Biocontamination Control – Up Close and Personal

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Abstract

The contaminant control garment industry has worked diligently with fabric and specialty finish suppliers to produce materials of construction that can be made into barrier and active protectants against microorganisms - sourced from people, the garment, or the environment. Proper choice of antimicrobial strategies can improve comfort and function of contaminant control garments. These choices must be balanced with comfort factors and the projected garment life and function. Fabric design, antimicrobial of choice, and in-use and cleaning care conditions all influence the life and utility of biocontaminant control garments.

This paper will present the dynamics of skin-sourced or environmental microorganisms, the garment as a flow-through or amplification site, and the choices available for active reduction of microbial contamination in the garment.

> *"Proper choice of antimicrobial strategies can improve comfort and function of contaminant control garments."*

Introduction

Garments form the buffer between skin-sourced microorganisms, work processes, and work products. In most work situations, garments can also become an amplification site for skin or environmentally sourced microorganisms.

The consequences of these microbes is that their waste products, somatic parts, and reproductive parts can destroy the value of parts or materials in a production environment, can negatively impact processes, and definitely affect human comfort and health.

A wide variety of industries are challenged with microbial contamination whether sourced from people, garments, process materials, raw materials, or the general environment. In the electronics industry even microbial metabolic products can ruin a semi-conductor let alone the spores and somatic parts of whole organisms. These are not biofilm problems that can happen on process equipment but are chemical and physical problems. In the pharmaceutical industry all of these same problems exist and millions of dollars or products are lost each year because of microorganisms. The food processing and preparation industry is challenged at all turns with the health implications and product life considerations impacted by microorganisms. The need to control microorganisms in a responsible way is even more critical in the health care industry. Staff, visitors, and patients are all impacted everyday by the ever-present array of microorganisms.

Microorganisms are very diverse in types and functions and are part of our everyday lives. There are many ways to prevent and kill microorganisms. Doing this in a way that does not cause more problems than it solves in the world of manufacturing takes a clear understanding of the organisms and modes of action of such control technologies.

The key to microbial control is understanding microbial sources, the life and habits of the organisms, their transfer routes, and their ability to cause problems. This paper explores the role of garments as problem sites and transfer vehicles and how they can be taken out of the microbial contamination equation.

Microorganisms

Mold, mildew, fungus, yeast, bacteria, and virus (microorganisms), are part of our everyday lives. There are both good and bad types of microorganisms. The thousands of species of microorganisms that exist are found everywhere in the environment, on our garments and on our bodies.

Microorganisms, their body parts, metabolic products, and reproductive parts, cause multiple problems to building materials, furnishings, and manufactured products. They are human irritants, sensitizers, toxic -response agents, causers of disease, and simple discomforting agents. Clearly, microorganisms are the most potent pollutants in the indoor environment, in our processes, on our products, on our clothes, and on our furnishings.

Medical care facilities, schools, hotels, residences, food storage areas, and manufacturing facilities such as electronics, food, pharmaceuticals, and other at-risk material production areas need to have a reaction plan for avoidance and control of airborne and surface sourced microbial contaminants. Strategies for control of microbes must exist for garments, beddings, linens, wipes, surgical fabrics, and other textiles used in healthcare operations and construction materials. In the case of skin sourced microbial risks, garments take the central role.

The human symptoms of building and process sourced microbial exposure involve an array of physical and systemic reactions affecting the skin, mucous membranes, eyes, upper and lower respiratory tracts and muscles. Some reactions are short-term (acute) and others are long-term (chronic). All affect productivity, health costs, and well-being. Similarly, microbes sourced from textile reservoirs such as garments can cause these same effects.

Microorganisms need moisture, nutrients, and most 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 other sources. Air conditioners, bathrooms, wall-to-wall carpets, draperies, wall coverings, furniture, bedding and ceiling tiles create ideal habitats for microorganisms. These types of surfaces are found in buildings including offices, hospitals, schools, manufacturing facilities, and 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 microflora, 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. This sourcing from the skin is a direct problem as a particulate pollutant and as an indirect source of contamination for receptive surfaces and habitats such as garments.

The garment/skin interface (Fig.1.) is a perfect incubator and amplification site for microorganisms. All of the key life sustaining factors are present and optimal for growth of microorganisms. Growth in the growth in the fabric provides a ready source for microorganisms moving to the workspace.

The Medical Impact of Biocontamination

The medical impact of microorganisms on an individual depends on genetic heritage, general health, and the physical and mental stress factors in the person's life. Work or other psychological pressures, diet, weather patterns, and environmental pollutants, contribute to the severity of human reactions. For people with a predisposition for respiratory problems - the infirm, elderly, babies, people recuperating from illness, and those being treated with immunosuppressive drugs, or under unusual stress - the need to minimize contact with microorganisms and other biogenic materials is magnified. Besides these "at risk" people, current research in the U.S., Canada, and Europe, clearly shows that microbial contaminants directly affect the productivity of workers, and that they are a major contributor to the phenomenon known as SBS.

Although this paper focuses on microorganisms as biocontaminants, there are, in fact, a wide range of other biocontaminants in the indoor environment.

In 1988, Dutkiewicz et al., in a review of occupational biohazards, noted that some 193 biological agents are known to produce infectious, allergenic, toxic, or carcinogenic reactions in workers. Many of these agents are microorganisms or are sourced from microorganisms. A broader view of biohazards is important since microorganisms are not the only biohazard in the indoor environment. Most of the identified bio-hazardous agents belong to the following groups:

- Microorganisms and their toxins: exposure leading to infection or allergic reaction.

- Arthropods [*crustaceans* including crabs, crayfish, lobsters, shrimp prawns, barnacles, and water fleas; *arachnids* including spiders, ticks, mites, scorpions, and daddy longlegs; and *insects* including flies, gnats, mosquitoes, moths, butterflies, ants, wasps, bees, and beetles): bites, stings, feces, and/or somatic body parts resulting in skin inflammation, systemic intoxication, transmission of infectious agents, or allergic reactions.

- Allergens and toxins from plants: dermatitis from skin contact, rhinitis, or asthma as a result of inhalation, or other allergenic reactions.

- Protein allergens from vertebrate animals (urine, feces, hair, saliva, and dander): allergic reactions.

Microbes are not as simple as the whole and intact organisms tested in the laboratory. Their somatic parts, reproductive parts, and metabolites, are implicated as potential human or building antagonists. Microorganisms are the only pollutant source that produces all forms of pollutants: particulates, gases, and infectious biologicals. They are particularly potent in that they can amplify and cause the full breadth of discomfort, irritation, sensitization, toxic reaction, and diseases that are associated with indoor environmental quality problems.

The Skin

The skin is made up of the general class of cells called epithelial cells. These are arrayed in a loose complex that supports the fatty tissue below. Besides the skin epithelial cells, this class of cells are also the basis of the mucus membranes of the naso-pharyngeal passages, the gastrointestinal tissues, and reproductive organs.

Besides the cellular nature of the skin, part of its "health" is predicated on the normal mix of microorganisms that live on the and in the layers and component structures of the skin. These organisms are usually a mix of aerobic Gram – and Gram + organisms that align themselves with the hair follicles and the sebaceous and sweat glands. Their balance is predicated on the genetics, health, and diet of the person, and external influences such as skin care products, soaps, and environmental conditions.

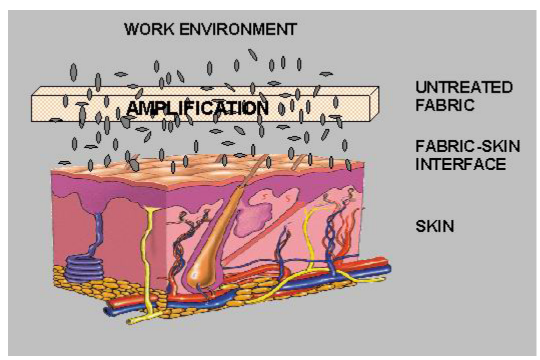

Fig. 1. Untreated Fabric-Skin Interface.

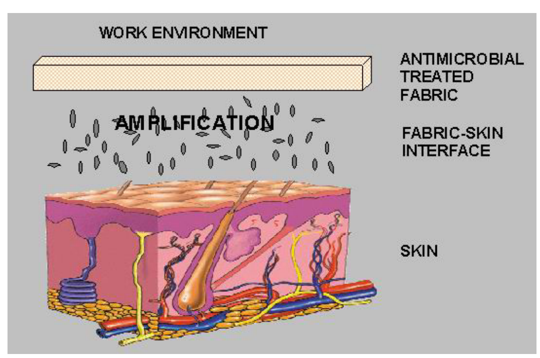

Fig. 2. Treated Fabric-Skin Interface.

Table 1
Bio Contamination Control Garments
Matching Fabric Design and Antimicrobial Technology
Desirable Properties[1]

Fabric Properties	Conventional Clean Room Fabrics	High Performance Fabric[2]
Nominal Pore Size[3]	75-300 micrometers	2-3 micrometers
Moisture Vapor Transmission Rate[4]	800-900g/m^2/24 hrs	900-1100g/m^2/24hrs
Splash Resistance Spray Rating[5]	0-70	90-100
Inductive Migration (Static Charge Decay)[6]	Variable	<0.1 sec. Charge Dissipation (+ & -)
Filtration Efficiency[7] (Particles ≥ 0.5 microns)	Variable	92%
Hydrostatic Resistance[8]	Variable	80cm (min.)
Autoclave Shrinkage	8-10%	3-5%
Antimicrobial Performance[9] – No Launderings	No reduction	99.99% Reduction
Antimicrobial Performance – After 100 Launderings	No reduction	99.2% Reduction

1. From: Business Briefing: Pharmagenerics, 2003, Daniel Edwards and Gunther Voegeli, Precision Fabrics Group, Inc.
2. INTEGRITY 1800®, Precision Fabrics Group, Inc.
3. Porometer Method
4. ASTM D 96, Method B @ 50%
5. AATCC Method 20
6. FTM-4046
7. IEST-RP-CC003.2
8. AATCC-127
9. ASTM E2140-1 (*Escherichia coli*)

No matter how you view the skin, the proper balance of microorganisms is essential. Under normal healthy conditions the skin can be a transporter and amplification site for microorganisms. When a person is ill or stressed their skin changes and so do the microbial flora – sometimes good and sometimes bad. When the skin is broken "bad" microorganisms can cause skin or systemic problems affecting both morbidity and mortality.

In the context of garments, these skin sourced organisms can be contaminants that can slough into and/or through the garment. Those that stay in the garments can amplify causing odors, staining, deterioration, and potential contaminants to the exterior environment. Those that pass through the garment are more immediate pollutants to the exterior environment.

Garments

The cut and sew garment industry has an almost unending array of fibers, fabrics, and performance and comfort enhancing finished to choose from as they design more and more sophisticated garments.

The choice of woven, non-woven, coated, and /or composite/laminate materials provides the ability to customize garments for any definable end-use including single use, multiple use, and life of the goods garments.

Complementing the basic composition of garment fabrics are a variety of functional and comfort enhancing finishes. Flame retardants, stain resists and/or release, wicking, thermo (hot and cold) enhancing, softening, draping, alcohol resistant, autoclavable, barrier properties, and antimicrobial agents are part of the existing and growing finishes available for garments.

For example, a typical garment for clean-room use would include barrier properties to protect the work environment from body-borne contaminants (skin scales, hair, microbes, etc.) and to protect the wearer from workspace pollutants. This same garment would also include vapor transmission properties, alcohol resistance cleanibility, meet wearer comfort and safety requirements, control electro-inductive migration, be launderable and sterlizable, and provide for bio/burden/biopermeation control.

Table 1 lists some of the desirable and attainable properties for biocontamination control garments. The level of sophistication and specialization offered by a variety of quality suppliers is very high

When considering the world of microbiocontaminants, garments can be part of the problem, but they also provide a useful matrix for being part of the solution. This is especially true when considering skin-sourced microorganisms or the garment as a “home” for microorganisms.

Antimicrobials

The term antimicrobial refers to a broad range of technologies that provide varying degrees of protection for products and buildings against microorganisms. Antimicrobials are very different in their chemical nature, mode of action, impact on people and the environment, in-plant-handling characteristics, durability on various substrates, costs, and how they interact with good and bad microorganisms.

Antimicrobials are used on textiles to control bacteria, fungi, mold, mildew, and algae. This control reduces or eliminates the problems of deterioration, staining, odors, product cross contamination, and health concerns that they cause.

In the broad array of microorganisms there are 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.

Microorganisms cause problems with textile raw materials and processing chemicals, wet processes in the mills, roll or bulk goods in storage, finished goods in storage and transport, and goods as they are used by the consumer. These effects are extremely critical to clean room operators, medical facilities, and food processing facilities. They are also an annoyance and aesthetic problem to athletes and consumers. The economic impact of microbial contamination is significant and the consumer interests and demands for protection is at an all time high.

Antimicrobial Finishes

Antimicrobials do not all work the same. The vast majority of antimicrobials work by leaching or moving from the surface on which they are applied. This is the mechanism used by leaching antimicrobials to poison a microorganism. Such chemicals have been used for decades in agricultural applications with mixed results. Besides the challenges of providing durability for the useful life of products, leaching technologies have the potential to cause a variety of other problems when used in nonwovens. These leaching properties can contact the skin and potentially affect the normal skin bacteria, cross the skin barrier, and/or have the potential to cause rashes and other skin irritations. A more serious problem with leaching technologies is that they allow for the adaptation of microorganisms.

An antimicrobial with a completely different mode of action than the leaching technologies is a molecularly-bonded unconventional technology. The bound unconventional antimicrobial technology, an organofunctional silane, has a mode of action that relies on the technology remaining affixed to the substrate - killing microorganisms as they contact the surface to which it is applied. Effective levels of this technology do not leach or diminish over time. When applied, the technology actually polymerizes with the substrate making the surface antimicrobial. This type of antimicrobial technology is used in textiles that are likely to have human contact or where durability is of value. Dr. M. Bourgeois and researchers at the "Institute Textile de France" in Lyon have also accomplished this type of surface modification by electron beam grafting of acrylic monomers with quaternary ammonium compounds to hydroxyl active surfaces. In either case, durability to wear and laundering with broad-spectrum antimicrobial activity have been demonstrated. The value of this kind of treatment is illustrated in Figure 4. Using a non-leaching antimicrobial treatment, the treatment is not an environmental contaminant and the fabric is not an amplification or source site for microorganisms to the work environment. Doing this such that he normal skin flora are not damaged is an important feature

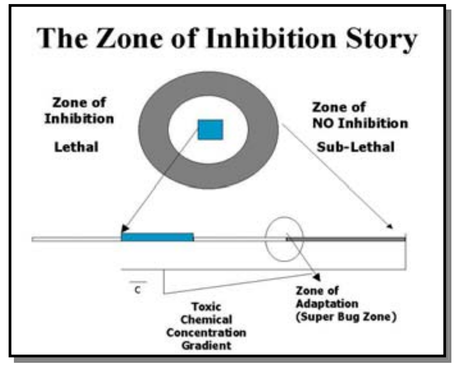

Fig. 3. Zone Of Inhibition Story

Fig. 4 Wash durability

Antimicrobial Function and Adaptation

Antimicrobials primarily function in two different ways. The conventional leaching types of antimicrobials leave the textile and chemically enter or react with the microorganism acting as a poison. The unconventional bound antimicrobial stays affixed to the textile and, on a molecular scale, physically stabs (the lipoprotein components of the membrane) and electrocutes (the anionic biochemicals in the membrane) the microorganism on contact to kill it. Like an arrow shot from a bow or bullet shot from a gun, leaching antimicrobials are often effective, but are used up in the process of working, wasted in random misses, or complexed by other chemicals in the environments of use and abuse. Some companies incorporate leaching technologies into fibers and slow the release rate to extend the useful life of the antimicrobial, even adding to them chemical binders and claiming they are now "bound." Whether leaching antimicrobials are extruded into the fiber, placed in a binder, or simply added as a finish to fabrics or finished goods, they all function the same. In all cases, leaching antimicrobial technologies provide a killing field or "zone of inhibition." This zone exists in real-world uses if it is assumed that the right conditions are present for leaching of a lethal dose at the time that it is needed. The zone of inhibition is the area around the treated substrate into which the antimicrobial chemistry leaches or moves to, killing or inhibiting microorganisms. This killing or inhibiting action of a leaching antimicrobial is witnessed when an AATCC 147 test or other zone of inhibition test are run. These tests are used to measure the zone of inhibition created by a leaching antimicrobial and clearly define the area where the antimicrobial had come off the substrate and killed the microorganisms in the agar. As fabrics treated with unconventional leaching antimicrobial are washed, treatments are easily removed. Figure

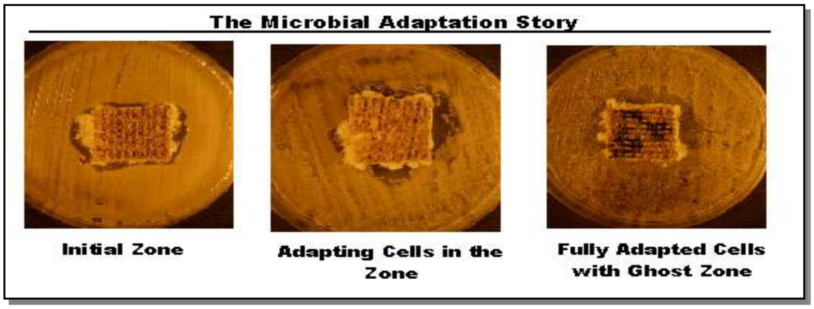

Fig 5a, 5b, and 5c. The microbial adaptation story.

3 presents graphically a typical zone of inhibition test method. The blue area represents a textile material treated with a leaching antimicrobial. The clear zone surrounding the substrate represents the zone of inhibition and the sublethal zone is shown in gray. The area at which the zones merge is presented as the zone of adaptation. Figure 4 shows actual results on the difference between the leaching and the non-leaching antimicrobial treatments on textiles both as first treated and then after five household launderings.

Microbes are living organisms and like any living organism will take extreme measures to survive. Microorganisms can be genetically mutated or enzymatically induced into tougher "super-strains" if they are exposed to sublethal doses (exposed to - but not killed) of an antimicrobial agent. This ability of microorganisms to adapt to potential toxicants has been recognized in the medical community for years. Sublethal levels of antibiotics are generated in patients who discontinue taking antibiotics once their symptoms subside instead of continuing through to the end of the period prescribed by the physician. The exposure of the microbe to a sublethal dose of an antimicrobial can cause mutation of their genetic materials allowing for resistance that is then replicated through the reproductive process creating generations of microorganisms that are no longer affected by the chemistry. This phenomena is of serious concern to the medical community and food processing industries and should be a serious consideration for the textile industry as it chooses the antimicrobials to which it will be exposing the public and their workers.

As with any chemistry that migrates from the surface - a leaching antimicrobial is strongest in the reservoir, or at the source, and weakest the farther it travels from the reservoir. The outermost edge of the zone of inhibition is where the sublethal dose can be found—this is known as the zone of adaptation (Fig. 3). This is where resistant microbes that have been produced by leaching antimicrobials are found. The ongoing challenge for leaching technologies is the control of the leach rate from their reservoir such that a lethal dose is available at the time that it is needed.

This is demonstrated in the following images from experiments where a microbe sample was taken from the outer edge of the zone of inhibition of a common leaching antimicrobial from treated carpet fiber (Fig. 5a) and used to inoculate a new test plate. This second test plate (Fig. 5b) shows the adapted microorganisms growing within the zone of inhibition. The adapted organism is taken from the second plate and used to inoculate a third plate (Fig. 5c). The microorganism used to inoculate this plate is fully adapted to the leaching antimicrobial and has overgrown the fabric. The ghost zone indicates the organism being slowed but not controlled by the leaching toxicant. All this occurred within just two generations of the test organism under these test conditions.

A significantly different and much more unique antimicrobial technology used in the nonwovens and building construction industries does not leach but instead remains permanently affixed to the surface on which it is applied. Applied in a single stage of the wet finish process, the attachment of this technology to surfaces involves two means. First and most important is a very rapid process, which coats the substrate (fabric, fiber, etc.) with the cationic species (physisorption) one molecule deep. This is an ion exchange process by which the cation of the silane quaternary ammonium compound replaces protons from water or chemicals on the surface. The second mechanism is unique to materials

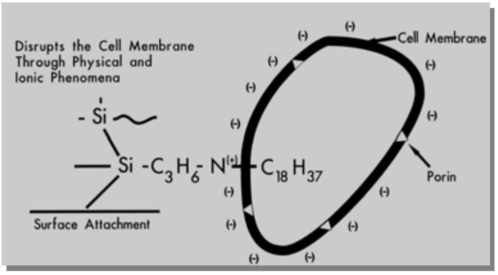

Fig. 6 Bonded chemical

such as silane quaternaryammonium compounds. In this case, the silanol allows for covalent bonding to receptive surfaces to occur (chemisorption). This bonding to the substrate is then made even more durable by the silanol functionality, which enables them to homopolymerize. After they have coated the surface in this manner, they become virtually irremovable, even on surfaces with which they cannot react covalently (Fig. 6).

Once polymerized, the treatment does not migrate or create a zone of inhibition so it does not set up conditions that allow for adapted organisms. Because this technology stays on the substrate, it does not cross the skin barrier, does not affect normal skin bacteria, nor causes rashes or skin irritations. This organofunctional silane technology has been used for over two decades to treat surfaces from leather and foams to virtually all types of fabrics and is not consumed by the microorganism. It does not poison the microorganism. When a microbe contacts the organofunctional silane treated surface of the fabric, the cell is physically ruptured by a sword-like action and then electrocuted by a positively charged nitrogen molecule (Fig. 7). This antimicrobial technology has been verified by its use in consumer and medical goods including socks, surgical drapes, and carpets in the USA, Asia, and other areas in the world. This technology has been used for nearly twenty-five years without any human health or environmental problems inside manufacturing facilities or in actual end use situations.

Fig. 7. Healthy and ruptured organisms

Conclusions

Garments in all kind of manufacturing and service environments are the first line of defense between skin-sourced microorganisms and the work place and work products. Antimicrobial treatments, chosen and used responsibly, offer the ability to extend the microbial barrier properties of garments to active antimicrobial surfaces. The ability to reduce the flow through potential and reservoir potential of microorganisms with antimicrobial treated garments offers a new measure of protection for wearers and products they produce.

Fabric and garment designers and manufacturers can now provide antimicrobial preservation treatment that extends the functional properties of biocontaminant control – up close and personal.

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