paper documents and fungal contamination

How Clean is Clean Enough?

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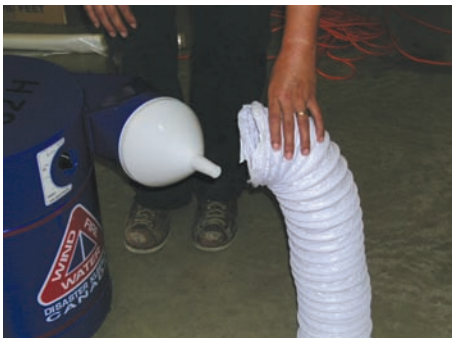

Figure 1a, b, c. Constructing the test chamber and ventilation system. Note the use of existing structures and equipment and readily available materials.

Paper-based documents, records and books have formed the foundation of the economies of industrialized countries and will continue to do so for the foreseeable future. Paper, a mixture of cellulose and additives, while chemically stable, is a preferred food source for fungi. This is the major reason that so few cellulose-containing artifacts from historic civilizations have survived to the present era.

The underlying necessity inherent in the use of paper as the foundation of the economy is the need to protect these documents against colonization by fungi. In colonizing paper in documents and books, fungi are merely performing their role in nature as decomposers.

Fungi require the following for growth: a food source, an appropriate level of moisture in the material and in the surrounding air, and an appropriate temperature. Coastal rainforests are ideal habitats for fungi. The humidity in the air is often close to that needed for growth, variously estimated to be around 60 percent to 65 percent RH at room temperature. Over biological time, members of fungal families have adapted to niches related to moisture, temperature and types of food source.

The proximity of normal airborne humidity to the range needed for growth means that growth could occur when moisture in the paper equilibrated from that in the air is supplemented by wetting following leakage through the building envelope or from additional humidification of the air. Prolonged or repeated leakage can lead to considerable infestation. Growth can occur on external and internal surfaces of bundles of paper or pages in books or similar documents.

Mold spores affect people primarily through allergic processes. Allergic processes affect the eyes, nose and throat, the middle airways and the alveolar region of the lung. Small quantities of spores are required to provoke a response in a sensitized individual compared to the normal population. The triggering agent for the allergic response is the outer configuration and constitution of the spore. Hence, the culturable status of the spore is not important in this discussion.

Individuals who become sensitized to the species of mold growing on the paper of books and records can experience considerable allergic respiratory symptoms. The only way to alleviate these symptoms is to remove the spores from the surface so that they cannot become airborne to be inhaled.

Depending on humidity and wetting, paper records can support growth of a number of fungal species, including *Stachybotrys*, but more commonly *Cladosporium*, *Aspergillus* and *Penicillium* species. A 'musty' odor, damp feel to the paper, the visible presence of spores on the pages and possibly the binding, and patches of visible growth all characterize active growth.

Treatments to salvage these documents can include freeze drying and exposure to highly reactive gases such as ozone or chlorine dioxide, or to mists of fungicide or biocide. These treatments are most effective on exposed surfaces and may or may not kill active growth or spores present on internal surfaces. Active growth or spores located on interior surfaces may not be affected by treatment.

Figure 2. The finished test chamber. The HEPA-filtered air scrubber provides spore-free air prior to starting the tests and purges the chamber following each test.

An additional complication to this strategy is that there is no assurance that dead spores are incapable of provoking allergic response in sensitized individuals. In fact, observation indicates that the exact opposite is the case, that spores present on pages long dried out are highly capable of provoking allergic symptoms. There is nothing to indicate that this response respects the status of viability of the spores. As a result, the presence of spores remaining on external and internal surfaces is a major concern to the restoration company given the task of decontaminating documents. This creates challenges for cleaning and removal of spores and growth from surfaces.

The normally advocated strategy for this kind of cleaning is to use a HEPA-filtered (High Efficiency Particulate Air) vacuum cleaner. Vacuum cleaning of books has limited effectiveness because the three dimensional structure opens out one page at a time. The surface of every page and the crevice formed by adjacent pages and the binding are potential sources of contamination. Accessing the crevice requires a specialized tool.

Vacuum cleaning is most effective when the surface is simultaneously roughened. This usually requires a brush, which is incorporated into some of the attachments of vacuum cleaners. In the absence of the brush to loosen material from a surface, removal is considerably less effective. Success of vacuum cleaning depends on breaking the forces of adhesion between the foreign material and the paper. These forces can be electrostatic in nature and can involve interaction between microscopic irregularities in the surface of the spores and the paper. Vacuum cleaning of every page is highly labor intensive and ultimately prohibitive in cost for records otherwise having no commercial value.

Another approach is the use of compressed air. Compressed air has the advantage of being considerably more aggressive at dislodgement from surfaces than vacuum cleaning. When the object to be cleaned is positioned appropriately, airflow potentially can reach all surfaces with the expenditure of considerably less effort and time by the worker.

A complicating factor, especially in the use of compressed air, is exposure of the worker performing the cleaning. Blowing compressed air could create extremely high concentrations of spores in the air for work occurring in an open space, as well as in enclosed structures. A worker exposed to this environment will need high level protective equipment, including a spore-impervious protective suit and air-line respirator, or alternate arrangement that provides equivalent protection.

The questions still confronting the restoration company and its external advisors are how to determine the effectiveness of the treatment for the owner of the documents and what should be deemed acceptable as a result. There is little, if anything, in print to guide in determining the success or failure of treatments for paper-based products. Yet, determining the level of contamination of pages of material in books and sheets of paper at the end of the process is a critical part of assessing the level of success of the cleaning effort.

Figure 3. Test equipment

Contact sampling using tape lifts is one possible technique. Contact sampling is very much a hit and miss situation, since this depends on testing where growth has occurred or where spores are trapped, and not an area where growth has not occurred and spores are not trapped. As well, there are no standards for fungal contamination of surfaces of materials.

A more global approach is to sample spores released into the air after aggressive handling. Fanning the paper mimics the action performed by end-users when opening a document to search for information. Aggressive, broad, deep fanning of the paper would release considerable numbers of spores into the air. The spores released in this manner would be readily available for inhalation by the worker. This technique, albeit exaggerated compared to what usually occurs in a real-world situation, provides the means to assess large quantities of material in one pass and a means for estimating exposure of an individual handling the document during worst-case, real-world use. This method, however, does not identify the exact location of the contamination on the tested material.

How clean should be clean enough? Well, the concentration of spores should not add materially to the indoor concentration or to the types of spores already present.

Case Study

This study involved paper documents. The first situation involved sheet music and music books stored in a building that had experienced long-term water incursion. The owner commissioned the restoration company to remove the contents from the building and to decontaminate them by vacuum cleaning with a HEPA-filtered machine and ozone treatment. The second situation involved bound and loose papers and engineering documents also stored in a building that had experienced water incursion. The owner commissioned the restoration company to decontaminate these records by vacuum cleaning and exposure to an anti-fungal agent.

To test the effectiveness of these approaches, a test chamber was constructed from a vertically oriented plywood storage container measuring 77 x 78 by 116 cm having a volume of 0.7 m^3 (25 ft^3) (Figure 1). The interior was vacuum cleaned using a HEPA-filtered vacuum cleaner to remove residual material. The open top and front were closed in using sheet plastic and TYVEK sleeves mounted into the front face to provide access to the interior of the chamber.

The chamber was purged prior to starting and between tests for at least five minutes by HEPA-filtered air from an Aller Air Model 4000 air cleaner (Figure 2). This unit provides 400 ft^3/min free air delivery. Actual volumetric flow to the chamber would have been less because of constraints imposed by the geometry of the connections. The HEPA-filtered air supply unit was not operated during sampling tests in order to enable entrapment within the volume of the container.

Boxes of paper were selected at random and partially emptied to provide representative samples affected by the wetting episode. A sheaf of material approximately five cm wide was hand-held inside the sampling chamber and fanned as widely as possible, 10 times during the early part of the sampling period (Figure 3). Fungal spores were collected using Air-O-Cell cassettes and a Zefon Mini Pump (Figure 4). The sampling unit operated at 15 L/min for five minutes (75 L of air or about 10 percent of the volume of the chamber). Sampling was started after the second fanning.

A ream of fresh photocopy paper provided comparison to new, previously unexposed paper. Records stored for a prolonged period in a cardboard box in an outdoor location subject to humid conditions provided untreated documents as a basis for comparison.

Results indicated the presence of fungal spores in all samples. By far the largest contributors to

the fungal population in the used paper were basidiospores (mushroom spores). Basidiospores and *Cladosporium* spores were present in all samples as the top two contributors. These spores are present in outdoor air. Pollen was present in some of the samples. Pollen, of course, is also present in outdoor air. Hence, there was a heavy contribution to the spore load in all samples from outdoor air.

Of the fungi identified in these air samples *Aspergillus*, *Penicillium*, *Cladosporium*, and mycelial fragments hold the greatest interest. *Aspergillus* and *Penicillium* grow on building materials and contents, and are associated with building-related conditions expressed by occupants. *Cladosporium* grows on leaves in the outdoor environment and indoors on wet building materials. *Cladosporium* species also are associated with building-related respiratory and eye allergies expressed by occupants. Mycelial fragments are indicative of recent mold growth.

The concentration of spores liberated during aggressive handling of these materials provides a basis for estimating the upper limit of a short inhalation exposure of an individual performing the same activity. This exposure would be very brief, as the ten-fold fanning during the testing procedure required only one to two minutes to complete. This action would never occur during normal real-world handling of these materials. As well, these spores were trapped within the volume of the sampling chamber and not permitted to disperse further into the room where the influence of spores in outdoor air would then occur. Outdoor air can contain 10,000 spores/m^3 or more in summer. Since outdoor air and the air in the chamber can contain the same kinds of spores, with the exception of *Aspergillus* and *Penicillium*, differentiating origin between outdoor air and these paper materials is impossible.

These efforts produced mixed results, supporting in some instances the contention that the restoration effort had succeeded in decontaminating the documents. Situations where excessive levels of spores and mycelial fragments were present necessitated a more aggressive approach.

Fungal growth occurs on individual pages in books, in the spinal area, and inside front and back covers. Vacuum cleaning alone, while minimizing spore generation, is very labour intensive and not capable of removing spores from these hard to reach areas of paper documents. These documents have included loose papers, file folders containing loose papers, file folders containing bound papers, booklets and bound books ranging from standard to ledger size.

Blasting with compressed air will dislodge spores adhering to the paper in these hard to reach areas. This treatment is more aggressive than the fanning technique employed to eject spores from the paper in the test chamber. Fanning the paper, in turn, is more aggressive than vacuum cleaning, since all of the pages are exposed to the air. Blasting with compressed air will dislodge spores adhering to the paper. Note that any technique requiring the use of compressed air for dislodging spores also requires an effective means of capturing them to prevent exposure of workers and circulation in the air of the building.

Editor's Note: See the December 2006 issue of *Cleaning & Restoration*, pp. 28-29, on how to construct a containment structure for this process. ■

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McManus has written numerous articles and short publications, and is the author of Safety and Health in Confined Spaces, Portable Ventilation Systems Handbook, The Confined Space Training Program*, and coauthor of The Hazcom Training Program and The WHMIS Training Program. He also teaches courses on these subjects and courses on topics of specific interest to the restoration industry.*

He has an M.Sc. in radiation biology and an M.Eng. in occupational health and safety engineering, as well as a B.Sc. in chemistry and a B.Ed. specializing in chemistry and biology.

Figure 4. Deep fanning the test papers during testing.