Mold Growth on Gypsum Wallboard - A Research Summary

M.Y. Menetrez [1], K.K. Foarde [2], T.D. Webber [2], T.R. Dean [1], and D.A. Betancourt [1]

(1) U. S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Air Pollution Prevention and Control Division, Research Triangle Park, NC 27711, USA, phone 919-541-7981, fax 919-541-2157, email menetrez.marc@epa.gov

(2) Research Triangle Institute, Center for Engineering and Environmental Sciences, NC 27709, USA, phone 919-541-8018, fax 919-541-6936, email kkf@rti.org

Abstract

Reducing occupant exposure to mold growing on damp gypsum wallboard is a research objective of the U.S. Environmental Protection Agency (EPA). Controlling mold contamination in the indoor environment has been studied through 1. the delineation of environmental conditions required to promote and avoid mold growth, and 2. efficacy testing of antimicrobial products on gypsum wallboard surfaces. The effects of moisture, and relative humidity (RH) on mold growth and transport are important to avoiding and eliminating problems. These effects have been demonstrated on gypsum wallboard and are discussed for use as control guidance. Often mold contaminated building materials are not properly removed, but instead surface cleaners are used and then paint is applied in an attempt to alleviate the problem. The efficacy of antimicrobial cleaners and paints to remove, eliminate or control mold growth on gypsum wallboard has been documented. Research to control *S. chartarum* growth using 13 separate antimicrobial cleaners and nine varieties of antimicrobial paint on contaminated gypsum wallboard has been performed in laboratory testing. A variety of gypsum wallboard surfaces were subjected to high RH for the six month period of testing. These gypsum wallboard control measures are summarized for public and commercial application use.

Key words: Mold, Antimicrobial, Cleaners, Efficacy, Biocontaminant, *Stachybotrys chartarum*.

Introduction

The past twenty years have brought the recognition that an important factor in the health of people in indoor environments is the dampness of the buildings in which they live and work (Dearborn, D. G. et. al. 1999; Vesper, S. J., and Vesper, M. J., 2002; Vesper, S. J., 2000). Furthermore, it is now appreciated that the principal biological contaminants responsible for the health problems in such buildings are fungi rather than bacteria or viruses (Dearborn, D. G. et. al. 1999; Vesper, S. J., and Vesper, M. J., 2002; Vesper, S. J., et. al. 2000; Scheel, C. M., 2000). Although traditionally, fungi in this context have been viewed as allergens (and in unusual circumstances, pathogens), data have accumulated to show that the adverse health effects resulting from inhalation of fungal spores are due to multiple factors (Sudakin, D. L., 2000). One factor associated with certain fungi are small molecular toxins (mycotoxins) produced by these fungi. Traditionally, mycotoxins are held to be important in human and animal health because of their production by toxigenic fungi associated with food and feed. However, mycotoxins tend to concentrate in fungal spores, and thus present a potential hazard to those inhaling airborne spores. Toxigenic spores strongly affect alveolar macrophage function and pose a threat to those exposed. Reports have indicated that *S. chartarum*, *A. versicolor*, and several toxigenic species of *Penicillium* are potentially hazardous, especially when the air-handling systems have become heavily contaminated (Vesper, S. J., et. al. 2000; Scheel, C. M., 2001; Sudakin, D. L., 2000; Murtoniemi, T., et. al. 2001).

One of the toxigenic fungi found in wet buildings is *S. chartarum*, a fungus known to produce the very potent cytotoxic macrocyclic trichothenes along with a variety of immunosuppressants and endothelin receptor antagonist mycotoxins (Dearborn, D. G. et. al. 1999; Vesper, S. J., and Vesper, M. J., 2002; Vesper, S. J., 2000). Infants have been admitted to Case Western University Hospital in Cleveland in very grave condition expelling blood from their nose and mouth from pulmonary hemorrhage (PH) (Dearborn, D. G. et. al. 1999; Vesper, S. J., and Vesper, M. J., 2002; Vesper, S. J., 2000). There have been 45 cases of PH in young infants, whom 16 have died. Most of these cases have occurred within 10 contiguous zip code areas in the eastern portion of the metropolitan area. In November/December, 1994, the Centers for Disease Control and Prevention (CDC) lead a case-control investigation on the first 10 cases. This study found an epidemiological association of PH in these infants with water-damaged homes containing the toxic fungi, predominantly *Stachybotrys* (Dearborn, D. G. et. al. 1999; Vesper, S. J., and Vesper, M. J., 2002; Vesper, S. J., 2000). The importance of environmental tobacco smoke (ETS) exposure in conjunction with *Stachybotrys* to produce PH has been discussed by Sudakin (2000). The importance of ETS as a multiplicative risk factor for toxic mold exposure and PH is unknown.

Stachybotrys requires water soaked cellulose to grow and has been found in homes where there had been water damage from flooding, plumbing leaks, or roof leaks involving wood or paper products [e.g., insulation, gypsum wallboard (GWB), ceiling tile]. The spores of this fungus contain mycotoxins which appear to be particularly toxic to the rapidly growing lungs of infants (Dearborn, D. G. et. al. 1999; Vesper, S. J., and Vesper, M. J., 2002; Vesper, S. J., 2000; Scheel, C. M., 2001; Sudakin, D. L., 2000;

Murtoniemi, T., et. al. 2001). Although not widely found, *Stachybotrys* has been studied for the last 20 years. The following is documented: (1) *S. chartarum* produces toxigenic spores that are potentially hazardous, (2) the prevalence of *S. chartarum* contamination in indoor environments is unknown, (3) currently there are no Environmental Protection Agency (EPA) regulations or guidelines for evaluating potential health risks of *S. chartarum* contamination and remediation, and (4) the exact environmental conditions necessary for the growth of *S. chartarum* have not been documented (Dearborn, D. G. et. al. 1999; Vesper, S. J., and Vesper, M. J., 2002; Vesper, S. J., 2000; Scheel, C. M., 2001; Sudakin, D. L., 2000; Murtoniemi, T., et. al. 2001).

Three research papers addressing the control of mold contamination in gypsum wallboard have been chosen for summarization. They are as listed:

1) Growth Responses of *Stachybotrys chartarum* to Moisture Variation on Gypsum Wallboard (Menetrez, M. Y., 2004),

2) Antimicrobial Cleaner Efficacy on Gypsum Wallboard Contaminated with *S. chartarum* (Menetrez, M. Y., 2007a),

3) Testing Antimicrobial Paint Efficacy On Gypsum Wallboard Contaminated with *Stachybotrys chartarum.*(Menetrez, M. Y., 2007b).

These papers focus on the delineation of environmental conditions required to promote and avoid mold growth, and the efficacy testing of antimicrobial products on gypsum wallboard surfaces (Menetrez, M. Y., 2004, Menetrez, M. Y., 2007a, Menetrez, M. Y., 2007b).

Materials and Methods

The materials and methods for testing *Stachybotrys chartarum* contamination on gypsum wallboard is summarized in the following 1. growth responses to moisture variation which promote or inhibit mold growth; and 2. efficacy testing of antimicrobial products (cleaners and paints).

Growth Responses of *Stachybotrys chartarum* to Moisture Variation on Gypsum Wallboard

Experiments were conducted at room temperature (21.1 ^{0}C or 70 ^{0}F) using four types of GWB material: 1) new GWB, 2) old GWB, 3) new GWB with vinyl-coated wallpaper applied to the top surface, and 4) new GWB with 100% vinyl wallpaper applied to the top surface. The materials were cut into 3.8 x 3.8 cm (1.5 x 1.5 in) squares, placed in self-sealing pouches, and steam sterilized by autoclaving. The pieces were then removed from the pouches and inoculated with 50 μL of *Stachybotrys chartarum* spores, resulting in approximately 10^5, or 100,000, colony forming units (CFUs) per test piece. When the spore inoculum was dry, the pieces were placed into the appropriate static chamber, (and some coupon pieces were wetted to the point of saturation with 4 ml of sterile water) depending on the relative humidity at which the experiment was being conducted (Foarde, K. K., VanOsdell, D. W., Chang, J. C. S., 1996, Menetrez, M. Y., 2004). The static chamber testing was based on ASTM Standard D6329-98.

Antimicrobial Cleaner Efficacy on Gypsum Wallboard Contaminated with *S.*

chartarum

Menetrez, et. al. (2007a) demonstrated the difference in efficacy of cleaning products that are advertised to prevent mold. Thirteen different cleaning products (one product was tested both diluted and full strength) were selected for their wide availability, and also for the product description which recommended their use for disinfecting surfaces, specifically removing mold and mildew (see Table 1, Cleaners Tested). The 13 cleaning products were purchased locally and manufactured by eight separate manufacturers; Reckitt and Colman (Slough, Berks, UK) produces Lysol, Lysol IC, and Lysol All Purpose Cleaner- Orange Breeze; The Clorox Company (Oakland CA) produces bleach, Formula 409, Pine Sol and Tilex; S.C. Johnson and Son (Racine, WI) produces Fantastik Orange Action; Johnson Commercial Markets, Inc. (a subsidiary of S.C. Johnson and Son) produces Mildew Stain Remover with Bleach; Orange Glo International, Inc. (Greenwood Village, CO) produces Orange Glo Multipurpose Degreaser; Steris Corporation (Mentor, OH) produces SporKlenz; and Knight Marketing Corporation (Johnstown, NY) produces Spray Nine. Each product was tested following the directions on the package and the recommended concentration. Six varieties of surfaces were used to evaluate *S. chartarum* growth. The surfaces were constructed over standard GWB, they were:

1.01_Plain GWB, no paint,

1.02_Vinyl (100 percent vinyl) covered GWB,

1.03_GWB with vinyl coated wallpaper removed before cleaning and replacement,

1.04_GWB with vinyl coated wallpaper not removed before cleaning, 1.05_GWB with oil-based paint,

1.06_GWB with acrylic (latex) paint.

The object of this research was to test the antimicrobial efficacy of these cleaning and disinfectant products for removing and preventing, or restricting growth of *S. chartarum* growth on the six varieties of GWB surfaces listed above, and with variations in RH (Menetrez, M. Y., 2007a).

After inoculation, wetting, and static chamber storage, visual inspection of coupons continued for a period of one to two months, until they were found to have extensive *S. chartarum* growth, covering the coupon surface. Growth was estimated to be sufficient at varying periods between one to two months. The time required for sufficient growth was not an important consideration, but rather the primary consideration was the extent of growth over the coupon surface. When the 7.6 x 7.6 cm (3.0 x 3.0 in) coupon surface was extensively covered with growth over the majority of the surface with few bare spots remaining the coupons were removed from the chamber for cleaning. At which time the coupons of all six types of GWB surface treatments were cleaned with the products and by the manufacturers directions as listed in Table 1. After these heavily contaminated coupons were cleaned by the methods and products listed in Table 1, they were returned to sterile static chambers at 100 percent RH and room temperature (21.1 ^{0}C, or 70.0 ^{0}F) and stored for up to 6 months to allow for time to demonstrate potential regrowth (Menetrez, M.

Y., 2007a).

Testing Antimicrobial Paint Efficacy On Gypsum Wallboard Contaminated with *Stachybotrys chartarum*

Seven varieties of encapsulant paint (see Table 2a) were chosen by Menetrez (2007b) for their advertised antimicrobial effectiveness. Two common interior paints (see Table 2a) were also chosen (acrylic/latex and oil-based) as a basis for comparison. Table 2a lists the antimicrobial paints and interior paints used in this research, the manufacturer, and the active ingredients which the manufacturer specifies as being responsible for the antimicrobial quality of the product. Table 2b lists the two interior paint products, the manufacturer, and type of paint. All paint products were purchased from paint product distributors. Experiments were conducted at room temperature (21.1 °C or 70 °F) using cut new GWB square coupons of 7.6 x 7.6 cm (3.0 x 3.0 in) (Menetrez, M. Y., 2007b).

Plain GWB coupons were cut and placed in self-sealing pouches, and steam sterilized by autoclaving. After inoculation with *S. chartarum* samples were placed in sterile petri dishes containing 4 mL of sterile water and then the dish was closed and placed into a static microbial test chamber maintained at 100 percent RH and room temperature (21.1 °C or 70.0 °F). The static microbial test chamber (SMTC) is constructed from acrylic sheeting (measures 32 x 39 x 51 cm) with shelves for samples and a saturated salt/water solution on the chamber bottom to control the equilibrium relative humidity. No air exchange through the chamber walls can occur, and measurable air movement within the chamber is not possible. The SMTC was tested using ASTM 6329-98, *Standard Guide for Developing Methodology for Evaluating the Ability of Indoor Materials to Support Microbial Growth Using Static Environmental Chambers* (2003). This method was developed as part of on-going indoor air biocontaminant research (Menetrez, M. Y., 2007b).

After inoculation, wetting and static chamber storage, visual inspection of coupons continued until they were found to have extensive *S. chartarum* growth, covering the coupon surface. Growth was estimated to be sufficient at varying periods between one to two months. When the coupon surface was extensively covered with growth over the majority of the surface with few bare spots remaining the coupons were cleaned. Two different cleaning techniques were used. One technique used sterile water only and a sterile sponge to wipe the surface. The second technique used a dilute solution of bleach and sterile water (one part bleach to ten parts water), and again was applied with a sterile sponge. Sterile sponges were used to clean contaminated coupons and then were discarded. A back and forth motion of approximately six times was used to clean the sample coupons until no visible mold was present. A new pair of sterile gloves was used for each cleaner and each surface type. After cleaning, samples remained in the biosafety cabinet for a minimum of 30 minutes to dry before paint was applied (Menetrez, M. Y., 2007b).

Only two of the six manufacturers (Zinsser Company, Inc., for Permawhite, and PPG Industries, for Potersept) gave specific instructions for preparation of contaminated surfaces. In both cases they recommended applying a solution of bleach and water using a sponge. Surfaces were recommended to be sponge wiped until clean and then allowed to dry before painting (Menetrez, M. Y., 2007b).

Paint (antimicrobial encapsulant paint, oil-based, or acrylic/latex) was applied using a clean, dry paintbrush for each type of paint. Samples were allowed to dry for 24 hours, then a second coat was applied. The coupons were then allowed to dry for 30 minutes (while in a biological safety hood BSL2), and placed in sterile petri dishes containing 4 mL of sterile water and then the dish was closed and placed into a static chamber maintained at 100 percent RH. The static chamber testing was again based on ASTM Standard D6329-98 (Menetrez, M. Y., 2007b).

Inspection for *S. chartarum* regrowth of triplicate coupons within the static chambers extended up to six months. And as described in previous section Antimicrobial Cleaner Efficacy on Gypsum Wallboard Contaminated with *S. chartarum,* the estimation of regrowth was made by visual inspection of the coupon surfaces and the numerical ranking of mold growth (0 represented no growth, to 5 which represented growth covering the majority of the sample with few bare spots remaining). Triplicate sample coupons were processed for each of the nine paint products and two cleaning techniques (Menetrez, M. Y., 2007b).

Results and Discussion

The results and discussion for testing *Stachybotrys chartarum* contamination on gypsum wallboard is summarized for 1. growth responses to moisture variation which promote or inhibit mold growth; and 2. efficacy testing of antimicrobial products (cleaners and paints).

Growth Responses of *Stachybotrys chartarum* to Moisture Variation on Gypsum Wallboard

As depicted in Table 3, *S. chartarum* will grow in saturated air conditions (100% RH) without any additional moisture. At an RH of 97% and below, wetting is necessary for the growth of *S. chartarum*. Variations in the type of GWB did not affect growth responses at the levels of RH above 64% (Menetrez, M. Y., 2004).

All GWB samples receiving 4 mL of water on a 3.8 cm (1.5-inch) square and incubated at 64% RH or greater were positive for mold growth. This indicates that GWB which becomes saturated (as specified by a moisture measurement) and allowed to stay in a marginally humid environment will result in mold growth. Although GWB measuring 100% moisture content (saturated) is not noticeably different in appearance from GWB with no measurable moisture, it is highly susceptible to mold growth (Menetrez, M. Y., 2004).

Growth responses above 64% RH were consistently similar for the three strains of *S. chartarum* tested. These strains could be expected to behave similarly at varying RH levels. Manufactured GWB which becomes wet and is allowed to remain wet for a protracted length of time is susceptible to mold growth (Menetrez, M. Y., 2004).

Antimicrobial Cleaner Efficacy on Gypsum Wallboard Contaminated with *S. chartarum*

Visual inspection for *S. chartarum* regrowth of the coupons within the static chambers extended up to six months. Only those samples that exhibited heavy amounts of regrowth were stopped prior to six months. The estimation of regrowth was made by optical inspection of the coupon surfaces. The results were numerically ranked from best (0 represented no growth) to worst (5 represented extensive growth) and are listed in Table 4. The names of products listed in bold in Tables 1 were used as shortened versions of the commercial manufacturer's product names which are listed in Table 4.

The mean results (of triplicate samples) of 14 cleaning products for the six types of GWB surfaces varied extensively (see Tables 4 and 5). However, three cleaning products exhibited significantly better results than others. Lysol All-Purpose Cleaner-Orange Breeze (full strength) demonstrated results which ranked among the best in five of the six surfaces tested. Both Borax and Orange Glo Multipurpose Degreaser demonstrated results which ranked among the best in four of the six surfaces tested (Menetrez, M. Y., 2007a).

Eight other cleaning products ranked among the best in at least one surface test, they were: Formula 409, Lysol IC, Pine Sol, bleach, Spray Nine, Mildew Stain Remover with bleach SporKlenz, Tilex, Fantastik Orange Action, and Lysol All-Purpose Cleaner-Orange Breeze (diluted). Every product tested demonstrated to be among the best in at least one surface test (Menetrez, M. Y., 2007a).

The results of *S. chartarum* regrowth listed in Table 4 was sorted in a comparative ranking of antimicrobial efficacy performance. Those products listed Table 4 which best limited regrowth were given a ranking of 1, and those that demonstrated the most regrowth were given a ranking of 5. The 14 products tested are listed from first (best performance) to last (worst performance) in Table 5. Numerous products received the same equivalent ranking in Table 5 when their test results listed in Table 4 were equal. Table 5 illustrates the comparison of antimicrobial cleaning product performance (Menetrez, M. Y., 2007a).

Testing Antimicrobial Paint Efficacy On Gypsum Wallboard Contaminated with *Stachybotrys chartarum*

The observed regrowth results were averaged for each of the seven antimicrobial paint products and the two standard paint products listed in Tables 2a and b. Results of regrowth of *S. chartarum* on GWB are listed in Table 6. The test results of Table 6 list paint used on water cleaned GWB, and paint used on bleach and water cleaned GWB (the method recommended by most manufacturers) (Menetrez, M. Y., 2007b).

Results for the nine types of paint products on GWB surfaces varied. However, three antimicrobial encapsulant paint products exhibited perfect results. Permawhite, M-1 Additive, and Porterscept demonstrated results which ranked among the best in tests (see Table 6). Mil-Kil ranked among the best for water cleaned GWB (Table 6), and near the best for bleach and water cleaned GWB (Table 7). The remaining three antimicrobial encapsulant paints and two common paints did not perform as well. The Kilz performance was not even as good as the acrylic/latex or oil-based paint (Menetrez, M. Y., 2007b).

Based on the study results the best antimicrobial encapsulant paints for dealing with *S. chartarum* contamination on GWB was Permawhite, M-1 Additive, and Porterscept. The results for Mil-Kil were close in comparison. Although two of these four products contain titanium-dioxide, they all contain unique formulations (or trace ingredients not listed on the MSDS) that make it difficult to draw conclusions regarding their successful performance (Menetrez, M. Y., 2007b).

The results of *S. chartarum* regrowth listed in Table 6 was sorted in a comparative ranking of antimicrobial efficacy performance. The nine products tested are listed from first (best performance) to last (worst performance) in Table 7. Numerous products received the same equivalent ranking in Table 7 when their test results listed in Table 6 were equal. Table 7 illustrates the comparison of antimicrobial paint product performance (Menetrez, M. Y., 2007b).

Summary of Conclusions

Conclusions for controlling *Stachybotrys chartarum* contamination on gypsum wallboard are summarized for: 1. growth responses to moisture variation which promote or inhibit mold growth; and 2. efficacy testing of antimicrobial products (cleaners and paints).

Growth Responses of *Stachybotrys chartarum* to Moisture Variation on Gypsum Wallboard

Saturated air conditions (100% RH) will promote *S. chartarum* growth on standard gypsum wallboard without any additional moisture. At an RH of 97% and below, wetting is necessary for the growth of *S. chartarum* (Menetrez, M. Y., 2004).

Antimicrobial Cleaner Efficacy on Gypsum Wallboard Contaminated with *S. chartarum*

Antimicrobial cleaners were tested for their ability to prevent or inhibit the regrowth of *S. chartarum* on heavily contaminated GWB. Three cleaning products exhibited significantly better results then the rest of the products tested on GWB; they were Lysol All-Purpose Cleaner-Orange Breeze (full strength), Borax, and Orange Glo Multipurpose Degreaser (Menetrez, M. Y., 2007a).

Testing Antimicrobial Paint Efficacy On Gypsum Wallboard Contaminated with *Stachybotrys chartarum*

Antimicrobial paints were tested for their ability to prevent or inhibit the regrowth of *S. chartarum* on heavily contaminated GWB. Four antimicrobial encapsulant paints showed comparatively favorable results for dealing with *S. chartarum* contamination on GWB. They were Permawhite, M-1 Additive, Porterscept, and Mil-Kil (Menetrez, M. Y., 2007b).

It was not the intention of this discussion to endorse any product. Reporting on the performance of these products under the stated conditions was and remains the only purpose. These results are not meant to endorse the incomplete removal of mold contaminated building materials. However, it is recognized that complete removal may not always be possible and solutions to control mold regrowth may contribute to reduced occupant exposure. Current recommendations of removal and replacement of porous building materials should be followed.

The U.S. Environmental Protection Agency, through its Office of Research and Development, funded and managed the research described herein. It has been subject to an administrative review but does not necessarily reflect the views of the Agency. No official endorsement should be inferred. EPA does not endorse the purchase or sale of any commercial products or services.

References

ASTM 6329-98, *Standard Guide for Developing Methodology for Evaluating the Ability of Indoor Materials to Support Microbial Growth Using Static Environmental Chambers* (2003).

Dearborn D. G., Iwona Y, Sorenson W. G., Miller M. J., Overview of investigations into pulmonary hemorrhage among infants in Cleveland, Ohio: Environmental Health Perspectives, 107 (Suppl. 3), June 1999, p 495-499.

Foarde KK., VanOsdell DW, Chang JCS, Static Chamber Method for Evaluating the Ability of Indoor Materials to Support Microbial Growth: In ASTM STP 1287, Characterizing Sources of Indoor Air Pollution and Related Sink Effects, Tichenor BA, West Conshohocken, PA, 1996, pp 87-97.

Menetrez, M. Y., and Foarde, K. K., "Testing Antimicrobial Efficacy on Porous Materials," Indoor Built Environment: The Journal of the International Society of the Built Environment, October, 2002;11:202-207.

Menetrez, M. Y., Foarde, K. K., Webber, T. D., Dean, T. R., and Betancourt, D. A., "Growth Responses of *Stachybotrys chartarum* to Moisture Variation on Common Building Materials," Indoor Built Environment: The Journal of the International Society of the Built Environment, June 2004; 13:183-188.

Menetrez, M. Y., Foarde, K. K., Webber, T. D., Dean, T. R., and Betancourt, D. A., "Testing Antimicrobial Cleaner Efficacy On Gypsum Wallboard Contaminated with *Stachybotrys chartarum*," Journal of Environmental Science and Pollution Research, March 2007a, espr 2007.03.397.

Menetrez, M. Y., Foarde, K. K., Webber, T. D., Dean, T. R., and Betancourt, D. A., "Testing Antimicrobial Paint Efficacy On Gypsum Wallboard Contaminated with *Stachybotrys chartarum*, submitted to Journal of Occupational & Environmental Hygiene (2007b, in Journal review).

Murtoniemi T., Nevalainen A., Suutari M., Toivola M., Komulainen H., Hirvonen M. R., Induction of cytotoxicity and production of inflammatory mediators in RAW264.7 macrophages by spores grown on six different plasterboards: Inhal Toxicol, 13(3), March 2001, pp 233-247.

Scheel C. M., Possible Sources of Sick Building Syndrome in a Tennessee Middle School: Arch Environ Health, 56(5),Sep-Oct 2001, pp 413-418.

Sudakin D. L., *Stachybotrys chartarum*: current knowledge of its role in disease, Medscape General Medicine, Veterans Administration Medical Center, Portland, Oregon, Feb 19, 2000, pE11, ISSN 1531-0132, Journal Code 100894134.

Vesper S. J., Dearborn D. G., Yike I., Allan T., Sobolewski J., Hinkley S.F., Jarvis B.B., Haugland R. A., Evaluation of *Stachybotrys chartarum* in house of an infant with pulmonary hemorrhage: quantitative assessment before, during, and after remediation: Journal of Urban Health, 77 (1), Mar 2000, pp 68-85.

Vesper S. J., Vesper M. J., Stachylysin may be a cause of hemorrhaging in humans exposed to *Stachybotrys chartarum*: Infection and Immunity, 70 (4), April 2002, pp 2065-2069.

Cleaning Product	Directions For Use	Concentration
Lysol (concentrated)	To disinfect/deodorize hard, non-porous surfaces, remove heavy soil first, then add 1.3 oz to one gallon water then apply with a sponge or mop wetting all surfaces thoroughly. Let stand 10 minutes, then wipe away excess.	189 mL H_2O 1.89 mL Lysol
Lysol All Purpose Cleaner Orange Breeze scent	For a cleaner, fresher household, dilute 2 oz. with a gallon of warm water. Good for everyday cleaning throughout the house. For your toughest household messes; use full strength and rinse thoroughly.	full strength
Lysol All Purpose Cleaner Orange Breeze scent	For a cleaner, fresher household, dilute 2 oz. with a gallon of warm water. Good for everyday cleaning throughout the house. For your toughest household messes; use full strength and rinse thoroughly.	250 mL H_2O 3.75 mL Lysol Orange Breeze
Lysol IC - Brand Quaternary Disinfectant Cleaner	Remove heavy soil deposits from surfaces, then thoroughly wet them with a solution of 1/2 oz of the concentrate per gallon of water. The solution can be applied with a cloth, mop, sponge or coarse spray or soaking. Let solution remain on surface for a minimum of 10 minutes. Allow to air dry.	378.5 mL H_2O 1.48 mL Lysol I.C.
Spray Nine Multi-Purpose Cleaner & Disinfectant	1. Spray on soiled surface. 2. Wipe immediately with a clean, damp sponge or cloth. 3. Repeat application making sure to wet all surfaces thoroughly. 4. Allow to stand for 3 minutes when treating for fungus. 5. Wipe off with a clean, damp sponge or cloth then rinse thoroughly.	full strength
Johnson Wax Professional **Mildew Stain**	Spray using full strokes, 6-8" from surface. Wait until stains disappear. Wipe with sponge. Rinse promptly.	full strength

Remover with Bleach		
Commercial Solutions Ultra Clorox Germicidal **Bleach**	Prewash surface, mop or wipe with bleach solution. Allow solution to contact surface for at least 2 minutes. Rinse well and air dry. Dilute 2/3 cup bleach to 1 gallon water.	189 mL H_2O 7.89 mL bleach
SporKlenz	Remove any obvious debris or organic material from the surface to be sterilized. Dilute Spor-Klenz concentrate 100x (1 part Spor-Klenz to 99 parts purified water). Spray onto surfaces using a plastic spray bottle. Allow to remain on surface for 10 minutes. Let air dry or rinse with purified water.	175 mL H_2O 1.75 mL SporKlenz
Borax	Sprinkle borax into water and wipe with damp sponge.	473 mL of warm water 1 Tablespoon Borax
Pine Sol	For general disinfecting: Apply Original Pine-Sol Brand cleaner with a sponge or cloth full strength. Wet surfaces, let stand 5 minutes, then remove excess. For highly soiled areas, clean excess dirt first.	full strength
Tilex	Spray surface until thoroughly wet, let stand 5 minutes and rinse. Do not use on wood or painted surfaces. Avoid contact with aluminum, clothes, fabric, carpet or paper surfaces as they will discolor.	full strength
Fantastik Orange Action	Spray 6-8 inches from surface. After spraying, wipe with a dry paper towel or cloth.	full strength
Orange Glo Multipurpose Degreaser	Spray on soiled area and wipe clean. Rinse if necessary. For baked-on grease or thick soap film, wait several minutes before wiping.	full strength
Formula 409 Multipurpose Cleaner	Spray 6-8 inches from surface. General cleaning: Spray product straight onto soils and wipe clean with a dry paper towel or lint free cloth. Repeat for heavily soiled areas. Not recommended for use on soft vinyl, varnishes or aluminum.	full strength

Table 1 Cleaning products tested for removing *Stachybotrys chartarium* growth

Manufacturer	**Antimicrobial Paint Products**	**Active Ingredients**
Alistagen Corp. New York, NY 10016	Caliwel 1 Caliwel 2 with BNA (Bi-Neutralizing Agent)	18.7 % Hydrated Lime (calcium hydroxide)
PPG Industries Pittsburg, PA 15272	Portersept	10.0-20.0 % wt Titanium dioxide 1.0-10.0 % Propylene glycol 1.0-10.0 % Kaolin <1% Crystalline silica-quartz
Homax Products Inc. Bellingham, WA 98226	Mil-Kil Additive	40.0 % wt diiodomethyl p-tolyl sulfone added to acrylic/latex paint
Jomaps, Inc. Alpharetta, GA 63052	M-1 Additive	51.8 % Chlorothalonil 2, 4, 5, 6-Tetrachloroisophthalonitrile added to acrylic/latex paint
Masterchem Industries, Inc. Imperial, MO 63052	Kilz (interior/exterior water based)	Acrylic resin emulsion Titanium dioxide Calcium carbonate Ethylene glycol
Zinsser Company, Inc. Somerset, NJ 08873	Permawhite (satin, water based)	Limestone Titanium dioxide Ethylene glycol Mica Zinc oxide Magnesium aluminum silcate

Table 2a Antimicrobial encapsulant paint products

Manufacturer	**Paint Products**	**Paint Type**
The Valspar Corporation,	American Tradition,	Acrylic/latex

Wheeling, Illinois 60090	Interior 100 % Acrylic	
The Valspar Corporation, Wheeling, Illinois 60090	Interior one coat Oil Semi-Gloss Enamel	Oil-based

Table 2b Paint products

Moisture/RH and GWB surface	**New GWB**	**Old GWB**	**Vinyl coated GWB**	**100 % Vinyl Wallpaper on GWB**
100 % RH + 4 ml water	Positive	Positive	NT	NT
100 % RH	Positive	Positive	Positive	Positive
97 % RH 4 ml water	Positive	NT	NT	NT
97 % RH	No Change	No Change	No Change	No Change
90 % RH	No Change	No Change	No Change	No Change
85 % RH + 4 ml water	Positive	NT	NT	NT
85 % RH	No Change	No Change	No Change	No Change
75 % RH + 4 ml water	Positive	NT	NT	NT
62 % RH + 4 ml water	Positive	NT	NT	NT
75 % RH + 1 ml water	No Change	NT	NT	NT
62 % RH + 1 ml water	Negative	NT	NT	NT

Table 3 Growth of *Stachybotrys chartarium* on four types of GWB and eleven RH levels.

Positive - positive mold response, or growth
Negative - negative mold response, or die off
No Change - no mold response.
NT - not tested

Mean growth ranked 0 to 5 for each surface type	**1**	**2**	**3**	**4**	**5**	**6**
Lysol All-Purpose Cleaner- Orange Breeze (full strength)	0.0	3.7	0.0	0.0	0.0	0.0
Borax	0.0	0.0	1.0	2.0	0.0	0.0
Orange Glo Multipurpose Degreaser	0.0	0.0	0.0	0.0	1.0	4.0
Fantastik Orange Action	0.0	3.3	2.3	0.7	0.3	2.3
Lysol IC - Brand Quaternary Disinfectant Cleaner	0.7	0.0	1.0	1.0	3.0	5.0
Formula 409 Multipurpose Cleaner	1.3	0.0	2.0	1.0	1.0	4.0
Lysol (concentrated)	3.0	0.0	1.0	3.0	0.0	1.7
Tilex	2.0	0.0	1.7	2.7	0.7	2.0
Spray Nine Multi-Purpose Cleaner & Disinfectant	2.7	0.0	1.0	3.0	1.0	1.7
SporKlenz	2.3	0.7	0.7	2.0	2.0	0.0
Pine Sol	2.0	0.0	0.3	2.0	0.7	0.7
Commercial Solutions Ultra Clorox Germicidal **Bleach**	5.0	0.0	1.0	3.3	1.7	0.7
Johnson Wax Professional **Mildew Stain Remover with Bleach**	3.7	0.0	1.0	2.3	1.7	1.3
Lysol All Purpose Cleaner Orange Breeze scent	4.	4.	5.	0.	3.	3.

(diluted)	0	3	0	0	0	3

Table 4 Comparison *Stachybotrys chartarium* growth for cleaners on six GWB surface types

7. Plain GWB, no paint,
8. Vinyl (100 percent vinyl) covered GWB,
9. GWB with vinyl coated wallpaper removed before cleaning and replacement,
10. GWB with vinyl coated wallpaper not removed before cleaning,
11. GWB with oil-based paint,
12. GWB with acrylic (latex) paint.

Cleaners ranked for each surface type	**1**	**2**	**3**	**4**	**5**	**6**
Lysol All-Purpose Cleaner- Orange Breeze (full strength)	1	13	1	1	1	1
Borax	1	1	5	7	1	1
Orange Glo Multipurpose Degreaser	1	1	1	1	7	12
Fantastik Orange Action	1	12	13	4	4	10
Lysol IC - Brand Quaternary Disinfectant Cleaner	5	1	5	5	13	14
Formula 409 Multipurpose Cleaner	6	1	12	5	7	12
Lysol (concentrated)	11	1	5	12	1	7
Tilex	7	1	11	11	5	9
Spray Nine Multi-Purpose Cleaner & Disinfectant	10	1	5	12	7	7
SporKlenz	9	11	4	7	12	1
Pine Sol	7	1	3	7	5	4
Commercial Solutions Ultra Clorox Germicidal **Bleach**	14	1	5	14	10	4

Johnson Wax Professional **Mildew Stain Remover with Bleach**	12	1	5	10	10	6
Lysol All Purpose Cleaner Orange Breeze scent (diluted)	13	14	14	1	13	11

Table 5 Comparison ranking of cleaners performance for six GWB surface types

1. Plain GWB, no paint,
2. Vinyl (100 percent vinyl) covered GWB,
3. GWB with vinyl coated wallpaper removed before cleaning and replacement,
4. GWB with vinyl coated wallpaper not removed before cleaning,
5. GWB with oil-based paint,
6. GWB with acrylic (latex) paint.

Paint products used on cleaned GWB	**Mean *S. chartarum* growth ranking for water cleaned GWB**	**Mean *S. chartarum* growth ranking for bleach and water cleaned GWB**
Permawhite	0	0
Portersept	0	0
Mil-Kil	0	0
M-1 Additive	0	0.3
Caliwell 1	4.0	1.7
Caliwell 2	4.0	0.7
Acrylic/Latex	4.0	4.0
Oil-Based	4.0	4.0
Kilz	5.0	5.0

Table 6 Growth ranking for cleaned and painted GWB

Paint products used on cleaned GWB	**Mean *S. chartarum* growth ranking for water cleaned GWB**	**Mean *S. chartarum* growth ranking for bleach and water cleaned GWB**
Permawhite	1	1
Portersept	1	1
Mil-Kil	1	1
M-1 Additive	1	4
Caliwell 1	5	6
Caliwell 2	5	5
Acrylic/Latex	5	7
Oil-Based	5	7
Kilz	9	9

Table 7 Comparison ranking of cleaned and painted GWB