PERFORMANCE OF RETURN-FLOW CHANNELS IN FLUIDIZED-BED EQUIPMENT

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Overflow of free-flowing materials into a fluidized bed from an upright channel in countercurrent gas filtration is investigated. Equations for calculating the weight rate of flow of the free-flowing material and the critical counterpressure are proposed.

Equipment in which heat- and mass-transfer processes are carried out in a fluidized bed is often used to move free-flowing material from a low-pressure zone to a high-pressure zone. The gas flow resulting from the pressure differential is directed in opposition to the pouring particles of friable material, and acts as an obstacle to their outflow from the vertical return-flow channel.

The return-flow channels operating under the conditions referred to above must bring about stable flow of the free-flowing material, exhibit little sensitivity to changes in the hydraulic operating conditions of the fluidized-bed equipment, function stably as the process material arrives in an uneven flow, and must be simple and of low cost.

The use of sluice gates, screw conveyors, and ejection devices [1, 2] complicates the design and maintenance of the equipment, is not advisable from the standpoint of power utilization, and apparently can only be justified when it is required to move poorly friable materials. Investigation of the simplest type of return-flow device, in the form of a cylindrical vertical tube with the lower end completely open, or with a horizontal bottom with outlet hole, is therefore of interest. Some information on the functioning of such channels may be found in [1-4].

In dealing with the overflow of free-flowing material from the vertical channel through the hole in the horizontal plane in countercurrent filtration of gas, we can take as point of departure the presumed existence of a dynamic unloading dome (vault) and the analogy between the overflow of liquid and the overflow of free-flowing solid material from the dome space, the basic points of which are presented and discussed in an earlier article [5].

On the basis of that analogy, we can readily establish the fact that the sensitivity of the return-flow channel to changes in the hydraulic operating conditions of the equipment is related to the dependence of ΔP on the velocity of the fluidizing medium. This underlines the importance of diminishing the effect of the gas flowspeed in the equipment on the pressure differential between the top and bottom levels of the layer of material present in the return-flow channel. From that vantage point, it would be helpful to bring about the overflow of free-flowing material at the level of the fluidized bed, the resistance of part of which, constituting a fraction of ΔP, is dependent only slightly on the flowspeed of the gas.

As the friable material flows into the fluidized bed, by contrast with overflow of the same material to the atmosphere, the "external" conditions of the process undergo changes, and it is to those conditions that the properties of the medium into which the overflow takes place are relevant. But we can assume that ΔP_{dome} is determined in accordance with the regularities discussed in [5]. The rate of overflow of the friable material into the fluidized bed can be determined, therefore, on the basis of an equation derived in [5]:

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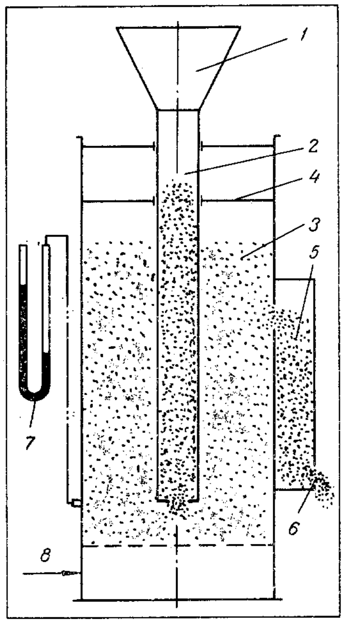

Fig. 1

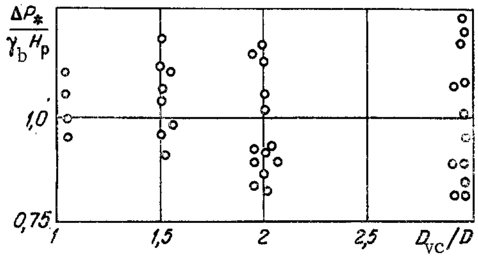

Fig. 2

Fig. 1. Schematic diagram of experimental arrangement: 1) hopper; 2) upright channel; 3) fluidized-bed equipment; 4) spacers; 5) auxiliary channel; 6) orifice; 7) differential manometer; 8) from fan.

Fig. 2. Generalization of the experimental data.

$$G = \mu_p \gamma_b F \sqrt{2gD \left\{ 1 - \frac{\Delta P}{\gamma_b \left[D + \frac{H - D}{0{,}78 + 0{,}22\,(D_{vc}/D)^2} \right]} \right\}}, \tag{1}$$

in which the minus sign before the fraction indicates that the overflow takes place in countercurrent filtration of the gas through the layer of material in the return-flow channel.

The investigation was carried out with return-flow channels immersed in the fluidized bed below the level corresponding to the height of the fixed layer, with the distance of the bottom tube cutoff from the grid extending 30 to 50 mm. A diagram of the experimental arrangement is shown in Fig. 1. The fluidized bed is set up in the reactor 3, plan dimensions 100 × 100 mm, and made of Plexiglas. The gas-distributor grid was made in perforated form, with an unimpeded flow area 8%. The vertical channel 2 fastened by the spacers 4 consisted of glass tubes with inner diameter 17, 29, and 38 mm. The pressure in the fluidized bed at the level corresponding to the bottom edge of the channel was measured by the differential manometer 7 or a MMN type micromanometer. The pressure was regulated by the height of the fluidized bed in the reactor 3.

The experiments were carried out with the height of the layer in the vertical channel ranging from 150 to 700 mm, at $\Delta P = 40$ to 400 kg/m^2, and hole diameter from 7.5 to 29 mm. Free-flowing materials with the characteristics shown in Table 1 were utilized in the investigations.

During each experiment the height of the layer in the vertical channel was kept unchanged by continuously feeding material in through the hopper 1, and the pressure in the fluidizied bed at the level corresponding to the bottom cutoff edge of the channel was maintained by proper selection of the size of the hole 6. This choice was made so as to keep the material flowing into the fluidized bed and the material overflowing from the fluidized bed via the auxiliary channel 5 equal.

The overflow rate was determined by weighing the free-flowing material passing down the investigated channel over a measured time interval.

The flow coefficient was calculated on the basis of Eq. (1), using the experimentally determined overflow rates.

TABLE 1. Characteristics of Free-Flowing Materials

Material	d, mm	γ_b, kg/m^3
River sand	0,22	1370
The same	0,8	1450
Millet	2,0	850
Corundum	0,33	1920

It was found that the flow coefficient is practically independent of the flowspeed of the fluidizing medium in the reactor over the time interval investigated in the range from 0.2 to 2.5 m/sec, while the fluidization number ranged from two to six. The explanation for this seems to be the low friction force due to the stream of gas impinging on a particle of friable material (calculations show that this is not greater than 5% of the weight of the particle itself under our experimental conditions) and due to the insignificant change in the porosity of the dense phase of the fluidized bed in the range of fluidization numbers referred to [6, 7].

It was found subsequently that μ_p is independent of the value of D/d (size ratio of holes and particles) over the interval investigated (D/d = 7 to 125). This conclusion must be entertained, of course, within the limits of accuracy of the experiment, with the error in calculations of μ_p based on Eq. (1) not exceeding 25%. It can be assumed that intense "bombardment" of the edges of the holes by particles through the fluidized bed occurs in this instance, bringing about the collapse and breakup of particles remaining on the edge of the hole and narrowing down the hole cross section.

A survey of the experimental data reveals that the flow coefficient determined under the above experimental conditions (overflow to the dense phase of the fluidized bed at N = 2 to 6, D/d = 7 to 125, D_{vc}/D = 1 to 3) is 0.295.

The equation thus obtained from Eq. (1) is

$$G = 0.33\gamma_b D^2 \cdot \sqrt{gD\left(1 - \frac{\Delta P}{\gamma_b H_p}\right)}, \tag{2}$$

in which

$$H_p = D + \frac{H - D}{0.78 + 0.22\,(D_{vc}/D)^2}, \tag{3}$$

generalizes the experimental data obtained at D_{vc}/D = 1 to 3, D/d = 7 to 125, H = 150 to 700 mm, and ΔP = 40 to 400 kg/m^2, with an average error ±9%, and a maximum error of ±25%. Some of the experimental data are entered in Table 2.

Note that the experimental data show very poor reproducibility in the range of values of the parameter $\Delta P/\gamma_b H_p > 0.7$, and may differ by as much as two to three times, though they seem to have been obtained under identical conditions. The apparent reason is not only the low experimental accuracy in the limit as $\Delta P/\gamma_b H_p$ approaches unity, but also the approaching time when overflow ceases, under these conditions, when a slight change in any decisive parameter brings about a drastic change in the rate of overflow. Experimental data reported by Molodov and Ishkin [3] were obtained in the range $\Delta P/\gamma_b H_p$ = 0.8 to 0.92, by the way, and the marked spread in the data is hardly surprising on that account.

Stable intense overflow of free-flowing material through that type of channel can be achieved in the range $\Delta P/\gamma_b H_p \leq 0.7$, as we see.

A crucial point in the design of a vertical channel is finding the critical pressure difference at which overflow of the free-flowing material comes to a halt.

The view has been expressed [3, 4] that overflow of free-flowing material terminates when the static pressure of the entire column of free-flowing material is offset by the total pressure drop. This assertion, valid in a formal sense when D = D_{vc}, is fundamentally invalid nonetheless, being based on an analogy drawn between the overflow of loose-flowing material and overflow of liquid which, as demonstrated earlier, can be applied only to the dome space, and not to the entire layer of free-flowing material in the channel.

In the derivation of Eq. (1) [5], it was suggested that the rate at which the free-flowing material overflows in the case of gas filtration is determined by the algebraic sum of the pressure exerted by the dome space filled with free-flowing material and the value of ΔP_{dome}. This implies that overflow comes to a half when the pressure drop in the opposing gas stream between the top and bottom levels of the dome space is balanced off by the static pressure exerted by the dome space. This conclusion had been drawn earlier in [8].

TABLE 2. Comparison of Experimental and Calculated Data

D, mm	D_{vc}, mm	H, mm	ΔP, kg $/m^2$	$\Delta P / \gamma_b H_p$	G, g/sec exptl.	G, g/sec calc.	Error, %
River sand, d = 0.22 mm, γ_b = 1370 kg/m^3							
7,5	17	500	110	0,30	6,5	5,9	+10,2
7,5	17	300	150	0,68	4,7	3,85	+22,0
9,8	29	600	132	0,42	11,4	10,2	+11,7
9,8	29	600	180	0,57	8,1	8,8	—7,9
9,8	29	400	150	0,70	6,6	7,35	—10,2
14,2	29	350	200	0,67	20,4	19,6	+4,0
14,2	29	550	140	0,31	35,8	28,5	+25,0
21,0	38	500	240	0,51	77,0	63,8	+20,7
21,0	38	300	200	0,70	45,3	50,2	—9,8
29,0	29	500	400	0,58	122,0	131	—6,8
29,0	29	250	150	0,44	170,0	152	+11,8
29,0	29	250	200	0,58	135,0	131	+3,0
River sand, d = 0.8 mm, γ_b = 1450 kg/m^3							
9,8	29	500	105	0,37	12,3	11,3	+8,8
9,8	29	600	220	0,66	6,2	8,3	—25,0
14,2	29	390	220	0,63	25,1	22,2	+13,0
14,2	29	370	160	0,48	30,8	26,3	+17,0
Corundum, d = 0.33, γ_b = 1920 kg/m^3							
9,8	29	700	60	0,12	20,4	17,7	+15,3
9,8	29	350	132	0,51	12,3	13,2	—7,0
14,2	29	400	250	0,54	30,3	32,7	—7,6
14,2	29	320	210	0,56	26,5	32,0	—17,1
21,0	38	280	120	0,32	93,7	102,0	—8,1
21,0	38	300	200	0,7	72,0	69,5	+5,0
Millet, d = 2.0 mm, γ_b = 850 kg/m^3							
14,2	29	470	160	0,66	12,8	12,4	+3,2
14,2	29	500	120	0,47	16,1	15,4	+4,6
14,2	29	600	120	0,39	16,3	16,6	+1,8
14,2	29	600	40	0,13	18,7	19,7	—5,1
21,0	38	300	90	0,51	35,3	39,5	—10,6

On the basis of Eq. (2), the critical pressure drop can be calculated as

$$\Delta P_* = \gamma_b H_p, \tag{4}$$

where H_p can be found from Eq. (3). The average error of Eq. (4), as shown in Fig. 2 where the experimental data obtained under the above conditions are plotted, is ±12%, the maximum error ±23%.

In processing the experimental data, use was made of the height of the layer in the channel at which the moving bed of free-flowing material came to a stop at a specified counterpressure. The movement of the free-flowing material was resumed when the height of the bed rose appreciably (of the order of 30%) in the channel, apparently because of the need to apply additional forces in order to overcome static friction and break up the closed dome of particles formed above the hole.

One serious disadvantage in the functioning of open-ended cylindrical channels ($D = D_{vc}$) is the possibility that the condition $\Delta P = \gamma_b H$ necessary for fluidization of a dense bed of free-flowing material might occur, thereby resulting in rapid depletion of the channel and impaired operating conditions for the entire reactor.

In the case $D < D_{vc}$ overflow ceases entirely, as is evident from Eq. (4), at $\Delta P < \gamma_b H$, so that fluidization of the layer in the vertical channel is a difficult, practically impossible task, since some D_{vc}/D ratio can be chosen at which $\Delta P = \gamma_b H$ becomes impossible even when pulsations of the pressure drop are taken into account.

Note that an increase in D_{vc}/D entails an increase in the height of the layer in the vertical channel needed to achieve the specified flowrate of free-flowing material, and in the height of the entire reactor. The optimum ratio arrived at is, therefore, D_{vc}/D = 1.5 to 2.

NOTATION

D is the hole diameter;
D_{vc} is the vertical channel diameter;
d is the predicted particle size;
G is the weight rate of flow of friable material in unit time;

g	is the gravitational acceleration;
F	is the hole area;
H	is the height of layer (bed) in vertical channel;
h_{dome}	is the height of dynamic dome;
k	is a coefficient;
ΔP	is the total pressure drop;
ΔP_{dome}	is the pressure drop between top and bottom levels of dome;
N	is the fluidization number;
γ_b	is the bulk weight of free-flowing material;
μ	is the flow coefficient.

Subscripts

p	denotes the predicted value;
*	denotes the critical value.

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