A New Technology for Producing Stabilized Foams Having Antimicrobial Properties

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Editor's Note: This paper was first published in the Journal of Cellular Plastics, Sept. – Oct., 1985, pp. 332-337. It has been edited to reflect product and technology name changes resulting from the transfer of Dow Corning Corporation's Antimicrobial Business to AEGIS Environmental Management, Inc. in 1996.

Introduction

It has been well documented that microorganisms, both fungi and bacteria grow and thrive in urethane foam cells[1]. It has also been demonstrated that antimicrobial agents can be added to urethane foam formulations to inhibit microorganisms that can cause allergic reactions, infections, odors, stains, and surface degradation[2]. Several potential applications for antimicrobial foam are listed below:

- Carpet Underlayment
- Furniture Cushioning
- Decubitus Pads
- Curtains/Upholstery
- Marine Flotation
- Wound Dressing
- Immobilizers
- Infant Changing Pads
- Air Conditioner Filters
- Fermented Spirit Filters
- Air Purification Filters
- Waste Water Filters
- Humidifier Belts
- Mattresses/Pillows
- Helmet Liners
- Shoe Insoles
- Thermal Insulation
- Scleral Sponge
- Mops
- Bath Sponge/Mats
- Furnace Filters
- Athletic Pads
- Aquarium Filters
- Swimming Pool Filters

Foams containing antimicrobial agents are currently being manufactured for several of these applications using conventional antimicrobial agents. The chemistries being used today however are known to have certain disadvantages. These materials are typically diffusible, which means they can leach off the substrate. Problems associated with this leaching phenomenon are as follows:

1. The continual diffusion of the antimicrobial agent results in a lower and lower concentration of the material on and near the substrate. When the antimicrobial agent reaches a certain minimum effective level, many of the microorganisms will survive even though some of the antimicrobial agent is still present. Subsequent generations of these microorganisms will become more and more resistant until even relatively high levels of the chemical will not affect them. The process is called adaptation.
2. Any chemical that diffuses from a substrate will eventually come in contact with humans or the environment. Therefore, its toxicity is of key importance. For example, the Water Quality Section of the North Carolina Department of Natural Resources suspended the discharge of antimicrobial agents containing heavy metals by the textile industry in their state because of toxicological concerns[3].
3. For long-term efficacy, many applications require that the antimicrobial agent not be extractable by water. While many diffusible chemistries are less soluble than others in water, they are all soluble in water to some degree. Use of these chemistries in applications where the foam is in constant or frequent

contact with water such as humidifier belts, sponges, and filters would be difficult since the material would leach into the water and no longer be effective in protecting the foam.

In addition to the disadvantages listed above for a diffusible antimicrobial agent, these pesticides are generally effective against limited classes of microorganisms. In other words they do not exhibit broad-spectrum activity.

The purpose of writing this paper is to introduce the industry to a new antimicrobial technology developed by Dow Corning Corporation which possesses advantages over the diffusible antimicrobial agents. This new product is long-lasting, safe, and possesses broad-spectrum antimicrobial activity.

Discovery

In 1969, Dow Corning Corporation undertook a screening project to measure minimum inhibitory concentrations (MIC) of various silicone and silane chemicals against a broad spectrum of microorganisms. MIC is the lowest concentration at which the growth of a particular microorganism is inhibited. These chemical agents were based on the trimethoxysilyl propyl functionality, the basic structure of many of Dow Corning's coupling agents. When materials of this type were evaluated, unexplained difficulties were encountered in running the test procedure. Values for the MIC could not be reproduced. Causes for these unexplained difficulties were investigated and finally ascribed to chemisorption of the compound from solution onto the walls of the equipment being used. The reaction of the test material with the walls of the containers should have reduced the concentration in solution and led to high estimates of the MIC. However, some values were unbelievably low, sometimes declining to zero when the same equipment was used repeatedly. Investigation of this phenomenon led to a number of United States patents and publications which described the use of these compounds as algicides, bactericides, and fungicides. Further examination of this phenomenon and the chemistry involved, resulted in the preparation of a single material which was more extensively evaluated. This material is chemically 3-(trimethoxysilyl) propyldimethyloctadecyl ammonium chloride. In the late 1970's, after extensive toxicological testing, Dow Corning applied to the Environmental Protection Agency (EPA) for an industrial registration which would permit the use of the chemical in a wide variety of applications. Once the registration was granted, Dow Corning's unique product, subsequently called the SYLGARD™ antimicrobial treatment (now known as the ÆGIS Microbe Shield® Treatment), quickly became accepted for applications where a safe method was needed to prevent defacement, deterioration, and odor caused by microorganisms. The ability of the product to electrostatically and covalently bond to surfaces and to homopolymerize into a nanocoating thereby rendering the substrate active against bacteria, fungi and algae, has made it especially suitable for treating hosiery, carpet, surgical drapes, orthopedic softgoods, aquarium filter floss, nurses' uniforms, upholstery, and many other surfaces[4].

Development

In 1982, utilizing fundamentally similar antimicrobial technology, Dow Corning succeeded in creating biologically active flexible polyurethane foam. After extensive developmental work with many types of foam formulations a patent application was filed on this unique technology. The designation for this newly patented product was Dow Corning® 5701 Antimicrobial Agent for Stabilized Foams and it is currently being marketed under the ÆGIS Microbe Shield® brand. Large scale plant trials have been run at five major foam manufacturers which were successful in producing foam having excellent antimicrobial activity. The antimicrobial treatment has been successfully incorporated into polyether flexible, semi flexible, high resiliency, and rigid foam as well as polyester flexible and vinyl foams. This incorporation is done by simply introducing the material into the formulation by itself in a separate stream, by adding it with a tin or an amine catalyst, or by adding it with the silicone surfactant. The effective use level of the antimicrobial depends on the formulation but is typically between 0.21 and 0.84 parts active ingredient per 100 parts polyol.

Chemistry and Features

The ÆGIS Microbe Shield technology utilizes a reactive silane quaternary ammonium compound. The key features of this antimicrobial are its durability, broad-spectrum activity, and favorable toxicological profile. Because the ÆGIS antimicrobial chemistry is reactive, it becomes an integral part of the foam and will not wash out, or leach into the environment. Microorganisms that subsequently contact foam are neutralized. It has been tested and proven effective against Gram-positive and Gram-negative bacteria, fungi (mold and mildew), yeasts, and algae. The ÆGIS treatment is not consumed by microorganisms. Foam containing the ÆGIS treatment reduces 99.9% of the micro-organisms it comes in contact with by disrupting their cell membranes. Because of this, microorganisms do not adapt and become resistant. In Figure 1 below we see a Scanning Electron Micrograph (SEM) of *Escherichia coli* bacteria on a nontreated substrate.

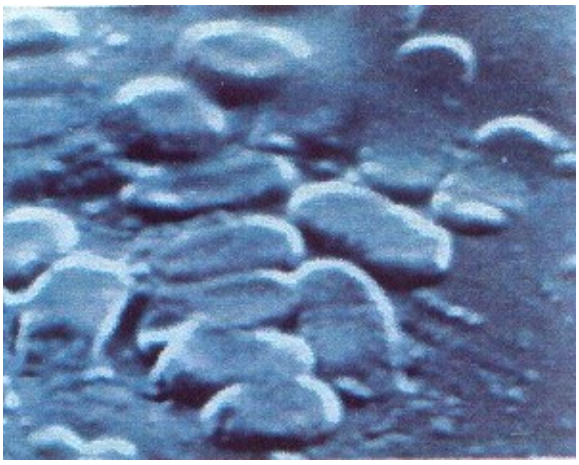

FIGURE 1:
E. coli bacteria on NONTREATED substrate

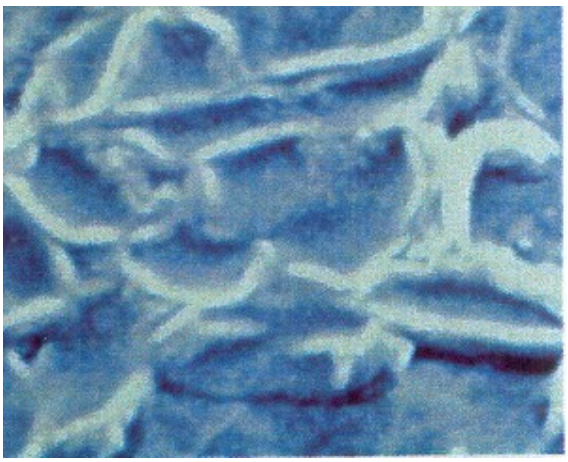

FIGURE 2:
E. coli bacteria as they have come into contact with a substrate protected by with the ÆGIS Microbe Shield.

Note that these bacteria in Figure 2 appear deflated. This is because contact with the antimicrobial surface has ruptured their cell membrane and resulted in their deaths.

Toxicological studies worth more than two million dollars have been performed to satisfy EPA requirements prior to granting product registration and to support Food and Drug Administration (FDA) listings.

Quality Control

Foam containing the ÆGIS Microbe Shield can be easily quality controlled by using a simple bromophenol blue qualitative stain test. A more sophisticated quantitative determination of level can be made using a standard ultraviolet spectrophotometer. Since a correlation can be made between the analytical test value and the antimicrobial effectiveness of the foam, the foam can be easily checked for efficacy without running the lengthy microbiological tests. This way foam that is not found to possess adequate bioactivity can be identified before it is shipped. This will save not only time and money but will assure the foam manufacturer's customers that they will always get a quality product.

In addition to performing the analytical tests, microbiological testing is also conducted. As mentioned previously, the ÆGIS treatment attacks microorganisms by disrupting their cell membranes while remaining an integral part of the foam. Because of this chemical bonding, the standard tests used to evaluate conventional diffusible type antimicrobial agents cannot be used to evaluate the effectiveness of foam made biologically active with the ÆGIS treatment. Instead, the efficacy of foam containing the

ÆGIS treatment is measured by the number of living microorganisms which are neutralized after they have simply contacted the biologically active foam for one hour. Efficacy is also judged by the ability of the product to prevent microorganism growth on the surface of the foam.

Unlike the ÆGIS treatment, which disrupts the microorganism's cell membrane, conventional antimicrobial agents pass through this membrane into the cell and disrupt some key metabolic process thereby killing the microorganism. These compounds act as poisons and to be effective, the active ingredient must be able to migrate off the treated substrate. Therefore, a test called a zone of inhibition test is used to evaluate the effectiveness of these antimicrobial agents. A piece of foam is placed on a nutrient medium which has been inoculated with bacteria or fungi and then is incubated to enhance growth. This conventional antimicrobial poison will leach off the foam and inhibit the growth of the test organism around the sample. This area will look like a halo. The size of this zone or halo is thought to correlate directly with the effectiveness of the material against a particular microorganism. No zone indicates little or no effectiveness. Figure 3 below illustrates this with the use of cotton fabrics.

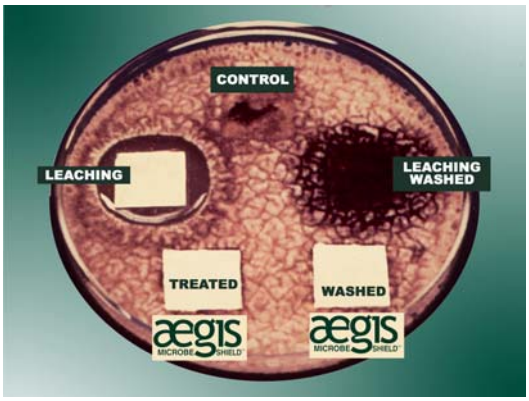

FIGURE 3

The control sample (untreated) is completely covered with mold. The sample treated with a conventional (diffusible) antimicrobial shows a large zone of inhibition and the area of no inhibition. The sample in which the ÆGIS Microbe Shield treatment was incorporated shows no zone of inhibition as expected, but any microorganisms that have come in contact with the sample have been eliminated. The result is complete protection of the sample and no unsightly or detrimental fungal growth. After 5x washings the conventional antimicrobial no longer shows effectiveness as a zone or surface contact.

Efficacy Evaluations

Table 1contains results on the biological activity of the ÆGIS Microbe Shield treatment against two common laboratory strains of bacteria, *Klebsiella pneumoniae* and *Staphylococcus aureus*. Test results indicate 100% of these bacteria were eliminated after 1 hour of constant agitation with the biologically active foam. Table II lists results showing the biological activity of the ÆGIS treatment against more resistant clinical isolate strains of microorganisms. The ÆGIS treatment is extremely effective against even these difficult to control species. Illustrated in Table III is the antimicrobial activity of the ÆGIS treatment against fungus. No fungal growth was observed on a treated sample after thirty days, while the untreated sample was completely overgrown.

Even after five successive generations of organisms were exposed to the ÆGIS treated sample, it maintained a 100% bacterial reduction. However, the zone of inhibition on the sample containing the diffusible antimicrobial agent was reduced from 2mm to zero. This indicates that within five generations, the organisms were able to adapt and become resistant to the organoarsenical compound.

Conclusion

As discussed in this paper, foam can harbor microorganisms which can cause allergic reactions, infections, odors, deterioration of the foam, and unsightly stains. The use of antimicrobial agents to combat these problems and to engineer a value added feature is gaining increasing acceptance by the foam industry. Currently this need is being filled with

chemistries that diffuse from the foam and poison the microorganism. Until now the industry has had to accept their shortcomings. The Dow Corning patented technology provides an alternative to these materials and will create biologically active foam that is superior to that which can be achieved by conventional diffusable chemistries. Now foam can be made that will:

1. Possess broad spectrum antimicrobial activity
2. Maintain its effectiveness over time
3. Be safe to humans and to the environment
4. Will resist adaptation by microorganisms

This technology makes it possible for foam manufacturers to meet increasing consumer demand for a wide variety of urethane and other stabilized foam products having antimicrobial properties.

References

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3).Action-Gram No. 72, National Association of Hosiery Manufacturers *Hosiery Industry Concerns with Biocides, October 4, 1983.*

4).Malek, J.R. and Speier, J.L., Development of an Organosilicone Antimicrobial Agent for the Treatment of Surfaces, Journal of Coated Fabrics, Vol. 12, July, 1982.

Tables

TABLE I:
Biological activity of the ÆGIS Microbe Shield® Treatment against laboratory strains of *Klebsiella pneumoniae* and *Staphylococcus aureus*.[1]

Microorganism	*% Bacteria Reduction*
Klebsiella pneumoniae	100
Staphylococcus aureus	100

1. Test Protocol. One hour contact. ASTM E-2149

TABLE II:
Biological activity of the ÆGIS Microbe Shield® Treatment against clinical isolate strains of bacteria.[1]

Microorganism	*Isolation Source*	*% Reduction*
Escherichia coli (-R)	*Urine*	*100*
Pseudomonas fluorescens (-R)	*Pus*	*100*
Proteus mirabilis (-R)	*Urine*	*89.2*
Staphylococcus aureus (+C)	*Pus*	*99.9*
Enterococcus (+C)	*Urine*	*99.9*

1. AATC 100 Test Protocol. One hour contact.

TABLE III: Biological activity of the ÆGIS Microbe Shield® Treatment against fungus.[1]	
Sample	***Growth After 30 Days***
Control	Sample 100% Overgrown
Treated	No Growth on Sample

1. AATC – 30 Part III Test Protocol. One hour contact. *Aspergillus niger*.

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