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Collection efficiency and design of microbial air samplers

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Abstract

The variables affecting the physical collection efficiency of air samplers of the type that impact microbe-carrying particles onto agar were investigated using a simplified analytical method and computational fluid dynamics. The results from these two techniques were compared, as were the effect of jet velocity, nozzle size, and nozzle distance from the agar surface; also considered was the optimisation of these variables to obtain an efficient design of sampler. A technique is described that calculates the proportion of microbe-carrying particles that a sampler will collect from a typical size distribution of microbe-carrying particles found in an occupied room; the three air samplers studied were found to collect from about 22% to over 99% of the micro-organisms in the room air.

Keywords: Air sampler; Microbial; Impactor; Collection efficiency

1. Introduction

Most microbial air samplers used in occupied rooms, such as hospitals and cleanrooms, draw air containing microbe-carrying particles and accelerate it through a hole, slit, or fan blade, and direct it towards a nutrient agar surface. As the air turns away from the agar surface the microbe-carrying particles that cannot follow the flow are impacted. The plate containing nutrient agar is then incubated at a suitable temperature and time, and the resulting microbial colonies are counted to ascertain the number of microbe-containing particles collected from a given volume of air.

Ljungqvist and Reinmuller (1998) compared a selection of air samplers currently used in rooms and demonstrated that some samplers collect up to 10 times less microbes than others, thus showing that when a low efficiency sampler is used, unhygienic rooms can incorrectly appear to achieve the correct cleanliness standard. To design a microbial air sampler to achieve a high sampling efficiency, consideration should be given to particle losses around the intake to the sampler but the most important problem is inefficient impaction of the smaller sizes of microbe-carrying particles on the agar surface, usually because there is too low an impact velocity.

The first microbial air samplers were produced in the 1940s and 1950s and designed to efficiently impact single-cell microbes with a size of about 1–2 μm. This size was chosen, as air samplers were often designed by investigators working in the field of microbial warfare, where microbes were generated as an aerosol of single cells with a size of about 1–2 μm. However, microbial air samplers are extensively used in hospitals and cleanrooms, where the requirement is for samplers that are quieter, smaller, and more portable than these earlier designs. As a consequence, modern samplers

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often have smaller less-powerful air pumps and therefore lower impact velocity. It is not clear what effect this has on the collection of microbe-carrying particles found in occupied rooms, although Möller (2002) considers that some of the samplers designed in the last decade or two, have too low an impact velocity to efficiently collect a high percentage of microbe-carrying particles. When early samplers were designed, it was not realised that the majority of microbes in an occupied room are carried on skin cells, or fragments of skin cells, dispersed by people in the room. This was not known until the 1960s (Davies & Noble, 1962), when it was also found that microbe-carrying particles had an average equivalent diameter of about 12 μm (Noble, Lidwell, & Kingston, 1963). Microbe-carrying particles with an average size of 12 μm are easier to impact than unicellular micro-organisms of 1–2 μm in size. It is therefore possible that microbial samplers with lower impaction efficiencies than early samplers may still collect a large proportion of the microbe-carrying particles of the sizes found in an occupied room.

The collection efficiency of microbial air sampler can be considered in two ways:

- physical collection efficiency,
- biological collection efficiency.

The physical collection efficiency measures the collection efficiency of inert particles. The biological efficiency measures the physical efficiency, but also the losses in viability of micro-organisms during sampling that are caused by cell damage or stress, through impaction or dehydration. The effect of impact damage and stress on microbes over a range of velocities from 24 to 250 m/s was studied by Stewart et al. (1995) who found that the highest rate of recovery of viable cells of *Pseudomonas fluorescens* was achieved at a velocity of 40 m/s, and for *Micrococcus luteus* it was 24 m/s. They investigated metabolic and structural damage, and found the Gram-positive micro-organism more robust than the Gram-negative one. Their conclusions differ from May and Harper (1957) who studied a liquid impinger sampler and found that the loss in the viability of *Serratia marcescens*, which was selected because of its known sensitivity to collection, was around 20% when impacted at near to sonic velocity (340 m/s). When the air velocity was reduced to about 130 m/s the losses were reduced to almost zero.

Information on how to design impactors has been reported by several authors, such as Hinds (1999), Nevalainen, Pastuszka, Liebhaber, and Willeke (1992) and Marple and Willeke (1976). Marple and Willeke (1976) based their design method on a study carried out by Marple and Liu (1974), who used computational fluid dynamics (CFD) to calculate the efficiency of particle impaction, the accuracy of the method being confirmed experimentally. Marple and Willeke (1976) suggested the following method:

1. Ensure that the Reynolds number of the air passing through the nozzle is between 500 and 3000.
2. Select an appropriate d_{50} 'cut-off' size of particle, and calculate and select the variables required to achieve this cut-off size. Marples and Willeke's method uses Stokes number, but their method is basically the same as the 'simplified analytical method' employed in this paper.
3. Ensure that the ratio of the separation distance (S) (known in this paper as the nozzle-to-surface distance[1]) to the diameter or width of the nozzle (W) is not less than 1.5 in rectangular nozzles and 1 in round nozzles. This ratio is given by a dimensionless number that is generally known as the S/W ratio.
4. If possible, the entrance to the nozzle should be tapered or conical, and of constant width or diameter, with a nozzle throat length at least as large as the width or diameter of the nozzle.

Marple and Willeke's method is widely used, and it is therefore appropriate that the results and conclusions in this research paper should be compare with their recommendations and, in particular, their S/W ratio requirements.

2. Simplified analytical method for calculating efficiency

A method used to calculate the collection efficiency of samplers of the impactor type was established many years ago by May (1945); Ranz and Wong (1950), and Davies and Aylward (1951). This is called in this paper the 'simplified

[1] In this paper we have avoided giving the meaning of the word 'jet' to a nozzle, but use 'jet' as a description of the fluid coming from a nozzle. Also, in microbial air samplers, plates containing nutrient agar are used to collect the microbe-carrying particles impacted onto the agar surface. In this situation it is best not to call the agar surface the 'plate'. We therefore use the term 'nozzle-to-surface' rather than the commonly used 'jet-to-plate'.