LEAKAGE OF SOLIDS THROUGH THE PERFORATED DISTRIBUTOR

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Experiments were conducted to explore the effect of free area, orifice diameter and grid thickness on the rate of backflow of particles (leakage, weeping) through the multi-orifice distributor. Air was used as a fluidizing medium. Two sieved fractions of glass beads and ash particles of different shape and density were employed in the experiments. The measured rates of backflow were fitted by an empirical correlation with an accuracy of ±30%.

Backflow of particles through the distributor in fluidized beds is usually an undesirable phenomenon. There is little information on this problem in literature. Moreover, it is difficult to compare the available results. The measurements of grid leakage were performed with different types of distributors such as a perforated plate[1] or bubble cap distributor[2]. These distributors are commonly used in practice and their proper design is essential for the satisfactory performance of large industrial beds.

Serviant *et al.*[2] found that at low gas flow rates the particles rhythmically fall trough the hole area of the perforated plates. The authors refer to such a state as to "dumping". It is a region where the rate of backflow does not monotonously decrease with the increasing flow rate of gas.

Tyyuryyaiev *et al.*[3] measured the backflow of solids through a thin perforated distributor. With the aid of dimensional analysis, the authors developed equations describing the dependence of the backflow of material through a plate at zero gas flow rate in the form

$$G_o = k \,.\, \varphi \,.\, \varrho_s \sqrt{(g \,.\, D_0)} \,. \tag{1}$$

The authors recommend the constant k as large as 0·4–0·75 in dependence on the type of material.

In the situation when the leakage of solids through a thin perforated distributor is negligible or zero, Builov *et al.*[4] present an equation for the prediction of gas flow rate in the form

$$u_{gh} = 1{\cdot}25 \,.\, \varphi^{0,2} \left(\frac{g D_o \varrho_s}{\varrho_g}\right)^{1/2} . \tag{2}$$

Guigon[5] deals in his work with the leakage of solids through the perforated distributor in the absorption of gas into a solution. The author does not present any experimental data of his own, but suggests a correlation for the leakage of solids in the form

$$\log\,(G/G_o) = -1{\cdot}36 \,.\left(\frac{u}{u_{gh} - u}\right)^{1/3} . \tag{3}$$

In the derivation of Eq. (3) Guigon[5] employed the analogy between the solids backflow and leakage of liquid in gas–liquid systems.

Dependence of the solids leakage on the gas flow rate is presented by Overcashier *et al.*[6]. The authors found that this dependence exhibited a maximum. The experiments were conducted during a study of gas and solids mixing in the fluidized bed column. Systematic investigation of the solids leakage was not, however, undertaken. The presented, graphical dependence of the ratio of leakage rate and gas flow rate on the ratio (u^2/gD_0) is in the logarithmic coordinates almost linear.

Geldart[7] explored the discharge of fluidized bed through a single hole located at the bottom or in the wall of the column. The effect of shape of this orifice was also investigated. The withdrawal tube was terminated with a straight or conical orifice. Particles ranging from $2 \cdot 10^{-5}$ to $2 \cdot 10^{-3}$ m were used in the experiments. The ratio of tube and particle diameters varied from 7 to 1 250. The author[7] developed an empirical equation for the rate of solids leakage through a single orifice in the form

$$G = c \cdot \varrho_s(\pi/4) \cdot (D_o - \psi \cdot d_p)^2 \cdot (2gH)^{1/2} \,. \tag{4}$$

The constant c varies from 0·45 to 0·55 for different materials.

Serviant *et al.*[2] investigated the leagae of solids both in a two-dimensional and in a 0·28 m diameter cylindrical column. They used a special distributor equipped with a single 13 mm or 19 mm diameter hole or with a single nozzle. The thickness of distributor was 13 mm. A commercial catalyst with particles of mean size 60 μm was employed in the experiments. The effect of both gas superficial velocity (0—0·3 m s^{-1}) and gas hole velocity (0.—30 m s^{-1}) was explored. The influence of height of the fluidized bed or its weight related to the unit area was also investigated. The authors express the effect of gas velocity in the holes by the equation

$$\frac{G_{\mathrm{ref}}}{G} = \left(\frac{u_{0,\mathrm{ref}}}{u_0}\right)^n \,, \quad u = \text{const.}, H \,. \quad \varrho_s/D_0^2 = \text{const.}\,, \tag{5}$$

where G_{ref} is the referential rate of leakage at the gas hole velocity $u_{0,\mathrm{ref}}$. The value of the exponent n is in the range 4—8·3 according to the type of apparatus and hole size in the distributor. Graphical dependences of the leakage are presented in the work[2] for distributors with different numbers of holes. The results indicate that the solids leakage is not an explicit function of the free area of distributor. It also follows that the leakage is only slightly dependent on the height of bed.

In their further work the authors[8] studied the leakage of a commercial catalyst in the laboratory column equipped with a single — or multi — orifice plate. They explored the influence of gas hole velocity and length of the leakage nozzle. The authors found that the dependence of the rate of leakage on the gas hole velocity is linear in the semilogarithmic coordinates except for the initial phase (dumping). The leakage decreases with the increasing gas velocity. Similar linear dependence was also found for the dependence of the leakage on the length of leakage nozzle. The authors state that the dependence exhibites a minimum for the length ranging from 0·1 to 0·15 m. In the case of both perforated plates and those with nozzles, observations are presented showing that the solids do not fall through all holes. This phenomenon is explained by the fact that the pressure does not fluctuate uniformly in the respective holes. Such a situation wase experimentally explored by Briens and Bergougnou[9] on the industrial column with a diameter of 0·61 m and height of 10 m. The used perforated distributor was 1·27 cm thick and had 16 holes. The diameter of holes was 12·7 mm, the free area of the distributor amounted only to 0·709%. 65 μm catalyst particles were used as solids during the work in which the dynamic pressure in the hole and under the distributor was measured. The authors formulated a model describing different situations in the soids leakage through a perforated distributor and corresponding pressure conditions above and under the distributor. Such situations are depicted in Fig. 1.

The following dynamic states can be differentiated for a given hole:

A. The pressure in the wind box is higher than the pressure above the distributor. Then the velocity of gas passing through a grid hole is given by an orifice equation

$$u_0 = C_g . [2 . (\Delta p)/(\varrho_g . g)]^{1/2} . \tag{6}$$

B. The pressure above the distributor is larger than the wind box pressure. The fluidized bed will then tend to flow back into the hole. The rate of leakage depends on the type of distributor and is given by an orifice equation

$$G_s = C_s . (2 \Delta p/\varrho_s)^{1/2} . \tag{7}$$

C. If the pressure in the wind box is slightly lower than the pressure above the distributor enlarged by the weight of particles in the hole, the rate of leakage is then given by

$$G_s = C_s . [2 . (\Delta p + \varrho_s . g . h_s)/\varrho_s]^{1/2} . \tag{8}$$

D. In this situation the above pressures or forces are in balance. The material does not fall through the distributor.

E. The pressure in the wind box is much lower than the sum of the pressure above the distributor and weight of all particles present in the whole volume of an orifice. The material will then freely flow through the orifice. The rate of leakage is given by an equation

$$G_s = C_s . [2(\Delta p + \varrho_s . g . T_1)/\varrho_s]^{1/2} . \tag{9}$$

F. The pressure in the wind box is larger than the pressure above the distributor enlarged by the weight of particles in the whole volume of the hole. The particles then fall through the grid hole at random. The particles can be re-entrained into the bed as well as fall into the wind box.

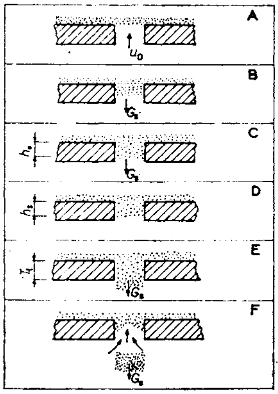

FIG. 1

Different phases of solids leakage corresponding to the hydrodynamic regime of bed. Presentation of the leakage model by Serviant *et al.*[8]

The authors present values of the constant C_s in the range 0·12—0·55 according to the gas velocity, type of distributor and above all according to its thickness. They observed that even at the low gas velocities, there are a certain number of grid holes through which the solids do not fall. They found that such a number amounts to 30—40% grid holes. The authors corrected the leakage for the inactive grid holes and obtained an equation

$$G^a = 6 \cdot 34 \,.\, 10^9 \,.\, (u_0^a)^{-7.81} \,. \tag{10}$$

As follows from the presented survey of available sources in the literature, little systematic work has been done on the solids leakage through the perforated distributors. These grids are commonly employed in large industrial beds.

Nevertheless, the following partial conclusions can be made:

The rate of leakage is an exponential function of the gas velocity in the plate orifices starting from a certain value of this operating variable. The exponent at the gas velocity is negative.

When the distributor is scaled up, it is necessary to bear in mind the nonhomogenities of bed which augment the nonuniformities in pressure and thus enlarge the solids leakage.

The leakage depends on the thickness of plate. It decreaes with the increasing thickness of plate to a certain value.

The shape and layout of grid holes are important. The conical holes suppress the solids leakage throuh a distributor if the larger holes are oriented toward the wind box.

The aim of this work is to examine in detail the effect of fundamental design parameters and operation conditions on the rate of solids leakage through the perforated distributor.

EXPERIMENTAL

Apparatus. The experimental set-up is sketched in Fig. 2. It encompassed the feeder 1 and fluidized column 2 equipped with the leakage distributor 3. The solids feeder ensured continuous introducing particles to the surface of fluidized bed 4. The feed rate of particles was continuously controlled by the rate of turning of the plate feeder 5. The cylindrical, 0·14 m diameter fluidized column 2 was made of transparent, organic glass. The column wall was equipped with a freely adjustable, built-in downcomer 6. The width of downcomer was 0·03 m. The height of fluidized bed 4 was maintained by the pre-set position of the downcomer.

The distributor grid 3 was inserted between the cylinder and wind box 7 which were connected with the aid of flanges. The wind box had the conical bottom equipped with an outlet valve 8 that discharged the leaked solids into a pressure vessel. The fluidizing air was introduced into the wind box under the conical bottom 9 which was made of a perforated sheet and covered with the filtration polyesther fabric. The amount of air was measured by a calibrated orifice meter and related to the standard conditions.

Description of distributors. 0·14 m diameter distributors with the drilled, sharp edged holes were employed in the measurements. The holes were drilled on a triangle pitch and their sharp edges were not cut off. The following parameters of gas distributor were investigated: open area, diameter of orifices and thickness of distributor. The parameters of gas distributor are summarized in Table I.

Materials used and measurements. Experimental measurements were conducted with two entirely different sorts of solids. The first types of material were glass beads of two different diameters of particles. The other type was ash of brown coal obtained by screening between the same sieves which were used in the classification of glass beads. The glass beads are smooth and almost spheres. In contrast to them, ash contains a heterogeneous mixture of irregularly shaped particles. The physical properties of the employed particles are summarized in Table II.

The solids leakage was measured as follows. For a given layout and at chosen hydrodynamic conditions, the airtight glass flask was connected to the bottom of the column. The collected solids were discharged from the bottom of the column. The valve was then closed and the elapsed time was measured with a stop watch during which the leaked particles were collected in the bottom of the column. The dumped material was then discharged into the flask and weighted. The respective measurements were not carried out neither with ever increasing, nor gradually decreasing air flow rate. The flow rates of air were chosen at random to cover the region of experiments. The measurements were well-reproducible. The experimental error determined by the statistical analysis amounted to $\pm 8\%$ rel. in the given experimental span.

RESULTS AND DISCUSSION

The measurements of solids leakage through the perforated distributor were carried out in the range of linear gas velocities from zero velocity to a gas velocity when the leakage through the distributor was negligible, *i.e.*, when the rate of leakage was

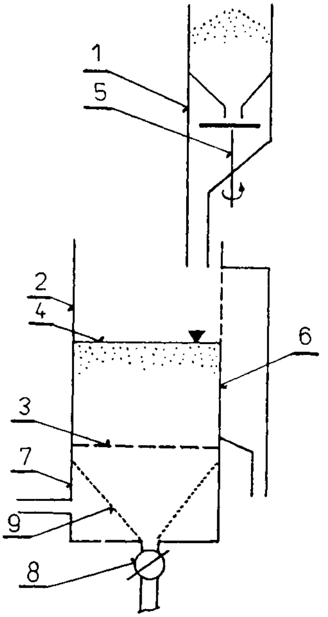

Fig. 2

Schematic diagram of the apparatus for measurements of the solids leakage. Details see Experimental.

lower than 10^{-4} kg m^{-2} s^{-1}. It was found by experiment that the leakage is the most rapid at zero gas velocity. If the pressure of fluidizing gas is increased under the distributor, *i.e.*, when a small gas flow rate is set up, the leakage through the

TABLE I

Design parameters of the employed distributors

Type	Free area %	Orifice diameter mm	Grid thickness mm
R 1	4·81	2·5	2
R 2	6·93	3·0	2
R 3	9·43	3·5	2
R 4	12·43	4·0	2
R 5	15·60	4·5	2
R 6	6·93	3·0	2
R 7	6·93	3·0	5
R 8	6·93	3·0	8
R 9	6·93	3·0	15
R 10	6·93	3·0	25
R 11	9·43	3·5	25
R 12	12·43	4·0	25
R 13	15·6	4·5	25
R 14	9·43	3·5	8
R 15	9·43	4·0	8
R 16	9·43	4·5	8
R 17	15·6	4·0	5
R 18	15·6	3·0	15
R 19	12·43	3·0	8

TABLE II

Characteristics of the solids

Material	Shape	u_{mf} m s^{-1}	d_p mm	$\bar{d}_p$ mm	ϱ_s kg m^{-3}
Glass beads	spherical	0·20	0·35–0·60	0·47	2 673
		0·535	0·80–1·1	0·93	2 673
Ash	irregular,	0·083	0·35–0·60	0·45	2 170
	sharp-edged	0·492	0·80–1·1	1·0	2 170

distributor completely ceases and the bed is entirely fixed. This state, with a slight flow rate of air at which the leakage is zero, can be attained when the flow rate of air is gradually decreased. It cannot be attained, if the corresponding flow rate of air is set up starting from zero flow rate of air. It follows from this observation that, for the given types of perforated distributors and mentioned materials, the rate of leakage is not a continuous function of the velocity of fluidizing gas. These two regions will, therefore, be considered separately.

Rate of Leakage Without Gas Flow

To measure the flux of particles through the perforated distributor, a small flow rate of air was set up at which the rate of leakage was zero. Then the flow of air was stopped. The time of leakage was measured with a stop watch. The experimental results for glass beads are summarized in Table III.

The experimental data were correlated by Eq. (*1*). It was found that this regression equation can be employed for such sets of experiments for which the ratios of orifice size and particle size are not widely different. But lower values of the constant k have to be used than the authors[3] recommend. Eq. (*1*) cannot, therefore, be taken as

TABLE III

Leakage of glass beads through the perforated distributors without air flow

Leakage G_0	Grid type	$\frac{D_0}{d_p}$	$\left(\frac{G_0 \cdot 10^3}{\varrho_s \cdot \varphi}\right)_{exp}$	$(g \cdot D_0)^{1/2}$	$\left(\frac{G_0 \cdot 10^3}{\varrho_s \cdot \varphi \cdot 0{\cdot}4}\right)_{calc.}$
kg m^{-2} s^{-1}		—	m s^{-1}	m s^{-1}	m s^{-1}
5·95	R 7	6·25	32·6	0·171	68·4
5·82	R 8	6·25	31·9	0·171	68·4
5·23	R 10	6·25	28·7	0·171	68·4
6·43	R 10	6·25	35·3	0·171	68·4
6·17	R 2	6·25	33·8	0·171	68·4
5·86	R 2	6·25	32·15	0·171	68·4
3·60	R 1	5·21	28·4	0·157	62·8
9·29	R 3	7·29	37·4	0·185	74·0
6·85	R 4	3·9	22·2	0·198	79·2
3·91	R 3	3·9	15·7	0·185	74·0
12·37	R 5	4·5	30·1	0·210	84·0
1·24	R 2	3·0	6·8	0·171	68·4
7·82	R 4	3·9	23·9	0·198	79·2
9·94	R 13	4·4	24·2	0·210	84·0

adequate means for describing the leakage of spherical particles through a distributor at zero velocity of air.

Similar experiments were conducted with the particles of ash. The experimental results are presented in Table IV. The correlation equation (*1*) fails also in this case to estimate the leakage rates of ash particles.

The values computed from Eq. (*1*) are by 300 – 1 000% larger than the experimental values and can be taken as a very conservative estimate. An appreciable influence of the ratio D_0/d_p also follows from the experiments. The discrepancy between the experimental and estimated values of leakage decreases with the increasing ratio D_0/d_p. Similar tendencies can be observed for non-spherical particales of ash.

Rate of Leakage at the Gas Flow

The dependence of the rate of leakage through the perforated plate on gas flow rate exhibites a maximum in all experimental measurements. The solids leakage rapidly, almost linearly increases from zero value, which corresponds to a gas velocity lower than the minimum fluidization velocity, to a maximum. In majority of the experimental sets, the maximum is located close to $1{\cdot}4 - 1{\cdot}7u_{mf}$. This maximum is relatively sharp.

The rest of the experimental data shows an exponential decrease of the leakage rate with increasing linear gas velocity from the maximum value to zero. This region is sufficiently wide and provides a potential possibility of utilization for the classification of particles. A typical dependence of the leakage on gas velocity is presented in Fig. 3.

For the given conditions, it follows from Eq. (*2*) that $u_{gh}/u_{mf} = 34{\cdot}7$. A comparison of this value with the experimental results in Table V shows that they differ on the

TABLE IV

Leakage of ash particles through the perforated distributors without air flow

Leakage G_0	Grid type	$\frac{D_0}{d_p}$	$\left(\frac{G_0 \cdot 10^3}{\varrho_s \cdot \varphi}\right)_{exp}$	$(gD_0)^{1/2}$	$\left(\frac{G_0 \cdot 10^3}{\varrho_s \cdot \varphi \cdot 0{\cdot}4}\right)_{calc.}$
kg m^{-2} s^{-1}		—	m s^{-1}	m s^{-1}	m s^{-1}
3·59	R 3	7·29	17·52	0·185	74·0
1·50	R 2	6·25	11·06	0·171	68·4
7·17	R 5	9·38	21·20	0·210	84·0
4·00	R 17	3·9	11·79	0·198	79·2
2·57	R 16	4·4	12·58	0·210	84·0

order of magnitude. The scatter of the experimental data is also apparent from Table V.

The following dependencies were investigated in the experiments: influence of the grid thickness, influence of the height of fluidized bed, influence of the diameter of orifice and particle size (or rather their ratio) and also the effect of particle sphericity and specific weight.

The solids leakage from a fluidized bed through the perforated distributor does not depend only on the linear velocity of gas, but also on the thickness of grid. The dependence of the rate of leakage on the dimensionless, normalized velocity of fluidizing air is shown in Fig. 3 for 0·47 mm mean diameter glass beads. The height of fluidized bed was 130 mm. The collected material was continously replenished by the feeder. The excess solids were withdrawn by downcomer and the height of bed was maintained at a constant level. As shown in Fig. 3, all the curves exhibite the maxima in the interval 1·5 – 1·8 u_{mf}. The height of maximum is directly proportional to the thickness of distributor. It is likely that the jet of gas is within a thicker grid stabilized more than in a thinner grid. It appears that the scattering of gas jet in the fluidized beds with thin grids prevents the particles from falling through the distributor.

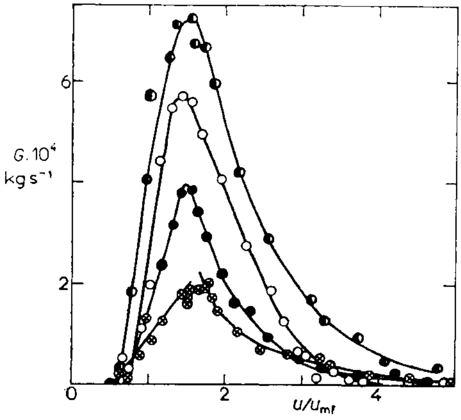

FIG. 3

Dependence of the leakage rate of glass beads ($\bar{d}_p$ = 0·47 mm) on the thickness of distributor. Height of fluidized bed 130 mm. Diameter of grid orifices 3 mm; ◐ T_1 = 25 mm; distributor R 10; ○ T_1 = 15 mm; distributor R 9; ● T_1 = 8 mm; distributor R 8; ⊗ T_1 = 2 mm; distributor R 2

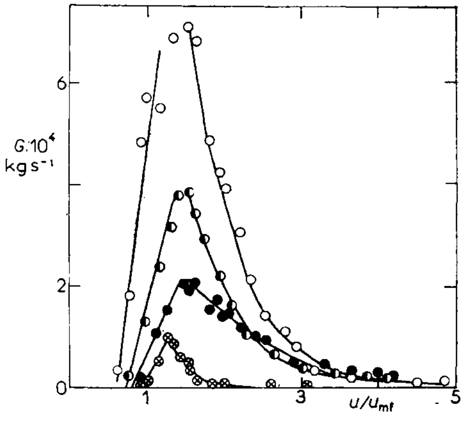

FIG. 4

Dependence of the leakage rate of glass beads ($\bar{d}_p$ = 0·47 mm) on the height of fluidized bed. ○ H = 190 mm; ◐ H = 130 mm; ● H = 90 mm; ⊗ H = 40 mm; distributor R 2

The dependence of the leakage of glass beads ($\bar{d}_p = 0{\cdot}47$ mm) on the linear, normalized velocity of gas is presented in Fig. 4 for different heights of fluidized bed. The curves exhibite again the maxima. The maximum for $H = 40$ mm is significantly shifted towards lower gas velocities. It is located at $u/u_{mf} = 1{\cdot}25$. The other maxima occur at $u/u_{mf} = 1{\cdot}6 - 1{\cdot}7$. The height of maximum increases with the increasing height of bed. It is apparent that the results are strongly effected by the grid region at $H = 40$ mm.

An effect of the ratio $D_0/\bar{d}_p$ on the rate of leakage of glass beads is shown in Fig. 5. The height of bed was maintained in all experiments at $H = 90$ mm. Two sieved fractions of glass beads with $\bar{d}_p = 0{\cdot}48$ and $1{\cdot}0$ mm were used in the experiments. The experimental curves exhibite again the maximum which is located in the interval $1{\cdot}6 - 1{\cdot}7\ u_{mf}$. The height of maximum is proportional to the increasing ratio $D_0/\bar{d}_p$. It is likely that the solids leakage through the distributor will practically be negligible for the ratio $D_0/\bar{d}_p \leqq 3$ in the whole range of gas velocities. On the other hand, the leakage through the perforated grid cannot be neglected for the ratio $D_0/\bar{d}_p \geqq 6$ even at $u = 5u_{mf}$.

A comparison was also made of the leakage rate of glass beads and ash which was obtained by burning brown coal in a fluidized bed reactor. The particles of ash were screened by sieving with the same sieves as the glass beads. Visual observations clearly show, however, that there is a striking difference between the two sorts of solids. While the glass beads are practically spherical, the ash particles are sharp-edged and of irregular shape. The comparison made with 0·48 mm particles is presented in Fig. 6. It is apparent from the figure that the glass beads leak more rapidly

TABLE V

Dependence of the gas velocity u_{gh} at which the leakage of glass beads is lower than 10^{-3} kg s^{-1}. $\varphi = 6{\cdot}93\%$; $D_0 = 0{\cdot}003$ m

Number of set	u_{gh}/u_{mf}	T_1 mm
1	7·0	2
2	6·2	5
3	5·5	8
4	4·5	25
5	3·2	25
6	4·8	2
7	7·5	2
8	4·6	2
9	3·8	2
10	2·4	2

than the particles of ash. This fact can be explained by lower specific weight of ash and lower sphericity of its particles. The particles of ash sometimes plugged the orifices of grid. Therefore, the distributor was checked after each experiment and all particles of ash were removed.

CORRELATION OF THE RESULTS

It is apparent from all the experiments that the dependence of leakage on the gas velocity exhibites a maximum. The height of maximum depends on the design of distributor and material of the fluidized bed. All the experimental curves decrease exponentially starting from the maximum value. The section of curve, where the leakage increases with gas velocity to the maximum, is apparently an atypical region. The fluidization of bed is not probably fully developed.

In the evaluation of data, such regions were treated in which the rate of leakage decreases monotonously with the increasing velocity of gas phase. These sections

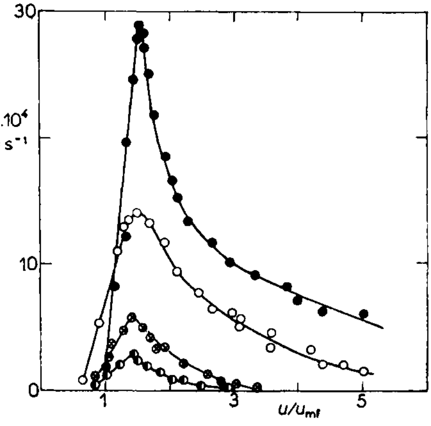

FIG. 5

Dependence of the leakage rate of glass beads through perforated distributors on the normalized superficial velocity of gas for different ratios of hole diameter and particle diameter D_0/d_p. Height of bed $H = 90$ mm. ● $D_0/d_p = 7·29$; $d_p = 0·48$ mm; R 3; ○ $D_0/d_p = 6·25$; $d_p = 0·48$ mm; R 2; ⊗ $D_0/d_p = 4·50$; $d_p = 1·0$ mm; R 5; ◐ $D_0/d_o = 3·90$; $d_p = 1·0$ mm; R 3

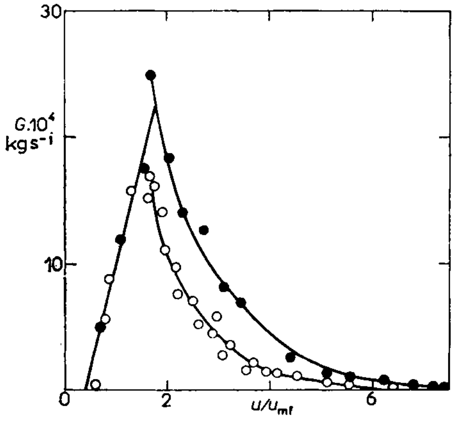

FIG. 6

Dependence of the leakage rate of glass beads ($\bar{d}_p = 0·47$ mm) and ash particles ($\bar{d}_p = 0·47$ mm) on the gas velocity thickness of distributor 2 mm; height of fluidized bed 90 mm; diameter of grid orifices 3·5 mm; distributor R 2; ● glass beads, ○ ash

TABLE VI

Correlation parameters of the experimental data sets on leakage

Number of set	*A*	*B*	Grid thickness mm	Bed height mm	Hole diameter mm	Particle size mm	Solids	Variance of data
1	1·357	0·668	2	130	3	0·48	Glass beads 2	0·621
2	1·245	0·899	5	130	3	0·48	Glass beads 2	0·970
3	1·495	1·065	8	130	3	0·48	Glass beads 2	0·966
4	2·651	1·687	25	130	3	0·48	Glass beads 2	0·965
5	3·715	2·903	25	75	3	0·48	Glass beads 2	0·964
6	1·533	1·285	2	130	3	0·48	Glass beads 2	0·985
7	0·906	0·575	2	190	3	0·48	Glass beads 2	0·944
8	2·521	1·655	2	60	3	0·48	Glass beads u	0·957
9	2·653	2·108	2	40	3	0·48	Glass beads 2	0·967
10	1·803	2·624	2	90	3	0·48	Glass beads 2	0·978
11	2·993	0·811	2	90	3·5	0·48	Glass beads 2	0·940
12	1·671	4·128	2	90	3·9	1·0	Glass beads 2	0·994
13	3·801	1·025	2	90	4·5	1·0	Glass beads 2	0·957
14	3·711	0·775	2	90	3·5	0·48	Ash 1	0·991
15	2·252	0·692	2	90	3·0	0·48	Ash 1	0·991
16	2·646	0·988	25	90	3·0	0·48	Ash 1	0·982
17	1·944	1·392	15	130	3·0	0·48	Glass beads 2	0·979
18	3·698	1·829	2	90	4·5	1·0	Ash 2	0·956

of curves were linearized and the parameters in the equation

$$\ln G = A - B\left(\frac{u - u_{\mathrm{mf}}}{u_{\mathrm{mf}}}\right) \tag{11}$$

were determined by a method of least-squares.

A survey of the computed parameters A and B for respective sets of data is presented in Table VI. Dependences of the parameters A and B on the experimental variables were established in further treatment. A regression formula was developed which covers the experimental span of the amassed sets of data. With the aid of an quasilinear optimization technique described by Kubíček[11], constants occurring in the formula were also estimated. This computational procedure was slower but it always converged. We obtained the following equation for predicting the rate of leakage

$$G = K_1 \, . \, \frac{D_0 \, . \, u_{\mathrm{mf}}}{d_{\mathrm{p}} \, . \, \psi} \, . \, \exp\left\{K_2 \, . \, T_1 - K_3 \, . \, H \, . \, \varrho_{\mathrm{s}} \, . \, g(1 - \varepsilon) - \right.$$

$$\left. - \left[\left(K_4 - K_5 \frac{D_0}{d_{\mathrm{p}}}\right) . \left(\frac{T_1}{H}\right)^{0{,}33}\right] . \frac{u - u_{\mathrm{mf}}}{u_{\mathrm{mf}}}\right\}, \tag{12}$$

where $K_1 = 16{\cdot}1 \text{ kg m}^{-1}$, $K_2 = 0{\cdot}06163 \text{ m}^{-1}$, $K_3 = 9{\cdot}15 \, . \, 10^{-4} \text{ m s}^2 \text{ kg}^{-1}$, $K_4 = $ $= 1{\cdot}508$ (–), $K_5 = 0{\cdot}743 \, . \, 10^{-2}$ (–). Eq. (*12*) correlates the entire experimental set including 520 data points with an accuracy of ±30% rel. for the linear velocities of gas in the interval $1{\cdot}5 \, u_{\mathrm{mf}} < u < 7 \, u_{\mathrm{mf}}$.

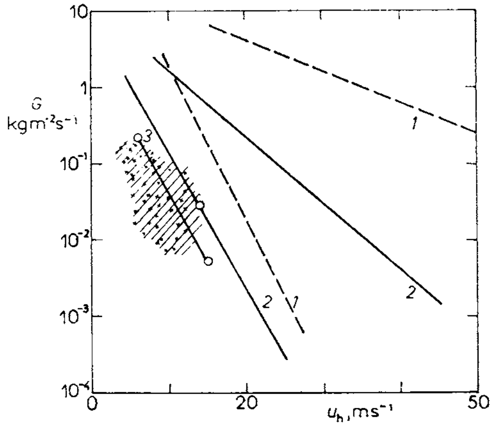

Fig. 7

Comparison of the data from literature with the experimental results for perforated distributors. Area outlined by the dashed lines *1* shows the experiments of Serviant[2,8]; area between the solid lines *2* shows the experiments of Briens[10]; crosses represent some data points of this work. Solid line *3* shows predictions of the regression formula (12)

The presented results indicate that the rate of solids leakage through the perforated distributor depends not only on the design parameters of grid, but also on the state and properties of fluidized bed.

Fig. 7 shows a comparison of our results with the experimental data in literature. Serviant[2] presents a broad region which somewhat overlaps the data collected by Briens[9]. Our experimental measurements closely follow these works and include the region of lower gas velocities in the grid orifices. This is given mainly by the open area of grids and type of solids. The solid line *3* in Fig. 7 represents predictions of the regression formula (*12*).

CONCLUSIONS

The rates of solids leakage through the perforated distributor measured by several authors are considerably different. One can assume, however, that for particles larger than 0·2 mm, the perforated distributor is practically leakage-proof, if the orifice diameter is not larger than three diameters of the smallest particles. This recommendation is well-founded for shallow beds with the height less than 0·4 m and is not confined to any specific regime of fluidized bed.

It was also found that the rate of leakage increases with the increasing thickness of distributor. This dependence was examined for distributors with the thickness ranging from 2 to 25 mm. Such a range covers practical needs for the design of industrial grids. The rate of solids leakage through the perforated distributor increases with the increasing height of bed and with the increasing ratio of the orifice diameter and particle size.

The experiments reveal that the irregular, sharp-edged particles of ash fall through a perforated distributor by 30–50% rel. more slowly than the smooth, spherical glass beads of the same sieve size.

LIST OF SYMBOLS

A, B	parameters in regression formula (*11*) (—)
c	constant in Eq. (*4*) (—)
C_g	constant in Eqs (*7*)—(*9*) (—)
C_s	constant in Eq. (*6*)
D_0	diameter of grid orifice (m)
d_p	particle diameter (m)
G	rate of solids leakage through the distributor (kg s^{-1})
G^a	rate of leakage in the active orifice by Eq. (*10*) (kg m^{-2} s^{-1})
G_0	rate of solids leakage through the distributor without air flow (kg s^{-1})
G_s	rate of solids leakage in the orifice (kg s^{-1})
g	gravitational acceleration = 9·81 (ms^{-2})
H	height of fluidized bed, height of downcomer (m)

h	height of fluidized bed above the leakage orifice (m)
h_s	height of bed in the grid orifice (m)
k	constant in Eq. (*1*) (—)
n	exponent in Eq. (*5*) (—)
Δp	pressure drop across distributor (Pa)
T_1	thickness of distributor (m)
u	superficial gas velocity ($m\,s^{-1}$)
u_0	gas velocity in the grid orifices ($m\,s^{-1}$)
u_0^a	gas velocity in the active orifices of grid ($m\,s^{-1}$)
u_{gh}	gas velocity at which the leakage is negligible ($m\,s^{-1}$)
u_{mf}	minimum fluidization velocity ($m\,s^{-1}$)
ε	porosity of bed (—)
φ	open area of distributor (—)
ψ	sphericity (—)
ϱ_g	density of gas phase ($kg\,m^{-3}$)
ϱ_s	density of solid phase ($kg\,m^{-3}$)

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