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STUDY OF ANTIBACTERIAL AND ANTIFUNGAL EFFICIENCY OF IMPREGNATED CARBON-SILICON MODEL FILTERS

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Abstract.

Air purification is a critical process aimed at removing harmful impurities and ensuring a safe and comfortable environment for human life and activity. Overall, rice husk demonstrates significant potential in environmental engineering as a source of valuable materials and a key component of the circular bioeconomy, contributing to pollution reduction and the enhancement of production system sustainability. A carbon–silicon sorbent produced from carbonized rice husk was used to fabricate filters because of its high porosity, large specific surface area, and carbon–silica structure. This paper presents the antibacterial and antifungal efficacy of impregnated carbon-silicon filters. Antibacterial activity was studied on Bacillus paramycoides and Pseudomonas koreensis strains using the diffusion method on a solid nutrient medium, and antifungal efficacy was studied on strains Fusarium spp. and Penicillium spp. Tests showed that sorbent samples with different active ingredient concentrations exhibited varying levels of bacterial and fungal growth inhibition, with sample No. 2 carbonized rice husk+10% I_2 demonstrating the highest activity. Optimizing the sorbent composition and increasing the concentration of active components can enhance its antibacterial properties. The developed sorbents have high potential for use in air purification systems with additional protection against bacterial contamination, making them promising for use in areas with increased hygiene and air purity requirements.

Keywords: carbon-silicon filters, antibacterial efficiency, antifungal efficiency, model filters, carbonized rice husk.

1. Introduction

In the context of rapid urbanization and industrial growth, the issue of maintaining air quality is becoming increasingly important. Air pollution is considered one of the most serious environmental threats of our time, significantly impacting public health, ecosystem health, and climate stability. According to the World Health Organization (WHO), millions of people suffer annually from diseases associated with exposure to air pollution, including acute and chronic respiratory diseases, as well as cardiovascular pathologies. Furthermore, air pollution contributes to an increase in premature mortality and leads to significant economic losses due to increased healthcare costs and decreased productivity [1–4].

Modern technologies for air purification from pathogenic factors include the use of filtration systems, catalytic units, biofilters, and innovative solutions based on nanostructured materials [5–7]. Atmospheric air constantly contains various pollutants, which are divided into mechanical, physical, and biological. Mechanical pollutants include solid particles of various origins—dust, soot, lead, mercury, and combustion products of organic fuels formed during construction, mining, and other industrial activities [8]. Physical pollution is associated with exposure to thermal, noise, electromagnetic, and radioactive radiation. Biological pollutants are caused by the anthropogenic spread of microorganisms in the air. The most toxic components of air pollution are carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), suspended solids, and various hydrocarbons [9].

The development of process lines in industrial enterprises, the construction industry, and mineral resource extraction sites has led to stricter sanitary and environmental requirements for air quality. This has necessitated updating the regulatory framework and introducing new standards [10]. In Europe, modern standards for assessing the efficiency of air filters have been adopted, including

EN 779:1993 and EN 1822:1998 [11,12], which regulate the performance characteristics of filters used in ventilation and air conditioning systems [13].

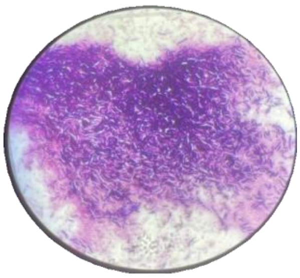
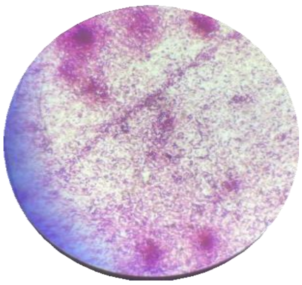
To impart antibacterial and antifungal properties to filters, they can be impregnated with antimicrobial substances such as iodine or Lugol's solution. These compounds have pronounced antiseptic properties and effectively destroy bacteria, viruses, and fungi on contact. Lugol's solution, a stabilized mixture of iodine and potassium iodide, increases the solubility of iodine and promotes its retention within the filter's porous structure, providing long-lasting antibacterial action. As air passes through the filter, microorganisms meet the iodine-saturated surface, resulting in their destruction [14].

The aim of this work is to investigate the antibacterial and antifungal efficiency of impregnated carbon-silicon model filters.

2. Materials and methods

To determine the antibacterial activity of the resulting tableted sorbent formulations, two bacterial strains described below were used (Table 1). Given that the Bacillus and Pseudomonas genera are widely distributed in the environment, including water, soil, air, and food products, and are extremely resistant to stress factors, as well as their high adaptability to various conditions, the selected bacterial strains were optimal for testing the sorbent's antibacterial properties. Bacillus paramycoides and Pseudomonas koreensis, isolated from soil, are active strains because they participate in many processes in the rhizosphere, indicating that they are PGPB bacteria with great potential in agriculture. Pure bacterial colonies were subpassaged into sterile liquid nutrient medium to obtain a 24-hour culture and placed in a thermoshaker at 35 °C and 150 rpm for 24 hours. After growth, optical density was measured using an APEL PD-303 spectrophotometer. Ten microliters of the liquid medium was then cultured using the Drygalski method on solid MPA nutrient medium in Petri dishes to form a continuous lawn, with tablets then placed in the center. After seeding, the Petri dishes were incubated in a thermostat at 35 °C for 24 hours.

Table 1 - Macro- and micromorphological characteristics of identified bacterial strains from museum culture

No.	Name of the strain	Macromorphological characteristics	Micromorphological characteristics
1	Bacillus paramycoides	White colony, forms hyphae on solid medium, edges and surface of the colony are uneven	 Gram-positive, large rod-shaped morphology
2	Pseudomonas koreensis	The colony is pale yellow in color, of medium consistency, with a smooth surface and edge	 Gram-negative, rod-shaped morphology

To determine the antifungal activity of the resulting tableted sorbent, two fungal strains described below (Table 2) were used. Given that the Fusarium and Penicillium fungi are widely distributed in the environment, including water, soil, air, and food products, and are extremely resistant to stress factors, as well as their high adaptability to various conditions, the selected fungal strains were optimal for testing the sorbent for antifungal properties. Fusarium spp and Penicillium spp, isolated from soil and spoiled food products, are active and rapidly germinate on organic substrates, indicating their high adaptability to environmental stress factors. Pure fungal colonies were subpassaged into sterile liquid nutrient medium to obtain a 24-hour culture and placed in a thermoshaker at 30 $^{\circ}$C and 150 rpm for 24 hours. After growth, optical density was measured using an APEL PD-303 spectrophotometer. Then, 100 μl of liquid medium was cultured using the Drygalski method on solid Sabouraud medium in Petri dishes to form a continuous lawn, with tablets placed in the center. After seeing, the Petri dishes were incubated in a thermostat at 30 $^{\circ}$C for 24 hours.

Table 2 – Drawing of the sorbent on a solid nutrient medium with bacteria

No.	Name of the strain	Macromorphological characteristics
1	Fusarium spp	
2	Penicillium spp	

3. Results and discussions

A carbon-silicon material obtained by carbonizing rice grain husks was chosen for the filter. This choice was determined by the material's porosity, high specific surface area, and pore volume, as well as the presence of finely dispersed carbon and silicon oxide particles. This means the material combines significant sorption capacity for various substances.The resulting multi-channel block had the following geometric dimensions: 48 mm in diameter and 120 mm in length. It was permeated with 1,000 longitudinal rectangular channels with a cross-section of 1 mm2. Thus, the contact surface of the channels within a single block was 480,000 mm2, or approximately half a square meter (Figure 1).

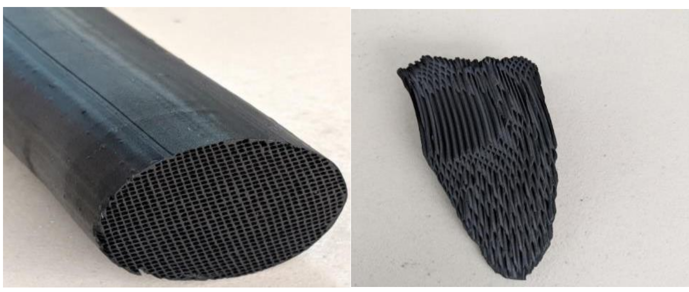


Figure 1 – Model filter made of carbon-silicon sorbent. a) Multichannel block end view b) Block in section

Further research focused on identifying optimal bactericidal additives for impregnating model filters.

As demonstrated in previous studies, Nazar solution has proven itself to be a successful bactericide. Works on, the determination of antifungal and antibacterial efficacy was carried out by the Kazakh-German-Chinese International Research Laboratory of Applied Microbiology of the AL-Farabi Kazakh National University.

There is a wide selection of substances with antiseptic properties that can be used as impregnating agents. However, their properties limit their use for air purification.

Iodine and its compounds have been used as antiseptics for over 150 years and are proven remedies. Iodine solution is rightfully considered one of the most common antiseptics in everyday life. However, using iodine preparations for air purification is difficult due to rapid inactivation. This problem can be solved by impregnating the iodine into a nanoporous carbon filter block.

When studying the bactericidal activity of activated carbon samples with varying levels of adsorbed iodine, we discovered that some of them exhibited high antibacterial activity. Iodine compounds possess strong antiseptic properties, effectively killing bacteria, viruses, and fungi upon contact. Lugol's solution, a stabilized mixture of iodine and potassium iodide, increases the solubility of iodine and its retention within the filter's porous structure, ensuring long-lasting antibacterial activity. When air passes through the filter, microorganisms are drawn to the iodine-saturated surface, resulting in their destruction.

Nazar, iodine and Lugol's solutions were chosen as antiseptics. To evaluate the antibacterial effect of a multichannel filter with iodine or Lugol's iodine solution, a comprehensive analysis, including microbiological testing, is necessary. These studies will help determine the filter's effectiveness in killing or retaining pathogenic microorganisms.

Powdered sorbent samples were converted into tablets. For all samples, a 0.5 g sample of powdered sorbent was used and subjected to a pressure of 10 atmospheres for 5 minutes. This resulted in sorbent tablets measuring 0.5 mm (Fig. 2) .

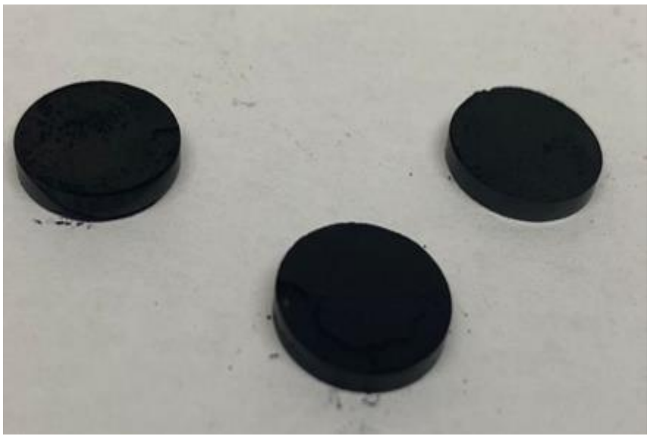


Figure 2 – Sorbent tablets obtained using a press

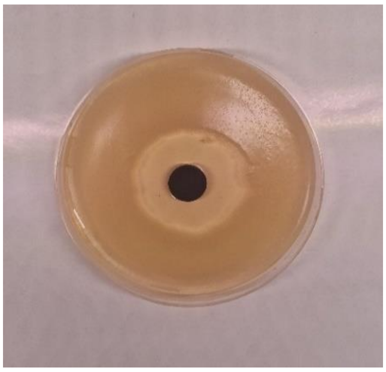
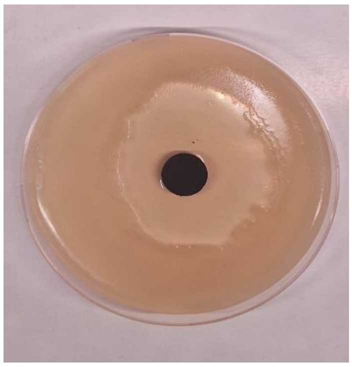
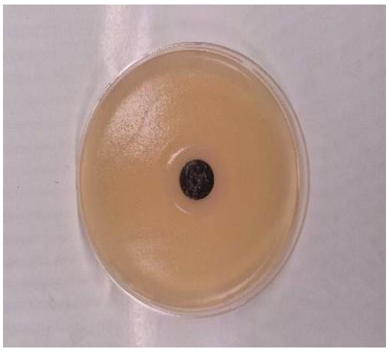
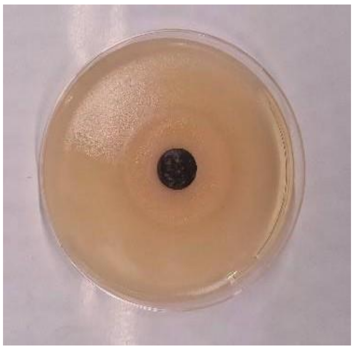
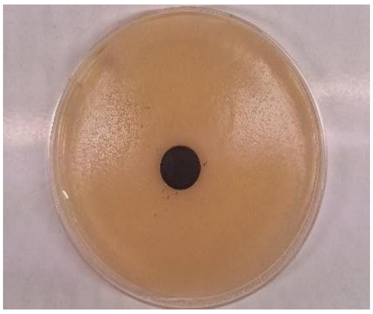
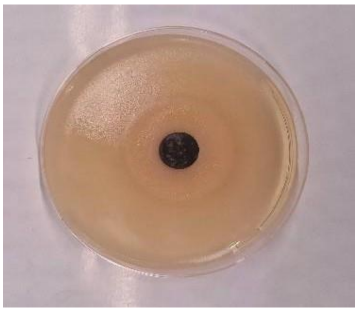
The test sorbent was prepared from three different variants, consisting of three samples. Table 3 shows the composition of the samples.

Table 3 – Concentration of reagents in the sorbent

No.	Samples
1	KRS + 10% J 2
2	KRS + Lugol
3	KRS + Nazar 5%

Bacillus and Pseudomonas bacteria were selected as bacterial cultures . Bacillus paramycoides and Pseudomonas koreensis, isolated from soil, are active strains as they participate in many processes in the rhizosphere, indicating that they are PGPB bacteria with great potential in agriculture. Table 4 shows the results of the antibacterial activity of carbon-silicon filters.

Table 4 – Antibacterial activity of carbon-silicon sorbents

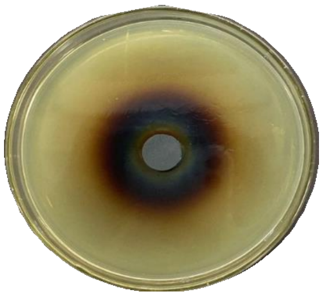
Sample	Bacillus paramycoides	Pseudomonas koreensis
KRS +10% J_2	 Growth inhibition zone 4 cm	 Growth inhibition zone 5 cm
KRS + Lugol	 The growth inhibition zone is 1 cm, but the strain has adapted and grown through the initial zone. Bacterial growth on tablets	 The growth inhibition zone is 2 cm, but the strain has adapted and grown through the initial zone. Bacterial growth on tablets
KRS + Nazar 5%	 No changes, no antibacterial activity	 No changes, no antibacterial activity

Thus, sample #3 showed no antibacterial activity on solid nutrient medium containing Bacillus paramycoides and Pseudomonas koreensis strains with a minimum optical density of 0.1 in the initial liquid medium. However, samples #1 and #2 exhibited antibacterial activity against the strains. Sample #2 initially exhibited antibacterial activity, but the tablet concentration was insufficient to inhibit growth. Sample #1 is more suitable for the growth-inhibiting agent and is considered the optimal, recommended composition.

Next, we determined the antifungal efficacy of the sorbents. To determine the antifungal activity of the resulting tablet forms of the sorbent, we used two strains of Fusarium and Penicillium fungi. Fusarium spp. and Penicillium spp., isolated from soil and spoiled food products, are active and rapidly germinate on organic substrates, indicating their high adaptability to environmental stress factors.

The study assessed the antifungal activity of various carbon-silicon sorbent samples against fungal strains of Penicillium spp. and Fusarium spp. The results revealed that sample 3 did not suppress the growth of these microorganisms, indicating a lack of significant antifungal activity. However, samples 1 and 2 demonstrated significant inhibition of fungal growth, with sample 1, containing 10% J2, demonstrating the greatest efficacy, completely suppressing colony development on agar medium. Table 5 shows the results of the antifungal activity of carbon-silicon filters.

Table 5 – Antifungal efficiency of carbon-silicon sorbents

Sample	Penicillium spp	Fusarium spp
KRS +10% J_2	 Agar color change due to a component. Inhibition of fungal growth in full volume.	 Agar color change due to a component. Inhibition of fungal growth in full volume.
KRS + Lugol	 Growth inhibition zone 3 cm	 Growth inhibition zone 1.5 cm
KRS + Nazar 5%	 No changes, no antifungal activity	 No changes, no antifungal activity

Thus, based on the results of the experimental work, the optimal composition of KRSh + 10% J2 was found, demonstrating the highest antibacterial and antifungal efficacy. This result confirms the potential of this sample as a potential fungicidal and antibacterial component for the development of filter materials or other antimicrobial technologies. Additional studies, including the mechanisms of action and long-term stability of the sorbents, will help determine the most effective conditions for their use in air purification systems or materials with antimicrobial properties.

4. Conclusion

The antibacterial and antifungal efficacy of impregnated carbon-silicon model filters was studied on a test bench. It was found that of the four sorbents tested, sample No. 2 carbonized rice husk+10% I_2 exhibited the highest antibacterial and antifungal efficacy, completely suppressing colony growth on an agar mortar: growth inhibition zone of sample was 5 cm for antibacterial test and inhibition of fungal growth was in full volume. This study represents an important step toward the utilization of agricultural waste, such as rice husk, for the development of cost-effective and highly efficient air purification technologies and environmental protection.

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Author Contributions

Conceptualization: Zhanar Kudyarova, Formal analysis: Zhanar Kudyarova, Investigation: Dauren Baiseitov, Methodology and Supervision: Dauren Baiseitov, Writing – original draft: Dauren Baiseitov, Writing – review & editing: Zhanar Kudyarova.

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Data availability statement: The data presented in this study may be obtained on request from the corresponding author.

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