# Effect of Distributor Plate-to-Bed Resistance Ratio on Onset of Fluidized-Bed Channeling

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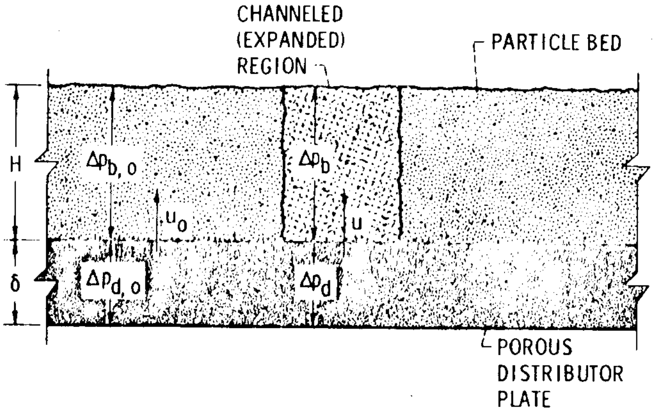


**Fig. 1. Channeled region in particle bed on a porous distributor plate.**

As the fluid velocity through a bed of particles is increased toward that required for minimum fluidization, channeling may occur wherein the fluid tends to pass through the bed along paths of lower particle concentration. This is undesirable, as it reduces the contact between the fluid and solids. Channeling can result from initial nonuniformities in the bed and tends to be accentuated by stickiness of the particles which prevents them from flowing in to refill the channeled region. A uniform bed of nonsticky particles, which is considered here, will tend to become well fluidized, and for conditions a little below or above minimum fluidization, the tendency to channel depends on stability considerations. The stability depends on the combined pressure drop characteristics of the particle bed and the porous or perforated distributor plate supporting the bed. Consider a perturbation where there is a local increase in velocity through the bed, the velocity then being above that for minimum fluidization. This causes the bed to locally expand, thereby altering the pressure drop through that portion of the bed. There will also be a change in the local pressure drop through the distributor plate. If the net result is that the pressure drop across the combined bed and distributor increases with an increase in local velocity, then the channel formation will tend to be damped out. Conversely, a channel will tend to become established if the local pressure drop through the bed-distributor system decreases with increased velocity.

The stability of a bed-distributor system was considered by Hiby (1964) who indicated that for a porous distributor plate and conditions near minimum fluidization, the pressure drop through the distributor should be at least 30% of that through the bed to provide uniform fluidization. The required ratio of distributor-to-bed pressure drop increased moderately with particle size. Agarwal et al. (1962) recommend a pressure drop across the distributor of 10% of the bed pressure drop when the bed is deep or of high density material so that the loss through the bed is the dominating pressure drop of the entire flow system. For shallow beds of low density material, it is recommended that the pressure drop through the distributor not fall below 3.45 kN/m² (0.5 lb/sq in.).

The purpose of this note is to relate the stability of a bed on a porous distributor plate to the dimensionless parameters characterizing fluidized bed behavior. In this way the tendency toward channeling can be examined with relation to such quantities as particle size, solids density, and gravity field acting on the bed.

## ANALYSIS

As indicated by Figure 1, the total pressure drop at any location in the bed is the sum of the drops through the distributor and particulate regions:

$$\Delta p_t = \Delta p_d + \Delta p_b$$

$$= \frac{\mu\delta}{\kappa} u + Hg[(1-\epsilon)\rho_s + \epsilon\rho_f] \quad (1)$$

where Darcy's law has been used for the distributor. The void fraction $\epsilon$ in Equation (1) is related to the local velocity $u$. If, owing to a perturbation, the $u$ changes locally, the stability depends on the change in local $\Delta p_t$. If $d(\Delta p_t)/du$ is positive, the bed would tend to be stable; that is an increase in $u$ would require an increased $\Delta p_t$ so that $u$ would tend to return to its original value. If $d(\Delta p_t)/du$ is negative, as the velocity at the location of the channel increases, the pressure drop required to drive the flow decreases. Since there is a fixed pressure difference available, the flow then tends to further increase, resulting in an unstable condition. The channel development is a local condition, and the local bed expansion in the channeled region would not be expected to appreciably affect the overall height of the bed; hence the bed height $H$ is assumed to stay constant. Then, by differentiating Equation (1)

$$\frac{d(\Delta p_t)}{du} = \frac{\mu\delta}{\kappa} - Hg(\rho_s - \rho_f)\frac{d\epsilon}{du}$$

For stability or neutral stability

$$\frac{\mu\delta}{\kappa} \geq Hg(\rho_s - \rho_f)\frac{d\epsilon}{du} \quad (2)$$

Let $R_d$ = flow resistance of distributor = $\mu\delta/\kappa$
$R_{b,o}$ = flow resistance of bed in the region away from the channel

$$= \Delta p_{b,o}/u_o = Hg[(1-\epsilon_o)\rho_s + \epsilon_o\rho_f]\frac{1}{u_o}$$

Equation (2) can then be put in the form

$$\frac{R_d}{R_{b,o}} \geq u_o \frac{1 - \frac{\rho_f}{\rho_s}}{(1-\epsilon_o)\left(1 - \frac{\rho_f}{\rho_s}\right) + \frac{\rho_f}{\rho_s}} \frac{d\epsilon}{du} \quad (3)$$

A relation between void fraction and fluid velocity is now needed.

Channeling can often originate near minimum fluidization. [For example, see Figure 7(b) in Chapt. 3 of Kunii and Levenspiel (1969).] For this condition, one characterization of the bed expansion for both gas and liquid fluidized beds is (Davidson and Harrison, 1971, p. 52)

$$\frac{u}{u_t} = \epsilon^n \quad (4)$$

Since the onset of channeling is being examined, the velocity $u$ in the channel is essentially equal to the velocity $u_o$ in the unchanneled region. Then, differentiate Equation (4), insert the result into Equation (3), and let $u_o = u$ to obtain the minimum required value of $R_d/R_{b,o}$ as

$$\frac{R_d}{R_{b,o}} = \frac{1}{n}\left(\frac{u}{u_t}\right)^{1/n} \frac{1 - \frac{\rho_f}{\rho_s}}{(1-\epsilon_o)\left(1 - \frac{\rho_f}{\rho_s}\right) + \frac{\rho_f}{\rho_s}} \quad (5)$$

Another formulation for bed expansion (relation between $\epsilon$ and $u$) is given by Loeffler and Ruth (1959) in the form

$$\frac{1}{u}\left[\frac{d^2(\rho_s - \rho_f)g}{18\mu}\right]\frac{\epsilon^3}{\epsilon^2 + 5.7(1-\epsilon)}$$

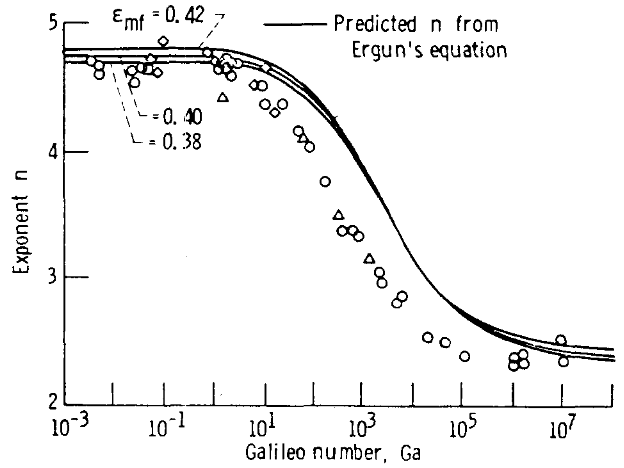


**Fig. 2. Experimental data and predicted values for exponent in bed expansion relation. Modified version of Fig. 2.10 from J. F. Richardson in "Fluidization," 51-53 (1971). J. F. Davidson and D. Harrison edit. Reproduced by permission of Academic Press Inc., (London) Ltd.**

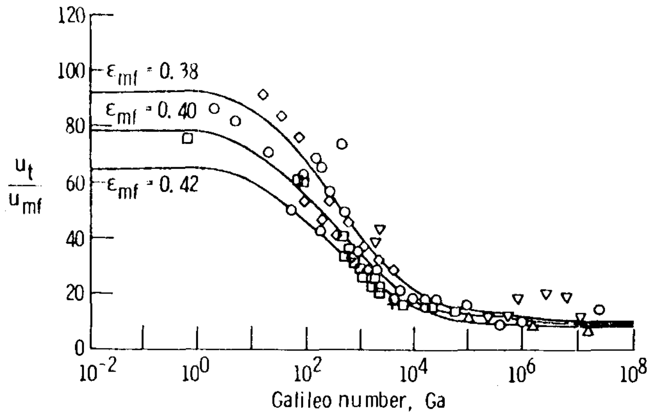


**Fig. 3. Ratio of terminal velocity to minimum fluidization velocity for spherical particles. Modified version of Fig. 2.9 from J. F. Richardson in "Fluidization," 51-53 (1971), J. F. Davidson and D. Harrison edit. Reproduced by permission of Academic Press Inc., (London) Ltd.**

$$= f\left(\frac{du\rho}{\mu}\right) = f(Re) \quad (6)$$

Differentiation yields

$$\left[\frac{d^2(\rho_s - \rho_f)g}{18\mu}\right]\left\{\frac{\epsilon^2(\epsilon^2 - 11.4\,\epsilon + 17.1)}{[\epsilon^2 + 5.7(1-\epsilon)]^2}\right\}\frac{d\epsilon}{du} = f(Re) + Re\frac{df}{d\,Re} \quad (7)$$

The $u$ on the left side of Equation (6) is substituted for $u_o$ in Equation (3), and the $d\epsilon/du$ from Equation (7) is also inserted. The result for the minimum $R_d/R_{b,o}$ for stability is

$$\frac{R_d}{R_{b,o}} = \frac{\epsilon[\epsilon^2 + 5.7(1-\epsilon)]}{\epsilon^2 - 11.4\,\epsilon + 17.1}\left[1 + \frac{Re}{f(Re)}\frac{df}{d\,Re}\right] \times \frac{1 - \frac{\rho_f}{\rho_s}}{(1-\epsilon_o)\left(1 - \frac{\rho_f}{\rho_s}\right) + \frac{\rho_f}{\rho_s}} \quad (8)$$

## RESULTS

The magnitude of $R_d/R_{b,o}$ will now be examined by evaluating typical values of Equations (5) and (8). Since channeling often occurs near minimum fluidization, let $u \approx u_{mf}$ and $\epsilon_o = \epsilon_{mf}$. Also, for simplicity, a gas fluidized bed

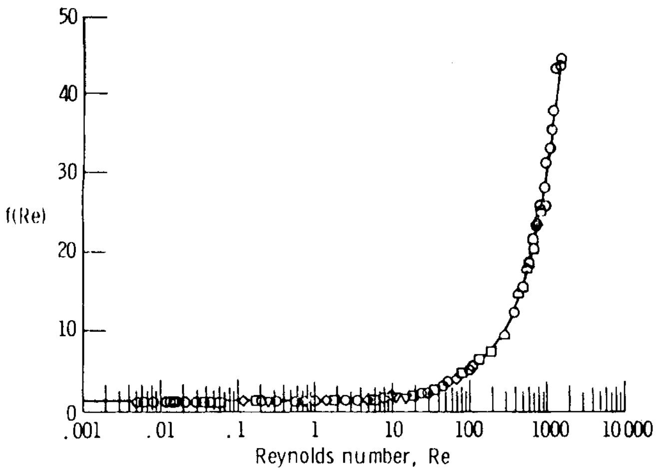


**Fig. 4. Bed-expansion data of Loeffler and Ruth (1959) correlated as a function of Reynolds number [ordinate is left-hand side of Equation (6)].**

will be considered first so that $\rho_f/\rho_s << 1$. Equation (5) then reduces to

$$\frac{R_d}{R_{b,o}} = \frac{1}{n}\left(\frac{u_{mf}}{u_t}\right)^{1/n}\frac{1}{1-\epsilon_{mf}} \tag{9}$$

From Equation (4), the $\epsilon_{mf}$ is related to $u_{mf}$ by $\epsilon_{mf} = (u_{mf}/u_t)^{1/n}$. Hence, to evaluate Equation (9), the $n$ and $u_{mf}/u_t$ are needed for typical fluidized beds. Figures 2 and 3, from Davidson and Harrison (1971), give $n$ and $u_t/u_{mf}$ as a function of Galileo number for spherical particles. From the scatter of the data, there are small inconsistencies when $\epsilon_{mf}$ and $(u_{mf}/u_t)^{1/n}$ are compared; hence, to more clearly reveal the trend of $R_d/R_{b,o}$ as a function of $Ga$, Equation (9) is evaluated with $\epsilon_{mf} = 0.4$, which is typical for a spherical particle bed. The following results are obtained:

| $Ga$ | $n$ | $u_t/u_{mf}$ | $R_d/R_{b,o}$ |
|---|---|---|---|
| 1 | 4.65 | 78 | 0.140 |
| 10 | 4.45 | 71 | 0.144 |
| 100 | 4.05 | 55 | 0.153 |
| 1 000 | 3.25 | 34 | 0.173 |
| 10 000 | 2.70 | 17 | 0.216 |

Over the entire range of $Ga$, the minimum ratio of distributor-to-bed resistance required for stability is from 0.14 to 0.22.

To evaluate Equation (8), the function $f(Re)$ is needed, and this is given in Figure 4 from Loeffler and Ruth (1959). For a gas fluidized bed, $\rho_f/\rho_s << 1$, and for a low $Re$, Figure 4 shows that $df/dRe \rightarrow 0$. Then, for conditions near minimum fluidization, Equation (8) reduces to

$$\frac{R_d}{R_{b,o}} = \frac{\epsilon_{mf}}{1-\epsilon_{mf}}\,\frac{[\epsilon_{mf}^2 + 5.7(1-\epsilon_{mf})]}{\epsilon_{mf}^2 - 11.4\,\epsilon_{mf} + 17.1} = 0.188$$

$$(\text{for} \quad \epsilon_{mf} = 0.4)$$

At a high $Re \approx 1\,000$, Figure 4 yields $\dfrac{Re}{f}\,\dfrac{df}{d\,Re} \approx 0.6.$

Hence, for large $Re$, $R_d/R_{b,o} \approx 0.30$.

The previous numerical results were all for $\rho_f/\rho_s << 1$. The bed expansion relations in Equations (4) and (6) are valid for both gases and liquids in beds near minimum fluidization. From Equation (5), at a fixed Galileo number the effect of $\rho_f/\rho_s$ can be found by examining the term

$$\left(1-\frac{\rho_f}{\rho_s}\right) \Bigg/ \left[(1-\epsilon_o)\left(1-\frac{\rho_f}{\rho_s}\right)+\frac{\rho_f}{\rho_s}\right] \equiv \Phi \tag{10}$$

For $\epsilon_o = 0.4$, this yields

| $\rho_f/\rho_s$ | $\Phi$ | $\dfrac{\Phi}{\Phi_{\rho_f/\rho_s = 0}}$ |
|---|---|---|
| 0 | 1.67 | 1.0 |
| 0.2 | 1.18 | 0.707 |
| 0.4 | 0.789 | 0.472 |
| 0.6 | 0.476 | 0.285 |
| 0.8 | 0.217 | 0.130 |
| 1.0 | 0 | 0 |

The final column shows how the required distributor resistance decreases as the density of the fluidizing medium is raised relative to that of the particles.

It is concluded that for large particles (high Galileo or Reynolds numbers) that are not sticky and can be well fluidized, to maintain uniform fluidization with a porous plate distributor, the pressure drop across the distributor should be greater than approximately 25% of the drop across the bed. For smaller particles, this decreases to about 15%. As an example to indicate particle sizes, for glass ballotini fluidized at 1g with air at room temperature, a high Galileo number of $10^4$ corresponds to a particle diameter of 496 $\mu$m, while a low $Ga = 1$ corresponds to $d = 23\ \mu$m.

## NOTATION

$d$ = diameter of particles
$f$ = function of Reynolds number
$Ga$ = Galileo number, $\rho_f(\rho_s - \rho_f)gd^3/\mu^2$
$g$ = gravitational acceleration
$H$ = height of bed
$n$ = exponent governing bed expansion
$p$ = pressure
$R$ = flow resistance
$Re$ = Reynolds number, $du\rho_f/\mu$
$u$ = upward fluid velocity
$u_t$ = particle terminal velocity

### Greek Letters

$\delta$ = thickness of distributor plate
$\epsilon$ = void fraction in particle bed
$\kappa$ = permeability of distributor plate
$\mu$ = viscosity of fluid
$\rho$ = density
$\Phi$ = function defined in Equation (10)

### Subscripts

$b$ = bed
$d$ = distributor
$f$ = fluid
$mf$ = minimum fluidization
$o$ = undisturbed region outside of channel
$s$ = solid

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*Manuscript received September 30, 1975; revision received and accepted January 12, 1976.*