THE EFFECT OF FIBER SIZE ON PROPERTIES OF PERMEABLE CARBON FIBER COMPOSITES

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Introduction

The removal of toxic, hazardous and polluting chemicals from industrial waste streams becomes of greater interest as more stringent environmental legislation takes effect. The use of activated carbons for gaseous and liquid waste stream clean-up is well known. However, the cost of using adsorptive carbon beds is prohibitive in many cases due to low rates of uptake, high pumping costs, and inadequate bed regeneration. Low density carbon fiber composites have the potential to counteract these problems as they have the advantages of high mass transfer rates, good mechanical strength, and high permeability to liquids and gases.

The carbon fibers that are best suited for activation (i.e., isotropic rather than anisotropic mesophase) and are commercially available, have diameters of about 20 µm. These have been used in the composite studies reported previously [1,2]. This paper describes the effects on permeability of varying the fiber length and diameter.

Experimental

Fibers with a nominal diameter of 50 µm were made from a coal tar pitch (ex. Reilly Industries) which was filtered and vacuum distilled prior to spinning using a single hole spinneret. The fibers were stabilized in air up to 310 °C, carbonized at 1100 °C and then chopped. However, most experiments were conducted using commercially available milled carbon fibers: 10 µm diameter PAN based (ex. R.K. Carbon Fibers Ltd.) and 17 µm diameter petroleum pitch based (ex. Carboflex Ashland). Fiber batches were also blended or subjected to further length reduction.

Composites were made by water slurrying the fibers with a particulate phenolic resin, prior to forming by filtration and finally drying and curing. Permeability data were collected by measuring pressure drops at various volumetric flow rates of air. Blank runs were conducted to correct for any contribution from the testing apparatus.

Results and Discussions

Density

Figure 1 shows how the composite density varies with average fiber length for various grades of the 17 µm diameter fibers. Generally, the density is inversely proportional to fiber length at high aspect ratios progressing to the square root of fiber length for low aspect ratios. There are insufficient data on fiber length and length distribution for the other fiber diameters to make firm conclusions, but increasing the fiber diameter by a factor of 3 increases the composite density by a factor of at least 2. If the same packing occurred, then the theoretical density should have increased by a factor of about 3.

Permeability

Stokes' law describes pressure drop as a function of fluid velocity for flow past objects in wide channels and is valid for particle Reynolds numbers less than 0.1. Stokes' flow is not expected in the practical operating regions for these composites since the Reynolds numbers will be greater than one.

Blake (1922) suggested an equation for flow in a packed bed which is a modification of Stoke's law:

$$\frac{\Delta p}{L} = \frac{150\mu}{D_p^2}\frac{(1-\varepsilon)^2}{\varepsilon^3}U \qquad (1)$$

Where $\Delta p/L$ is pressure drop per length, U is the superficial velocity, D_p is the effective particle diameter, μ is the fluid viscosity, and ε is the composite void fraction. This equation has been tested for laminar flow and packed bed void fractions ε, less than 0.5.

Typical plots of $\Delta p/L$ versus U are shown in Figure 2 for fibers of 17 µm diameter. It will be noted that the slope of the log-log plot is near 1, meaning that the flow is near laminar. Applying the correction for void fraction from the known densities of the composites and fibers (1.9 g/cc) enables plots of $\Delta p/L$ versus corrected velocity U^* to be made, where $U^*=U(1-\varepsilon)^2/\varepsilon^3$. These are shown for all three fiber diameter groups in Figure 3. The correlations are good considering the wide range of permeabilities. For any given fiber diameter it seems unimportant how the density is achieved, i.e., a blend of lengths could be used. The general equation that has previously been suggested [2], $\Delta p/L = K(U^*)^n$ where n varies from 1 to 2 as the flow moves from laminar to turbulent seems to be a good fit with n being close to 1 for fiber diameters of 10 and 17 μm. For the 50 μm diameter fibers the value of n is 1.4, implying a transition towards turbulent flow.

For the 10 and 17 μm diameter fiber based composites effective fiber diameters calculated from Equation 1 (ignoring the slight deviation of n from 1.0) are 8.4 and 15 μm respectively. For the 50 μm diameter fiber based composites the effective calculated diameter is, after forcing n to be equal to 1.0, 41 ± 8 μm.

In practical applications, diffusion into a 50 μm diameter fiber will be slower than for a 20 μm diameter fiber, but may still be fast compared to alternative forms of granulated or powdered activated carbons; the substantially lower pressure drop (i.e., by a factor of 5) for the same density would make larger diameter fiber composites attractive in many applications. Alternatively for the same pressure drop, a composite of the same shape and size, but with a density 50 % higher could be substituted which would increase the system's adsorptive capacity. Against this, the cost of longer processing time during manufacture of larger diameter fibers has to be weighed (e.g., during stabilization and activation).

Conclusions

The pressure drop through composites can be accurately predicted using a modified form of Equation 1. Mean fiber lengths can be varied to give fairly wide ranges of density (and hence permeability) and length distribution can be narrow or wide without significant difference between the relationship between density and permeability. Thus the use of two grades of milled fibers would enable composite properties to be varied within close limits. The use of fibers of larger diameters to those currently available offer the potential of better performance in certain applications.

Acknowledgments

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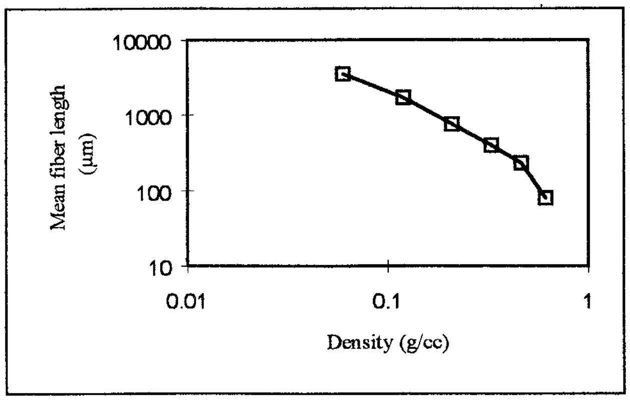

Figure 1. Composite density vs. mean fiber length for 17 μm diameter fibers.

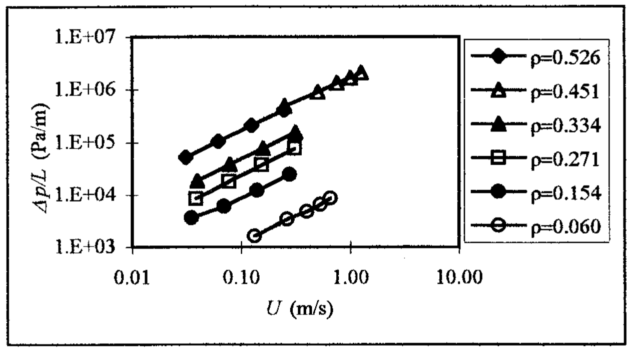

Figure 2. Pressure drop per length vs. superficial velocity for 17 μm diameter fibers.

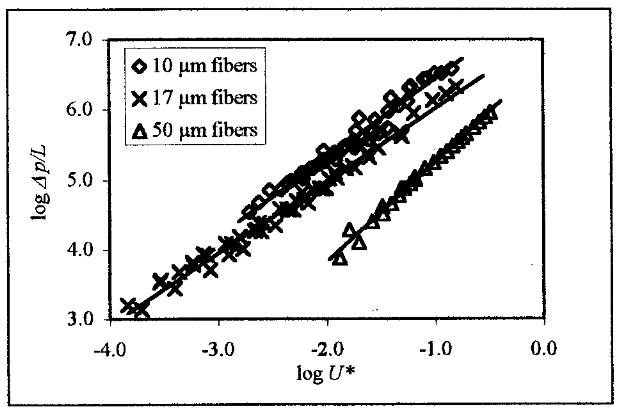

Figure 3. Pressure drop per length vs. corrected superficial velocity for all three fiber diameter groups

References

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