FORMATION OF THE SILICON-CONTAINING POROUS CARRIER MATERIALS USING BACTERIAL CELLS

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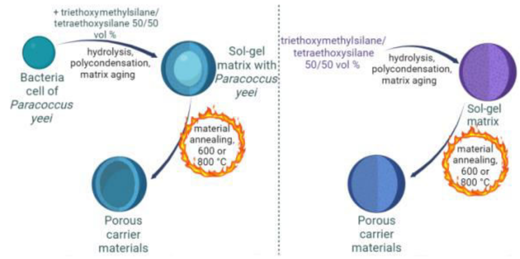
Abstract

Four types of the loading matrices based on triethoxymethylsilane and tetraethoxysilane in the 50/50 vol % ratio were prepared. The matrices were obtained either using *Paracoccus yeei* bacterial cells VKM B-3302 as templates or without them. The materials were annealed at 600 and 800 °C. The effect of the cells on the resulting loading matrices was analyzed using scanning electron microscopy. It was found that the addition of *P.yeei* allows for the formation of the more branched surface, which is likely to result in a higher specific surface area.



Key words: sol-gel technology, antibacterial material, porous carrier material, *Paracoccus yeei*.

Introduction

Biofilms are a leading cause of infectious diseases and a significant contributor to economic losses in industry. Microorganisms in biofilms are more resistant to drugs and environmental influence [1]. Liquid antiseptics are traditionally used to control biofilms, but this method leads to increased consumption, bacterial resistance, and environmental pollution. A more effective strategy for controlling microbial biofilms is to prevent their adhesion to the substrate surface, which results in the inability to form a matrix around the bacteria. Another strategy involves killing microbial cells by releasing an antimicrobial agent or by physical contact with the functionalized surface, which leads to the disruption of cell integrity and cell death [2]. The creation of antibacterial materials with extended effectiveness using potent antimicrobial agents is pertinent to this approach.

In order to obtain the platform materials for loading antiseptics, these materials must have a porous surface. Porous composites can be obtained using a sol-gel technology. Mesoporous silica nanoparticles have the ability to load various molecules, including pharmaceuticals and therapeutic peptides [3]. Template molecules, typically surfactants, are used to create nanomaterials with tunable porosity. An organosilicon matrix is formed around a suitable template molecule, which is subsequently removed with a solvent or by annealing, resulting in the pore formation. In addition to molecules, microorganisms can also be used as templates [4]. Although cells have been used as templates for battery formation, microorganism cells have not yet been employed as templates for antibacterial materials. Furthermore, implementing a sol-gel technology to obtain a porous loading surface could enhance the material's efficiency.

Results and discussion

Four samples of organosilicon matrices were created based on a 50/50 vol % mixture of triethoxymethylsilane and tetraethoxysilane. Bacterial cells were used as pore-forming agents in some samples, while others were created without them. The temperatures of 600 and 800 °C were chosen for annealing the resulting sol-gel matrices, because above 400 °C the pyrolysis of microorganisms occurs and pores are released, allowing more antiseptic to be sorbed. Scanning electron microscopy was used to study the structure of the materials obtained and to evaluate the effect of the cells and temperature (Fig. 1).

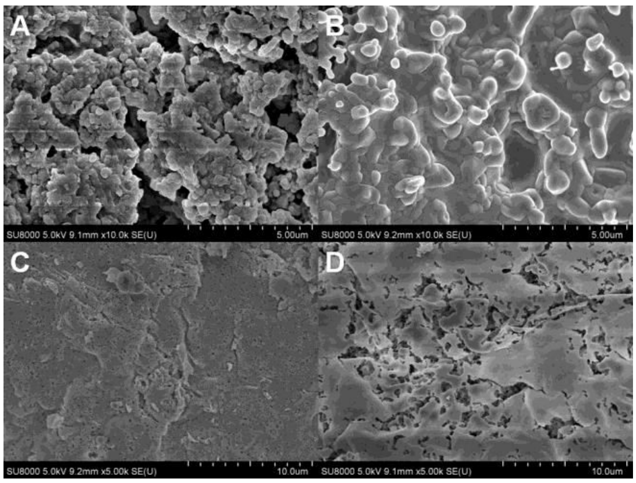


Figure 1. Morphology of the materials obtained: with *P. yeei* annealed at 600 °C (**A**), with *P. yeei* annealed at 800 °C (**B**), without *P. yeei* annealed at 600 °C (**C**), without *P. yeei* annealed at 800 °C (**D**).

The matrices with the bacterial cells are characterized by the presence of large spherical particles on the surface of the porous substrate. The matrices without the cells are characterized by a smoother structure and small pores (Fig. 1A). An increase in the temperature above 800 °C resulted in sintering of the organosilicate material and a change in the morphology (Figs. 1B, 1D). The materials acquired a smoother surface and the pores are changed. Such changes in the morphology lead to changes in the sorption properties of the materials. Therefore, the use of the cells leads to the formation of a more complex material structure with more pores and probably a higher specific surface area.

Experimental section

Paracoccus yeei bacteria VKM B-3302 were selected to create the pores in the sol-gel materials. They were previously immobilized in the sol-gel material, and the formation of an organosilicate matrix around them was experimentally confirmed, allowing the strain to be used as a pore-forming agent [5]. To synthesize the matrix, 0.05 cm of the microbial suspension ($1.2 \pm 0.1 \cdot 10^9$ CFU/mL) was added to 0.02 mL of 5% polyvinyl alcohol solution and stirred for 5 min. An organosilicon framework was formed around the cells by adding 0.05 mL of triethoxymethylsilane and 0.05 mL of tetraethoxysilane. NaF (0.005 mL, 0.2 mol/L) was added as a catalyst, and the mixture was stirred for 15 min.

Using the same procedure, the cell-free organosilicon materials were prepared. For this purpose, 0.05 mL of a phosphate buffer solution (pH = 6.8) was used to replace 0.05 mL of the microorganism suspension. The materials were dried on Petri dishes at 55 °C for 2 h. Then they were annealed at 600 and 800 °C to remove the microorganism cells and methyl groups, increasing the effective surface area.

Conclusions

In this study, four types of the porous carrier organosilicon materials were obtained either with the use of *Paracoccus yeei* VKM B-3302 bacterial cells or in their absence. The results of the SEM analysis showed that an increase in the temperature above 800 °C significantly changes the morphology of the matrices, which affects the number of pores on the surface. In addition, the bacterial cells allow for the formation of a more branched surface, which is likely to result in a higher specific surface area.

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