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Evaluation of polyurethane foam materials as air filters against fungal contamination

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ABSTRACT

Current air filters used in food processing or storage facilities are expensive and disposable. The ability to use polyurethane foam as air filters against fungal spores would be beneficial as they are both cheap and re-usable. The aim of this study was to evaluate the air filtration capabilities, in terms of fungal spores, of a selection of polyurethane foam(s) of differing combinations of pores per inch (PPI) (50 and 90 PPI) and thickness (15 and 20 mm). Environmental air was used as a source of fungal spores and membrane filtration was used to assess the filtration capabilities of the foams. Spores capable of passing through the foams were captured on cellulose nitrate membrane filters and quantified in CFU counts. Apart from the 50 PPI foam of 15 mm thickness, all the foam samples were effective at significantly reducing the number of spores. The PPI was found to be 2 times more influential on the efficiency of the foam material than the foam thickness. This may be explained through the higher number of pores present and the decrease in thickness of the ribs composing the microstructure of the foam as shown through scanning electron microscope (SEM) micrographs. These studies show that reticulated polyurethane foams at the selected PPI and thickness can be used as effective air filters against fungal spores.

1. Introduction

Airborne particles of biological origins, known as bioaerosols, may include, amongst other living material, fungi and fungal entities (Yoon et al., 2008). Highly-resistant fungal spores are found in all environments, including air inside buildings and facilities. This characteristic of fungal spores would not be an issue were it not for the fact that fungi are capable of causing seriously adverse effects; they can damage buildings (May, 2001; Miller, Rand, & Jarvis, 2003), they can cause spoilage of certain foodstuffs in food storage facilities and they may cause allergic diseases of the airways in individuals who inhale the spores (Portnoy, Barnes, & Kennedy, 2004; Żukiewicz-Sobczak et al., 2013). There are several ways by which bioaerosols can be controlled. These include ultraviolet germicidal irradiation (UVGI), air ionisation, dielectric barrier discharge and others (Griffiths, Bennett, Speight, & Parks, 2005; Jankowska, Reponen, Willeke, Grinshpun, & Choi,.2005; Ko, First, & Burge, 2002; Park, Yoon, Kim, Byeon, & Hwang, 2009; Park & Hwang, 2013; Schmid et al., 2013; Woo et al., 2012). The most commonly used means of eliminating bioaerosols from the internal environment of facilities is by air filtration (Brincat et al., 2016).

Air filtration systems are important for different types of protected environments, such as medical and food processing facilities, and less commonly in food storage environments. The most common air filtration systems to reduce the abundance of fungal spores in protected environments (especially in medical wards) are High Efficiency Particulate Air (HEPA) filters. HEPA filters have been shown to reduce the incidence of invasive aspergillosis (Abdul Salam, Karlin, Ling, & Yang, 2010; Alberti et al., 2001; Araujo et al., 2008; Vonberg & Gatsmeier, 2006). Studies have shown that fungal spores are much more abundant in environments that lack an air filtration system (50–500 CFU per m^{-3}) than in those which have functioning and effective air filtration systems (0–50 CFU per m^{-3}) (Brenier-Pinchart et al., 2009; Dassonville

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et al., 2008; Sautour et al., 2009). In order for this to be true, air filtration systems must be appropriately maintained and replaced when necessary so as to ensure the utmost quality of filtration. In fact, it is not uncommon for outbreaks (most commonly involving *Aspergillus fumigatus*) to occur due to the negligence of faults and contaminated air filtration systems (Lutz, Jin, Rinaldi, Wickes, & Huycke, 2003; Muñoz et al., 2004; Reboux et al., 2014).

The importance of optimally functioning air filtration systems is not restricted to medical environments. The quality and quantity of air in food manufacturing and storage facilities is regulated so as to prevent or significantly reduce the growth of fungal organisms which would otherwise cause severe spoilage of food stuffs, particularly grains, flours, nuts, ripening cheeses and fruits (Isaac, 1996). The primary concern of fungal contamination of food stuffs is the generation of mycotoxins, which are toxins generated by toxigenic fungal organisms within certain temperature and relative humidity ranges. Fungal species commonly of interest in terms of food contamination include those belonging to the *Aspergillus*, *Alternaria*, *Claviceps*, *Fusarium*, *Penicillium* and *Stachybotys* genera (Milićević, Škrinjar, & Baltić, 2010). The durability and heat resistance of these toxins makes them particularly difficult to eliminate as they are not destroyed by common cooking procedures such as frying and boiling (Magan & Olsen, 2004; Milićević et al., 2010). When consumed, food stuffs contaminated with mycotoxins can cause a variety of acute and chronic health disorders in both humans and animals alike (Milićević et al., 2010). As a result, considerable attempts are made to prevent the contamination of food stuffs by fungal organisms (Magan & Olsen, 2004).

The regulation of air is most commonly brought about by filtration, which eliminates potentially harmful micro-organisms from the air that is being introduced into the facility by capturing and retaining them in the filter medium (EHEDG, 2006). Fungal spores may enter food production and storage facilities via drains, doorways, hatches, disinfection tunnels, compressed air supplies, raw materials, packaging, people handling and poorly designed, cleaned and maintained air filtration systems, amongst others. The latter source of airborne contamination is of particular interest. Functioning air filtration systems are designed to distribute fully conditioned air as required at the desired rate. The air handling systems must be able to not only remove contaminating micro-organisms from the air by filtration, but also to reduce or prevent growth of micro-organisms, prevent their ingress, curtail cross-contamination, direct bioaerosols away from the food stuffs and not act as an additional source of contamination (EHEDG, 2006). Systems must be designed in such a way to allow maintenance to be performed on the filter media. Lack of proper maintenance might lead to the filter itself becoming a source of spores in the down-stream air, which is known to be a huge health risk in hospitals (Price, Simmons, Crow, & Ahearn, 2005).

Polyurethane is a synthetic polymer which forms from the reaction of a polyol (a long chained alcohol) with a diisocyanate. Depending on the type of polyol used, different types of polyurethane can be formed. The reticulated type of polyurethane foam is a porous, low-density type of foam characterised by a three-dimensional skeletal structure lacking membranes between the strands (Polyurethane Foam Association, 1994). The porosity of the foam is typically 95% but it can be as high as 98% (Gliganic, 2008). Currently reticulated foam is used in water filters and air filters found in air-conditioning units. No previous studies have adequately assessed the true potential of reticulated polyurethane foam as an air filter against fungal spores.

In light of the above, the aim of this study was to assess the air filtration capabilities in terms of fungal spores of a selection of polyurethane foams of differing combinations of pores per inch (PPI) and thickness so as to identify the foam PPI and thickness combination that is most effective for filtering fungal spores in air environments of different temperature and relative humidity.

2. Materials and methods

2.1. Sample collection

Outside air at the area of Msida in Malta (site of the Faculty of Health Sciences, University of Malta) was selected as the source of fungal spores. A filtration manifold with 3 ports was attached to an air flow meter which was in turn attached to a vacuum pump (Sartorius AG, Goettingen, Germany). The vacuum pump was subsequently connected to a power supply. The components were linked together by means of rubber tubing (See Fig. 1). Sterile cellulose nitrate membrane filters of pore size 0.45 μm were placed on the base of each manifold port (Sartorius AG, Goettingen, Germany). The ends of the tubing and the entirety of the setup were sealed by means of multiple sheets of parafilm M sealing film (Bemis NA, Neenah, Wisconsin) so as to ensure that the setup was thoroughly air-tight. A lack of air-leaks was confirmed by closing each of the valves of the 3 manifold ports, switching on the vacuum pump and noting an absence of air flow in the flow meter.

Three acrylonitrile butadiene styrene (ABS) plastic adapters, generated by a 3D printer, were designed in a manner that allowed for them to be inserted into the manifold ports while providing a platform into which any foams under assessment could be placed. The dimensions of the platforms were 45 mm × 45 mm × 20 mm. The adapters were sealed to the 3 manifold ports by means of further sheets of parafilm M sealing film.

Membrane filters were put into place by means of sterilised forceps and the adapters were duly sealed to the body of the manifold using sheets of parafilm M. The sampling of air occurred as the vacuum pump was switched on, air was drawn through foams supported by the adapters in the manifold ports, and spores were collected on the membrane filters. The necessary volume of air was sampled by running the vacuum pump for a period of time while the flow rate was measured by an air flow meter. Upon completing the sampling, the membrane filters were placed onto a separate Dichloran Rose Bengal Agar (DRBA) (Sigma Aldrich, St. Louis, USA) with Chloramphenicol plate. The inoculated plates were incubated in a cooling incubator (Leec P3C, Leec Limited, UK) at 25 °C for 72 h. Following the incubation period, the number of colony forming units present on the membrane filters was counted.

A pilot study was performed to determine the ideal volume of air (or rather the minimum number of spores) to be sampled for the evaluation of the filtration aptitude of the foam materials. The volume of air sampled had to be large enough to allow some fungal spores to pass through the foam samples in order to reveal the different filtering capabilities of the different foams. The sampled volume of air had to also yield a countable number of colonies upon culturing. Therefore, the volumes of air sampled varied between 10 L and 1000 L. All experiments were performed on 3 separate days by running triplicates each time.

2.2. Evaluation of air filtration capabilities of polyurethane foams

The polyurethane foam samples (Articoli Resine Espanse (ARE), Italy) were cut using a Proxxon Thermocut 230/E (Proxxon, Föhren, Germany). Sheets of foam were cut along the direction of maximum cell elongation to thicknesses of 15 mm and 20 mm. Four polyurethane foams were selected for evaluation of air filtration capabilities against fungal contamination; 50 PPI foam of 15 mm thickness, 50 PPI foam of 20 mm thickness, 90 PPI foam of 15 mm thickness and 90 PPI foam of 20 mm thickness.

The experimental runs carried out consisted of the use of all 3