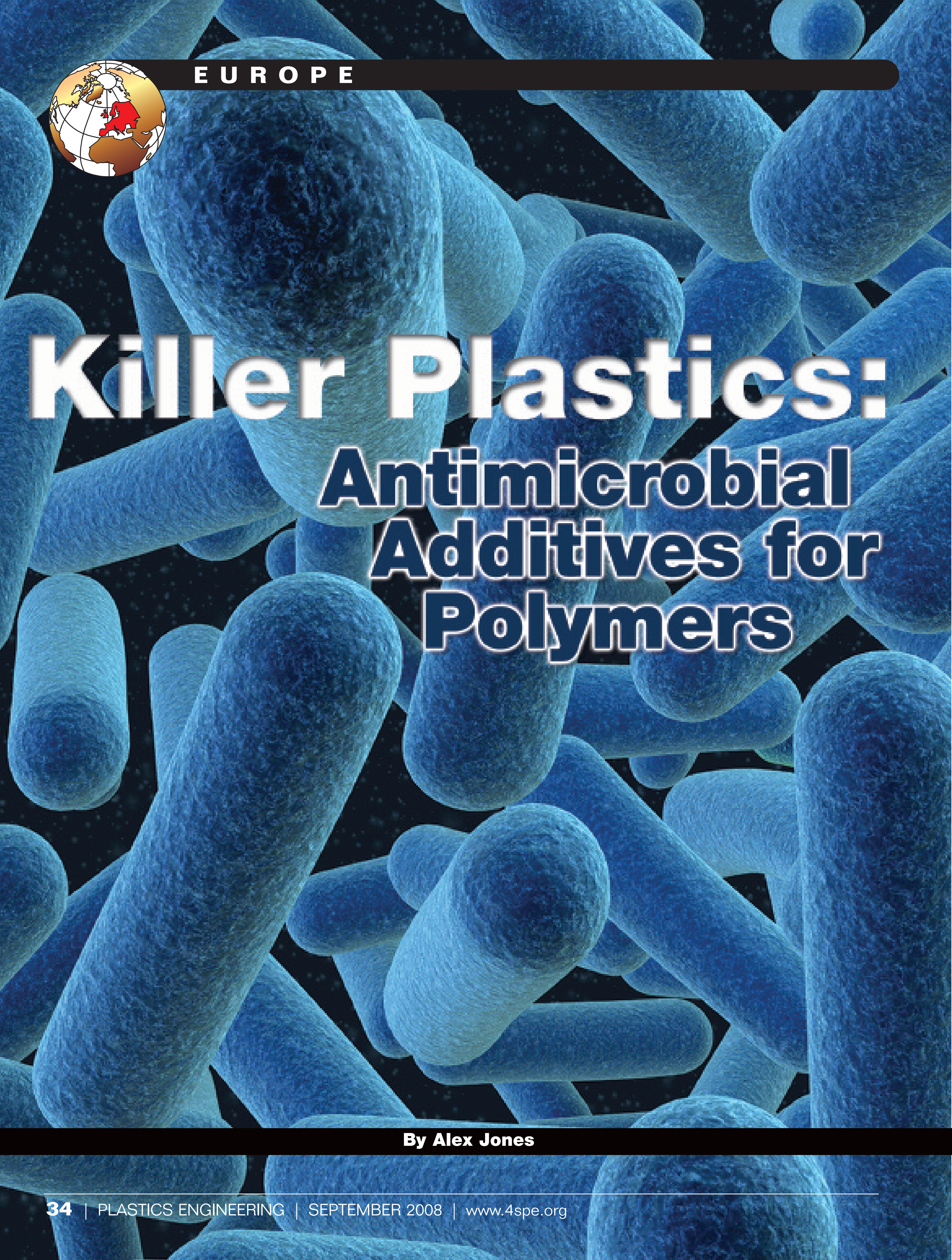


Killer Plastics: Antimicrobial Additives for Polymers

By Alex Jones

Geoflow uses tributyltin maleate that is inorganic; and Netafim uses OBPA that is organic

The term "microbe" is used as a general description for any bacteria, fungus, mould, or mildew. In one form or another, these microscopic organisms have adapted to their environments and thrive even in the harshest conditions. They have a unique ability to quickly evolve and adapt and in some cases to go dormant for extended periods, which has made them extremely resilient. While the vast majority are harmless, and indeed many are beneficial, there are pathogenic strains that have gained notoriety, most notably the hospital "superbugs" MRSA and *Clostridium difficile*.

The role of biocidal agents is to reduce the "bioburden" in certain environments where, in worst-case scenarios, unchecked microbial growth can lead to food poisoning or potentially fatal infections. The need to reduce the incidence and proliferation of microbes is far-reaching.

Antimicrobial polymer additives can be fit into two broad categories: organic or inorganic. These systems have different attributes and therefore different ideal end-applications. While many antimicrobial additives are referred to as biocides, there are in fact two different methods of effect: biocidal (killing the organism) and biostatic (preventing reproduction). Organic additives are biostatic, and inor-

Alex Jones

ganic additives combine biocidal and biostatic properties.

Organic Systems

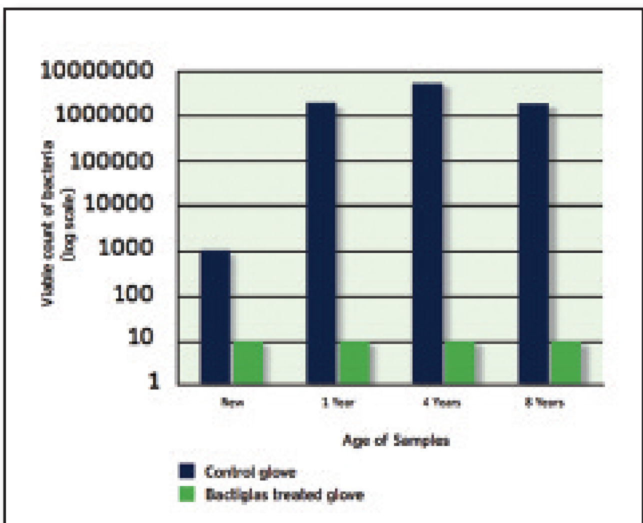
Organic-based systems, which include the organometallic class of molecules, rely on small migratory molecules to introduce an antimicrobial effect at the polymer's surface. Once incorporated into plastic, they migrate, over time, out of the polymer matrix and onto the polymer surface, where an antimicrobial "film" is formed.

Migration occurs as the molecules move down a concentration gradient out of the plastic. The migration is driven by the inherent compatibility differences between the organic antimicrobials and the polymer substrates in which they are dispersed. The resulting film on the polymer's surface is replenished by additives within the substrate whenever the surface is wiped or washed, or when the additive is lost to the environment.

The benefit of this mode of action is that it can have a very high activity rate, and the migratory molecules can interact with large numbers of microbes very quickly. This does, however, affect the lifespan of activity, as the additives leach out over time, leaving little in the polymer's reservoir. The addition rate and choice of organic additive itself are functions of the level of efficacy required and the duration of action needed.

Organic technologies often fit better commercially with disposable items that have shorter lifespans than more durable and environmentally demanding products. Further limitations include the lack of food-contact approval for organic-based systems, primarily because of the mobility and solubility of these additives in food simulants. Therefore, when one is choosing a system for direct food contact, an inorganic-based technology is the only real option.

Another consideration with organic systems is the effect of temperature during processing. As temperatures increase, organic molecules become more highly mobilised, resulting in excessive loss rates from the plastic.



Antimicrobial activity of PE glove samples tested over an eight-year period against *E. coli*.

Also, organic antimicrobials often have thermal-decomposition temperatures similar to the temperature of the polymer-processing window. Polymers such as PVC and some low-temperature polyolefins are best suited to these additives. The environmental temperature in which finished products will be used should also be considered, as this can influence the migration rate and longevity of the active system.

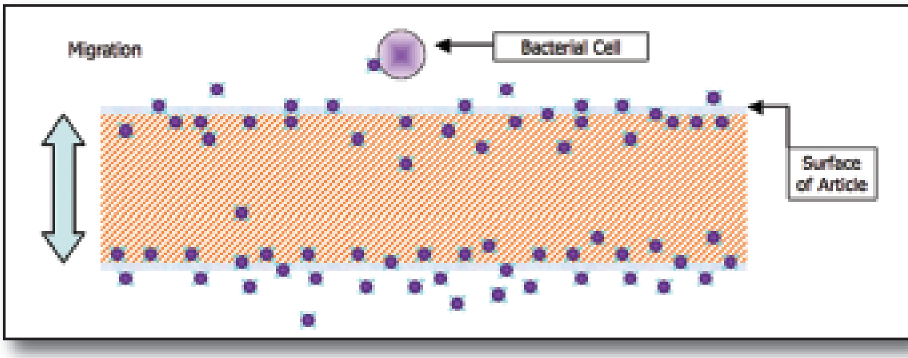
Soft PVC products are good examples of where organic systems are successfully employed to guard against microbial degradation such as black-pitting and pink-staining. PVC itself can intrinsically heighten microbial growth, and this is exacerbated when it is used for applications in wet environments such as shower curtains, paddling pools, and waterproof linings.

Many organic biocides are in the marketplace, but only a few have the thermal stability required for surviving the processing rigours of plastics. The most common organometallic antimicrobials are arsenic-based materials such as oxybisphenox arsine (OBPA). While these additives are very efficient and cost-effective, their use has been limited because of environmental concerns and market perception regarding their long-term toxicity. Even though OBPA has been registered by the Environmental Protection Agency (EPA) in the USA, these fears have unfortunately had a negative impact on market confidence.

As a result, demand for non-arsenic-based formulations, such as the non-metal-containing isothiazalone family of biocides, and other types, such as triclosan (chlorinated diphenyl ether), is growing rapidly. Growth is currently predicted to be between 10%/yr and 20%/yr in Europe. Arsenic-based formulations still tend to offer cost advantages over their non-arsenic counterparts, though.

Inorganic Systems

Inorganic antimicrobials utilise metal ions as their active biocidal agent, and once incorporated into the poly-



Function of organic-based additive system in plastic substrate.

mer matrix, these remain in-situ. The most commonly used metal ion is silver; others include copper and zinc.

Silver ions are thought to disable bacterial cells by acting on them in several ways, and this multiplicity of action results in a strong biocidal effect. In the primary mode of attack, ions bind to the cell membrane, affecting its ability to regulate the diffusion and transport of molecules in and out of the cell. Similarly, once inside the cell, the ions target thiol groups on the proteins, which function as enzymes in their critical metabolic pathways. This denatures the enzymes, bringing about a loss of cell functional ability, which leads to cell death.

The success of these systems relies on the delivery of minute quantities of ionic metal at the cell membrane. The metal ions are usually bound within a delivery system that stabilises them, allowing their incorporation into the polymer, and then releases them through a process of ion exchange at the plastic's surface.

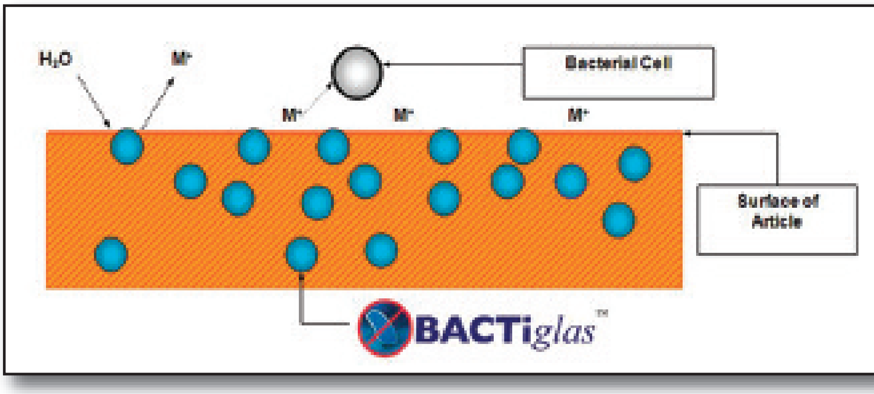
The metal ions remain stored within the polymer and are continuously made available over the lifetime of the particular finished product. While there is no migration of the ions, as with organic systems, it is the delivery system that ensures a constant replenishment at the surface. The additive-addition level and delivery mechanism regulate how quickly ions are released and the duration of the action. Some systems favour rapid release, such as wound-care applications, while others have a more controlled mode of action continuing over the lifespan of the substrate.

Delivery systems on today's market include those relying on ceramic glasses, doped titanium dioxides, and even zeolites as their carrier and release mechanisms. Inorganic systems tend to be much more thermal-

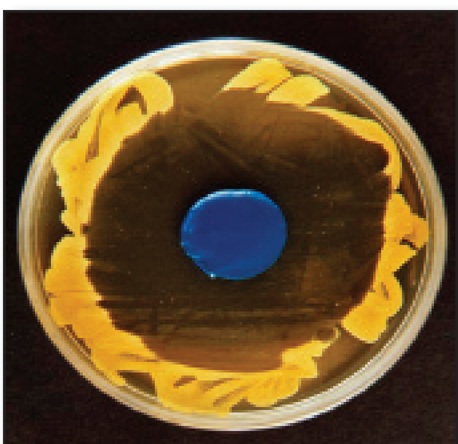
ly stable than their organic counterparts, although some are subject to discolouration. Their thermal stability means there are a wide range of polymers that can benefit from these additives.

Variations on the inorganic theme are metal-ion systems based around nano-sized particles. These, for the most part, have been developed to explore the possibilities that rapid ion release can offer (as a result of their high particulate aspect ratio). The active ingredient, the metal ion, remains the same, but coupled with this are adverse issues such as unquantified toxicity, excessive discolouration resulting from rapid oxidisation, and the increased complexities of producing nano-scale active grades. Currently, nano-silver is not recognised by the Biocidal Products Directive (which implements Europe permissioning schemes for biocides and non-agricultural pesticides) or the EPA.

While the incorporation of additives can successfully reduce the microbial loading on surfaces, the surfaces themselves can also play an important part, and this should be given attention at the product-design stage. For example, surfaces with very high energies, such as those composed of silicone, are extremely hydrophobic and therefore less attractive to colonising bacteria. However, this hydrophobic characteristic alone is not enough to prevent growth; we only have to look at bathroom mould on silicone sealant to prove that. Surfaces that are very smooth at a microscopic level can also reduce the rate at which bacteria adhere and colonise.



Example of an inorganic system: residual levels of atmospheric moisture combine with the hydrolytically reactive glass delivery system to release silver ions at the surface of the plastic.



The "Halo" test, showing the effect of an organic antimicrobial.

Test Procedures

In discussions of the performance of the different systems on the market, it is important to outline the three commonly used types of test methods for determining efficacy.

In the "Halo" or "Zone of Inhibition" test, AATCC 147, an article containing the antimicrobial additive is placed in the centre of an agar plate that has been surface-inoculated with a strain of microbe. The plate is then incubated for a defined period. The test measures the size of the circle or "zone of inhibition" surrounding the test piece where no microbial growth has occurred following incubation (see picture).

This test method is well suited to the organic migratory types of additive systems, as these freely move out of the plastic article and diffuse across the agar medium, creating a "zone of inhibition." This does not tell us if the bacteria are dead or dormant; it tells us only if they have been inhibited from colony-forming.

It is a quick and cheap test, but difficult to use for discerning quantitative results; at best, a qualitative statement can be made based on the size of the halo.

Inorganic systems, on the other hand, despite being highly efficacious, will show only an extremely thin halo because of the lack of migration of the additive, highlighting the limitation of this test method.

The "Shake Flask" test ASTM E2149-01 is another method that demonstrates good results for migratory systems; however, only highly soluble inorganic systems can show reasonable results. In this test, inherited from the textile industry, a specimen article containing the antimicrobial additive is placed into a flask containing a known volume of nutrient agar broth challenged with a defined number of bacterial cells. The flask is incubated on a shaker for a set period of time to allow bacterial proliferation, and then the number of bacteria remaining in the

nutrient broth is determined.

The third method, which is well suited to all kinds of systems, measures the antimicrobial effect on the surface of the plastic component itself. This is therefore most appropriate when one is trying to determine the level of antibacterial efficacy on the surface of a finished article rather than its surrounding environment. It also has the advantage of generating data that can be quantitative, qualitative, and time-related.

Examples of this test method include ISO 22196 (JIS Z 2801), in which the plastic article is challenged with a nutrient broth containing a known cell count. This is then incubated for a defined period before the number of remaining viable cells is determined. The resulting efficacy is given as a log or percentage reduction against a control, with a minimum 99% (log 2) reduction being required to pass the test specification.

Inorganic and organic systems on the market today generally deliver efficacy up to and above log 6 (99.9999%) reduction in cell count against controls, depending on the precise addition level of additive and the delivery system used. In general, organic and inorganic systems find good efficacy at anywhere from 100 ppm to 2500 ppm in the plastic, depending on the performance requirement.

While organic systems are often used in PVC and very-low-temperature polyolefins, as previously mentioned, inorganic systems perform well in many different polymers and processes; polymer types include (but are not limited to) PO, HIPS, ABS, PEEK, PET, PC, PU, PA, PMMA, EVA, and PVC.

The market for antimicrobial additives is growing rapidly; the increase in use of silver as a biocide in polymeric formulations alone is reported to have risen in excess of 600% worldwide since 2001.

Whether incorporated in medical gloves, packaging films, contact-lens cases, swimming-pool liners, food-preparation counters, high-performance sportswear, floor tiles, or shower fittings, the use of antimicrobial plastics is bringing real benefits across a wide range of sectors, a trend that is definitely set to continue.

Based in the UK, Alex Jones is product specialist for Wells Plastics' Bactiglas range of antimicrobial additive products (www.wellsplastics.com). He has a BSc (Hons) in Biological Sciences, has worked in consumer microbiology, and spent the last five years in the polymer additives industry.