Surface Mold Prevention with Chlorothalonil/ Disodium Octaborate Tetrahydrate Systems

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A laboratory study has confirmed the merit of topically applied chlorothalonil and chlorothalonil/disodium octaborate tetrahydrate combination systems for the prevention of fungal growth on wood (and gypsum drywall) substrates. This article describes the extension of this work to a field study performed on construction lumber under harsh climatic conditions (southern Florida), highly favorable to mold growth. This more realistic study also confirmed the effectiveness of chlorothalonil-based systems in prevention of surface infestation by mold fungi. The practical application of these systems for mold prevention in new home construction is discussed.

INTRODUCTION

Mold prevention in new homes and remediation of mold in storm-damaged properties are both contributing to a growing market in this area of pest control. Many factors in new home construction, including poor building practices (leaks), use of synthetic stucco (does not breathe), longer construction times (larger homes), and efforts for higher energy efficiency contribute to the increased incidence of mold. Changes in life style (longer time spent indoors) also contribute to higher moisture levels favorable to mold infestation. Normal weather extremes linked with the increased utilization of indoor climate control, and the longer-term cyclical

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changes in climatic conditions currently giving rise to increased hurricane incidence, are also significant contributors to mold infestations in habitable structures.

Many chemical treatments have emerged for mold prevention and remediation but the number of truly effective materials is limited. The first step in providing products for mold prevention and remediation is normally a preliminary laboratory study that screens and compares likely candidates for efficacy against known mold-forming fungi. Such a study in surface mold control was recently completed and reported by Lloyd, Micales-Glaeser, and Woods.[1] This study constituted tests performed in-vitro on wood (southern yellow pine and aspen) and gypsum wallboard with four mold fungi commonly encountered in human habitations. The active ingredients compared in the fungicidal treatments were chlorothalonil (CTL), didecyl dimethyl ammonium chloride (DDAC), and disodium octaborate tetrahydrate (DOT). Combination systems based on DOT with the other two active substances were also included in this study. This was a comprehensive study, the results of which were presented at the Ljubljana IRG meeting in 2004. In summary, the data obtained clearly demonstrated that the most effective fungicide, when used alone, was CTL.

Combinations of CTL with DOT also performed more effectively than the DOT/DDAC combinations but the difference in efficacy for the combined systems was rather small. Some of the results from this study obtained on southern yellow pine (SYP) are presented here for direct reference.

To increase the level of confidence in CTL-based systems for mold prevention, studies were extended to a full-scale field trial performed under harsh climatic conditions. This study was performed on bundles of construction lumber stored under tarpaulins in southern Florida. Intermittent examination of the exposed lumber stacks indicated that significant differentiation of fungicidal treatments could be observed in a relatively short period of time (three months).

EXPERIMENTAL

Materials

CHEMICALS: disodium octaborate tetrahydrate was provided by Nisus Corporation in the form of a 40.6% active solution in glycols. Chlorothalonil was employed as a 40.4% active water-based suspension concentrate (Sostram Corporation) and didecyl dimethyl ammonium chloride was employed in the form of an 80% active aqueous solution and was supplied by the original study co-sponsor, Nisus Corporation.

Table 1—Fungicidal Treatments—In-vitro Study

Sample Number	Fungicidal Treatment	Concentration (%) (Active Ingredient)
1	None	NA
2	Chlorothalonil (CTL)	1.0
3	Didecyl dimethyl ammonium chloride (DDAC)	1.0
4	Disodium octaborate tetrahydrate (DOT)	8.5
5	DOT/DDAC	8.5/1.0
6	DOT/CTL	8.5/1.0

Petri Dish Study

A complete description of the method employed in the in-vitro study is given in reference 1 and will not be detailed here.

Standard microbiological Petri-dish techniques were employed for determining the effectiveness of each treatment against mold fungi in axenic culture. The mold fungi evaluated were: *Stachybotrys chartarum, Aspergillus niger, Penicillium brevicompactum,* and *Cladosporium cladosporioides*. In all, 16 single active and combination active fungicidal treatment systems were evaluated including some evaluations at multiple levels. Test substrates were southern yellow pine, aspen, and boron-free gypsum wallboard. Samples were rated at intervals up to a total of 12 weeks for macroscopic discoloration and microscopic sporulation and mycelial growth. A modified version of ASTM D 3274-95[2] was employed with all properties being rated on a scale of 0–3. In all cases a higher rating corresponds with lower efficacy of the fungicidal treatment to control the respective deterioration.

Select fungicidal systems from the above study are reported here (*Table* 1) for comparison with the field study, which is the main object of this paper.

Field Study

TEST SPECIMENS: 2″ x 4″x 8′ pieces of kiln-dried SYP construction lumber were selected as test specimens for the field trial. Four full bundles (A, B, C, D—approximately 190 pieces in each bundle) of each treatment were prepared.

Table 2—Fungicidal Treatments—Field Study

Sample Number	Fungicidal Treatment	Concentration (%) (Active Ingredient)
1F (A,B,C,D)	Water control	NA
2F (A,B,C,D)	DOT/DDAC	8.5/1.0
3F (A,B,C,D)	Chlorothalonil (CTL)	1.0
4F (A,B,C,D)	DOT/CTL	8.5/1.0

Figure 1—Effect of fungicidal treatments on the discoloration, sporulation, and mycelial growth of *Stachybotrys chartarum* on pine (each point is the average of six replicate samples after 12 weeks incubation).

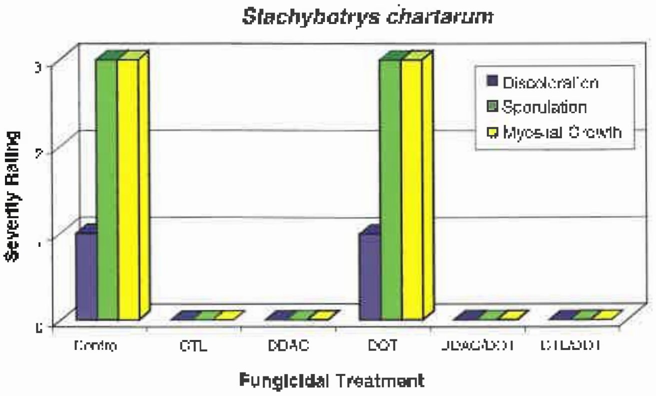
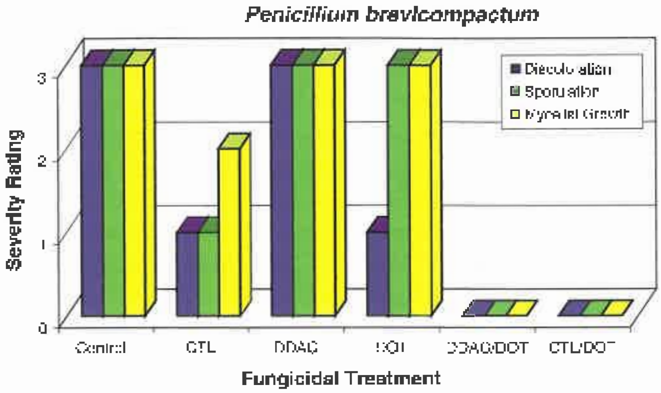


Figure 3—Effect of fungicidal treatments on the discoloration, sporulation, and mycelial growth of *Penicillium brevicompactum* on pine (each point is the average of six replicate samples after 12 weeks incubation).



Fungicidal Treatments

In addition to water-treated control specimens the fungicidal treatment systems were selected as the three best systems from the laboratory study identified above. *Table* 2 lists the fungicidal treatments undertaken for the field study.

Treatment Procedure

The construction lumber bundles were split and each piece of lumber was individually treated by flood-coating (a high volume, low pressure spray technique). This was followed by air-knife drying prior to reconstitution of the lumber bundles. The treatments were performed at the establishment of Triad Pre-finish and Lumber Sales Inc., Greensboro, NC. Reconstituted bundles were re-strapped and shipped to the Atlas test site in southern Florida for exposure and evaluation. At the time of shipment, only the treating facility was aware of the identity of the treated bundles. Any downstream evaluation of these specimens was, therefore, performed on a totally unbiased "blind" basis.

Specimen Exposure

The bundles were arranged randomly on the test site and were covered by tarpaulins in order to conserve moisture within the bundle and create an aggressive environment with regards to mold growth. The tarpaulins were removed in order to subject the bundles to any natural rainfall that occurred. When natural rainfall was absent for more than one week the bundles were watered artificially on a weekly basis. The wet bundles were re-tarped after natural rainfall or watering. The test was initiated in mid-January 2005 and terminated in early April 2005.

Evaluation

Bundles were evaluated on an intermittent basis for development of surface mold. When mold had developed sufficiently to differentiate the treated specimens,

Figure 2—Effect of fungicidal treatments on the discoloration, sporulation, and mycelial growth of *Cladosporium cladosporioides* on pine (each point is the average of six replicate samples after 12 weeks incubation).

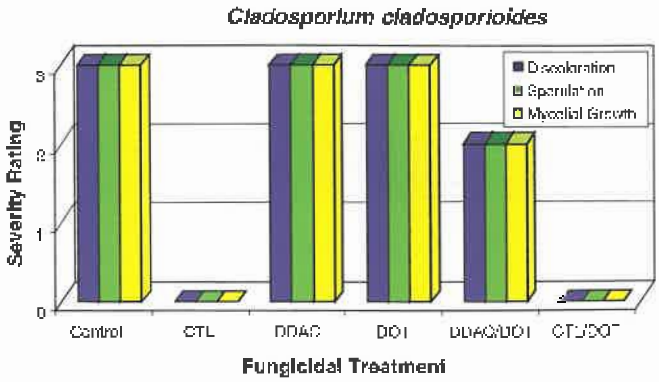
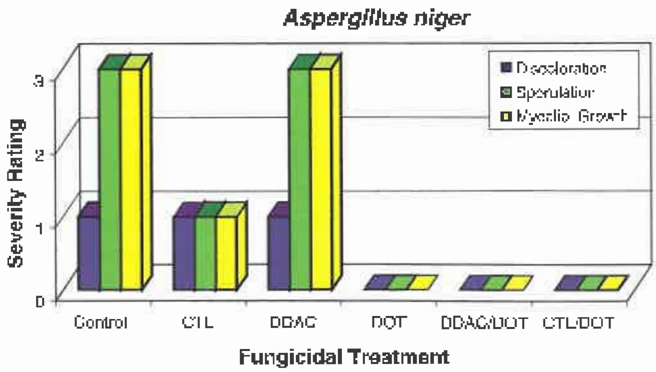


Figure 4—Effect of fungicidal treatments on the discoloration, sporulation, and mycelial growth of *Aspergillus niger* on pine (each point is the average of six replicate samples after 12 weeks incubation).



a comprehensive assessment was performed. This constituted a piece-by-piece evaluation and allocation of a rating based on the percentage of clean wood present on the worst of the two broad faces of each piece. This involved the evaluation of some 1500 wood surfaces for any given treatment type and was performed by Prof. Terry Amburgey of TASkpro Inc. Only the incidence of mold growth was rated, not the severity. Even if a lumber surface was lightly covered with mold and this covered the whole surface, a 0% clean rating was assigned. Additionally, photographic documentation of the partially dissembled wood bundles was performed.

RESULTS AND DISCUSSION

Laboratory Study

Data extracted from the laboratory study have been used to construct *Figures* 1–4 for the four microorganisms listed above on southern yellow pine (SYP). These figures illustrate the efficacy of the individual active ingredients and combination systems for a limited number of the samples evaluated in the original study. *Table* 1 outlines the systems for which data are presented.

The results of this study are reported in detail in Lloyd et al.[1] This study concluded that the best overall efficacy of the single active ingredient fungicidal treatments is observed with CTL. This perspective is also reached from the condensed data presented here for SYP treatments. Of the combination systems studied, the CTL/DOT system is the most effective but the deficiency of the DDAC/DOT system is limited to *Cladosporium cladosporioides*. The above observations related to the efficacy of DOT alone are consistent with the findings of Barnes et al.,[3] who concluded that DOT is only marginally effective at controlling mold fungi, and the observations of Clausen and West,[4] who found that SYP specimens dip treated with a solution containing 15% DOT were moderately resistant to *Aspergillus niger* in a standard laboratory mold test, but only when the specimens were kiln-dried prior to fungicidal treatment.

Field Study

Based on the observations from the in-vitro study the three fungicidal treatments with the best efficacy (*Table* 2) were chosen as the basis of a field study in southern Florida. Southern yellow pine was chosen as the test substrate and full bundles of construction lumber were utilized. The test was designed to give a "worst case" study consistent with the ambient temperatures and humidity conducive to surface mold growth. In addition, moisture levels in/on the test specimens were maintained by enclosure in tarpaulins. This protocol also ensured little air movement around the wood bundles, further enhancing the potential for mold growth.

The field test was initiated in mid-January 2005. Early inspections indicated relatively little mold growth attributable to the initial dryness of the test specimens and the lack of natural rainfall. It was then decided that artificial watering would be required on a weekly basis if no natural rainfall occurred. This practice was successful at inducing mold growth and by early April 2005 sufficient differences in surface mold were evident such that an objective assessment of these differences could be made. No attempt was made to identify the mold species, although both *Trichoderma spp.* and *Penicillium spp.* appeared to be the predominant species. The wood bundles were split to approximately half the depth and differences were recorded by photography. The black and white versions of these colored photographs are not suitable for reproduction here but the following order of efficacy, DOT/CTL>CTL>DOT/DDAC=control (water), was apparent. A more objective assessment of performance was obtained by a detailed inspection of the two broad faces of every piece of lumber that received treatment. In all, some 6000 (1500 per treatment type) individual assessments were performed. This procedure is described in the experimental section and resulted in approximately 750 pieces of data per treatment type. These data are not presented here but several statistical assessments of these data were performed and are presented in *Figures* 5–7.

Figure 5 illustrates the effect of fungicidal treatment upon the mean percentage of surface area free of mold after approximately 90 days of exposure. In comparison to the water-treated control, CTL gave a significant positive effect on the mean percentage of surface area free of mold while the combination of CTL with DOT gave even more positive results. In contrast, the combination of DOT with DDAC had apparently little effect on the proportion of surface area free of mold.

An alternative statistical view of the data, presented in *Figure* 6 (median value of percentage surface area free of mold), suggests a similar relative order of performance for the CTL and CTL/DOT systems but a greater differentiation between these systems and the DOT/DDAC system and the water control. There is some indication from the data presented in *Figures* 5 and 6 that the DOT/DDAC system performs somewhat worse than the control but this is likely of little statistical significance. A final perspective on this data is presented in *Figure* 7, which shows the effect of treatment type upon the relative incidence of perfectly clean boards at the end of the exposure period. Again the same conclusion is reached with regards to relative efficacy.

Independent of the statistical representation of the acquired data, it is clear that the field results for the

Figure 5—Effect of fungicidal treatment on the overall mean percentages of surface area free of mold (worst broad face) after approximately 90 days exposure in southern Florida.

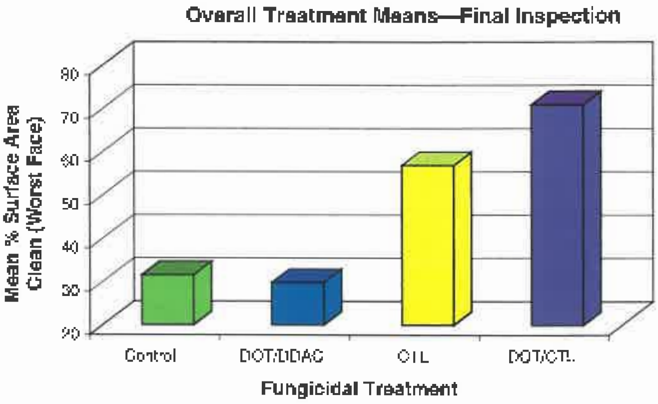


Figure 6—Effect of fungicidal treatment on the median values of surface area free of mold (worst broad face) after approximately 90 days exposure in southern Florida.

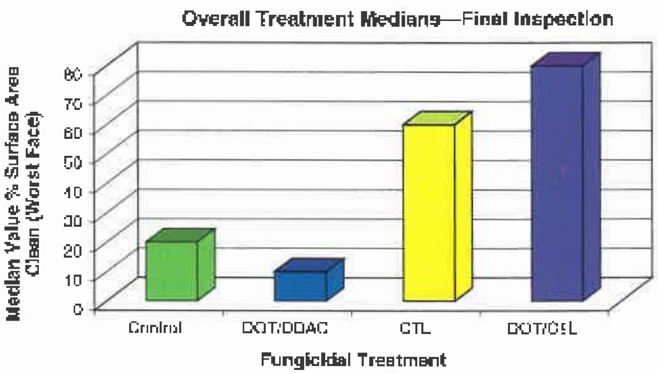
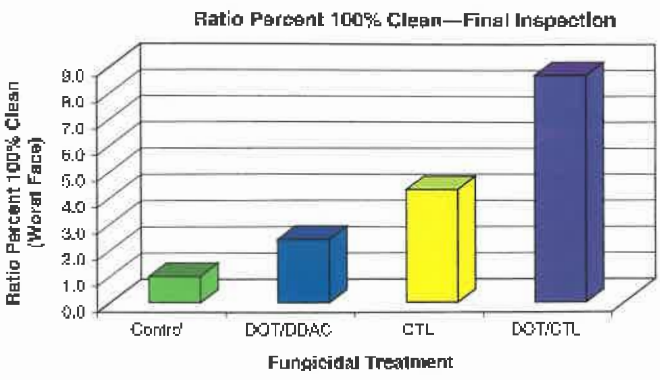


Figure 7—Ratios of the percentage of 100% clean (worst broad face) boards after approximately 90 days exposure in southern Florida.



CTL and CTL/DOT systems confirm the observations made in the laboratory study. The data generated in the field study for the DOT/DDAC system, however, do not parallel the results of the laboratory study. Indeed, the DOT/DDAC system performs significantly worse than the DOT/CTL system under the harsher conditions of the field study. This effect is possibly a simple consequence of the high water solubility of DDAC (miscible in all proportions) since the bundles were exposed to natural rainfall and artificial watering. Additionally, CTL has extremely low solubility in water (approximately 10^{-6} in distilled water) and has high resistance to leaching from wood.[5] Despite the fact that the laboratory study indicates that the DOT/DDAC system performed well against the DOT/CTL system, the narrower spectrum of activity for DDAC alone in comparison with CTL raises the possibility that the DOT/DDAC system could offer inferior performance to the DOT/CTL combination dependant upon the mold fungi encountered. Clausen and Yang[6] have observed that Borate/quat systems have high minimal fungicidal concentrations [MFC_{90}], suggesting the limited efficacy of this type of combination for surface mold inhibition.

Development of test methods with which to prove efficacy for surface mold prevention is a subject which has attracted some interest. Clausen and West[4] employed an experimental rain chamber in an attempt to evaluate the effect of repeated wetting of construction lumber as frequently happens following delivery to construction sites. The results did not correlate well with evaluations performed by a standard ASTM method (ASTM D 4445-91) for surface mold evaluation and failure times were extended from weeks to months. They concluded that under such circumstances not only is active ingredient depletion important but also removal of the mold spores and some mold from the wood surface by the "rain event." Such observations indicate how difficult it is to simulate what happens in the "real world" and also serve to emphasize that it should be no surprise that the Florida field study gave somewhat different results than the earlier laboratory study.

Products containing CTL and DDAC, alone or in combination with DOT, are registered by the U.S. Environmental Protection Agency for use in mold prevention. While the results of the laboratory study give a good indication of relative performance where the treated materials are protected from becoming wet (e.g., dried-in stage of framed construction), it is obvious that under circumstances where unintentional chronic exposure to water occurs (rain or condensed moisture), the CTL and particularly the DOT/CTL systems would be expected to offer superior resistance to mold infestation.

THE REAL WORLD

Despite attempts to mimic the real world application of antimicrobial products, the practical use of these materials inevitably produces the biggest challenge to their efficacy. Mold prevention products are no exception to this rule and it is worthwhile to make a few general comments regarding their application/use.

The targets for mold prevention products are principally new building construction and integral constituents of remediation in existing structures. One of the biggest challenges to be faced by mold prevention products is their use in the crawlspace environment. It is not uncommon in new home construction to proceed as far as the sub-floor and then be followed by weeks or months of exposure to the elements. Under these circumstances, moisture contents can reach levels consistent with fungal decay. Surface mold prevention products are virtually useless under these circumstances and the building industry appears to have unrealistic expectations of mold prevention products in this area.

In unison with the development of surface mold prevention products, the building community must also accept its responsibility in reducing moisture ingress during the construction process. Closed crawlspaces are becoming more popular in some areas of the U.S. When correctly installed (use of mold prevention products and proper moisture management), these areas can be kept free of mold during and after the construction process. It is, however, common practice to construct the crawlspace and leave construction debris in the crawlspace for long periods. It is also not uncommon for the surface moisture barrier to be installed long after the basic construction of the crawlspace. This effectively creates a large-scale mold chamber with conditions conducive to mold infestation. There should be no surprise, therefore, when poorly managed crawlspace construction results in the incidence of surface mold on the wooden constituents, which are present in this environment.

CONCLUSIONS

The Micales-Glaeser laboratory study concluded that, while CTL performed the best of the single fungicides, the DOT/DDAC and DOT/CTL combination systems had superior efficacy to any individual fungicide (CTL, DOT, and DDAC) against common mold forming fungi. Extending this study to a field trial with selected treatments further confirmed the superiority of the CTL and DOT/CTL systems and indicated that these latter systems will offer the greatest resistance to surface mold infestation should repeated exposure to moisture occur in buildings after construction is completed. The successful application of these products requires a responsible approach to moisture management and the adoption of good building practices by the building community.

ACKNOWLEDGMENTS

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The authors also acknowledge the contribution of Dr. T.L. Woods (formerly of Sostram Corporation) to the field study performed in south Florida. CT

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