UDC 544.725:66=111

STRUCTURES OF FILTER MEDIA AND MECHANISMS OF FILTRATION

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Separation systems are a vital part of most industrial processes. These systems account for a large fraction of the equipment and operating costs of industrial processes. Inorganic membranes have the potential for providing separation systems that can reduce both equipment and operating costs. Some optimistic thoughts will be given on how several industries can be operationally and economically revolutionized with inorganic membranes systems.

How efficiently a filter medium causes the separation of finely divided solids from a liquid or a gas depends on many variables. The first variable that usually comes to mind is the size of the pores in the medium. How important is a pore size? What do we mean by a pore size?

Some investigators have studied the efficiency with which a single fiber held in a gas stream captures particles from that stream. It follows that the more fibers you have, the greater the number of particles captured. Indeed, where fibrous mats are used to separate particles from a gas, the particles separated are much smaller than the distance between fibers. That is, the particles captured are much smaller than what we call pores.

The efficiency with which a filter medium separates particles from a fluid depends on the internal surface of the medium with which a unit volume of fluid comes in contact. Yet, given this surface-to-volume ratio, filtration efficiency also depends on the viscosity of the fluid and the temperature (independent of viscosity), the velocity of the fluid, and the affinity which the particles have for the material of the filter medium. This affinity, or repulsion, also depends on the material of the fluid.

With this list of variables, it should be clear that pore-size measurements cannot be made from filtration tests. The most obvious reason is seen in considering two media of the same material and the same pore-size distribution, but different thicknesses. In this situation the thicker medium will be a more efficient filter. The investigator who deduces pore sizes from filtration tests can be led astray.

There does remain the view, however, that under some conditions, filtration is a sieving operation, in this case pore size does loom high in interest. For example, a medium which is very efficient at filtering small particles from a gas is much less efficient at filtering those particles from a liquid, especially a highly viscous liquid. Liquid-borne particles, smaller than pores, when passing through the medium, tend to remain in the liquid stream, whereas in the less viscous gas stream, the particles are much more likely to find the pore wall. Once the particles touch the wall, where fluid velocity is nil - in laminar (viscous, or Poiseuille) flow - they fairly well stick there. Thus, where a filter medium is to separate small particles from a liquid, the pores must be smaller.

Sieving is the operation we have in mind when we want to make sure certain size particles or microbes are stopped, regardless of such variables as fluid velocity and viscosity.

The first thing to understand about fine filter media is that the length of the average-size pore is hundreds of times greater than the diameter. Of course, some media are relatively thin, being supported on a coarse (large-pore) support. But even then the length of the pore is greater than the diameter.

The present discussion is limited to those filter media composed of a random array of building blocks, specifically, three kinds: mats of fibers; sponge like membranes (manufactured by solvent-cast methods without surface skins); and membranes manufactured by stretching a solid plastic sheet so that as the sheet opens, it creates fibers emitting from clusters. Further, this discussion is limited to homogeneous media. That is, no matter where we inspect a plane in the medium (perpendicular to the flow of fluid). We see the same pore-size distribution.

The size of a pore in this plane is expressed as a linear measurement and generally means diameter. Yet that meaning depends on the method of measurement understanding that the pore is not a circle. For example, the measurement may be the square root of the cross-sectional area, or it may be the ratio of area to perimeter.

On moving from this Flatland (Abbott 1963), two-dimensional view, and moving into threedimensions to better address pore geometry, we see two concepts.

In the case of the spongelike membranes, Williams and Meltzer (1983) view the structure as skeletons of polyhedra. Where two skeletons touch with a common face, the opening in that face is a pore. The diameters of the polyhedra are larger than the diameters of the pores. And, of course, there exists a distribution of both kinds of diameters.

The statistical view of a pore tunnel that passes through this filter medium is really not different from that of a tunnel in a fibrous mat. That is, the diameter of the tunnel varies along the bending length; and if we consider only sieving filtration, then we view this scenario:

A single particle (or microbe) approaching the face of the medium may be stopped on the surface if it hits the surface at a spot where there is no pore, or the pore is smaller. On the other hand, the particle may encounter a large pore, which it enters and then travels through to a depth before it is stopped by a choke point in the tunnel.

In the case of fibrous mats, or those stretched membranes resembling fibrous mats, a three-dimensional view is explained by considering that the medium is composed of many theoretical, thin layers, with some finite space between layers. The pore-size distribution in one layer is the same as the next; however, a large pore in one layer does not necessarily lie in the same spot on the next layer.

Both of these three-dimensional views allow us to understand somewhat how a fluid divides into many different-diameter streams when it flows through a filter medium. Of course, each stream likely divides and rejoins with itself or another stream. Yet, referring to what we said earlier, we can envision an average stream within the medium, so that we can speak of an average diameter and an average length.

The view of a pore-size distribution we obtain with a microscope, on inspecting the face of a filter medium, is the number distribution. We make a list or a plot of pore diameter versus the numbers of pores of each diameter. From that we deduce a number-average pore diameter. If now we consider the cross-sectional area of a pore (a function of the square of the diameter) and view each pore as having unit depth, we can deduce the volume-average pore diameter.

In conclusion, while some conditions of filtration may approach a sieving operation, most filtration processes consist of particles falling into the depth of the medium before they are stopped. This means that the efficiency with which particles are stopped depends not only on a pore size (whatever that means), but also on many other variables, such as the thickness of the medium, the velocity of the fluid, the viscosity, the temperature (independent of viscosity), and the affinity, or the repulsion, that particles (or microbes) have for the pore walls and for the fluid.

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