

Caught in the crossflow

Elizabeth L. Brainerd

Suspension-feeding fishes filter water through complex structures in their throats. Food particles could clog the filters, but the fishes have a cunning system to prevent that happening.

Beverage manufacturers use a clever process known as crossflow filtration¹ to produce sparkling clear wines, beers and fruit juices. In this process, the fluid to be filtered flows parallel to the filter surface, rather than directly through it. By mechanisms that are not yet fully understood, any particles in the fluid tend to be transported away from the surface of the filter, minimizing clogging. Clear filtrate passes through the filter pores, and the particles are ejected from the system in a concentrated solution. On page 439 of this issue, Sanderson and colleagues² report that some fish species also use crossflow filtration — in this case to remove small food items, such as zooplankton and phytoplankton, from the water.

'Suspension-feeding' fishes have a filter-like set of structures called gill arches and gill rakers in the back of the throat (Fig. 1). Gill rakers have been assumed to function as a 'dead-end' filter, collecting small food items by sieving³ (Fig. 2a, particle 1, overleaf) or by hydrosol filtration, in which particles smaller than the size of the filter pores stick to the filter's elements^{4,5} (Fig. 2a, particle 2).

A potential problem with dead-end filtration, however, is that a lot of tiny food particles become trapped on the gill rakers. How can a fish remove the particles for swallowing without resuspending them and undoing all of the previous filtering? Some species solve this problem by using large amounts of mucus to trap particles on the gill rakers or on the roof of the mouth^{6,7}. Clumps of particle-laden mucus are then transported to the oesophagus. Other species, however, have little or no mucus on their oral surfaces⁸. For these species, as Sanderson *et al.*² show, crossflow filtration neatly avoids the problem because food particles remain in suspension rather than sticking to the gill rakers.

In a creative application of medical technology to zoological research, Sanderson *et al.* used a miniature fibre-optic endoscope to spy on the paths of food particles inside the mouths of three fish species: the gizzard shad, ngege tilapia and goldfish. They find that more than 95% of the particles travel towards the oesophagus without coming into contact with the gill rakers or any other oral surface. As water and suspended particles flow over the gill rakers, water exits between the gill rakers and food particles become more concentrated in the remaining water (Fig. 2b). A concentrated slurry of par-

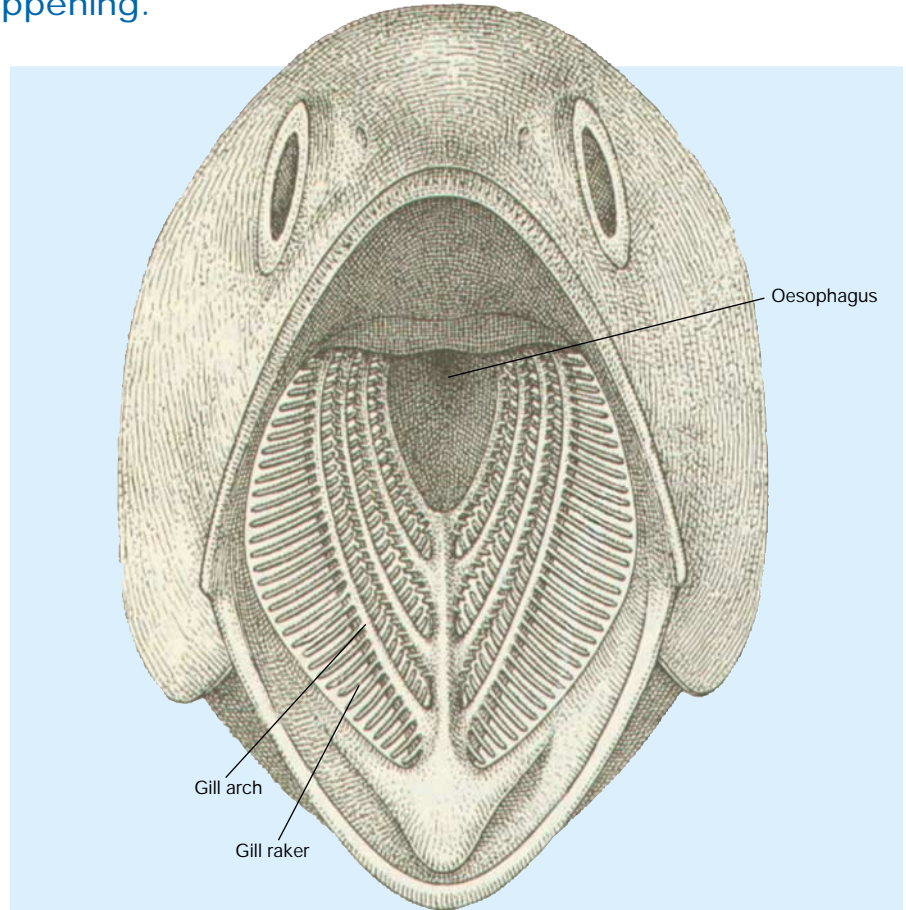


Figure 1 Suspension feeder. Gill arches and gill rakers form a filter-like surface at the back of the mouths of suspension-feeding fishes. Sanderson *et al.*² used a miniature endoscope to study the flow of water-suspended particles in three fish species: the gizzard shad, ngege tilapia and goldfish. The authors observe that more than 95% of food particles do not come into contact with the gill rakers but instead remain suspended as fluid flows parallel to the filter surface and water leaves between the gill rakers (crossflow filtration; Fig. 2b). Particles become more concentrated as they travel towards the oesophagus, and the fish swallows a concentrated slurry of food particles. (Figure reproduced from ref. 5.)

ticles accumulates in the back of the throat and is swallowed.

Neat though it is, this study leaves unanswered the question of precisely how crossflow filtration in fishes works. In fact, although crossflow filtration has been an important industrial process for decades, the underlying physical mechanisms here, too, are not yet fully understood. Why do particles tend to remain in the crossflow, rather than leaving with the filtrate or getting trapped in the filter pores?

During reverse osmosis — a type of crossflow filtration — simple diffusion seems to be sufficient to transport macromolecules and ions (less than 10^{-3} μm in

size) away from the filter surface¹. But fishes consume much larger particles (40–1,000 μm in size) and the mechanisms of particle transport for relatively large particles are more controversial. Using appropriate fluid-flow conditions, Sanderson *et al.*² tested one theoretical transport mechanism — radial inertial migration — and found that it is inadequate, by an order of magnitude, to explain particle transport in fishes that feed by crossflow filtration. Further theoretical developments in the field of filtration engineering, combined with more precise measurements of fluid flow inside the mouths of fishes, will be necessary to explain the physical mechanisms underlying cross-

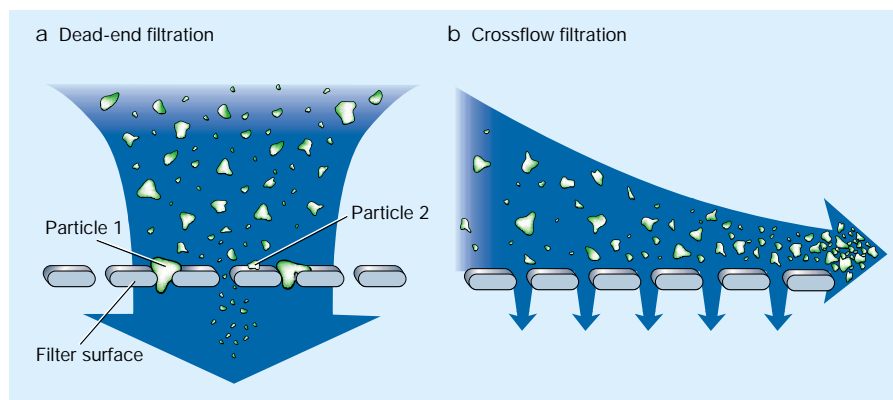


Figure 2 Dead-end and crossflow filtration. **a**, In dead-end filtration, fluid flow is perpendicular to the filter surface and the filter rapidly becomes clogged with particles. Particles may be retained by sieving when they are larger than the filter's pore size (particle 1), or by hydrosol filtration⁴ when they are smaller than the pore size (particle 2); in this case, the small particles stick to the elements of the filter. **b**, In crossflow filtration, fluid flows parallel to the filter surface and particles become more concentrated as filtrate leaves through the filter's pores.

flow filtration in suspension-feeding fishes.

Results from studies of suspension feeding have broad implications for ecological studies of freshwater and marine ecosystems⁹. Different suspension-feeding mechanisms select differently sized particles. Only particles larger than the filter pore are retained in a dead-end sieve (Fig. 2a, particle 1), whereas particles smaller than the pore size may be retained in dead-end hydrosol filtration (Fig. 2a, particle 2) or in crossflow filtration (Fig. 2b). The filtering mechanism determines which species and life stages of planktonic organisms are consumed, and this in turn has profound effects on the structure of aquatic populations and communities. The discovery by Sanderson and colleagues² of a fundamentally new mechanism of suspension feeding in fishes

may contribute to more realistic models of the dynamics of aquatic ecosystems. ■

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Chemistry

How green was my ester

Giorgio Strukul

Hydrogen peroxide is an ideal oxidant. It cannot yet be used widely, because viable catalysts aren't available for many industrially important processes. But there are encouraging indications of progress.

Chemistry has turned green^{1,2}. The increased awareness of environmental problems has generated an overly simplistic division, however, especially in the media, between 'bad' chemistry — which first pollutes and then (sometimes) cleans up — and 'good', green chemistry. Chemists themselves are partly responsible for setting up this misleading contrast. But they are nonetheless among the leaders in trying to find less wasteful or damaging ways to handle the planet's resources. A lovely example appears on page 423 of this issue³, as described by Corma and colleagues.

Environmental protection and economic growth are not necessarily in antithesis, but improved chemical technologies can be needed to combine them. Industrial organic chemistry often involves multistep methods in which the yield of valuable end-product is largely outweighed by the amount of waste that has to be disposed of. The synthesis of complex molecules used as pharmaceutical or agrochemical products may involve up to 10–15 steps and can generate more than 100 kg of waste for each kilogram of end-product. In this respect, the use of catalysts that can simplify stepwise synthetic procedures,

or of cleaner reagents, is in principle more environmentally friendly.

The approach reported by Corma and colleagues³ fits the bill nicely. The authors have produced a new class of catalysts for the Baeyer–Villiger oxidation of ketones. This reaction, shown in Fig. 1a, was first described in 1899 by German chemists Adolf Baeyer and Victor Villiger⁴. It involves the transformation of a ketone into an ester (an organic molecule containing an extra oxygen atom with respect to the parent ketone), using an organic oxidant. Organic chemists have used the reaction for over a century. It is applied in the synthesis of a wide variety of chemicals, ranging from simple monomers used in the plastics industry to the more complex molecules that constitute pharmaceutical or agrochemical products⁵. However, as shown in Fig. 1a, the oxidant (generally an organic peroxy acid) produces waste — and often in larger amounts than the desired esters. So there has long been an interest in finding more environmentally friendly oxidants for this and similar reactions, hydrogen peroxide being the ideal choice.

Hydrogen peroxide, H₂O₂, is familiar because just about every household has a bottle of it, in dilute solution, for use as a disinfectant. Its main industrial applications are in the bleaching of paper, cellulose or textiles, or in making detergents; its applications in the manufacture of organic chemicals are minimal. The great advantage of hydrogen peroxide as a reagent is that it produces water as the waste product, and in small amounts only (Fig. 1b). The problem is that hydrogen peroxide does not react directly with substrates, but needs a catalyst to mediate the reaction. Over the years the search for such catalysts has progressed slowly^{6,7}, especially so in the case of the Baeyer–Villiger oxidation of ketones, for which the use of catalysts is relatively recent⁸. Unfortunately, the few catalysts capable of promoting hydrogen peroxide oxidation are almost exclusively metal complexes that are soluble in the reaction medium (homogeneous catalysts). These are not desirable for industrial purposes because they require several costly operations to separate the catalyst from the end-products.

Corma *et al.*³ open a new avenue for exploiting the Baeyer–Villiger process, based on insoluble (heterogeneous) catalysts that can be easily separated from the reaction medium by filtration. These catalysts are derivatives of a particular class of synthetic zeolite to which a metal — tin — has been added (Fig. 2). Zeolites are crystalline materials, many of which can be found in nature, that have a regular array of internal channels. They are composed of oxides of silicon and aluminium, and are similar to clays but with a different structure.

Incorporating tin atoms into the zeolite framework requires a special synthetic