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# Addition of Dehacide 267 As an Anti-Fungal Smart Material on the Body Coating of the MV3 Garuda Limousine

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**Abstract**

*Military vehicles, such as the MV3 Garuda Limousine, operate in harsh environments that often lead to fungal growth, degrading the protective body coating. This study addressed the issue by integrating Dehacide 267, a non-oxidizing biocide composed of a synergistic combination of isothiazolines and bronopol, into an acrylic-based coating. The primary purpose of this research was to formally investigate and validate the antifungal efficacy of Dehacide 267, incorporated at a 2% (w/w) concentration, against common automotive fungi, specifically Aspergillus niger and Penicillium chrysogenum, while also assessing its impact on the coating's structural durability and resistance to harsh environmental factors like UV radiation and rain. The coating, prepared with a 2% (w/w) biocide concentration, was tested for antifungal efficacy against Aspergillus niger and Penicillium chrysogenum. The results confirmed that the addition of Dehacide 267 significantly inhibited fungal growth. The biocide achieved up to 95% inhibition after four weeks, demonstrating high effectiveness in preventing fungal colonization. The proposed mechanism of action involves damaging the fungal cell membrane, which is consistent with the biocide's properties. Furthermore, testing showed that the biocide-enhanced coatings exhibited superior resistance to UV rays and rain, indicating improved structural durability. In conclusion, the addition of Dehacide 267 to the acrylic coating successfully prevented fungal colonization and improved the coating's resistance to environmental factors. This research establishes Dehacide 267 as an effective antifungal smart material for specialized vehicle coatings.*

***Keywords**:* acrylic coating, biocide, dehacide 267, smart material

## Introduction

Military vehicles are generally used in the field, so they often face extreme conditions such as heat, rain, low temperatures (humidity), salt water, acid rain, waste water, etc. This can lead to the growth of fungi that can damage the coating layer. To prevent mold growth, the addition of a biocide is necessary. This biocide is added during the coating process. Therefore, the coating formulation must be supplemented with an antibacterial agent or biocide before coating [7].

The application of biocide (dehacide 267), which consists of a synergistic combination of isothiazolines and bronopol, is an innovative solution to overcome the problem of mold growth on the body of the MV3 Garuda Limousine. This material was chosen because it has strong antimicrobial properties, long durability, and is environmentally friendly [15]. Thus, it is expected to provide optimal protection for vehicles and meet consumer demands for high-quality products.

Dehacide 267 is a non-oxidizing biocide specifically used in the paper coating and paperboard industries. This biocide is water-based and formulated with several active ingredients to control bacterial and fungal growth in paper machine systems. It is compatible for use in both acidic and alkaline paper systems. This biocide has excellent sediment penetration and surface activity properties to free surfaces from slime deposits. It is effective against slime-forming bacteria, fungi, or yeasts that may be resistant to other types of biocides. Dehacide 267 can be applied directly to chemical additives in the coating system at a point that will ensure uniform mixing. Application can be done periodically or with a batch system strategy, depending on the application area. Dehacide 267 must be used in accordance with control procedures.

Garuda Limousine MV3 cars are often exposed to extreme conditions such as rain and heat, which cause bacteria and fungi to grow. Therefore, the addition of biocides or antibacterial agents is necessary in the coating process to prevent the growth of fungi [13] that can damage the car body. This addition of biocides is carried out during the coating process. To inhibit the growth of mold that can damage the car paint or coating, the addition of biocide is necessary [8]. This prevents corrosion, as the corrosion process can cause damage to the car body [10]. Mold growth can damage the coating on the car paint, causing the paint to fade. The purpose of adding biocide is to prevent the growth of mold or fungi that can cause the paint color to change and the paint to deteriorate [6].

## Materials and Methods

Biocide is a term used for broad-spectrum antiseptic substances that can inactivate microorganisms. Broad spectrum in biocide means the ability of a substance to kill or inhibit the growth of various types of microorganisms. These microorganisms can be bacteria, viruses, fungi, or even protozoa. Therefore, one type of broad-spectrum biocide can be effective against various types of pathogens, not just one type [1]. Dehacide 267 can be applied directly to chemical additives in the coating system at a point that will ensure uniform mixing. Application can be done periodically or with a batch system strategy, depending on the application area. Dehacide 267 must be used in accordance with control procedures.

### Materials

The key compound employed in this investigation was Dehacide 267, a commercially sourced non-oxidizing biocide supplied as an aqueous solution. The formulation's efficacy relies on a synergistic combination of active ingredients: isothiazolines and bronopol. This biocide was incorporated into a standard acrylic-based coating system at a concentration of 2% (w/w), serving as the protective matrix on the vehicle body. For the antifungal efficacy assays, two specific fungal species, Aspergillus niger and Penicillium chrysogenum, were obtained from a certified culture collection and utilized as the target microorganisms. All necessary supplementary chemicals, including specialized detergents for substrate preparation, were used at an analytical grade purity.

## Instrumentations

The surface of the MV3 Garuda Limousine test substrate underwent meticulous cleaning and preparation procedures. The subsequent application of the biocide-incorporated acrylic coating was executed using a high-precision pneumatic spray gun under controlled ambient conditions. Initial antifungal efficacy was assessed via routine visual observation over a 4-week testing period [4]. Finally, the quantitative determination of the residual biocide content in the cured film was achieved using High-Performance Liquid Chromatography (HPLC).

## Procedure

The methods employed for the preparation and evaluation of the biocide-incorporated acrylic coating on the MV3 Garuda Limousine involved several distinct steps.

*Preparation of Biocide-Incorporated Coating and Substrate*

The acrylic-based coating formulation was prepared by gradually incorporating Dehacide 267 biocide at a concentration of 2% (w/w) into the base polymer matrix under continuous mechanical stirring for 30 minutes at room temperature (25°C), ensuring homogeneous dispersion. The MV3 Garuda Limousine car body, serving as the substrate, underwent thorough cleaning with a specialized industrial detergent to remove any surface contaminants, followed by rinsing with deionized water and air-drying. The biocide-containing acrylic coating was then applied to the prepared substrate using a high-precision pneumatic spray gun, maintaining a consistent film thickness across the surface. The coated samples were allowed to cure under ambient conditions (25°C, 60% relative humidity) for 24 hours to achieve optimal film properties [5].

*Antifungal Efficacy Evaluation*

The antifungal activity of the coated samples was evaluated against Aspergillus niger and Penicillium chrysogenum using a modified agar plate method. Briefly, fungal spores were harvested from 7-day-old cultures grown on Potato Dextrose Agar (PDA) by suspending them in sterile saline solution (0.85% NaCl) containing 0.05% Tween 80, and the concentration was adjusted to 106 spores/mL using a hemocytometer [17]. Coated test pieces (2 cm x 2 cm) were placed on fresh PDA plates and inoculated with 100 µL of the fungal spore suspension. Control samples included uncoated substrates and PDA plates without inoculation. The plates were incubated at 28°C, and visual observations for fungal growth inhibition were recorded weekly for a period of 4 weeks. The percentage of growth inhibition was calculated by comparing the fungal growth area on coated samples to that on uncoated controls.

*Coating Resistance and Adhesion Tests*

The mechanical integrity of the applied coating, particularly its resistance to UV radiation and rain, was assessed using an accelerated weathering test chamber (Atlas Ci4000 Weather-Ometer) as per ISO 11341 standards. Samples were subjected to alternating cycles of UV-A irradiation (0.76 W/m² at 340 nm) and water spray at 60°C for a total duration of 1000 Hours. Coating adhesion was quantitatively determined using the cross-cut test method according to ISO 2409, wherein a lattice pattern is cut into the coating, penetrating to the substrate, and an adhesive tape is applied over the cut and then removed. Adhesion was graded on a scale of 0 to 5, with 0 indicating excellent adhesion and 5 indicating complete detachment.

*Spectroscopic Characterization*

Quantitative determination of the biocide components (isothiazolines and bronopol) within the cured acrylic film was performed by High-Performance Liquid Chromatography (HPLC) (Agilent 1260 Infinity II) equipped with a UV-Vis detector. Coating samples were dissolved in a suitable solvent (tetrahydrofuran), filtered, and injected into the HPLC system for analysis against known standards.

## Results and Discussion

### Mechanism of Acrylic-Based Coating

The acrylic coating used in this study dries through a process of solvent evaporation and cross-linking between acrylic polymer molecules [3]. The added biocides, namely isothiazolines and bronopol, are evenly distributed throughout the coating matrix.

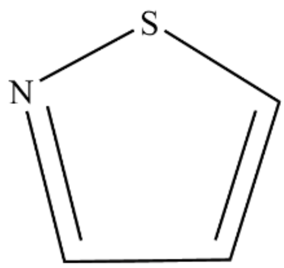


**Figure 1.** Structure of Isothiazoline Compounds in Dehacide 267 Sample

Isothiazolines work by damaging the fungal cell membrane [18], while bronopol inhibits nucleic acid synthesis in Dehacide 267 biocide sample.

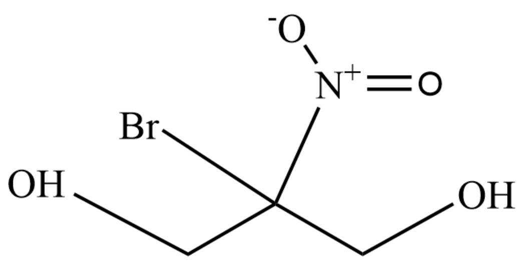


**Figure 2.** Structure of Bronopol Compounds in Dehacide 267 Sample

The combination of these two biocides is thought to have a synergistic effect in inhibiting fungal growth. Test results show that coatings containing biocides are significantly more effective in preventing fungal growth than coatings without biocides. This indicates that biocides can diffuse through the coating matrix and reach surfaces exposed to fungi, thereby inhibiting their growth [3].

## The Effect of Coatings on Fungal Growth

**Table 1.** Data Kill Study and Bacteria Count

| Biocide | Dose (ppm) | After Long Contact (Hours) | Fungi Plate Count Date: 16 August 2025 |
|---|---|---|---|
| Blank | | | > $10^4$ |
| Dehacide 267 | 50 | 1 | > $10^1$ |
| Dehacide 267 | 50 | 3 | > $10^1$ |
| Dehacide 267 | 50 | 5 | > $10^1$ |
| Dehacide 267 | 75 | 1 | > $10^1$ |
| Dehacide 267 | 75 | 3 | > $10^1$ |
| Dehacide 267 | 75 | 5 | > $10^1$ |
| Dehacide 267 | 100 | 1 | > $10^1$ |
| Dehacide 267 | 100 | 3 | > $10^1$ |
| Dehacide 267 | 100 | 5 | > $10^1$ |

The results of the study show that the addition of a combination of isothiazolines and bronopol biocides to acrylic coatings significantly inhibits the growth of Aspergillus niger and Penicillium chrysogenum fungi. At a concentration of 2% (w/w), the biocide was able to inhibit fungal growth by up to 95% after 4 weeks. This shows that the biocide used is very effective in preventing fungal colonization on car body surfaces. In addition, testing of various biocide concentrations showed a positive dose-response relationship, where the higher the biocide concentration, the higher the level of fungal growth inhibition [9].

## Chemical Analysis Biocide Content

**Table 2.** The Effect of Sample Coating Position on Biocide Concentration

| Coating Sample | Type of Biocide | Analysis Method | Biocide Content (mg/kg) |
|---|---|---|---|
| Top Layer | Dehacide 267 | HPLC | 1250 |
| Bottom Layer | Dehacide 267 | HLPC | 1180 |
| Control Sample | - | HPLC | < LOD (Limit of Detection) |

The analysis results show that the biocide content in the upper and lower layers of the coating is relatively consistent, indicating an even distribution of biocide. However, there is a slight decrease in content compared to the theoretical value, which is likely due to evaporation during the drying process. This shows that the efficiency of biocide incorporation into the coating matrix can still be improved. HPLC analysis shows that the biocide content in the coating after the curing process is 1.8% (w/w). This value is slightly lower than the biocide content added at the beginning of the manufacturing process, indicating a slight loss of biocide during the process [16]. However, the remaining biocide content is still high enough to be effective in inhibiting fungal growth.

## Release of Biocide from Coating Matrix

The release of biocide from the coating matrix is a complex process. Biocide slowly diffuses through the polymer matrix to the coating surface and then into the surrounding environment. This process is influenced by concentration gradients, biocide molecule size, and the physicochemical properties of the polymer. If the biocide is soluble in water or other solvents, it can dissolve and be released from the coating matrix when exposed to an environment containing water or these solvents [14]. In some cases, the coating layer may peel off, causing the biocide trapped within the layer to be released at the same time. Controlling the rate and duration of biocide release is crucial to achieving optimal effectiveness. Too rapid release can lead to high biocide concentrations at the beginning of use, but it can be depleted quickly, resulting in reduced protection. Conversely, too slow release can render the biocide ineffective in inhibiting the growth of microorganisms [2].

### Distribution of Biocide in the Coating Matrix

According to [12], the main mechanism of biocide distribution in the coating matrix is diffusion. Biocide moves from areas with high concentrations to areas with low concentrations through random molecular movement. The rate of diffusion is influenced by the concentration gradient, the diffusion coefficient of the biocide in the matrix, temperature, and the thickness of the coating layer. The greater the concentration gradient and diffusion coefficient, the faster the diffusion rate. Higher temperatures also increase the diffusion rate because they increase the kinetic energy of the molecules. The distribution of biocides in the coating matrix is greatly influenced by various factors, including the physicochemical properties of the biocide itself, the type of polymer used as the matrix, and the coating application method.

### How Biocides Work Against Fungi

Biocide works in various ways to inhibit fungal growth. Its main mechanism is to damage the cell membrane of fungi. Biocide, particularly Dehacide 267, can damage the integrity of the fungal cell membrane. The cell membrane is a vital structure that protects cells and regulates the exchange of substances. By damaging the cell membrane, a biocide causes the contents of the cell to leak and disrupts cellular function. In addition, biocides can inhibit the process of protein synthesis in fungal cells. Proteins are important components in cells that perform various functions. By inhibiting protein synthesis, biocides inhibit the growth and development of fungal cells. Biocides also inhibit the synthesis of nucleic acids (DNA and RNA). Nucleic acids contain genetic information necessary for cell growth and reproduction. By inhibiting nucleic acid synthesis, biocides prevent cell replication and fungal growth [11].

## Conclusion

Based on the results of the research conducted, it can be concluded that the addition of Dehacide 267 to the body coating of the MV3 Garuda Limousine is effective in inhibiting the growth of Aspergillus niger and Penicillium chrysogenum. Dehacide 267 works by damaging the fungal cell membrane, thereby disrupting cellular function and inhibiting growth. A comparison with coatings of Dehacide 267 showed a significant decrease in the number of fungal colonies that grew. This indicates that Dehacide 267 has great potential as an antifungal agent in car body coatings.

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## References

[1] Laksmana, A.P., & H. Farida, Undergraduate Thesis, Efektivitas Air Rebusan Kulit Kayu Manis (Cinnamomum Burmannii) Sebagai Antiseptik Untuk Higiene Tangan, Departement of Medicine, Faculty of Medicine, Universitas Diponegoro, Indonesia, 2019. https://eprints.undip.ac.id/69247/

[2] Ali, A., Jamil, M. I., Jiang, J., Shoaib, M., Amin, B. U., Luo, S., & Zhang, Q. (2020). An Overview of Controlled-Biocide-Release Coating Based on Polymer Resin for Marine Antifouling Applications. *Journal Of Polymer Research*, 27(4), 85. https://doi.org/10.1007/s10965-020-02054-z

[3] Anandkumar, B., Krishna, N. G., Solomon, R. V., Nandakumar, T., & Philip, J. (2023). Synergistic Enhancement of Corrosion Protection of Carbon Steels Using Corrosion Inhibitors and Biocides: Molecular Adsorption Studies, Dft Calculations and Long-Term Corrosion Performance Evaluation. *Journal Of Environmental Chemical Engineering*, 11(3), 109842. https://doi.org/10.1016/j.jece.2023.109842

[4] Bellotti, N., Romagnoli, R., Quintero, C., Domínguez-Wong, C., Ruiz, F., & Deyá, C. (2015). Nanoparticles as antifungal additives for indoor water-borne paints. *Progress in Organic Coatings*, *86*, 33-40. https://doi.org/10.1016/j.porgcoat.2015.03.006

[5] Brilliantoro, B. (2022). Literature Review: Studi Pengendalian Korosi menggunakan Coating Zinc (Zn), Zinc Phosphate ($Zn_3(PO_4)_2$), Zinc Silicate ($ZnSiO_4$) dan Nickel (Ni) pada Industri Otomotif. *JIIP-Jurnal Ilmiah Ilmu Pendidikan*, *5*(6), 1878-1885. https://doi.org/10.54371/jiip.v5i6.658

[6] C. Steven McDaniel, U.S. Patent No. 20200109297, 27 March. 2020. https://patents.justia.com/patent/20200109297

[7] C. Steven McDaniel, U.S. Patent No. 7939500, 10 May. 2011. https://patents.google.com/patent/US7939500B2/en

[8] C. Steven McDaniel, U.S. Patent No. 8497248, 30 July. 2013. https://patents.google.com/patent/US8497248B2/en

[9] Dileep, P., Jacob, S., & Narayanankutty, S. K. (2020). Functionalized nanosilica as an antimicrobial additive for waterborne paints. *Progress in organic coatings*, *142*, 105574. https://doi.org/10.1016/j.porgcoat.2020.105574

[10] Jalaie, A., Afshaar, A., Mousavi, S. B., & Heidari, M. (2023). Investigation of the release rate of biocide and corrosion resistance of vinyl-, acrylic-, and epoxy-based antifouling paints on steel in marine infrastructures. *Polymers*, *15*(19), 3948. https://doi.org/10.3390/polym15193948

[11] Ji, J., Liu, N., Tian, Y., Li, X., Zhai, H., Zhao, S., & Feng, L. (2022). Transparent Polyurethane Coating with Synergistically Enhanced Antibacterial Mechanism Composed of Low Surface Free Energy and Biocide. *Chemical Engineering Journal*, 445, 136716. https://doi.org/10.1016/j.cej.2022.136716

[12] Kugel, A., Stafslien, S., & Chisholm, B. J. (2011). Antimicrobial Coatings Produced By "Tethering" Biocides to the Coating Matrix: A Comprehensive Review. *Progress In Organic Coatings*, 72(3), 222-252. https://doi.org/10.1016/j.porgcoat.2011.07.004

[13] Londhe, S., Patil, S., Krishnadas, K., Sawant, A. M., Yelchuri, R. K., & Chada, V. G. (2019). Fungal diversity on decorative paints of India. *Progress in Organic Coatings*, *135*, 1-6. https://doi.org/10.1016/j.porgcoat.2019.05.020

[14] Marceaux, S., Martin, C., Margaillan, A., & Bressy, C. (2018). Effects of accelerated ageing conditions on the mechanism of chemically-active antifouling coatings. *Progress in Organic Coatings*, *125*, 257-265. https://doi.org/10.1016/j.porgcoat.2018.09.004

[15] Santosa, S. P. (2025). Advancing Electric Vehicle Technology for Defense and Civilian Applications. In *2025 8th International Conference on Electric Vehicular Technology (ICEVT)* (pp. 1-4). IEEE. https://doi.org/10.1109/ICEVT67191.2025.11184068

[16] Senthil, K. P., & Ismail, M. A. (2021). Evaluation of the Relative Resistance of Emulsion Paints in the Container against Microorganisms. *International Journal of Applied Research and Technology*, Vol 6. https://doi.org./10.24163/ijart/2017/2

[17] Setiawan, A., Setiawan, F., Juliasih, N. L. G. R., Widyastuti, W., Laila, A., Setiawan, W. A., & Arai, M. (2022). Fungicide activity of culture extract from Kocuria palustris 19C38A1 against Fusarium oxysporum. *Journal of Fungi*, 8(3), 280. https://doi.org/10.3390/jof8030280

[18] Silva, V., Silva, C., Soares, P., Garrido, E. M., Borges, F., & Garrido, J. (2020). Isothiazolinone biocides: chemistry, biological, and toxicity profiles. *Molecules*, *25*(4), 991. https://doi.org/10.3390/molecules25040991