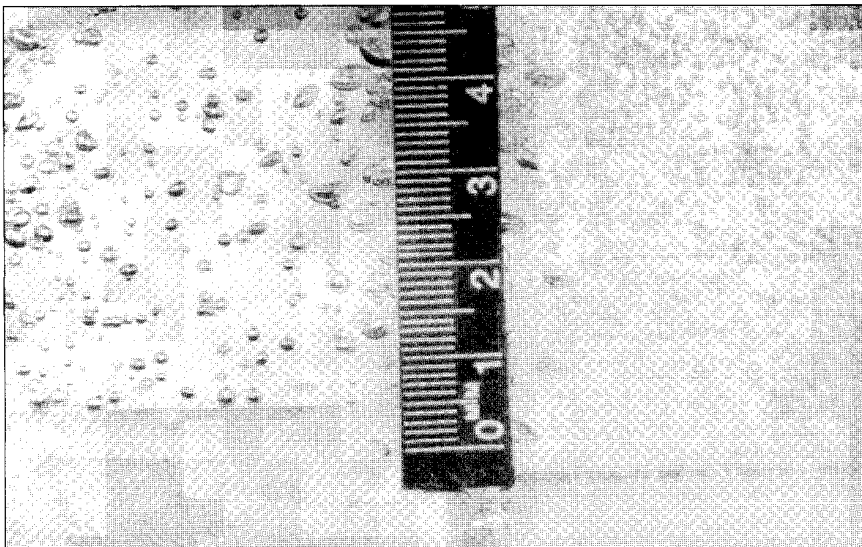


# Discovery of factors affecting bubble size in water

Bubble size important for aeration, ozonation and other processes.

By W. Alan Burris



A side-by-side comparison of a conventional ceramic diffuser (left) and a new proprietary diffuser.

**A**lthough it is usually assumed that the principal determinant of bubble size in water and other liquids is the pore size of the diffuser, experiments have shown that this is one of the less important factors.

Surprisingly, the most important factor has been found to be the ratio of the surface energy of the diffuser material at the water interface to the surface tension of the liquid. The higher the ratio, the smaller the bubbles.

There is substantial literature on the role of bubbles in mass transfer and other applications. Bubble creation is important for processes such as ozonation; aeration of drinking and wastewater, aquariums, fish farms, ponds and lakes; air stripping of volatile organic compounds, radon and hydrogen sulfide; iron and sulfide removal by oxidation; and separation by flotation. However, there is surprisingly little published about the factors affecting

bubble size, or about methods of controlling the bubble size.

For water with normal surface tension, the higher the diffuser surface energy (the more hydrophilic), the smaller the bubbles. Reducing the surface tension of the water also reduces

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the bubble size, but it is usually undesirable to add surfactants to water.

Using patented technology, high-surface-energy materials have been combined with low-surface-energy materials to obtain bubbles less than 1 millimeter (mm) in average diameter, compared to 2 to 3 mm for commercial ceramic diffusers

at comparable gas flows. The small bubbles were obtained with thin, low-cost materials at low pressure drops.

Pore uniformity provides high turn-down ratios with even bubble distribution across the diffuser surface. The diffusers act as check valves by resisting water intrusion, reducing fouling by waterborne contaminants.

## The significance of bubble diameter

Bubble diameter can critically affect process efficiency because it determines the surface area of the bubbles. For two different spherical bubble diameters with the same total volume of gas, the ratio of the total surface areas is inversely proportional to the ratio of the diameters. For example, at the same air flow rate, decreasing the bubble diameters from 2.5 mm to 0.5 mm would increase the interfacial contact area between the air and water by a factor of five for spherical bubbles.

The actual improvement factor would be greater for bubbles smaller than 1 mm because of the longer rise time. The improvement factor would be less for larger bubbles because the surface area of larger bubbles is increased by frictional distortions as they rise.

Commercial ozone sparging systems with 4 to 7 meters (m) of water depth are less sensitive to bubble size than portable ozone water purifiers with less than 0.2 m depth. Ozone transfer efficiency with a conventional diffuser's 2- to 3-mm bubble diameter is poor at this depth, and unacceptable for a contact lens disinfecting device with a liquid depth of less than 0.03 m.

However, few practical methods exist for affecting bubble size. An

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example of an impractical way to make smaller bubbles is adding a surfactant to reduce the surface tension of the water. Not only it is undesirable to add a surfactant to drinking water or aquariums, but in other applications surfactants can create a foam problem and, used in large quantities for applications such as ore flotation, would be costly and create a pollution problem. Mechanical agitation or ultrasonics would increase the cost, size and complexity of systems. Methods involving higher pressures or additional pumps are unappealing for the same reasons.

A finer-bubble diffuser appears to be the best solution for increasing ozone transfer efficiency. Ceramic diffusers with very fine pores produce smaller bubbles than the standard types. However, they are not popular, apparently because of the higher pressure drops and propensity to clog.

#### Finer pores, finer bubbles?

There are questions about the theory that finer pores are the way to make finer bubbles. For example, why is it that 50-micron-pore-sized ceramic diffusers produce 2- to 3-mm bubbles? And why is it that similar pore sizes in different materials produce different-sized bubbles?

Experiments have shown that the diffuser material property that is the primary determinant of bubble size is not the pore size, but the free energy at the surface, which is a result of intermolecular attraction. In the bulk of a homogeneous material, molecules are attracted to each other equally. These forces of attraction are the same as those that determine whether a substance is in a gas, liquid or solid phase at a particular temperature and pressure.

The strength of intermolecular forces depends on the chemical structure. However, at the boundary between phases, the forces are unequal because the molecules are in contact with molecules with different forces of attraction. This causes the interface to act as if it

were under tension — a condition called surface tension.

The surface tension of liquids is easily and accurately measured, but the surface tension (surface free energy) of solids can only be measured indirectly and approximately. Measurements are expressed in dynes/centimeter. Polar and metallic liquids and solids have high surface tension/energy compared to nonpolar substances.

The significance of such data for bubble formation is that the degree of wetting of a solid by a liquid is determined by their relative surface energies. A solid is generally completely wetted by a liquid that has equal or lower surface energy. This is why surfactants that lower the surface tension of water improve the wetting of greasy surfaces. An interesting phenomenon is that water does not wet hydrocarbons, such as oil or paraffin, but oil wets solid ice. Figure 1 illustrates the forces acting on a drop of

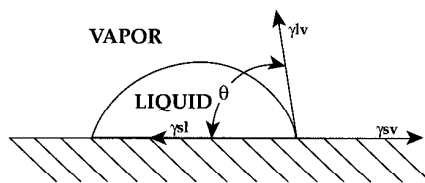


Figure 1

water on a lower energy surface.

The equilibrium between the solid, liquid and vapor phase interfaces is expressed by the Young equation:  $\gamma^{sv} = \gamma^{sl} + \gamma^{lv} \cos \theta$ .

In this equation  $\gamma$  is the tension between the phases,  $sv$  refers to the solid-vapor interface,  $sl$  to the solid-liquid interface,  $lv$  to the liquid-vapor interface, and  $\theta$  is the contact angle. The contact angle expresses the degree of wetting of the solid by the liquid.

Conventionally, when the contact angle is zero, wetting is complete and the liquid displaces air to spread over the surface. For partial wetting or non-wetting, the contact angle may increase up to 180 degrees when a drop is con-

tacting the solid at only one point. While the theory applies to the wetting of solids by all liquids, the primary concern is wetting by water. This is because hydrogen bonding makes water's surface tension much higher than the critical surface tensions at which many common solids can be wetted. In aqueous systems, high-surface-energy materials are referred to as hydrophilic, and low as hydrophobic.

To relate this information to bubble formation, consider why some bubbles leave the diffuser surface while they are very small, while others grow to a much larger size before detaching from their surface. This is explained by the two diagrams in figure 2 on the next page, one for a low-surface-energy diffuser and the other for a high-surface-energy diffuser.

With the small contact angle, water displaces the gas from the high-energy diffuser surface pore so that the tension holding the bubble to the surface is minimized. A smaller upward force from the gas "balloon" suffices to detach it to rise through the liquid. In contrast, the contact angle for a low-surface-energy diffuser is greater so that the gas displaces the water. The bubble must grow bigger before the upward force produced by the density difference between gas and liquid is sufficient to overcome the surface tension of the larger area and produce "lift-off."

#### Other factors that may affect bubble size

It may turn out that pore size is a more important factor for diffusers with a high-energy surface. In other words, bubble size may proportionally vary more with the pore size of high-energy diffusers. Lower surface energy may overpower the effect of pore size. Needed research in this area will be difficult because of the problem of holding constant the other factors involved while varying the pore size.

Uniformity of pore size is an important factor in average bubble size. Nonuniformity causes a higher gas flow through the larger pores, which

increases the bubble size from those pores, and reduces the number of active pores producing bubbles.

Often, to compensate for nonuniformity, diffusers are made thicker. The greater thickness more uniformly distributes the gas flow to the pores, but makes the diffuser more prone to clogging. Clogging from waterborne pollutants and fouling from biological growths can change the size and number of active pores, change the diffuser's surface properties and increase its pressure drop.

The ideal diffuser would have a uniform small bubble pattern across its surface over a wide range of gas flow rates. It would resist clogging, maintain a low pressure drop and be inexpensive to manufacture.

New technology has been developed that offers substantial progress toward this ideal. The basic concept is to use a porous material that has a high surface energy at the liquid inter-

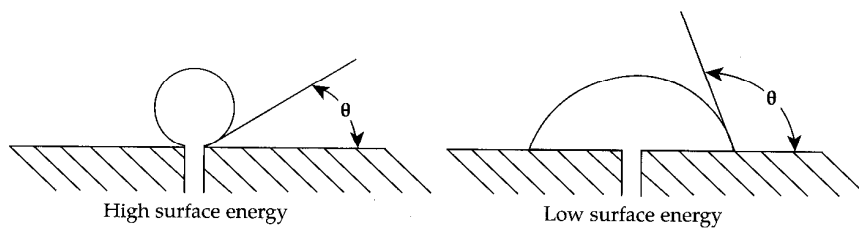


Figure 2

face, but a low surface energy below the interface. The high-surface-energy interface produces fine bubbles, and the low surface energy material, being hydrophobic, resists water intrusion, acting as a check valve. Thus, only a thin flexible layer at the interface is exposed to waterborne contamination.

The finer the pores of the hydrophobic layer and the lower its surface energy, the more the water pressure that can be resisted. And, because the hydrophobic layer resists water and waterborne clogging, its pores can be made finer. The fine pores enable a thin layer to evenly distribute gas flow through the

hydrophilic surface. This combination enables a 0.5-mm-thick membrane to produce bubbles close to 0.5 mm in diameter at a low pressure drop, while acting as a check valve.

Experiments have shown that the small bubbles produced with this technology substantially improve oxygen transfer efficiency as well as solving problems with ozone transfer efficiency in very small systems. □

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