Preventing microbial contamination in water and air filtration

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While filters are crucial for removing particulates and microorganisms from liquids and gases, they are vulnerable to microbial contamination and biofouling. This not only spreads pathogens but also reduces filter performance. To overcome these shortcomings, antimicrobial technologies are essential for this type of application. The European Biocidal Products Regulation (BPR) has led to restrictions on many existing antimicrobial agents, emphasizing the need for new, effective, and safe solutions. The antimicrobial technology from Heraeus Precious Metals emerges as a novel technology that generates reactive oxygen species (ROS) in situ.

Microorganisms on water and air filters pose a serious health threat

Contaminants in various processes pose significant risks to human health and product quality, necessitating the use of effective filtration systems. Filters are essential for the removal of particulate matter and microorganisms—including viruses, bacteria, fungi, and protozoa—from both liquids and gases. While microorganisms are integral to many environmental and biological processes and often play beneficial roles, their presence can also lead to significant health and ecological challenges. Pathogenic microorganisms, such as *Escherichia coli*, *Salmonella*, and *Norovirus*, are particularly concerning due to their potential to cause severe water- and foodborne diseases in humans and animals. These pathogens represent substantial public health risks, for example during epidemics, when their spread can have catastrophic effects.

While water filtration is critical for ensuring safe drinking water, treating wastewater, and maintaining swimming pools, air hygiene is also becoming increasingly important for eliminating pathogen-carrying aerosols from indoor environments, particularly in sensitive areas such as healthcare facilities and research laboratories. Pollen, as a common air pollutant, also contributes to allergic reactions, further emphasizing the need for effective air filtration.

However, filters are susceptible to microbial contamination and biofouling, which not only endangers consumer health but also reduces the service life of filtration products. In air filtration systems, some pathogens remain infectious over extended periods and can be released during maintenance of ventilation systems. Air filters and air conditioning units in vehicle interiors create humid environments that are beneficial to microbiological colonization, allowing bacteria to multiply rapidly.

These challenges underscore the urgent need for antimicrobial technologies in filtration systems that prevent biofilm formation to inhibit microbiological contamination. Implementing such technologies can reduce public health risks and decrease costs by extending the life cycle of filters.

Current antimicrobial technologies are being re-evaluated within the framework of the European Biocidal Products Regulation (BPR) to assess their risks to human and environmental health in respect to their efficacy. This re-evaluation has led to considerable restrictions on the use of proven antimicrobial agents, highlighting the necessity for developing

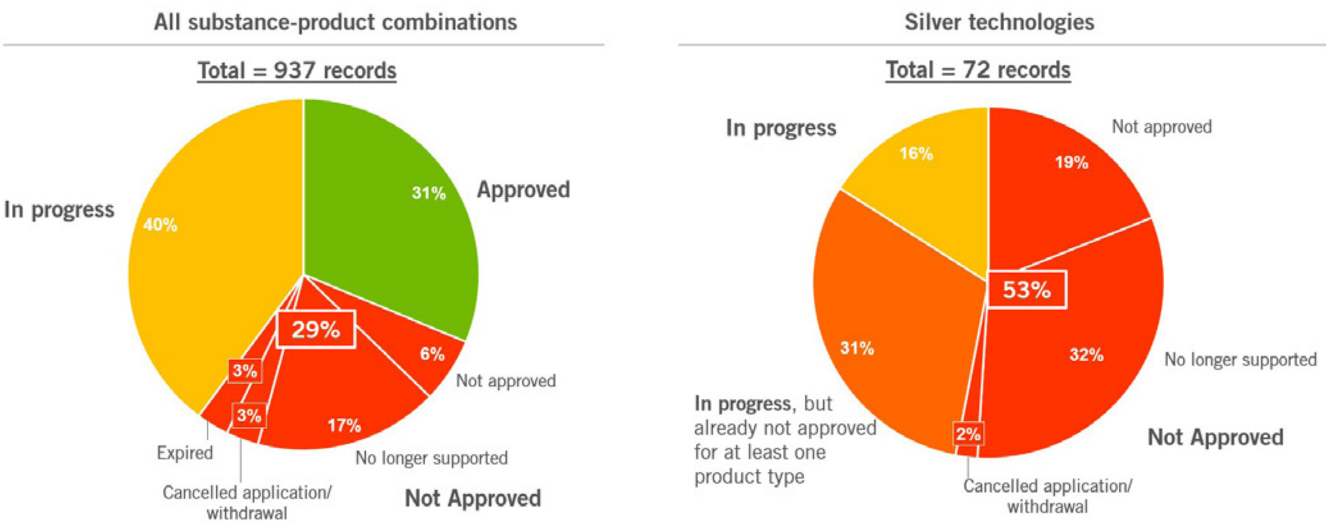

Figure 1: *Current status of ECHA Review Programme (October 10, 2024)*

new, effective, and safe antimicrobial solutions that comply with regulatory standards and ensure public safety [1].

Antimicrobial technologies in the context of the BPR

While biocides could still be placed on the market without an authorization procedure until the mid-1990s, this has changed dramatically since the Biocidal Products Regulation (BPR) came into force in 2012. The aim of this regulation is to protect people and the environment from negative influences caused by the excessive use of substances with biocidal properties. Consequently, all antimicrobial technologies that were already available on the market at that time are required to undergo a rigorous review process in accordance with the new regulations. New evaluation criteria have been established based on intended use, resulting in the classification of 21 Product Types (PTs) under the BPR framework.

In the course of this ECHA Review Programme to date, shown in **Figure 1**, more than ten years after the start of the evaluation, only 562 out of a total of 937 active substance/product type combinations have been evaluated and only slightly more than half of these have been approved. It can therefore be assumed that a large proportion of the active ingredients available today will disappear from the market. An even clearer picture is emerging with regard to silver-ion technologies, i.e. technologies that are used in particular for the antimicrobial functionalization of filter systems (both textile and activated carbon filters). To date, 53% of the corresponding active ingredient-product combinations have been tested, all of which have received non-approval, i.e. none of the silver-ion technologies has so far been able to meet the evaluation criteria with regard to efficacy and risk to human health and the environment [2].

Chance for new technologies arises to fill the gap

This situation creates an opportunity for new and regulation-compliant technologies to address the shortcomings. Developing and implementing innovations in biocidal active substances is particularly challenging due to several factors. The main hurdles include strict regulatory requirements designed to ensure that new products do not harm humans or the environment. These regulations demand extensive and costly testing procedures, which, combined with high barriers to market entry and concerns about the acceptance of new technologies, pose significant economic risks for developers. Despite these challenges, the need for effective antimicrobial solutions opens the door for advancements that can meet regulatory standards while providing safer and more efficient filtration systems.

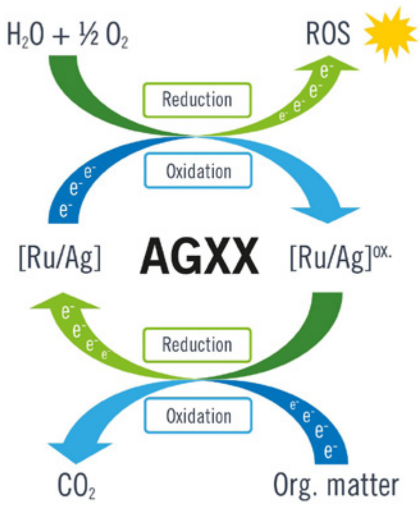

Figure 2: *Catalytic cycle for the generation of reactive oxygen species (ROS) using the example of "AGXX".*

Technology opens a new class of active substances - In-situ generated free radicals

One of the few new active substances currently in the approval process is the in-situ generated free radicals from air and water. In these antimicrobial technologies, reactive oxygen species (ROS) such as hydroxyl radicals are generated through reaction of oxygen and water. A key technology that incorporates this active substance within the BPR is AGXX.

Figure 2 shows a schematic representation of this concept using the example of the antimicrobial catalyst system. The catalytic material creates these radicals without being consumed in the process, allowing for a sustained antimicrobial effect. The generated ROS are highly reactive and possess strong antimicrobial properties, effectively eliminating microorganisms by damaging essential cellular components like membranes, proteins, and DNA [3]. Since larger cell complexes, e.g. the human skin, possess defense mechanisms

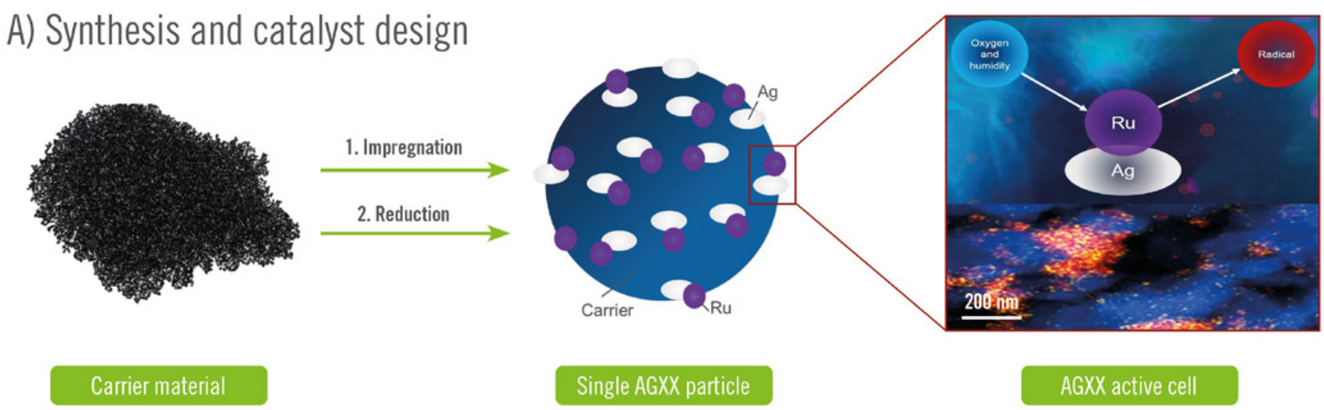

Figure 3: *Synthesis of an active catalyst for the generation of reactive oxygen species.*

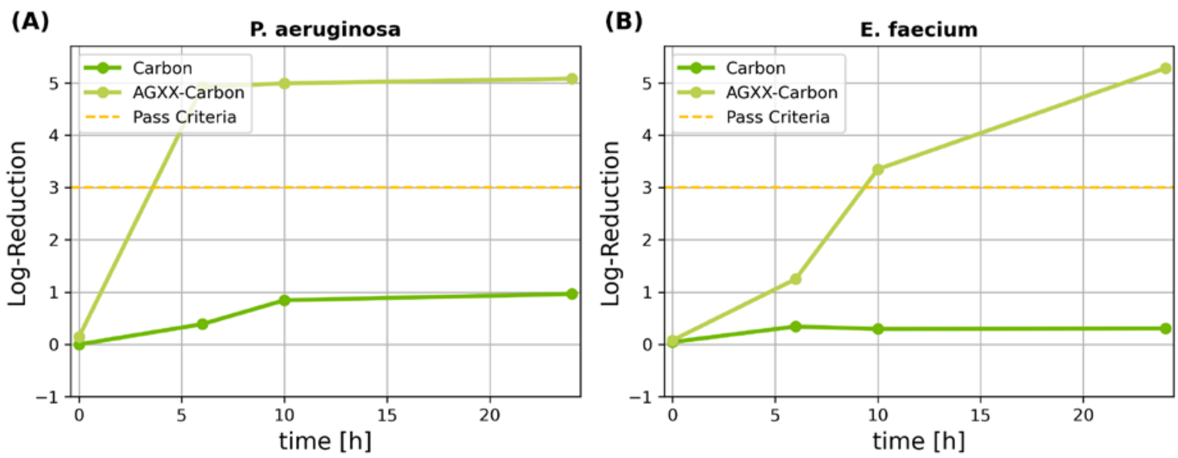

Figure 4: *AGXX-Carbon vs. pure carbon in modified ASTM E 2149 under real use conditions. The efficacy is shown against P. aeruginosa and E. faecium Teltow 11*

against oxidative stress, there is no risk to humans, animals and the environment at the same time.

This approach offers a promising solution that complies with regulatory standards while providing effective microbial control without the need for additional chemical agents. The approval process for the active substance of in situ generated free radicals is currently underway for eleven PTs. However, the use of products based on this active concept is already permitted in a large number of applications through Article 93 of the Biocidal Products Regulation.

A wide range of intend uses

AGXX represents a technology for the in-situ generation of ROS due to its particle-based nature, making it versatile for numerous applications. The technology is available in various product forms, each tailored for specific uses. Fundamentally, the catalyst comprises silver and ruthenium, which are deposited as discrete islands on different carrier materials (see **Figure 3**). This flexibility in attaching the catalyst to various carrier materials enables a wide range of applications.

For example, the fine particles in which the precious metals silver and ruthenium are deposited are a boehmite-based carrier material (D50 < 1 µm). Known as AGXX-Hybrid-A, this product is particularly well-suited for use in textile filters. The particles can be incorporated into the polymer during the manufacture of a masterbatch or compound. This is subsequently used to produce fibers or the final textile filter. Furthermore, the particles can be attached to the filter through padding or by innovative techniques on the filter fleece. Another product example, which is designed for filtration applications, are impregnated active carbon products comprising powder, granules, pellets.

Antimicrobial efficacy of functionalized activated carbon

In order to evaluate the antimicrobial performance of AGXX-Carbon a modified ASTM E 2149 test protocol, specifically for adipates used in drinking water was employed. The microorganisms tested included *S. aureus*, *P. aeruginosa*, *E. hirae*, *E. coli*, and *E. faecium Teltow 11*. Its efficacy was assessed using two sample types: one consisting of pure carbon, and the other of the same carbon functionalized with the technology. The tests were conducted at time intervals of 6, 10 and 24 hours.

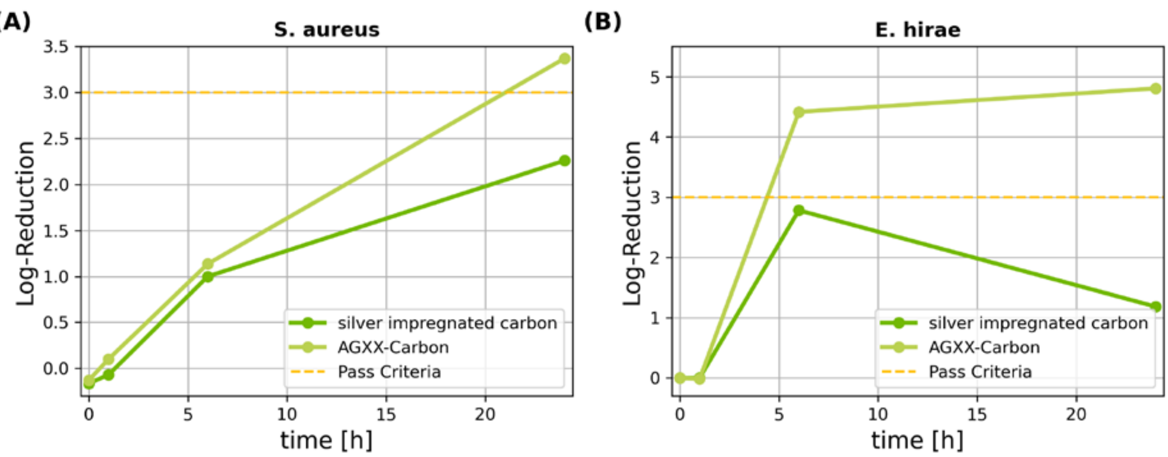

Figure 5: *Efficacy testing of AGXX-Carbon against a commercially available silver impregnated product in a modified ASTM E 2149 conducted against S. aureus and E. hirae*

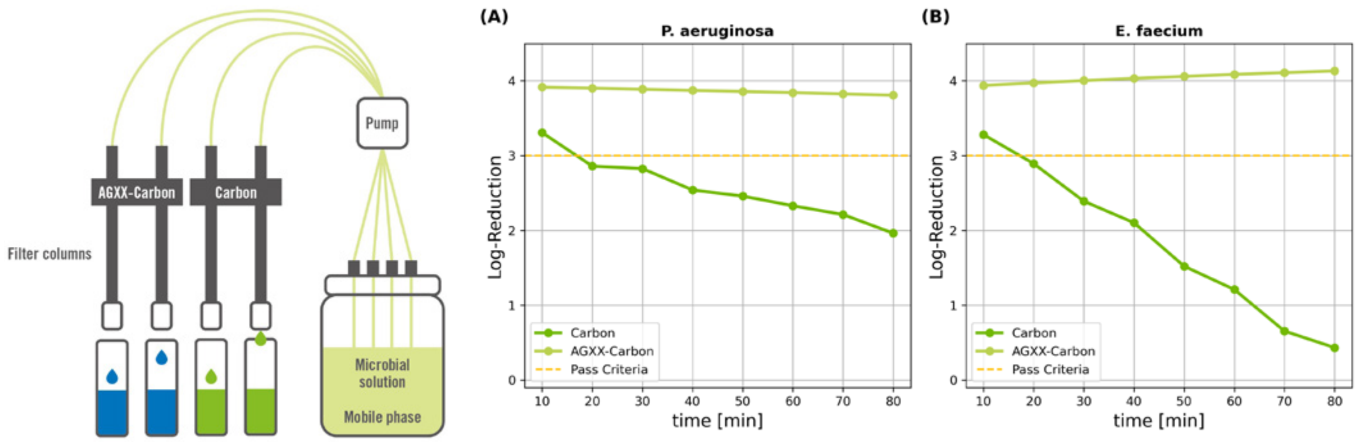

Figure 6: *AGXX-Carbon vs. pure carbon in filter column under real use conditions*

Further, a germ reduction >99.9 % was implemented as a pass criterion (corresponding to a log reduction >3 compared to the inoculum). The tests were performed at QualityLabs BT GmbH. AGXX-Carbon exhibited a full germ reduction across all tested microorganisms, while none of the tests involving pure carbon met the pass criteria.

Especially important is the excellent efficacy against P. aeruginosa, known for ability of biofilm formation on various surfaces and *Enterococcus faecium Teltow 11*, which is noted to be highly resistant towards various biocides (see **Figure 4**) [4]. The germ reduction of log 1 after 24 h for pure carbon may be explained by an adsorption of microorganisms on the surface without being fully eradicated, which is consistent with previous findings [5].

In a next step, the performance was compared to a commercially available silver-impregnated carbon product in an ASTM E 2149 test against *S. aureus* and *E. hirae* (**Figure 5**). The results clearly demonstrate that AGXX-Carbon exhibited strong antimicrobial activity against both bacterial types tested, whereas the silver-impregnated carbon showed insufficient efficacy. Particularly in the case of *E. hirae*, there was a significant decline in antimicrobial activity, with *E. hirae* even exhibiting microbial growth between 6 and 24 hours. Long-term efficacy tests in various applications comparing both materials are ongoing to ensure a prolonged lifetime of products based on the antimicrobial technology.

Antimicrobial efficacy in flow-through filtration system

To evaluate its efficacy in filtration applications, a laboratory-scale unit was developed in partnership with QualityLabs BT GmbH (see **Figure 6**). Bacterial suspensions were prepared in hard water and introduced into glass columns using a peristaltic pump. The columns contained either pure carbon or AGXX-Carbon in equivalent volumes. The filtrate was collected in fractions and its microbial load was analyzed using the standard plate counting method. The pass criterion corresponds to a microbial load reduction >99.9 % (log reduction >3).

Figure 6 illustrates that both samples showed microbial load reduction initially, likely due to the natural adsorption properties of activated carbon. However, as the test continued, a clear difference between the two materials became evident. Microbial reduction exceeding 3-log were maintained with AGXX-Carbon throughout the entire testing period, whereas an exponential breakthrough in microbial load occurred in all columns containing pure carbon. The discrepancy in performance regarding pure carbon may be explained by a variability in adsorption strength, likely influenced by the surface charge of the microorganisms [6].

Antimicrobial efficacy of AGXX-Hybrid in Textiles

AGXX-Hybrid is an excellent additive for textile products, either by incorporating the powder directly into the fibers or through a finishing process. For instance, these particles have been successfully integrated by extrusion into PA6 and PA6/66 pellets, which were then processed into textile nylon fibers, yarns, and fabrics. The additive-modified plastics demonstrated good processability during extrusion and subsequent processing of the AGXX-modified PA pellets. Since there were no changes in the processing parameters compared to the additive-free reference, it can be inferred that the additive does not affect the manufacturing processes.

Microbiological tests conducted on these final products confirmed their efficacy in accordance with ISO 20743 for porous surfaces. The antimicrobial effectiveness of the treated material was tested against *S. aureus* and *K. pneumoniae* strains. All tested additive concentrations, as shown in **Figure 7**, exhibited a very high antimicrobial effect, reducing bacterial concentration by more than 99.99 % in all test specimens.

Additionally, the technology was incorporated into both hydrophilic and hydrophobic PU coatings for textile finishing purposes. This finishing was applied to PET textiles, which were then tested according to DIN EN ISO 22196 against *S. aureus* bacteria. The test results, shown in **Figure 8**, indicated that AGXX is highly effective, reducing bacterial presence by more than 99.9 %.

In addition to its antimicrobial effect, AGXX can deactivate allergens

In addition to their antimicrobial properties, the particles have also demonstrated effectiveness against allergens in initial proof-of-concept tests. To demonstrate this effective-

Figure 7: *AGXX demonstrates high antimicrobial efficacy, achieving more than 99.99% germ reduction in PA6 fabrics according to ISO 20743.*

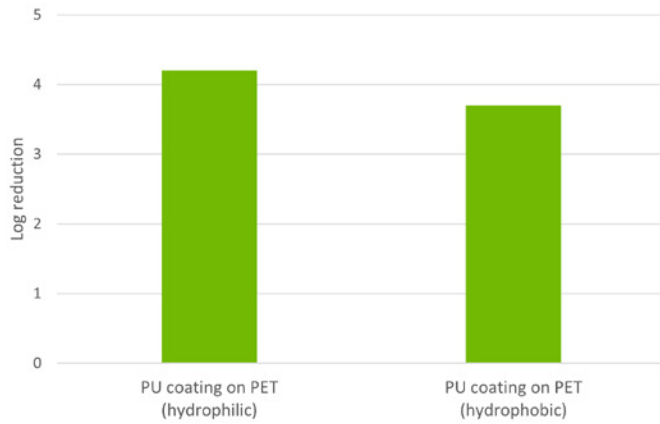

Figure 8: *AGXX was tested according to ISO 22196 standards and demonstrated high effectiveness against S. aureus.*

ness, a standard air filtration test (LAH.000.819.A) was modified. This test examined whether pollen, after contact with AGXX, had its allergen-activating genes deactivated. As part of a study, the elimination rates of the antimicrobial particles against modified birch pollen were determined in an in vitro test. For this purpose, tests were conducted with a defined birch pollen suspension applied to AGXX samples. The mixture was then incubated for 24 hours at room temperature with shaking. The supernatant was subsequently examined using an ELISA test. In all samples, the total allergenic activity was reduced by more than 99%.

Conclusion

Microbial contamination of filtration systems is a pressing public health concern that requires innovative solutions compliant that meet stringent regulatory standards. The antimicrobial technology from Heraeus Precious Metals offers a promising approach by harnessing in situ generated reactive oxygen species to effectively eliminate a wide range of microorganisms. By preventing biofilm formation and extending filter longevity, it enhances the safety and efficiency of water and air filtration processes. Its integration into filtration systems represents a significant step forward in mitigating health risks associated with microbial contamination, contributing to improved public health outcomes and reduced maintenance costs.

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