A Commercial, Registered, & Durable Antimicrobial Available for Use on Wood & Wood Products

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Abstract

All antimicrobial agents are not equal. They differ in their ease of use, mode of action, spectrum of activity, and toxicity to humans and the environment. The call for greener, safer, antimicrobial agents with low mammalian and aquatic toxicity is made in every industry that uses chemicals as performance enhancers. The Building/Construction industry is no different. Antimicrobial/water repellent formulations with such low toxicities that are odorless (water-borne) and that do not alter the color or texture of historic fabric are particularly useful when restoring/renovating historic wooden structures.

The development of these new performance chemicals can be challenging. For biocide product manufacturers, the R&D involved is relatively simple compared to costs and regulatory issues that occur on global levels. The time and expense involved in creating new antimicrobials seals the fate of new development. The use of older, well-tested technologies currently used in other industries provides a new source of registered antimicrobial agents with excellent safety profiles.

This paper presents laboratory test data on one such immobilized antimicrobial agent currently used in the textile industry and its applicability in the construction industry, both in OEM and during renovation and restoration. The development of an antimicrobial and water repellent formulation using the quaternary amine-Silane technology that can be applied to both painted and non-painted surfaces of both historic and modern structures is discussed. Its potential utilization in controlling molds and facilitating clean-up in homes subjected to flooding and rain damage associated with storms such as hurricanes will also be discussed.

Introduction

Hypersensitivity resulting from continued exposure to mold and mildew or other microbially sourced antigens is well documented. Today's consumers are better educated about the hazards of mold and mildew in newly constructed buildings, however, these hazards are not just regarding the health and well being of the occupants but also the problems associated with deterioration and rot of the building itself.

Liquid water and water vapor in the envelope of a building set the scene for microbial contamination. Every element of the construction process offers opportunity for microbial growth. Warm temperatures, moisture, adequate food sources, and a hospitable surface for growth are all that these organisms need to thrive. Unless protected, damp framing will be attacked by mold and/or decay fungi, and as the microbes develop, they can spread through walls and over interior surfaces. If mold (mildew) fungi are not controlled, they will continue to find food and moisture and will continue to cause problems of odor, staining, and deterioration.

The microorganisms represented in a building are complex. Every element of a building, its furnishings and the people within offers homes for microorganisms. Microorganisms need moisture and nutrients, and more than 95% of them need to be associated with a surface. Moisture can come from catastrophic and normal events - a leaky roof, a sweaty pipe, a leaky radiator, condensation on windows, condensation on more subtle surfaces where dew points are reached, humidified air from the HVAC system or any of hundreds of other sources. A hotel or resort facility compounds the problem with moisture from pools, spas, individual air conditioners and literally hundreds of bathrooms. This coupled with the wall to wall carpets, draperies, wall coverings, furniture, bedding and ceiling tiles, create ideal habitats for microorganisms.

All of these types of surfaces and factors are found in the full array of buildings from offices to hospitals to schools to homes. Nutrients utilized by microorganisms can be organic material, inorganic material, and/or living tissue. For example, bacteria play an important role as part of the body's micro flora, and, along with the skin, are shed continuously. Given acceptable growth conditions, they can multiply from one organism to more than one billion in just 18 hours. Although a building may be infested during construction and catastrophic events (particularly with fungi), more typically the organisms are routinely brought into the building by its occupants or air infiltration routes. Fungi - typically outdoor organisms known as mold, mildew, and yeasts - enter the building on clothing, are wafted in through the open doors or are pulled in as “make up” air by the HVAC system. Bacteria follow these same routes, but are usually limited to the human carrier and very wet areas such as drain pans or other areas with constant or standing water. The HVAC systems, chases, and elevator shafts efficiently transport airborne microorganisms throughout the building. One good growth source can quickly result in outbreaks in every part of the building. Also, with the almost universal use of air conditioning, recycling indoor air to improve energy efficiencies takes place. Yet, that recycling tends to concentrate indoor air pollutants - including microorganisms and their annoying irritating, sensitizing, and/or toxic by-products.

The problems of deterioration of house framing, non-structural materials, and furnishings are manifested in manufacturing, storage, and the use of a variety of materials. Such deterioration costs the economy billions of dollars each year in bio-corrosion and the rotting of these once useful materials. Besides the deterioration of materials, microorganisms, both good and bad, use the surfaces of these materials as "harbors" of sites for reproduction and proliferation.

Ever since microorganisms were recognized as a major cause of problems in buildings occupants have struggled against such organisms in an effort to provide a clean, pleasant and safe environment. There has been an unending array of products, cleaners, chemicals, devices, strategies and methods available to combat microbial problems caused by organisms as diverse as mold fungi to pathogenic bacteria.

Housekeeping professionals regularly scrutinize building spaces and remove any visible growth. Detergent/sanitizer products are effective short term tools against visible mold and mildew, but some areas require harsh bleach or mildew removers. When musty odors develop, cleaning personnel frequently use perfumes and fragrances to mask or disguise the problem (and the often offensive odors of the sanitizers). These often create more of a problem than they solve.

Most engineering tactics include selection, operation, modification and maintenance of HVAC systems to permit “better” temperature and humidity control and better filtration. This does nothing to prevent microbial infestation, but it does occasionally reduce the rate of growth of mildew. The air handling/engineering specialists have worked with filtration and extraction of pollutants but have generally concentrated on dilution. Filtration significantly reduced the amount of pollutants in the air and this gave immediate human health benefits. Unfortunately, since the sources of microbial contamination were not being dealt with, the health problems frequently returned.

Antimicrobial Treatments for the Prevention of Mold and Mildew

In the broad array of microorganisms, there are certainly both good and bad types. Antimicrobial strategies for bad organisms must include ensuring that non-target organisms are not affected or that adaptation of microorganisms is not encouraged. For instance, antimicrobial agents applied to textiles must control all microorganisms on the textile without leaching into the environment and affecting the natural biological skin flora. In addition, sublethal doses of antimicrobial agents may lead to adaptation. The antimicrobial agent used must not loss effectiveness over time and cannot diminish in concentration.

Antimicrobial agents can be classified in to two main types; leaching and non-leaching. Leaching antimicrobial agents are defined as agents that must come off of a treated substrate in order to express its antimicrobial properties. Any antimicrobial agent that must enter the cell to work is considered a leaching agent. Non-leaching agents are fixed to the treated surface (usually by covalent bonds). Since these agents are physically attached, there is generally no means for removal and therefore no means to diminish their overall strength. The need for new and safer antimicrobial technologies is obvious. These new agents must be safer to the end-use, the applicator, and also to the earth. Antimicrobial agents that do not leach from the original treatment site can provide for this protection.

But even non-leaching is not enough. Antimicrobial agents in general must have broad spectrum antimicrobial activity (equally effective against bacteria, fungi, and algae), have little to risk to the product or to the people applying the product, easily fit current production systems, be environmentally friendly, and be compliant with all global biocidal regulations (U.S. EPA, EU BPD, etc). This is often a difficult task, and with today’s regulatory environment, it is practically impossible. As antimicrobial agents are used in many different industries, it is wise to search different industries for more environmentally friendly ways of combating the growth of unwanted microorganisms without hurting either the earth or her inhabitants.

Controlling Microbial Growth by Creating Functional Surfaces

Microbial control can come on many levels. Protecting surfaces from moisture is a key ingredient to protecting the total environment from mold/mildew fungi. This moisture control can be augmented with active antimicrobial agents that will kill organisms on contact. The textile industry has been using antimicrobial agents for decades to control the growth of microorganisms on fabric that can lead to deterioration and odor formation. The movement of water is critical in fabrics as the ability to absorb and release water is directly related to the "breathability" of fabrics. Textile surfaces can be functionalized using a variety of chemistries to provide softness, UV resistance, flame retardency, and antimicrobial activity. These chemistries have been used in sensitive, "close-to-the-skin" areas on humans and have been successful in the textile marketplace for decades.

This article presents data that supports the use of one particular, EPA registered, antimicrobial agent on wood and wood- containing products.The Si-quat technology, when properly applied, can provide both antimicrobial and water repellent properties.

Silane Quaternary Amine Antimicrobial protection

In the mid-1960's, researchers discovered that antimicrobial organofunctional silanes could be chemically bound to receptive substrates by what were believed to be Si-O linkages. The method was described as orienting the organofunctional silane in such a way that hydrolyzable groups on the silicon atom were hydrolyzed to silanols and the silanols formed chemical bonds with each other and the substrate. The resultant surface modification, when an antimicrobial moiety such as quaternary nitrogen was included, provided for the antimicrobial to be oriented away from the surface. This covalently linked siloxane polymer has since been demonstrated to produce broad spectrum antimicrobial activity while also providing a strong water repellent feature directly to the surface of the treated product (Figure 1).

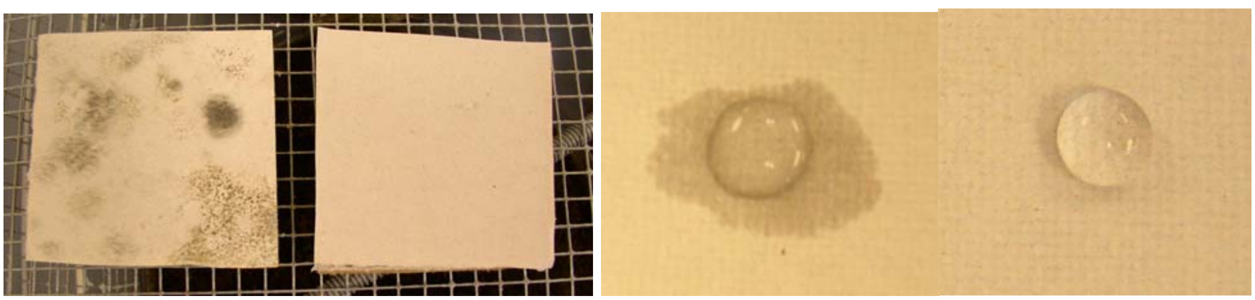


Figure 1. **Antimicrobial and water repellent properties of Si-Quat treated surfaces.**

Studies have indicated that the application of an immobilized antimicrobial agent, 3-trimethoxysilyl propyldimethyl octadecyl ammonium chloride (Si-Quat), can help eliminate the cost, inconvenience, loss of lifestyle and additional burdens imposed by the traditional remedies of controlling microbial infestation. The antimicrobial agent transforms surfaces into active control devices that not only destroy the organism on contact but also provide a water repellent barrier. The following sections will highlight the chemical reactions that take place during the formation of the coating, the ability to detect this treatment specifically on surfaces and also the broad spectrum antimicrobial activity of the resulting surface.

Covalent Bonding to the Surface – From Monomer to Siloxane Polymer

The attachment of this chemical to surfaces appears to involve two processes. First and most important is a very rapid process that coats the substrate with the cationic species one molecule deep. This is an ion exchange process by which the cation of the silane quaternary ammonium compound replaces protons from water on the surface. It has long been known that most surfaces in contact with water generate negative electrical charges at the interface between water and the surface. This mechanism is further supported by data generated with a radioactive silane quaternary ammonium compound. During the treatment, depletion of the radioactivity from solution was almost immediate by an amount corresponding to that sufficient to cover the surface one layer deep, even on surfaces which contain no functionality. Similar results are published for many organic quaternary ammonium compounds. The second process is unique to materials such as silane quaternary ammonium compounds that have silicon functionality enabling them to polymerize, after they have coated the surface, to become almost irremovable even on surfaces with which they cannot react. Covalent bonding to that surface will also occur and it is also possible to have intermolecular polymerization. The end result of this hydrolysis and condensation reaction is the formation of a siloxane polymer networked durably attached to a surface that provides both antimicrobial protection and water repellency (Figure 2).

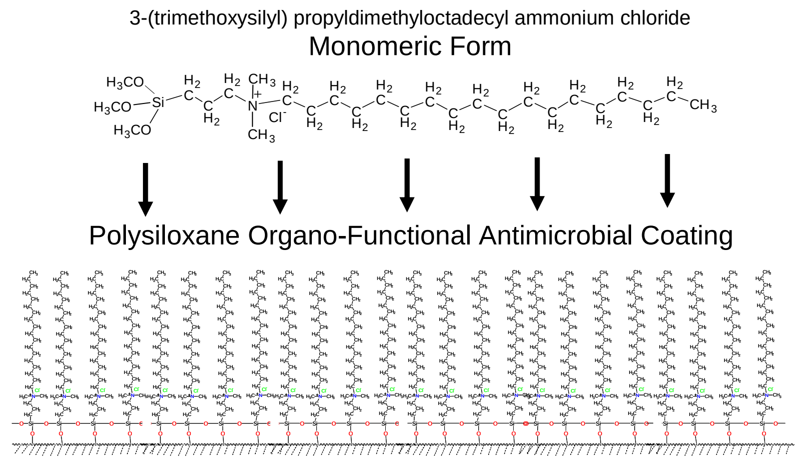
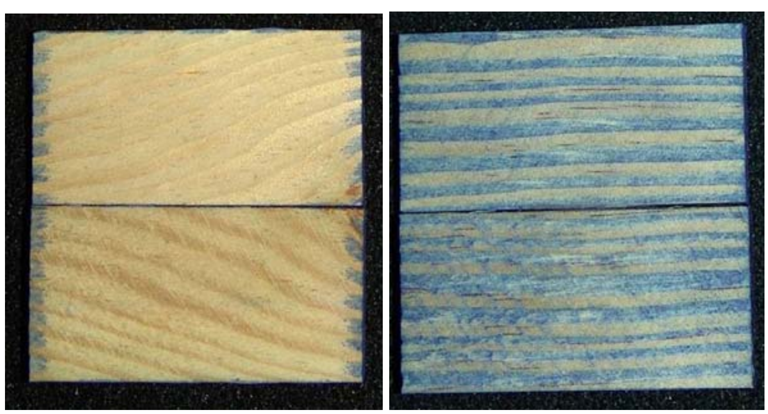


Figure 2. Formation of the covalently bound siloxane network that is formed from the silane-quat monomer.

Antimicrobial Treatment Levels and Uniformity Verification

Another important property of a useful antimicrobial is that its presence should be easily verifiable. In effect, this is the only way to know that an antimicrobial is really on the product without performing extensive microbiological laboratory tests. There is no easy way to tell whether leaching antimicrobials are present on a product. The only known verification technique for a leaching chemistry is to use exacting laboratory tests, which take days or weeks to perform. With the bound antimicrobial technology though, a simple staining test can be performed in a matter of minutes at the mill or on the construction site to verify proper treatment of a product. This is a very important part of a quality assurance program that gives manufacturers, retailers and consumers confidence that a feature, normally invisible to the senses, can be seen and is actually on the product providing the protection for which they have paid. This detection test uses a specific reactive blue dye that recognizes the presence of the quaternary silane and creates an ionic bond that is resistant to removal by water. This stain can be used to measure the penetration of the biocide on wood samples that have either been pressure treated or surface coated (Figure 3).



Dip treated **Pressured Treated**

Figure 3. Wood samples were treated with the silane-quat technology and then stained for the presence of the agent with a specific reactive blue dye. Samples were then cut in half and the inside of each block was analyzed.

In addition, with the correct equipment, the staining test can be used as a sensitive quantitative tool to measure not only the uniformity of the treatment but treatment levels. Specific blue stain tests can be used to detect not only the distribution of the Si-quat antimicrobial agent but also the relative blue intensity is directly proportional to the concentration (Figure 4).

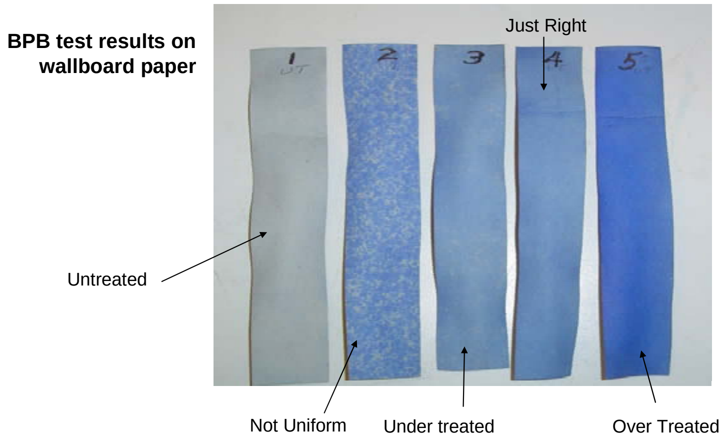


Figure 4. Bromophenol Blue staining of treated wallboard paper.

Broad Spectrum Antimicrobial Activity

Most microorganisms function as saprophytes or parasites degrading materials in their environment to gain nutrients and to defend themselves. The saprophytes degrade non-living materials while the parasites attack living materials. The diversity of microorganisms is so broad that the degrading ability of microbes can be at the full range of temperatures, in the presence of oxygen or not, and affect all natural and most human- made substrates. This can include building materials such as wood, concrete and steel, textiles from clothes to medical garments and materials, furnishings from carpeting to wall coverings, domestic bedding and towels, and of course obvious things such as food- and water-based materials from paints to fiber finishes. We see the negative effects of these organisms in our everyday lives and are affected by the "out-of-sight" "out-of-mind" actions of these deteriorating, staining, and disease causing organisms.

To fully appreciate the level of testing that has been performed on the ÆGIS antimicrobial agent, a brief review of the literature and specific test results is appropriate. The following data and peer reviewed publications demonstrate antimicrobial activity against bacteria (Gram + and Gram -), fungi, and algae. These data only summarize the broad spectrum antimicrobial activity of the Si-Quat antimicrobial agent applied onto a variety of both porous and non-porous surfaces. The data represent over 35 years of experience and microbiological and chemical testing measuring the effectiveness of the Si-Quat antimicrobial agent after being applied onto surfaces such as furniture, carpets, wood and vinyl flooring, woven and non-woven textiles, aquariums, etc.

Since inception in 1969, the antimicrobial activity of the 3-trimethoxysilyl propyldimethyl octadecyl ammonium chloride Si-Quat) has been studied extensively on a variety of treated surfaces. The antimicrobial activity of solid surfaces treated with the Si-Quat agent was first published by Speier and Malek (1). In this study, dose dependent antibacterial activity was demonstrated against both the Gram – *Escherichia coli* and the Gram + *Staphylococcus aureus* after treating a solid surface of clearly defined dimensions. The rate of kill and surface kinetics of these treated surfaces were further defined and demonstrated by several groups (2, 3). This work was followed by a companion study which measured the broad spectrum antimicrobial activity against a mixed fungal spore suspension (*Aspergillus niger, Aspergillus flavus, Aspergillus versicolor, Penicillium funiculosum, Chaetomium globosum*). With the use of radioactive tracers, Isquith and McCollum demonstrated that “biological activity of the Si-Quat bonded to surfaces may offer a method of surface protection without addition of the chemical to the environment”. Algicidal (*Chlorophyta, Cyanophyta* and *Chrysophyta*) activity of the Si-Quat applied to glass was demonstrated by Walters et al (4) in which the top half of the glass slide received the antimicrobial treatment. Application to glass aquariums further demonstrated Algicidal activity. (Figure 5)

Figure 5. Algicidal activity on glass slide (left) and fish aquariums (right).

Demonstration of the broad spectrum antimicrobial activity of surfaces treated with the Si-Quat antimicrobial agent can be found in the peer reviewed literature almost on a monthly basis. Further work demonstrates the ability to apply this material to a variety of substrates. This work includes surfaces from glass (4) and aquariums (5) to entire hospitals (6). Kemper et al, studied the microbial colonization of environmental surfaces in hospitals and the effectiveness of the Si-Quat to control these organisms. This 30 month study measured persistent antimicrobial activity on surfaces treated with the Si-Quat agent and how the presence of the antimicrobial agent provided better air quality, see below (6).

Isquith et al (7) demonstrated antimicrobial activity on a variety of surfaces. The Si-Quat antimicrobial agent was applied to surfaces as diverse as stone and ceramic, cotton and wool, vinyl and viscose, Aluminum, stainless steel, wood, rubber, plastic, and Formica. These authors state that these surfaces "were found to exhibit durable antimicrobial activity when treated with Si-Quat, against a spectrum of microorganisms of medical and economic importance". Recently, investigators from Hiroshima University and the University of Groningen demonstrated significantly reduced microbial colonization *In Vitro* on commercially pure wrought titanium (8) and silicon rubber material (9) treated with the Si-Quat agent and used in the medical industry. Further independent testing confirms antimicrobial activity on air filters and fabrics treated and used directly in the hospitals settings (10, 11).

These data, when examined as a whole, demonstrate the broad spectrum activity of the Si-Quat technology (Dimethyloctadecyl [3-(trimethoxysilyl)propyl] ammonium chloride) and that a variety of surfaces found in the private and public health settings can be effectively treated.

Use of the Si-Quat Antimicrobial treatment in Restoration and Renovation

The Si-Quat antimicrobial has been used in the textile industry for over 30 years. In these "close to the skin" applications, it is critical that the antimicrobial technology be both durable and safe, but still be effective against a variety of harmful organisms. Furthermore, the Si-Quat technology has been used in the construction industry for almost as many years. From Gypsum Wallboards to ceiling tiles, products treated with the Si-Quat technology have provided protection from mold and mildew in a variety of environments. Using the Si-Quat as part of an entire renovation and restoration package when cleaning homes and businesses "after the flood", allows for long lasting protection from repeat contamination (6).

In January 1990, just prior to the scheduled opening of the Arthur G. James Cancer Hospital and Research Institute on the campus of Ohio State University, a major water pipe froze and ruptured at the roof level of the building. All twelve floors of the completely furnished building were flooded with an estimated 500,000 gallons of water. The water flowed down stairwells, elevator shafts, utility service shafts and spread out over and under each floor. Water moving over the floors wicked up into the wallboard and insulation and soaked the carpeted areas in offices, patient rooms and hallways. The water running on the undersurface of floors dropped onto the acoustical ceiling tile below. In some areas the weight of the water broke the acoustical tile insets and the water fell onto upholstered furnishings and equipment below. Ceilings, walls, carpeted floors and upholstered furniture were either wet or exposed to high humidity due to the moisture in the building throughout the days following the flood. Removal of water and drying of surfaces was an immediate priority. It was also recognized that a conventional approach with water removal, drying, cleaning repair would not restore the microbial integrity the facility. To properly restore the building intended use as a cancer treatment facility, two basic objectives needed to be accomplished: Eliminate the natural microbial reservoirs in building materials that had been activated by wetting and control the proliferation of during demolition and reconstruction.

Continuous re-evaluation of the air quality in the facility was performed during the seven months of reconstruction. The facility is presently free of odor and has a new appearance unaffected by the extensive application of a surface antimicrobial. All renovations or reconstruction in the facility are strictly controlled and all newly added or modified surfaces are treated with the silane antimicrobial. Re-evaluation for airborne fungi and surface microbial contamination continues yearly.

This extensive study indicated that the natural microbial contamination of a building environment and the escalation of that microbial contamination with wetting can be reversed and controlled by the extensive surface application of a silane antimicrobial. This silane offers both extended broad spectrum microbial activity but also hydrophobicity that reduced surface moisture.The findings show that this unique treatment is an important proactive measure for the reduction of colonization and aerosolization of fungal flora. This unique control strategy provides an exceptional level of continuing microbial protection and should be considered as part of infection prophylaxis in any medical care facility.

Conclusions

The development of an antimicrobial and water repellent formulation using Silane-Quat technology has allowed us one more tool in the restoration and renovation of buildings contaminated with mold / mildew fungi. The Si-quat technology with the antimicrobial and water repellent formulations provides a functional coating in and on surfaces that has proven effectiveness against a broad spectrum of microorganisms responsible for the deterioration and destruction of products. These coatings have demonstrated remarkable performance in controlling the spread of microbial contamination not only in laboratory settings but in practical applications for over 30 years.

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