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SUBJECT: Fluidization Characteristics of Particulate Filter Media

TO: A. C. Schafer

FROM: W. J. Lee

ABSTRACT

Predictions of water velocities at which fluidization and massive entrainment of filter media (sea sand, Ottawa sand, silica, and alumina) will occur in special filter beds are presented. Pressure gradients in the various fluidized beds and the maximum bed expansions expected are tabulated.

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1.0 INTRODUCTION

A development program for sand filters to be used for clarification of radioactive process streams is proposed and discussed by E. L. Nicholson in Reference 1. It is desired that the sand used in such filters be replaced occasionally, and thus data on the fluidization and transportation of the sand are needed. It is the purpose of this report to present calculated predictions of such fluidization characteristics, based on the correlation of existing data by W. Brotz, (Ref. 2).

Predictions of the fluidization velocity, "escape" velocity (the velocity at which transportation of the particles away from the fluidized bed begins), bed expansion, and pressure gradient are made for each of three filter beds. The first consists merely of a 12-inch diameter pipe, 24 inches long, in which a bed of sand 12 inches deep is supported on a wire screen. The outlet from the bed is a 2-inch pipe at the top of the bed. The second bed, (Figure 1), is a conceptual design proposed for the 3019 pilot plant. The third bed is one that will be used in preliminary Unit Operations development work. It is similar to that presented in Figure 1, except that the sand container will be a 6-inch glass column; the tubes used for jetting (in the center) will be 1/2-inch and 1-inch tubing, respectively.

Calculations are presented for each of four types of filter media in each bed: sea sand, Ottawa sand, silica, and alumina.

2.0 SUMMARY

A summary of those results which could be predicted is presented in Table I. It will be noted that the linear fluidization and escape velocities, pressure gradient, and ratio of height of the fully expanded bed to that at the fluidization point are properties of the filter media, theoretically independent of both bed height and diameter.

It should be realized that the escape velocities presented are the upper limit. Even so, it is seen that the volumetric flow rate required in a bed with a water jet transfer line is considerably less than in a bed without a jet. It is probable that the time required to remove the sand and the total volume of water associated with such removal would be considerably greater if the fluidized bed were jetted out, but there is no good way of estimating the time or volume of water required.

3.0 DISCUSSION OF RESULTS

As stated by Brotz, (Ref. 2) the results obtained using his methods cannot be expected to be exact in any sense. His correlation is based on experimental work from several sources, and there is a great deal of scatter in the data. It is expected that the calculated fluidization velocities are near those to be found in actual practice, and that the escape velocities given here will certainly transport the solids, although somewhat lower velocities may be adequate. In order to check the method it was calculated that fluidization velocity for 0.54 mm diameter sea sand would be 0.00879 fps; the experimental value is 0.0086 fps (Ref. 3), which is in excellent agreement.

Figure 1

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Table I

Filter Material	Filter Apparatus	Linear Fluidization Velocity, fps	Volumetric Fluidization Rate, GPM	Linear Escape Velocity, fps	Volumetric Escape Rate, GPM	Pressure Gradient in Bed at Fluidization Point lb/in. ² -in.	Ratio of Height of Fully Expanded Bed to that at Fluidization Point
Sea Sand	12" Bed	0.0119	4.20	1.10	389	0.0356	3.2
Sea Sand	12" Bed w/Jet	0.0119	4.09	1.10	6.07	0.0356	3.2
Sea Sand	6" Bed w/Jet	0.0119	1.02	1.10	2.37	0.0356	3.2
Ottawa Sand	12" Bed	0.0167	5.91	1.10	389	0.0360	2.8
Ottawa Sand	12" Bed w/Jet	0.0167	5.75	1.10	6.07	0.0360	2.8
Ottawa Sand	6" Bed w/Jet	0.0167	1.43	1.10	2.37	0.0360	2.8
Silica	12" Bed	0.0119	4.20	0.780	278	0.0260	2.8
Silica	12" Bed w/Jet	0.0119	4.09	0.780	4.35	0.0260	2.8
Silica	6" Bed w/Jet	0.0119	1.02	0.780	1.69	0.0260	2.8
Alumina	12" Bed	0.0162	5.72	1.07	377	0.0336	2.8
Alumina	12" Bed w/Jet	0.0162	5.56	1.07	5.89	0.0336	2.8
Alumina	6" Bed w/Jet	0.0162	1.38	1.07	2.30	0.0336	2.8

It has been demonstrated experimentally that for a given material, the fluidization and escape velocities (linear) are constant, i.e., independent of bed diameter and depth (except perhaps in 1-inch diameter or smaller columns, where there is a "wall effect"). In a filter bed, as shown in Fig. 1, only the minimum fluidization velocity need be achieved in the large portion; once the material is suspended, it should be easily jetted out by maintaining the escape velocity (theoretically, a factor of at least 66 greater than the fluidization velocity) in the small jet tube alone. Since the linear escape velocity is constant, it is easily seen that if one wishes to keep the water flow rates small, using a jet tube is one plausible method. In the filter with no jet tube, the escape velocity must be maintained throughout the entire bed; thus the great difference in flow rates required to remove the sand in the two cases for a bed of given diameter. As mentioned previously, if one wishes to have a small flow rate, the time required to empty the bed will probably be much greater; and because of dilution of the sand slurry in the jet stream, the total volume of water required to remove the sand will likely be greater.

The predicted escape velocity may be overestimated, because the size of the actual filter beds may not be such that there is room for the bed to expand fully; i.e., it may begin entraining when it is actually expanding. If the filter height is made about three times the depth of the packed sand bed, this should not occur.

The data given for the pressure gradient will be useful in studying the operation of the bed after fluidization has taken place. The maximum pressure drop will occur at start-up, when the bed is firmly packed. Unfortunately, this value cannot be calculated. In some cases the pressure drop at start-up is so great that the bed will channel or even rise as a whole, still compacted. These extremes would not be expected with sand, but it is probable that the maximum pressure drop will be several times greater than the steady-state value given here.

The volume of the bed will change only about 5-10% from the compact state to the point at which it is just fluidized. Since the volume increase from the minimum fluidized state to the fully expanded fluidized state is about 300%, the 5-10% expansion is negligible, and thus one may estimate that the bed will expand to about three times its original depth before massive entrainment begins. Expansion is not desirable in the bed with a jet, hence the fluid velocity should be kept near the minimum required for fluidization unless it appears desirable to jet a more dilute slurry.

4.0 CALCULATIONS

4.1 Fluidization and Escape Velocities

The fluidization velocity may be found if one knows the Reynolds number for flow past the individual particles at the fluidization point.

$$R_e = \frac{V_d * \gamma_m}{\eta_g} \quad (1)$$

where

- V = velocity of medium in the absence of particles
- d^* = particle diameter
- γ_m = density of flowing medium
- η = dynamic viscosity
- g = gravity

The Reynolds number is found by a graphical technique (see Fig. 2), in conjunction with the equation

$$\phi_w R_{e_{wp}}^2 = \frac{2}{f} \frac{(\gamma_f - \gamma_m) \gamma_m}{\eta^2} \cdot \frac{d^{*3}}{g} \quad (2)$$

where

- ϕ_w = resistance coefficient for individual particles
- f = shape factor
- γ_f = density of the particles, kg/m^3

The subscript "wp" refers to the property of the substance at the fluidization point. The form factor, f , is an experimentally determined number which depends primarily upon the shape of the particles; it is 138 for sea sand near the size under question, and is assumed to be about 100 for the other rounder particles. (Brotz suggests $f=100$ as the average value for a large number of different types of particles.) $\phi_w R_{e_{wp}}^2$ is a function of $R_{e_{wp}}$ only, so when this number is known, $R_{e_{wp}}$ can be read directly from the figure.

Using equation (2), $\phi_w R_{e_{wp}}^2$ was found for each type particle and using Fig. 2, $R_{e_{wp}}$ was found for each particle. Since $R_{e_{wp}} = \frac{V_{wp} d^* \gamma_m}{\eta}$, V_{wp} was thus determined. The data used for the equation and the results are given in Table II.

$\phi_w \cdot R_e^2$ vs R_e

Figure 2
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Table II

Material	f	γ_f , kg/m ³	$\phi_w \cdot R_{e_{wp}}^2$	$R_{e_{wp}}$	V_{wp} , fps
Sea Sand	138	2.64×10^3	76	2.5	0.0119
Ottawa Sand	100	2.66×10^3	106	3.5	0.0167
Silica	100	2.2×10^3	76	2.5	0.0119
Alumina ^a	100	2.55×10^3	99	3.4	0.0162

$$\gamma_m = 1.00 \times 10^3 \text{ kg/m}^3; \quad \eta = 1.02 \times 10^{-4} \text{ kg-sec/m}^2; \quad d^* = 6.88 \times 10^{-4} \text{ m};$$

$$g = 9.81 \text{ m/sec}^2$$

It will be noted that the particle diameter is given as 0.688 mm; this is based on the fact that the particle size of interest is 20 to 30 mesh. The aperture in a standard 20-mesh Tyler screen is seen to be 0.03287 inch (Ref. 3); using linear interpolation between the apertures given for 28- and 32-mesh screens, a 30-mesh screen is estimated to have a 0.0214-inch opening. The average of these two sizes is 0.0271 inches = 0.688 mm.

Brotz shows that $\frac{V_{\text{escape}}}{V_{wp}} = \frac{2}{3} f$; since f averages about 100, the escape

velocity is thus on the average some 66 times the minimum fluidization velocity (92 times in the case of sea sand). This limiting value can almost be reached for liquids, according to Brotz. Using this equation, the results presented below were calculated.

Table III

Material	V_{wp} , fps	$\frac{2}{3} f$	V_{escape} , fps
Sea Sand	0.0119	92	1.10
Ottawa Sand	0.0167	66	1.10
Silica	0.0119	66	0.79
Alumina	0.0162	66	1.07

^aAssumed to be the normal commercial form, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$

The cross-sectional area of a 12-inch diameter bed without a jet tube is $\pi [0.5]^2 = 0.785 \text{ ft}^2$; that of a 12-inch diameter bed with a sch. 80, 1-1/2-inch pipe as a central water jet is $0.785 - 0.020 = 0.765 \text{ ft}^2$. The inside cross-sectional area of the 1-1/2-inch pipe is $1.225 \times 10^{-2} \text{ ft}^2$. The cross-sectional area of a 6-inch diameter bed with a 1/32-inch wall thickness, 1-inch o.d. jetting tube in the center is $\pi [(0.25)^2 - (4.17 \times 10^{-2})^2] = 0.190 \text{ ft}^2$; the inside cross-sectional area of the jet tube is $\pi (3.90 \times 10^{-2})^2 = 4.79 \times 10^{-3} \text{ ft}^2$. Using these data, the volumetric flow rates for fluidization and escape as given in Table I were calculated.

4.2 Pressure Drop and Bed Expansion

The pressure gradient across the fluidized bed is given by the expression

$$\Delta P/L (\gamma_f - \gamma_m) (1 - \epsilon)$$

where

ΔP = pressure drop

L = bed height

ϵ = free volume per unit volume (void space)

Using the densities previously tabulated and the value of 0.40 for ϵ in each case (such values were found in Ref. 2 for sea sand, Ottawa sand, and silica; this value was assumed for alumina), the pressure gradients were calculated for each material and are presented in Table I.

The bed expands some 5-10% from the packed state to the minimum-volume fluidized state; this is negligible compared to the ratio of the height of fully expanded bed to that of the minimum-volume fluidized bed, and hence will be neglected. The ratio of the maximum possible fluidized bed to the minimum is a function of the shape factor and of the particle diameter. With these data known for the different filter media, the required ratio is readily obtained from Figure 16 in Ref. 2 and is found to be 3.2 for sea sand, 2.8 for Ottawa sand, silica, and alumina. Thus, a bed with an original depth of 12 inches might be expected to expand to about 36 inches before massive entrainment of the suspended solids begins.

4.3 Remarks on Calculations

It has been assumed thus far that the jetting tube will be centered in the beds using such a tube; this may not be the case in actual practice. It appears desirable to have the jetting pipe external to the sand bed with a small connecting tube between the bed and the jet. There is no apparent reason why the sand, when once fluidized, could not be removed in this manner. This sort of filter apparatus appears to be easier to construct. All the calculations made here for the centered jet should be equally valid for a bed with side jet, excepting a slight correction that must be made in the

cross-sectional area exposed to flow. (The area occupied by the central pipe has been subtracted in these calculations; it should be added back if the tube is exterior, thus increasing slightly the volumetric flow rate required for fluidization.)

No corrections for the peculiar geometry in a bed, such as shown in Fig. 1, were made; it was tacitly assumed that the bed would behave essentially as would a bed with a flat bottom. This probably will not be true--one might predict more turbulence in this bed and thus perhaps an entrainment problem even at fluid velocities far below the escape velocity.

A word of caution must be added pertaining to the use of the English translation of Brotz's paper for other calculations. Several errors of omission and commission were found in both the text and figures of this work and were corrected by comparison with the original German version. One should be careful in using the equations and graphs as presented.

5.0 REFERENCES

1. "Sand Filter and Head-End Development Program", by E. L. Nicholson, letter to J. C. Bresee and R. E. Blanco, May 13, 1958.
2. "Principles of Fluidization", by W. Brotz, from Chemie-Ingenieur-Technik, Vol. 24, No. 2, pp. 60-81, 1952. Translated by R. C. Murray. A.E.R.E. Lib/Trans 715.
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