AN EXPERIMENT TO CHARACTERIZE A CONSOLIDATING PACKED BED

Mark Gerrard, Mark Hockborn, Jason Glass
University of Teesside • Middlesbrough TS1 3BA England

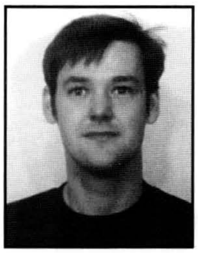
Packed beds are much used as contactors for interphase mass transfer and chemical reaction. An interesting example involves their use in the biofiltration[1] of air streams laden with volatile organic compounds (VOC). In this instance, the bed may consist of naturally occurring materials such as soil, heather, peat, or compost. The resident (or seeded) micro-organisms then digest the VOC in the incoming stream. With natural packing materials, however, the bed can collapse in time, leading to increased pressure drop and higher operating costs etc. In this short article we will describe an inexpensive modification to a standard undergraduate laboratory experiment that studies such consolidating behavior.

THEORY

The pressure drop in fixed beds can be predicted using the well-known Kozeny[2,3] equation for low gas flowrates:

$$\Delta p = 5a^2(1-\varepsilon)^2 \mu h v / \varepsilon^3 \tag{1}$$

A.M. Gerrard is Reader in Chemical Engineering at the University of Teesside in northeast England. His research and teaching interests include process economics and optimization.



Mark Hockborn (left) and Jason Glass (right) work for international chemical companies and are part-time students currently completing a Higher National Diploma program in chemical engineering.

where the symbols are defined in the nomenclature. As these natural beds tend to collapse and compress, so the height, h, voidage, ε, and specific surface, a, change from the original values, h_0, ε_0, a_0, and hence the bed pressure drop increases.

If the structure of the bed is assumed not to alter, then

$$\varepsilon = \frac{hA - (1-\varepsilon_0)h_0 A}{hA} = 1 - \frac{(1-\varepsilon_0)h_0}{h} \tag{2}$$

$$a = \frac{a_0 h_0}{h} \tag{3}$$

Putting these back into Eq. (1), we find

$$\Delta p = \frac{5a_0^2 h_0^4 (1-\varepsilon_0)^2 \mu v}{\left\{h - (1-\varepsilon_0)h_0\right\}^3} \tag{4}$$

or

$$\Delta p = \frac{kv}{(h-G)^3} \tag{5}$$

where

$$k = 5a_0^2 h_0^4 (1-\varepsilon_0)^2 \mu \tag{6}$$

and

$$G = (1-\varepsilon_0)h_0 \tag{7}$$

Thus, for Eq. (5) we would predict an inverse cubic relationship between pressure drop and bed height for a given bed velocity. So a small change in bed height can have a profound effect on Δp.

Rearranging Eq. (5), we have

$$\left(\frac{v}{\Delta p}\right)^{0.333} = k^{-0.333} h - Gk^{-0.333} \tag{8}$$

So, a plot of $(v/\Delta p)^{0.333}$ versus h will yield a straight line whose slope is $k^{-0.333}$ and the intercept is $Gk^{-0.333}$. From the intercept, we find G and then ε_0 from Eq. (7). Finally, Eq. (6) leads directly to a_0.

We can extend the analysis by calculating the mean equiva-

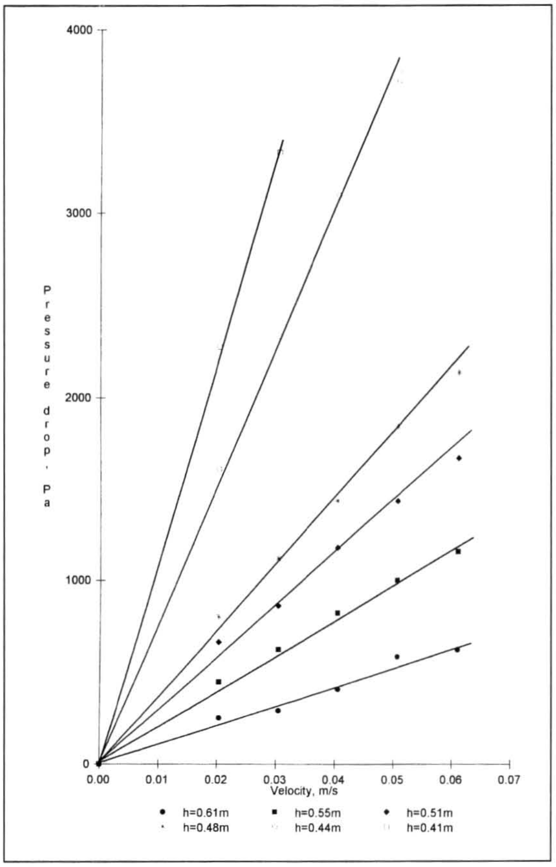


Figure 1. *Graph of pressure drop versus velocity for various bed heights.*

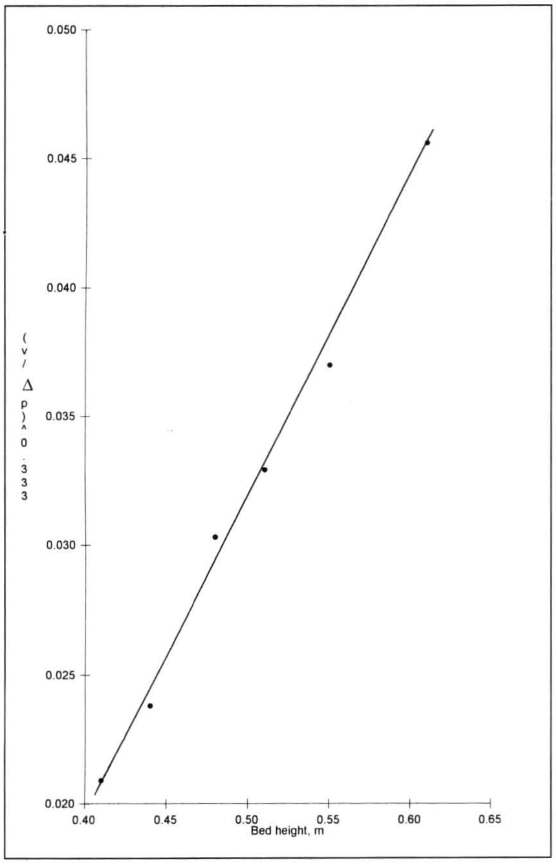


Figure 2. *Graph of (velocity per pressure drop)$^{0.333}$ versus bed height.*

lent particle diameter

$$D_p = \frac{6(1-\varepsilon)}{a} \qquad (9)$$

and can also check to see if the Reynold's number is in the right range.[3]

EXPERIMENTAL

We used an existing 6-inch diameter glass column, complete with manometer and rotameter, which is usually used as a sand-air fluidized bed. The natural packing material was a commercial peat-moss-based potting soil purchased from a local plant nursery. An original packed height of some 0.61m gave reasonable results. The pressure drop-flowrate curve for the empty vessel was determined, then the column was filled with the compost, and the measurements were repeated. The contents were gently compressed by hand and the net pressure drops were again found. Some five compressions were applied, leading to Figure 1.

The gradients from Figure 1 allow us to calculate $(v/\Delta p)$, which when raised to the one-third power, can be plotted against the bed height, h, to give Figure 2, which is an excellent straight line. Finally, we compute the original voidage and specific surface to be 0.6 and 17000m^{-1}, respectively

CONCLUSIONS

Existing equipment can be used with unconventional packings to measure the effect of bed consolidation. The experiment gives the student an unconventional use of the Kozeny equation, together with an interesting opportunity to linearize Eq. (5). It is also an extremely inexpensive addition to the undergraduate lab.

NOMENCLATURE

- a specific surface area (variable)
- A bed cross-sectional area
- D_p mean particle size
- G constant defined by Eq. (7)
- h bed height (variable)
- k constant defined by Eq. (6)
- v superficial bed velocity
- Δp pressure drop
- ε voidage (variable)
- μ gas viscosity

Subscripts

- 0 indicates original value before compressions

ACKNOWLEDGMENT

This work is part of an EU-funded project on the purification of waste gases.

REFERENCES

1. Bohn, H., "Consider Biofiltration for Decontaminating Gases," *Chem. Eng. Prog.,* **88**, 34 (1992)
2. Coulson, J.M., and J.F. Richardson, *Chemical Engineering,* Vol. 1, Pergamon, Oxford, England (1990)
3. Bird, R.B., W.E. Stewart, and E.N. Lightfoot, *Transport Phenomena,* Wiley & Sons, New York, NY (1960) ❐