparatus. In particular, for the specific case of the moistening of sodium sulfate the output of the apparatus increases by 2.34 times upon the transition to a two-stage scheme, with other conditions being equal, since the ratio of the specific outputs of the two-stage countercurrent apparatus and the one-stage apparatus equals 1.86: 0.8 = 2.34.

The dependence of the lowest temperature of the material discharging from a two-stage countercurrent apparatus on the total height H of the fluidized bed in the two sections is presented in Fig. 3. This dependence is plotted for the most favorable conditions: The material is fully moistened in the second section of the apparatus and the bed heights in the sections are equal, i.e., the conditions of operation of the two-stage apparatus correspond to point C of curve 5 in Fig. 1. Point D in Fig. 3 (the total height of the fluidized bed in the two sections is H = 0.47 m) corresponds to point C in Fig. 1. With a decrease in the total height of the bed (with the optimum ratio of heights h_1/h_2 retained) the temperature of the material discharging from the apparatus progressively increases. When the temperature of the discharging material reaches 21.25°C, i.e., the temperature level of the material discharging from a one-stage apparatus, the total height of the bed in the two sections is only 0.09 m, i.e., 5.2 times less than the bed height in the one-section apparatus. Such a marked decrease in the bed height gives a significant reduction in the energy expended on blowing, which is very considerable for fluidized-bed apparatus. As seen from Fig. 3, a twofold decrease in the total bed height in a two-section apparatus leads to an increase of only 0.6°C in the temperature of the discharging material.

We analyzed the reduction in the temperature of the material discharging from the apparatus when the amount of heat of hydration is constant (we took μ = 75 kcal/kg of water going into the moistening).

The dependence of the effect of reduction in the temperature of the material discharging from a two-stage countercurrent apparatus on the value of the specific heat of hydration is presented in Fig. 4. As is seen, with the countercurrent sectioning of the fluidized bed the temperature-reduction effect increases with an increase in μ. When $\mu = 0$ (the absence of heat release) the effect is small and it can be both positive and negative. In this case the magnitude of the effect and its sign depend on the temperature T_{out} of the discharging material, the temperature θ_0 of the air supplied to the apparatus, the temperature T_0, and the amount of the water supplied for moistening.

From what has been presented it is clear that in a whole series of cases the sectioning of a fluidized bed by height is advantageous when complex heat- and mass-exchange processes are used in industrial apparatus, especially when there is a considerable release of reaction heat. It is known, however, that the return-flow devices which are required in this case create an additional complication in the construction of the apparatus and its operation, especially in the case of the processing of a moist material.

The lengthwise sectioning of the apparatus is considerably more promising from the point of view of the structural design. In this case the sectioning can be accomplished very simply through the mounting of a transverse partition in the apparatus.

Let us examine the effect of such sectioning of a fluidized bed. The parameters adopted in the calculations are the same as in the "countercurrent" case. The height of the fluidized bed in the two sections is taken as the same and equal to H = 0.47 m. The main relationships of the behavior of the curves noted in the analysis of the "countercurrent" scheme are retained in this case.

With an increase in the moistening of the material in the first section along the path of the material the temperature of the product discharging from the apparatus is reduced. The greatest temperature reduction is observed with full moistening of the material in the first section. In this case the second section is supplied with the amount of moisture which can be fully evaporated in it. Thus, the second section operates as a refrigerator in this case.

When the relative area of the first section is $n_1 = 1$ the two-section apparatus becomes a one-section apparatus. Since all the parameters of the process are analogous to those adopted earlier for the "countercurrent" case, the temperature of the material at the outlet from the one-section apparatus is also equal to 21.25°C. The same temperature of the material at the outlet occurs when $n_1 = 0$. The maximum reduction in the temperature of the material discharging from the apparatus corresponds to $n_1 = 0.5$. The lowest temperature of the material in this case is 19.4°C. We note that the lowest temperature of the material discharging from an apparatus operating by the "countercurrent" scheme was 17.9°C, i.e., considerably lower. However, in the case of a transverse current the temperature of the material discharging from the apparatus is lower than the temperature of the air supplied to the apparatus ($\theta_0 = 25°C$) in a considerable number of the modes.

With a decrease in the degree of moistening of the material in the first section the temperature of the material discharging from the apparatus is raised. An especially considerable temperature rise is observed upon a decrease in the relative area of the second section. This can be explained as follows. The relative area of the second section decreases while the percentage of moistening of the material, i.e., the amount of water supplied to it, and thus the amount of heat released in this section, increases. In the limiting case all the water moistening the material is supplied to the second section.

It was established by the calculations that with the change to sectioning one can increase the output of an apparatus operating by the "crosscurrent" scheme by 1.54 times, providing the same temperature of the material at the outlet as in the one-section apparatus.

In the case of the operation by the "concurrent" scheme with a decrease in the relative height of the fluidized bed in the second section and variation in the degree of moistening of the material over the sections the behavior of the curves characterizing the temperature of the material at the outlet has a certain similarity to the schemes examined earlier. For example, the lowest temperatures of the discharging material are observed with full moistening of the material in the first section along the path of the gas. The temperature of the material in the extreme cases, when the apparatus becomes one-sectioned, equals 21.25°C, as in the schemes examined earlier. The temperature of the discharging material increases with a decrease in the relative height of the bed in the second section.

However, there is also an important difference in the temperature dependence of the material discharging from the apparatus. First and foremost, the temperature of the material in all the modes of operation of the sectioned apparatus is higher than in a one-section apparatus. Thus, the "concurrent" scheme does not provide any advantage for the process which we are considering.

However, certain properties of the temperature dependence are traced which might possibly find application to other processes. For example, the temperature of the material discharging from the apparatus when it is fully moistened in the first section is almost independent of the distribution of bed heights between the sections. The temperature of the discharging material depends very little on the distribution of moisture between the sections when h_2 varies from 1 to 0.7.

NOTATION

θ_0, Z_0	are the temperature and moisture content of air at inlet to apparatus,°C, g/kg;
θ_{out}, Z_{out}	are the temperature and moisture content of air at outlet from apparatus;
T_0	is the temperature of material at inlet to apparatus;
T_{out}	is the temperature of material at outlet from apparatus;
W_0	is the moisture of material at inlet to apparatus, kg/kg;
W_{out}	is the moisture of material at outlet from apparatus;
H	is the total height of fluidized bed in apparatus; for concurrent and countercurrent $H = h_1 + h_2$, where h_1 and h_2 are the heights of the fluidized bed in first and second sections, respectively;
n_1, n_2	are the first and second sections as fractions of the total grid area for crosscurrent;
μ	is the specific heat of hydration in kcal/kg of water going into moistening.

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