Don Clark explains how micro-organisms survive and are spread in the air.

Microbe-laden aerosols

▲ High speed photograph showing jets of droplets erupting from a man's nose as he sneezes. *Dr John Brackenbury / Science Photo Library*

The term aerosol has become associated over the years with the products of spray cans that produce coarse droplets or particles of materials as diverse as de-odorants and oven cleaners. The term has also become associated, in the minds of many people, with the CFCs that were used as propellants in cans, and so 'aerosols' are often, quite wrongly, blamed for the destruction of the protective ozone layer.

In fact the term aerosol was originally coined to describe a quasi-stable suspension of particles, either solid or involatile liquid, in air. Of course stability is relative and may be applied differently in various contexts, but as far as aerosols of the type that might contain micro-organisms are concerned they may have lifetimes that range from at least an hour or two to weeks or even months.

Atmospheric aerosols

The air we breathe is an aerosol. The concentration of particles varies enormously with location, altitude and weather conditions, but even 'clean' air will normally contain billions of particles in every cubic metre. The majority are very tiny indeed, typically some tens of nanometres in diameter, but there will be a significant number (perhaps 10^5 or 10^6 per cubic metre) that have micrometre dimensions and of these a significant proportion will be of biological origin.

The atmosphere acts, like the oceans, as a global medium of transport for a wide range of different materials. This enables the living world to function by distributing the components vital to maintaining ecosystems and diluting or enabling the destruction of waste products. Many living systems use the atmosphere as their means of distribution, perhaps the most obvious example being plant pollens that are wind-disseminated. This has an interesting side-effect for the human population. As the probability of a pollen grain that becomes air-borne being deposited in the appropriate part of a plant of the same species is tiny, to be successful the plant must disseminate huge numbers of pollen grains. This results in seasonal clouds of pollen that cause allergic reactions when they are inhaled by susceptible individuals.

Bacteria and viruses can also use the atmosphere for distribution. An infected host can be induced, by a variety of mechanisms, to release the organisms into the atmosphere. Once air-borne, these can be inhaled by a new host where they will deposit in the airways to begin a new infection cycle.

Generation of microbiological aerosols

All aerosols of micro-organisms are generated by some type of disruptive process. This may be by the break-up of sheets or columns of liquid suspensions or by air movement lifting deposited particles and separating them into single units.

An example from the natural world of the break-up of liquid suspensions to generate a potentially infectious aerosol is sneezing. A sneeze is caused by a rapid muscular spasm that expels air at high velocity through the nose where the shear forces tear the mucus from the nasal hairs and lining, breaking up the ligaments into droplets. The greater the energy input to the process, the smaller will be the droplets that are produced.

At the other end of the energy scale is the dispersion of pollens and spores. Here, plants have evolved complex strategies that use the geometry of the pollen grains, coating of the grain and the lining of the pollen sac to overcome the effect of Van der Waals forces that hold small particles both to surfaces and to each other. So pollens and spores are effectively dispersed even in very light winds.

Clearly natural systems have evolved so that, whatever the aerosolization process, the mechanism does not compromise the viability of the organism. However, generation techniques used in the laboratory or field to produce aerosols artificially, are generally highly energetic and can deliver very high shear and impaction forces. It is important to understand, when designing experiments, that such forces can seriously damage delicate organisms and may reduce viability or culturability significantly.

Dispersion

An aerosol, being a quasi-stable suspension of particles in air, will act in many ways just like one of the gaseous components of the atmosphere. So wherever the wind blows or convection currents move the air, the particles will be carried with it. However, there are some important differences in the way that particles behave as compared to gaseous components of the atmosphere and these can be of particular significance in the case of micro-organisms.

Diffusion. When a source of gas is added to the atmosphere, it will dilute very rapidly as the molecules diffuse through the other gaseous components. When a source of particles enters the atmosphere they will also diffuse, due to Brownian motion, but very much more slowly and with a diffusion coefficient that is a function of particle size. So for micro-organisms, which are relatively large particles, their diffusion coefficient will be many orders of magnitude smaller than that of a gas molecule. This can be important in the spread of disease. For example, a flock of coughing sheep infected with foot-and-mouth disease may produce an aerosol cloud that will travel many miles with only a low dilution factor and so retain the potential to infect any other animals it passes over.

Table 1. Velocity of fall in relation to particle size

Particle size (μm)	Velocity of fall (mm s⁻¹)
0·1	0·00085
1·0	0·035
5·0	0·78
10·0	3·0

Deposition. Particles, unlike gas molecules, do fall through the atmosphere under the influence of gravity, the rate of fall being, once again, a function of their size. As can be seen from Table 1, the velocity of fall is extremely slow, even for particles larger than a micrometre and so the effects of convection and Brownian motion can result in particles being kept in semi-permanent suspension.

Impaction. When the wind carries particles among solid objects, particles can be deposited due to their greater inertia carrying them to the surface of a body as the air flows around it. This is the principal mechanism by which air-borne pollen grains reach their target.

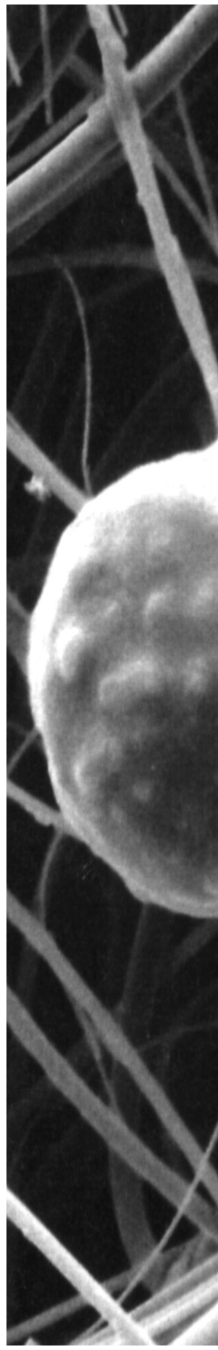
Rain. This is undoubtedly the mechanism by which most particles are removed from the atmosphere. Removal occurs either by the particles acting as condensation nuclei on which rain clouds grow or by the scavenging of particles, beneath the clouds, by falling raindrops.

Survival of micro-organisms in the atmosphere

Microbes can remain in suspension in the atmosphere almost indefinitely, but this is a challenging environment and for many species their lifetime in it will be limited. Clearly, some organisms have evolved to survive in the atmosphere: pollens and spores are obvious examples, but also some bacteria, such as the bacilli, have evolved techniques by which they form spores that are highly resistant to environmental attack.

The primary destructive agent is the ultra-violet component of sunlight, which, with long exposure, is effective in sterilizing most living cells. Other factors include humidity (both low and high) and a variety of pollutant materials commonly found in the atmosphere. It is well established that the combined effects of these factors needs to be taken into account when attempting to predict air-borne lifetimes. However, experiments carried out in laboratories have often shown poor correlation with field observations and this has led some investigators to invoke an 'open air factor'. This is perhaps another way of saying that there is some destructive mechanism, or combination of mechanisms, that has not been reproduced effectively in the laboratory.

J.M. (Don) Clark
Chief Scientific Officer, BIRAL, PO Box 2, Portishead, Bristol BS20 7JB, UK (t 01275 847787; f 01275 847303; e d_clark@biral.com)



▶ A mucus droplet containing bacteria. *Don Clark*